ARBITRARY WIDTH AND POSITION PULSE TRAINS APPLICATION FOR ULTRASONIC IMAGING: INITIAL STUDY

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Abstract

Novel spectrum spread technique is presented: the arbitrary width and position pulse trains. We suggest to a use specially formed square pulse sequences (APWP), applying specific limitations on duration and positions in time and use the discreet time: this would increase temporal stability and save system resources. Efficiency of excitation electronics would increase, maintaining small size, cost of the spread-spectrum equipment can be reduced. Such signals would allow increasing imaging resolution and quality, increasing the sensitivity of the measurements.

Initial investigation results of the influence on signal spectral and correlation properties are presented. Results are applicable in ultrasonic imaging systems and high accuracy measurements employing the time of flight information.

1. INTRODUCTION

Requirements for non-destructive testing and biomedical imaging systems resolution and sensitivity are increasing, and greater flexibility of the equipment is demanded [1]. In case of straight bandwidth increase, shorter excitation pulses are required. But short pulses do not posses the high energy, required for sensitivity [2-4]. Complex, spread spectrum, excitation signals are used which inherit both long duration (high energy) and wide bandwidth. Most popular, arbitrary waveform signals are complicated to excite, hard to deliver the high power, such equipment is inefficient, not portable and expensive. Chirp signals have relatively simple spectrum which can be easily controlled if nonlinear modulation is used. Binary single pulse or CW pulse trains were used for decades in ultrasonic imaging. Scientific papers report binary chirps use for excitation. Phase manipulated sequences are close to this class, but do not allow to have a full control of the shape the correlation function and spectrum. The novel spectrum spread technique did not receive the proper attention in ultrasound: the arbitrary position and width pulses trains (APWP) [5,6]. Technique is using a chaotically placed train of square pulses with arbitrary position and duration. We suggest new technique – use specially formed square pulse APWP sequences, applying specific duration and position in time limitations and use the discreet time: this would increase temporal stability and save system resources. APWP signals would allow for increased imaging resolution and precision, sensitivity. Excitation electronics efficiency can be increased, size and cost reduced.

Initial study of such signals spectral and correlation properties is presented. Results are documented as figures and numerical values.

2. APWP SIGNALS

Resolution of any imaging system operation on pulsed signal reflection principle is defined by the envelope bandwidth of the signals used for probing. Improving the resolution can be accomplished by using short rectangular pulses. But such signals will have low energy; therefore the accuracy of imaging will be reduced. SS signals offer high energy, wide bandwidth and posses spectral spread in time (Figure 1).

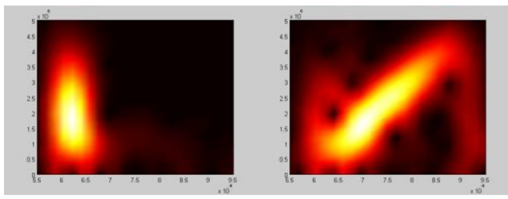

Figure 1. Pulse (left) vs. chirp (right) spectrograms

Several techniques can be applied for SS: phase manipulated sequences, chirp or arbitrary waveform excitation [2-4]. Narrow, matched properties single pulse and chirp were used in our study as reference signals. APWP sequences (Figure 2) [7] should also posses the spectral spread properties.

Aim of our investigation was to perform the initial study on how these signals can be optimized and what correlation and spectral properties can be obtained compared to the aforementioned signals.

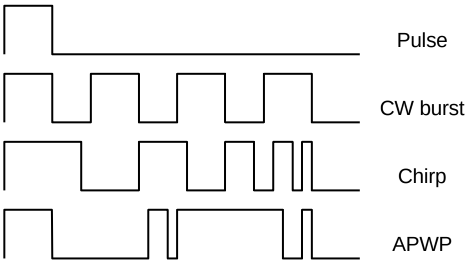

Figure 2. Pulse, CW burst, chirp and APWP signals comparison

3. ANALYZED PARAMETERS

Both chirp, pulse and APWP signals content can be optimised (Figure 3) based on one of the convergence parameters:

i) maximum value of all the side lobes beyond the first zero crossing (max(SL): Figure 3);
ii) energy of sidelobes(E(SL));
iii) main lobe duration minimum.

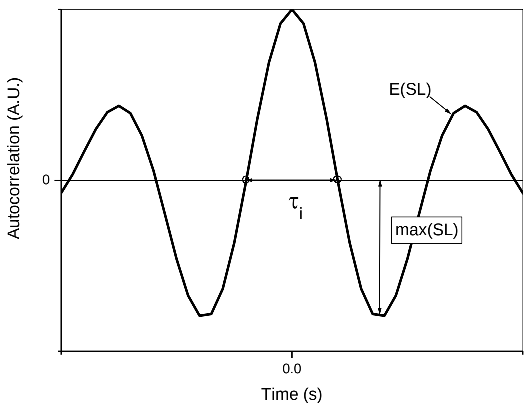

Figure 3. Explanation of pulse width, peak sidelobe and sidelobes variation

4. ULTRASOUND TRANSMISSION MEASUREMENT

The ultrasound propagation frequency response was determined by probing the system input with a chirp signal (0.5 MHz to 15 MHz) while measuring the input and the output signals u_{in} and u_{out} and the channel frequency response was obtained by taking the ratio of Fourier transforms of the two:

$$G(f) = \frac{u_{out}(f)}{u_{in}(f)}, \quad (1)$$

Results obtained were used for ultrasonic signals propagation modeling in iterative optimization.

5. NUMERICAL MODELING AND OPTIMIZATION RESULTS

Ultrasound transmission was used to calculate the transmitted signal as if it was used in real-world experiment. If for pulse all duration were used in optimum search, one combination (f_{min} to f_{max}) was used for chirp and Monte Carlo was used for APWP. Total 10000 Monte Carlo iterations were used. Results obtained for narrowest mainlobe duration are presented in Figure 4 (RF cross-correlation) and Figure 5 (cross-correlation envelope taken using magnitude of the Hilbert transform of the original cross-correlation function).

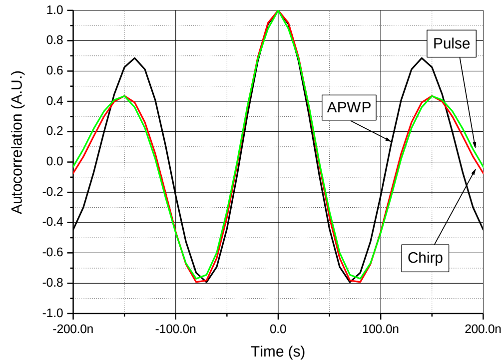

Figure 4. Mainlobe duration minimization result for three signals, cross-correlation function

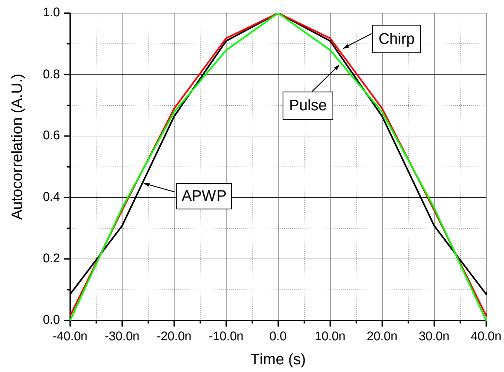

Figure 5. Mainlobe duration minimization, cross-correlation function Hilbert-envelope

It would be expected that pulse would posses lowest sidelobes. It can be seen that optimized APWP has similar to pulse performance and in case of correlation envelope has slightly better performance over the other signals.

Same optimization was performed on lowest variation on spectral response (refer Figure 6 and Figure 7 for correlation functions for such case).

APWP has the worst performance. Reason could be that performance of the spectrum was optimized not in transmission window but in whole 0 to Nyquist region.

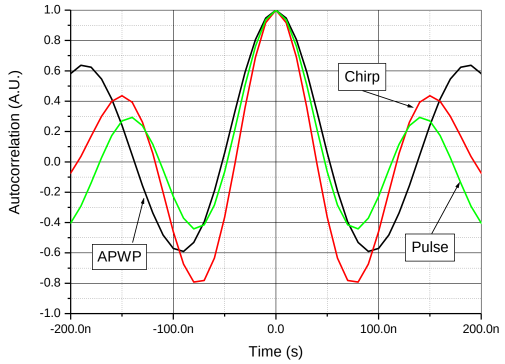

Figure 6. Spectral optimization cross-correlation function

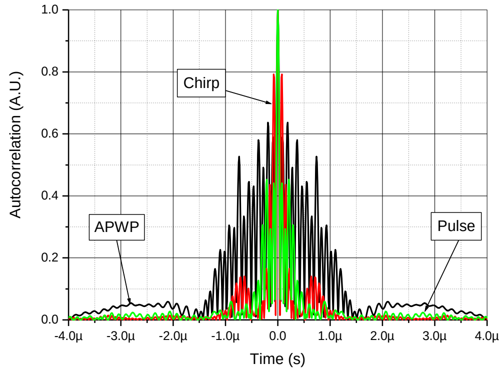

Figure 7. Spectral optimization result for three signals, Hilbert-envelope of the cross-correlation function

Results for sidelobes maximum reduction are presented in Figure 8 and Figure 9.

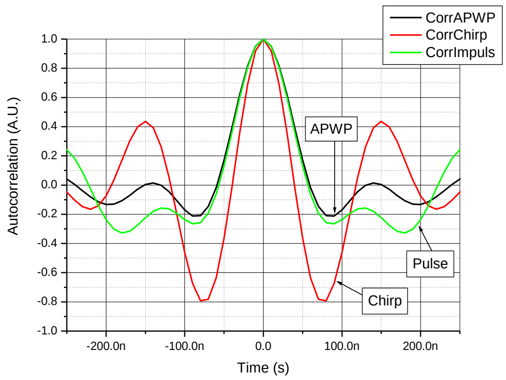

Figure 8. Sidelobes' maximum reduction result: correlation function

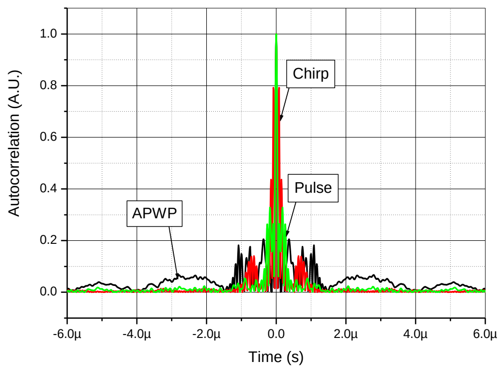

Figure 9. Sidelobes' maximum reduction result: correlation magnitude

Results for sidelobes' energy reduction are presented in Figure 10 and Figure 11.

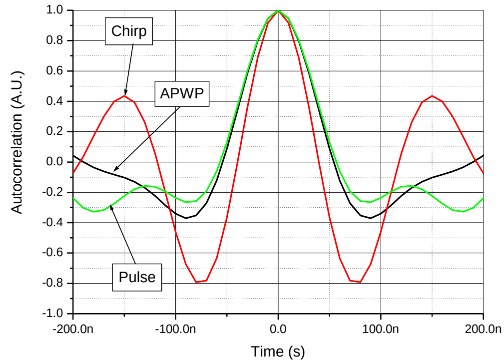

Figure 10. Sidelobes' energy reduction result: correlation function

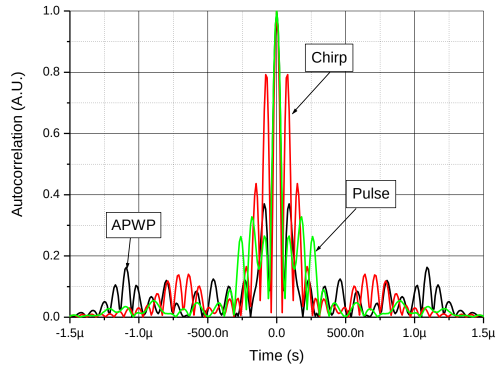

Figure 11. Sidelobes' energy reduction result: correlation magnitude

It can be noted that APWP performance in this initial investigation allows to expect better or similar performance to classical chirp and pulse signals: in some cases APWP performance was the best among the classical signals.

6. CONCLUSIONS

Initial investigation indicates that APWP signals can have properties similar to those of chirp and pulse signals. After optimization, some gain in correlation mainlobe width or sidelobes level compared to pulse or chirp signals can be obtained.

Acknowledgment

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