Simulation Setup for Optimum Energy-Constrained and Amplitude-Constrained Waveform Design

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Technical Report #03-02
April 15, 2003

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Introduction

Using the new MATLAB program it is possible to design energy-constrained or amplitude con-
strained waveforms so as to maximize the signal-to-interference ratio (SIR) for arbitrarily shaped
clutter maps (subject to certain integrability constraints). The program provides a flexible mecha-
nism for defining scenario parameters like clutter map shape, number of sub-pulses, amplitude
constraints (if any), target SNR, target-to-clutter cross section ratio, initial waveform, etc. Clutter
maps are assumed to be defined by a set of parallelograms (as required by DeLong et al. (1967,
1969)). In the program, the clutter maps are defined using a sequence of way-points. A sample
scenario definition file, which corresponds to the experiments conducted in DeLong (1969), is
given below.

%% simulation parameters

scenario_name = 'DeLongExpr1'

% target clutter environment
% column1: normalized range delay (tau/delta)
% column2: normalized Doppler frequency (f * delta)
target = [0 0.95];
clutter = [-10 0
  8 0.9
 31 0.9
 31 1.0
  8 1.0
-10 0.1];

% number of subpulses in the waveform
N = 32;

% minimum waveform amplitude
a = 0.1;

% target's single pulse SNR in the absence of clutter
rho1 = 10^(5/10);

% one half the ratio of clutter cross section seen by
% waveform to target cross section
lambda = 50;

%% optimization parameters

% step size
epsilon = 0.25;
efactor = 1;

% initial signal amplitude and phase
u=ones(N, 1);

% number of iterations for waveform design
num_iter = 30;

% number of trials for finding optimum step size
max_trial = 10;

The corresponding target clutter environment (plotted by the MATLAB program) is shown in Figure 1. Other clutter map shapes can be defined by changing the variable clutter above.
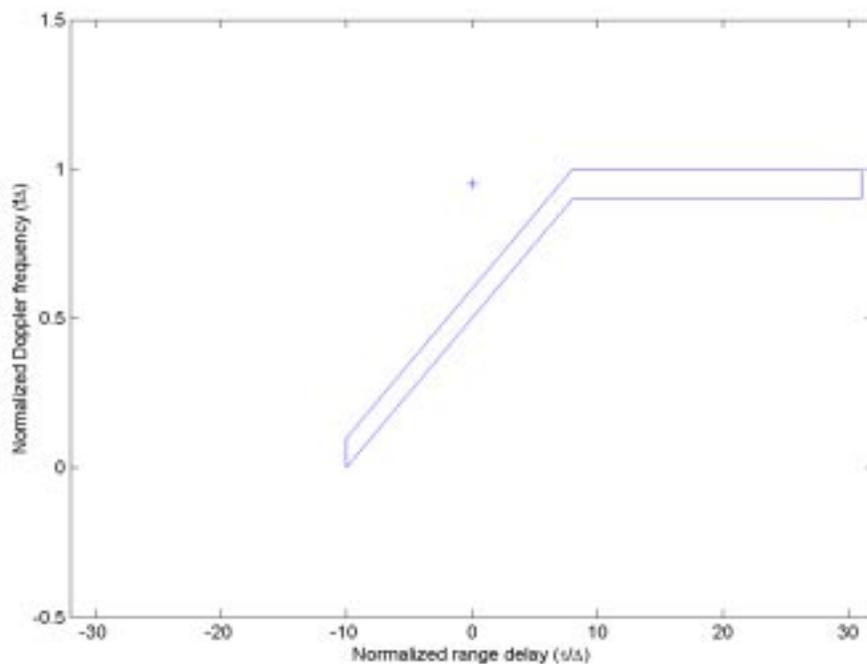

Figure 1: Target clutter environment for the first example from Delong et al. (1969)

Experiment 1

As defined in the scenario file, the single-pulse SNR of the target is 5dB. The number of sub-pulses in the burst waveform of the radar is assumed to be 32. With 32 pulses it is possible to attain a maximum SNR of 20dB. The ratio of the clutter cross section seen by the waveform to the target cross section is 100. For the amplitude constrained waveform, the minimum and maximum single pulse amplitudes are 0.1 and 1.0, respectively. Waveform adaptation is carried out for 30 iterations. For the energy-constrained waveform, the energy used by the last amplitude-constrained waveform is specified as the energy constraint.

In the first experiment with amplitude constrained waveform design, constant amplitude zero-phase burst was used as the initial waveform. For energy-constrained design, the last waveform from amplitude-constrained optimization is used as the initial waveform. Figure 2 shows the SIR values obtained with amplitude-constrained and energy-constrained waveforms. The former achieves a maximum SIR of 14.4dB after 30 iterations (compared with the maximum attainable SIR of 20dB) while the latter reaches up to 19.1dB. Energy-constrained optimum waveform design results in superior results and faster convergence to the optimal SIR as reported by DeLong et al. (1969). The SIR results with amplitude-constrained design are slightly better (compared with 11.6dB) than those reported by DeLong et al. (1969). The iterative search procedure has been modified slightly in our implementation.
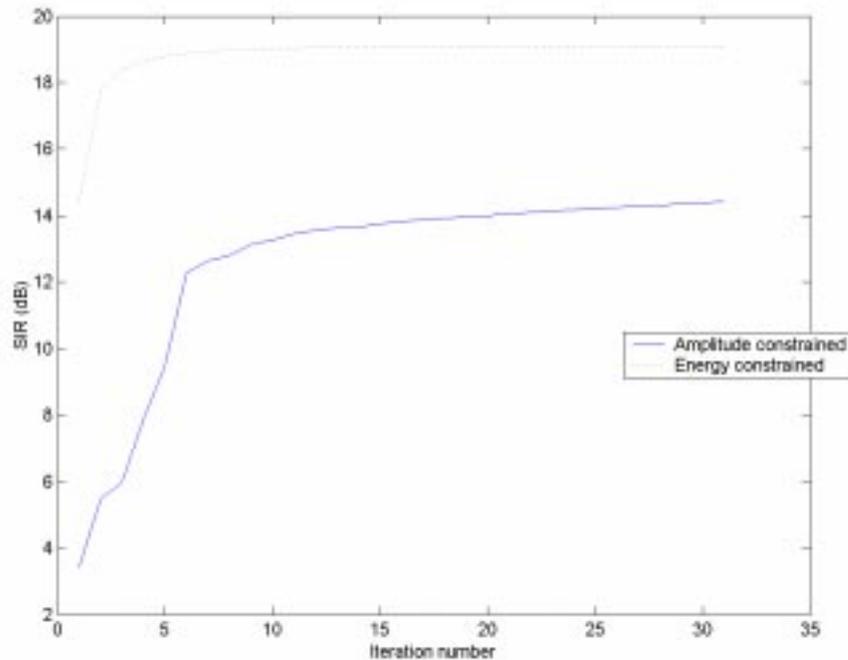

Figure 2: SIR values obtained by amplitude-constrained and energy-constrained waveform design with constant amplitude zero phase initial burst.

The waveforms obtained at the end of 30 iterations from amplitude-constrained design are shown in Figure 3. These, together with the SIR values, compare very well with those obtained by DeLong et al. (1969). Note that the phase values can be unfolded to obtain a smooth progression. The corresponding optimal weighting vectors are shown in Figure 4.
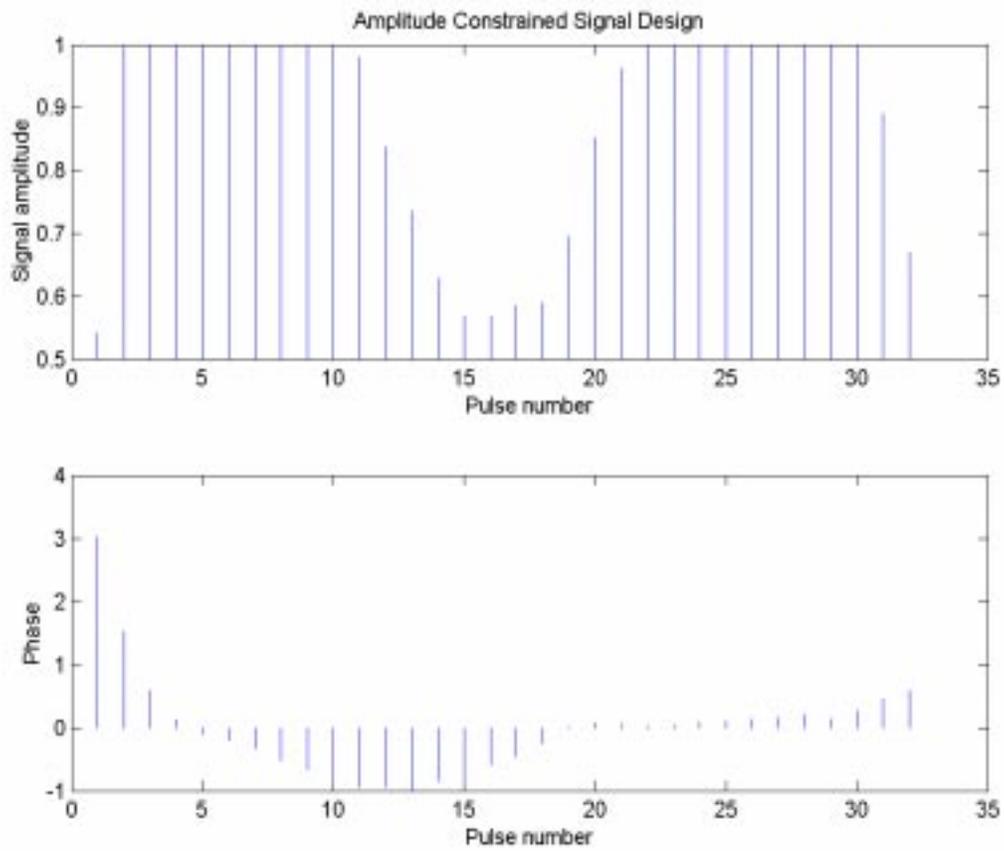
Figure 3: Pulse train at the end of 30 iterations of amplitude-constrained waveform design with constant amplitude zero phase initial burst
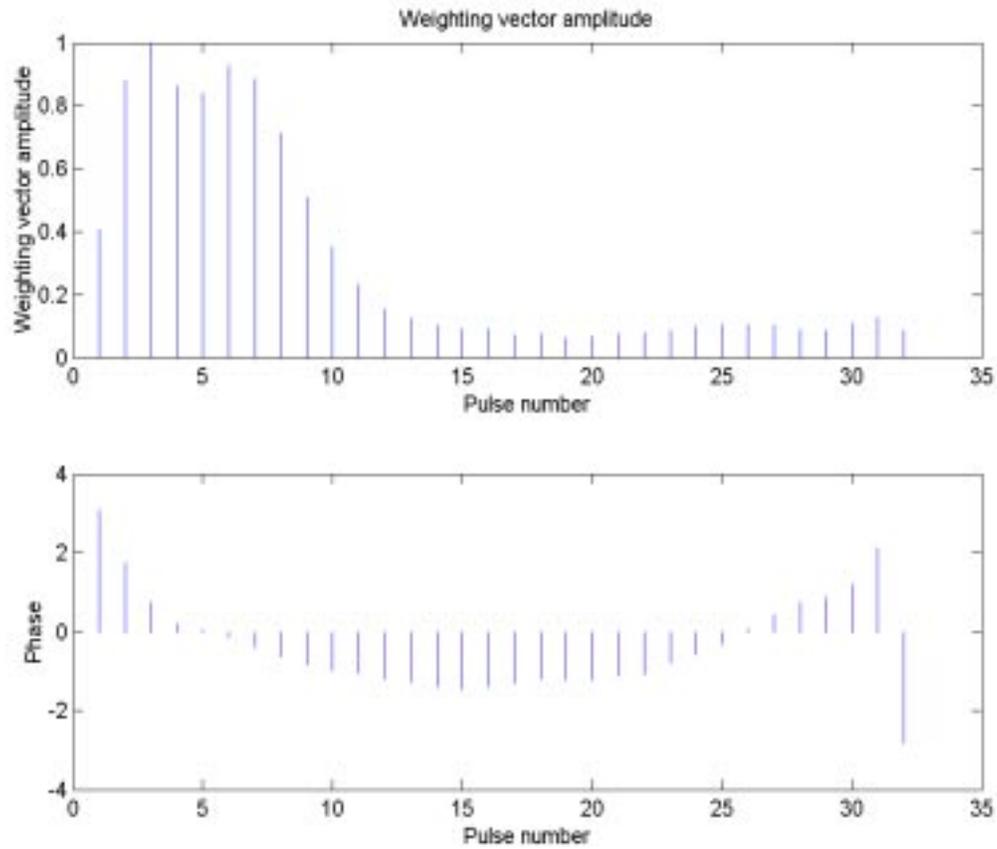
Figure 4: Optimal weighting vector at the end of 30 iterations of amplitude-constrained waveform design with constant amplitude zero phase initial burst

The waveform obtained by energy-constrained optimization is shown in Figure 5. Note that, as expected, the amplitudes obtained by this method are higher than those obtained by amplitude-constrained optimization. Also note that that the optimal waveforms are obtained within almost 5 iterations.
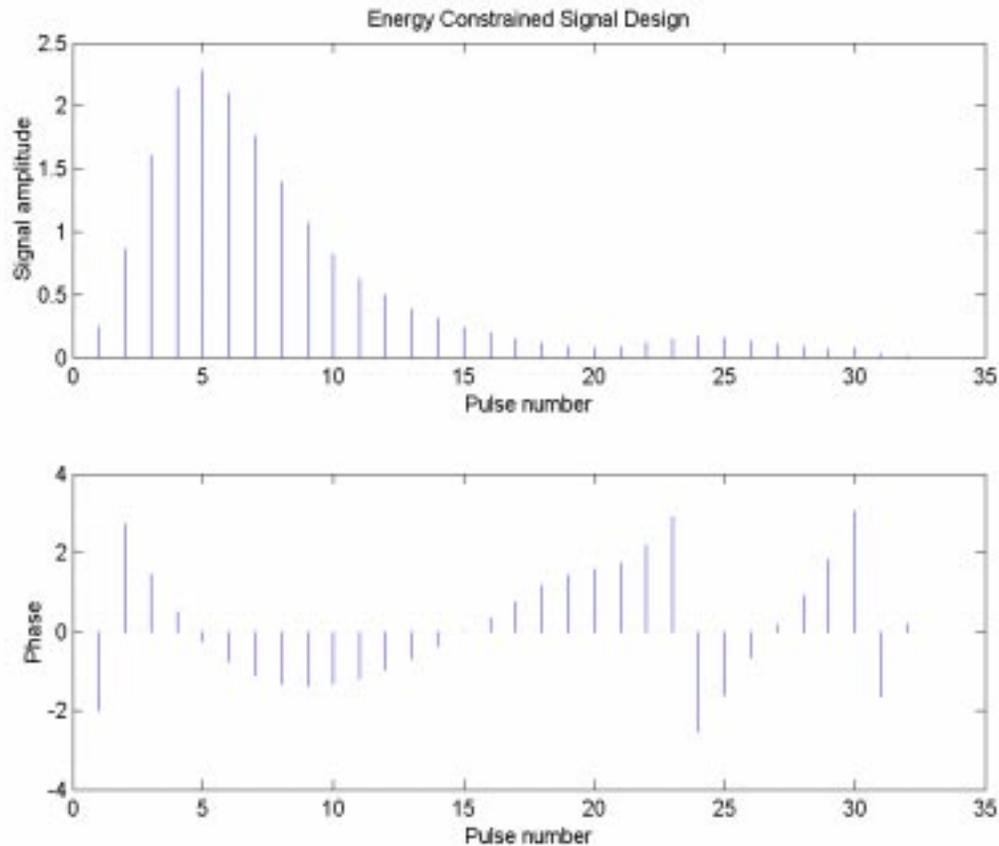
Figure 5: Pulse train at the end of 30 iterations of energy-constrained waveform design with constant amplitude zero phase initial burst

Experiment 2

For experiment 2, the same scenario as above, with the exception of the initial signal, was used. The initial signal was constant amplitude quadratic phase burst, which provides a better ambiguity pattern than constant amplitude zero phase burst. This is apparent from Figure 6, which shows the SIR of amplitude-constrained and phase-constrained waveform design techniques with this initial waveform. Amplitude-constrained design reaches a maximum SIR of 16.9dB after 30 iterations, while energy-constrained design reaches 19.9dB compared with the 20dB, which is possible only with complete clutter suppression. With energy-constrained design, the maximum SIR is reached within about 5 iterations.
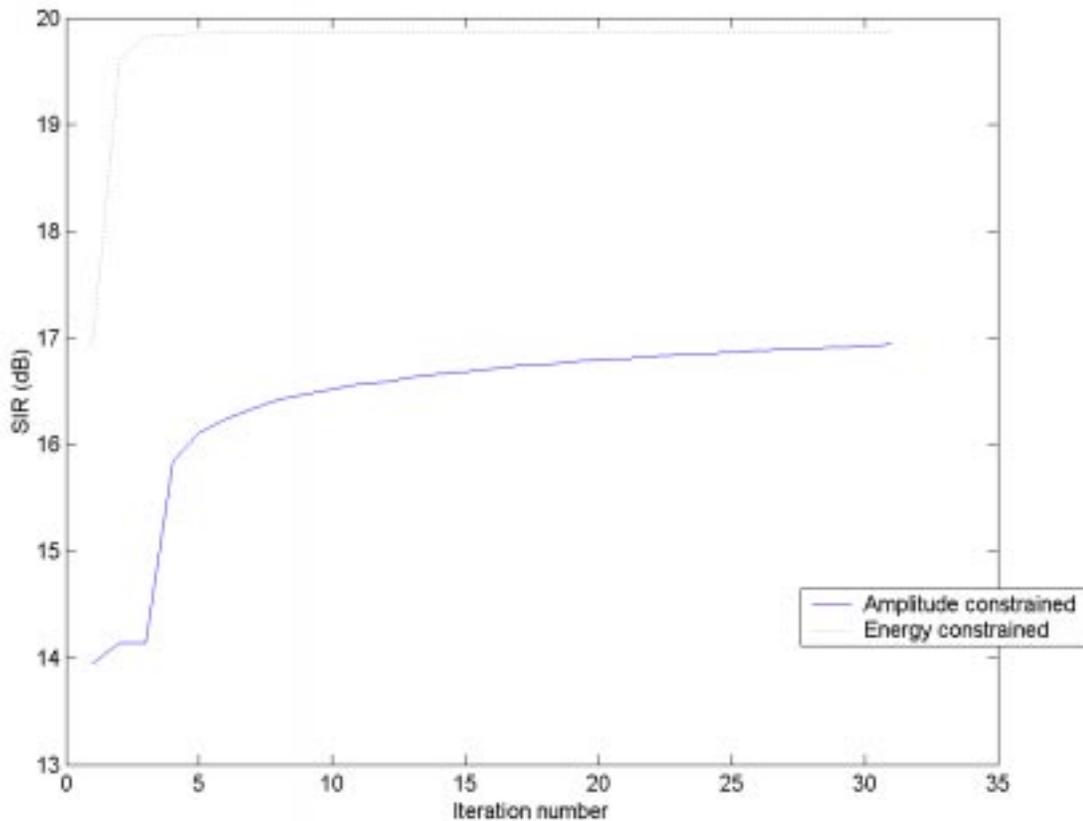
Figure 6: SIR values obtained by amplitude-constrained and energy-constrained waveform design with constant amplitude quadratic phase initial burst

Figure 7 and 8 show the final signal obtained with amplitude constrained optimization and the corresponding optimal weighting vector, respectively. Figure 9 shows the signal obtained with energy-constrained optimization. Note that the amplitudes of the energy-constrained signal are lower than those obtained by the same method with constant amplitude zero phase initial burst (see Figure 5).
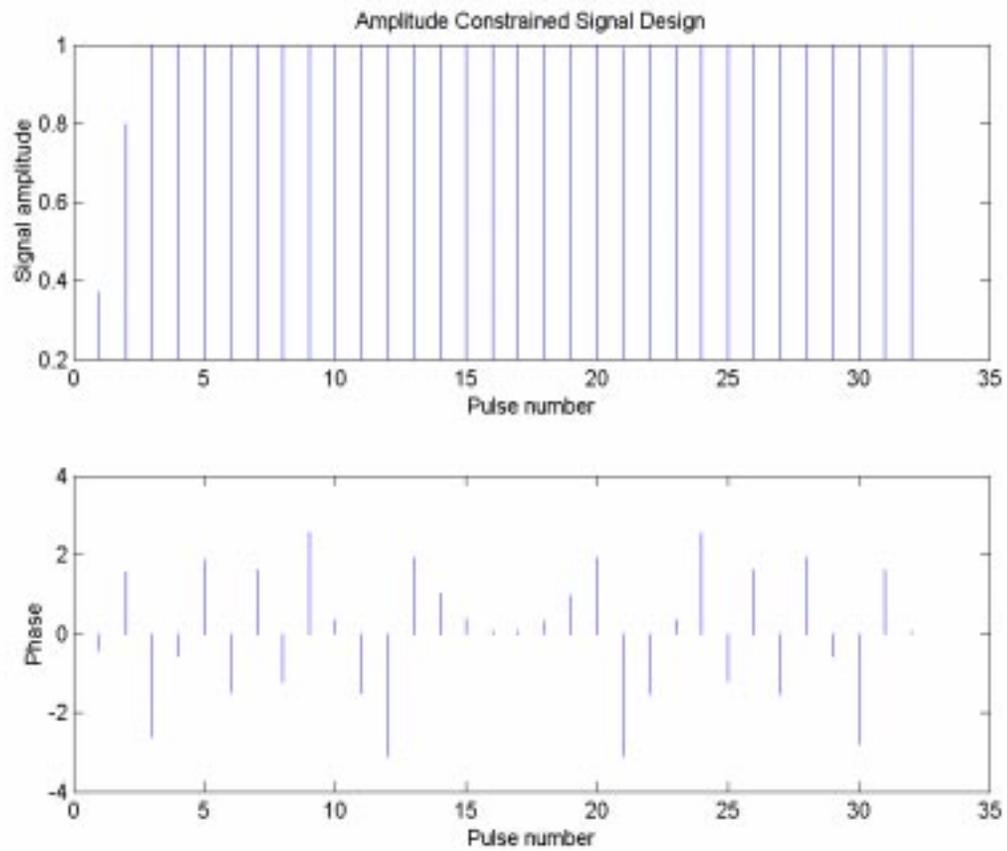
Figure 7: Pulse train at the end of 30 iterations of amplitude-constrained waveform design with constant amplitude quadratic phase initial burst
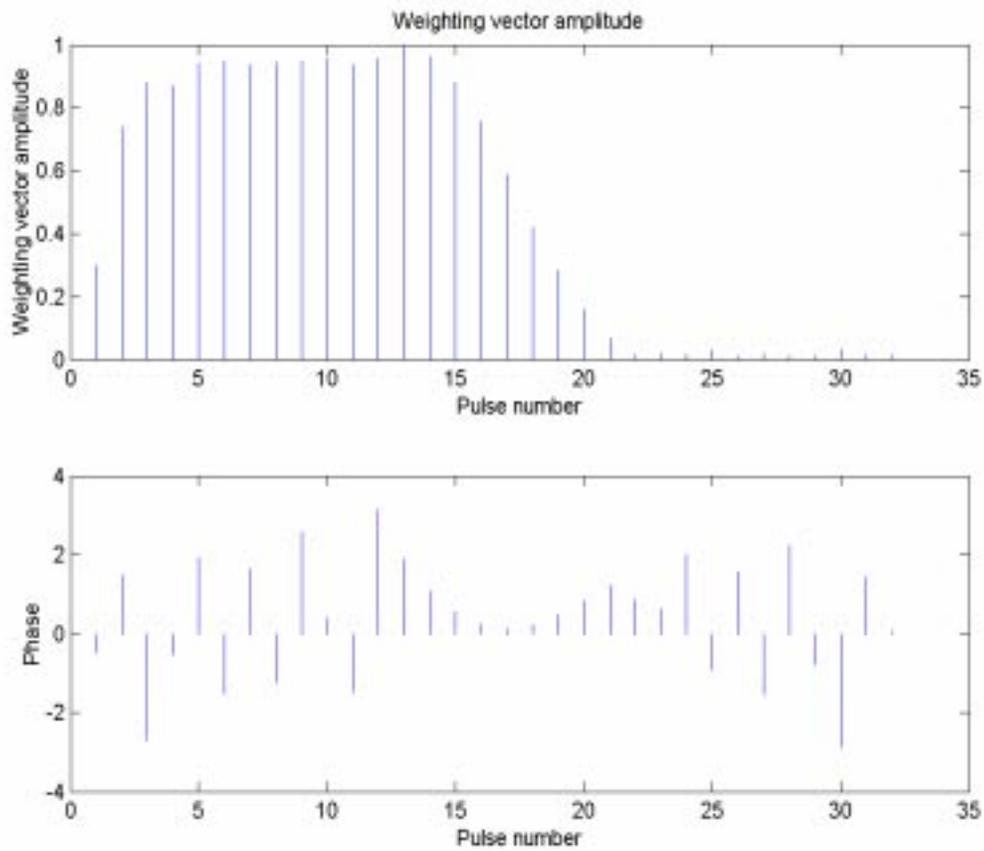
Figure 8: Optimal weighting vector at the end of 30 iterations of amplitude-constrained waveform design with constant amplitude quadratic phase initial burst
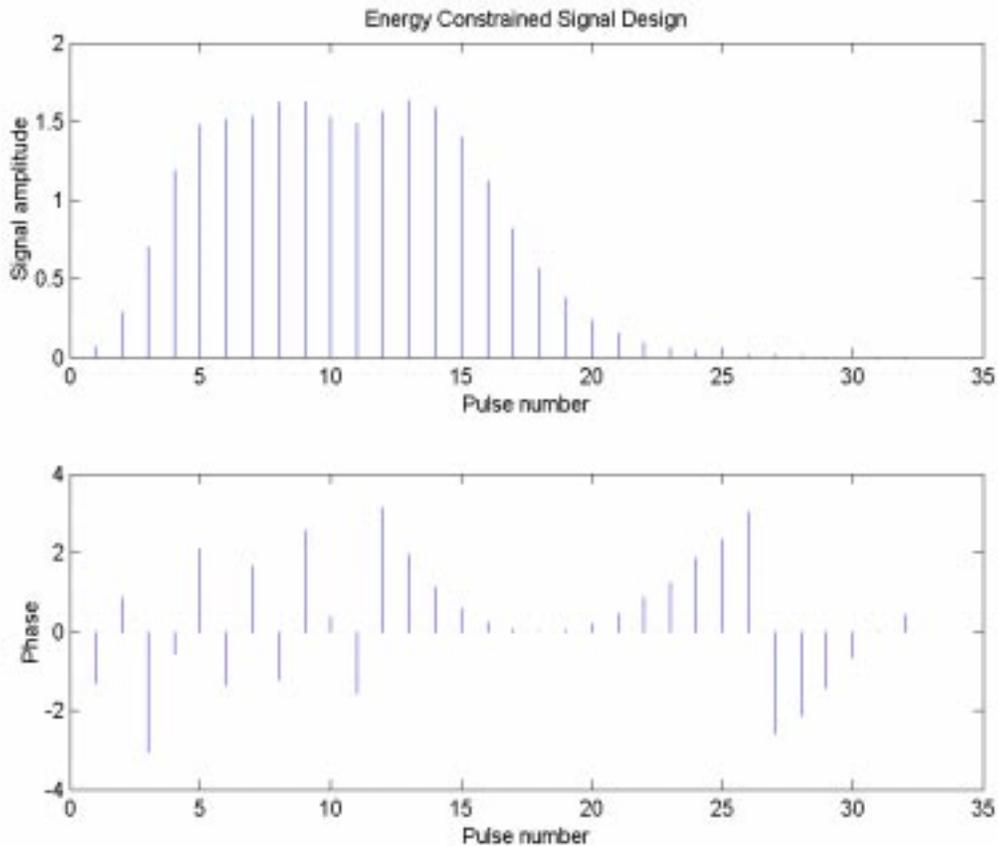
Figure 9: Pulse train at the end of 30 iterations of energy-constrained waveform design with constant amplitude quadratic phase initial burst

Discussion

The above results show that it is possible to achieve better SIR by the judicious selection of initial burst as well as the subsequent signals. Energy-constrained waveform design yields better SIR as well as better convergence properties, enabling better detection. The results show that is in possible to attain the ideal SIR with energy-constrained waveform design (i.e., nearly 100% clutter suppression). Amplitude-constrained waveform design yields comparable results, but always results in lower SIR. However, in some radar applications, amplitude constraint is preferred over energy constraint.

With the current simulation program it is possible to experiment with different waveforms and clutter maps and adaptively design improved waveforms for better target detection. The program is written in a modular fashion so that different waveform design techniques can be used within the same framework.

References

DeLong, D.F. and E. M. Hofstetter, 1967, "On the design of optimum radar waveforms for clutter rejection", IEEE Trans. on Information Theory, IT-13, no. 3, July.

DeLong, D.F. and Hofstetter, 1969, "The design of clutter-resistant radar waveforms with limited dynamic range", IEEE Trans. on Information Theory, IT-15, no. 5, May.

Appendix

MATLAB program files:
1. AdaptWave.m - main MATLAB program file (called from MATLAB prompt)
2. scenario1.m, scenario2.m, etc. - sample scenario files (called at the beginning of AdaptWave.m; change this to use different scenario setup files)
3. Optimization routines:
 findc.m
 findminmax.m
 findrhocf.m
 updatescale.m
 updatesignal.m
4. Plotting routines:
 plot_scenario.m
 plot_results.m
 plotbars.m
5. Utilities:
 eyetilde.m

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1	ORIGINATOR (the name and address of the organization preparing the document Organizations for whom the document was prepared, e g Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8) Adaptive Systems Laboratory Institute for Life-related Systems, McMaster University 1280 Main Street West, Hamilton, Ontario, L8S 4L8	2	SECURITY CLASSIFICATION (overall security classification of the document, including special warning terms if applicable) UNCLASSIFIED

3   TITLE (the complete document title as indicated on the title page Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title)

    Simulation Setup for Optimum Energy-Constrained and Amplitude-Contrained Waveform Design (U)

4   AUTHORS (Last name, first name, middle initial)

    Kirubarajan, Thia; Haykin, Simon; Currie, Brian

5 DATE OF PUBLICATION (month and year of publication of document) April, 2003	6a NO OF PAGES (total containing information Include Annexes, Appendices, etc) 12	6b NO OF REFS (total cited in document) 2

7   DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum If appropriate, enter the type of report, e g interim, progress, summary, annual or final Give the inclusive dates when a specific reporting period is covered)

    Contractor report

8   SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development Include the address)

    Defence R&D Canada – Ottawa
    3701 Carling Avenue, Ottawa, Ontario
    K1A 0Z4

9a PROJECT OR GRANT NO (if appropriate, the applicable research and development project or grant number under which the document was written Please specify whether project or grant) 11ar11	9b CONTRACT NO (if appropriate, the applicable number under which the document was written) W7714-020643/001/SV
10a ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity This number must be unique to this document) . Technical Report #03-02	10b OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor) DRDC Ottawa CR 2003-096

11   DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

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