EE617: Sequences and Codes in DSP Applications

Description for Catalog:

The main focus of this course is on waveform design that achieves certain desirable properties. The most important property is that the sequence's absolute value is constant, but its autocorrelation approaches a single monopulse with small sidelobes. It is also desirable for a set of such sequences to be as close as possible to being mutually orthogonal. This is of importance mainly in radar and communications applications. Various sequences and codes are studied, and open research problems considered. The course grading is based totally on individual studies and a final project.

Course Outline:

Course Objective:

The main focus of this course is on waveform design that achieves certain desirable properties. The most important property is that the sequence's absolute value is constant, but its autocorrelation approaches a single monopulse with small sidelobes. It is also desirable for a set of such sequences to be as close as possible to being mutually orthogonal. This is of importance mainly in radar and communications applications. Various sequences and codes are studied, and open research problems considered

Course Contents:

- Matched filters and system-level cosiderations
- Frequency modulated and phase-coded pulses
- Complete discussion of band-limiting schemes
- Coherent LFM pulse trains signal
- Diversity in pulse trains, including stepped frequency pulses
- Continuous-wave signals
- Multicarrier phase-coded signals
- Code division multiplexing signature design

The phase-coded topic will receives special attention. A more detailed content of this follows:

Phase-Coded Pulse

Aperiodic correlation function of phase-coded pulse
Properties of the cross-correlation function of a phase code
Barker codes
Minimum peak sidelobe codes
Nested codes
Polyphase Barker codes
Chirplike phase codes
Frank code
Perfectness of the Frank code
P1, P2 and Px codes
Zadoff-Chu code
Perfectness of the Zadoff-Chu code
Rational invariance of the Zadoff-Chu code aperiodic ACF magnitude
P3, P4 and Golomb polyphase codes
Phase codes based on nonlinear FM pulse
Asymptotically perfect codes
Golomb's codes with ideal periodic correlation
Deriving the perfect Golomb biphase code
Deriving the Golomb two-valued code with ideal periodic
Cross-correlation
Ipatov code
Optimal filters for sidelobe suppression
Huffman code
Bandwidth considerations in phase-coded signals
Concluding comments
Appendix: Galois fields
Appendix: Quadriphase Barker 13
Appendix: Gaussian-windowed sinc

Grading: The course grading is based totally on individual studies and a final project.

Course Material:
1- Lecture Notes and Transparencies
2- Research papers in the open literature
3- References such as:
a- Nadav Levanon and Eli Mozeson, *Radar Signals*, John Wiley & Sons, Inc. Hoboken, NJ. 2004
b- Fredric J Harris, *Multirate Signal Processing for Communication Systems*, Prentice Hall, 2004

Rationale:

The area of waveform design is of interest in several fields, including communication, radar and signal processing. It is a fertile ground for innovation, and has a number of significant open research problems. A course dedicated to such sequences and codes will be highly motivating to the graduate students, and will be of interest to a wide audience. It is expected that most students in our communications/radar/signals group will be interested in such a course.

Duplicate Check:

The following courses were consider for possible overlap:

EE606 Advanced Concepts in Sar Signal Processing, Prof. Saumekh.

No overlap was found. In a discussion with Prof. Saumekh, he confirmed absence of overlap, and found new course to complement his course and research activity, and to be of interest to his students.

EE538 Principles of Modern Digital Communication. Prof. Batalama.

No overlap was found. In a discussion with Prof. Batalama, she confirmed absence of overlap, but recommended I check with Prof. Pados, which I did next.

EE614 Smart Antennas, Prof Pados.

Prof. Pados confirmed that while there is no overlap with his course, some of the material in the new course reflects active current research interest of his, and he recommended adding material on certain sequences and on code division multiplexing signature design, which I have done.

Crosslisting: NONE

A the design and analysis of waveforms with applications mainly in radar and communications.

Topics covered include:

* Matched filters and system-level cosiderations
* Frequency modulated and phase-coded pulses
* Complete discussion of band-limiting schemes
* Coherent LFM pulse trains signal
* Diversity in pulse trains, including stepped frequency pulses
* Continuous-wave signals
* Multicarrier phase-coded signals
* Code division multiplexing signature design

Combining lucid explanation, preferred signal tables, MATLAB codes, and problem sets in each chapter, Radar Signals is an essential reference for professionals-and a systematic tutorial for any seeking to broaden their knowledge base in this dynamic field.

Detailed Analysis

Many radar texts have a chapter or two on radar signals, but not since Cook and Bernfeld's classic Radar Signals: An Introduction to Theory and Application (1967), was there a book dedicated entirely to radar waveforms. The progress in waveform design and analysis since 1967 deserves more than sporadic chapters in general radar texts. Levanon and Mozeson's new text fills the void in an authoritative and comprehensive way.

The preface mentions an interesting theme of the book: present hardware limitations will not censor worthwhile waveforms. Indeed, progress in digital signal processors, coherent sources and linear amplifiers, provided immense freedom in the design of communications signals. Radar is more conservative but will most likely follow communications and expand the breadth of the signals used. An example of signals that stretch the limits of present hardware are signals with variable amplitude, discussed in several chapters of the book. With such signals it is possible to drastically reduce the frequency sidelobes and meet spectrum emission limitations.

The book starts with introductory chapters (2, 3 and 4) on matched filter, ambiguity function and basic radar signals (constant frequency pulse, linear FM and coherent train of pulses). These chapters combine, in a concise and insightful way, both theoretical analysis and numerical results with clear and precise plots. They are followed by a chapter (5) on frequency modulated signals, which covers Costas signals and presents an intuitively appealing discussion of non-linear FM.

One of the highlights of the book is Chapter 6. It provides a comprehensive coverage of phase-coded signals, with unparalleled breadth and depth. Even seasoned experts in radar signals are likely to find in this chapter material they were not aware of. The many signal tables in the chapter contain up-to-date phase sequences, some of them presented in conferences held within the last year. The chapter's list of references (about 60) is of value by itself.

The most popular pulse compression signal - a coherent train of LFM pulses, gets a theoretical and numerical analysis in chapter 7. The analysis includes both intra- and inter-pulse weighting, for delay and Doppler sidelobe reduction. Chapter 8 is devoted to MTI signals with emphasis on diversity in pulse repetition interval.

"Coherent train of diverse pulses" is another exceptional chapter (8). Diversity can provide autocorrelation near-sidelobe reduction and recurrent lobes mitigation. Diversity can be obtained by making the pulses complimentary, orthogonal, or diverse in other ways. Diversity can also provide wider bandwidth, as in stepped-frequency pulses, which get extensive analysis in this chapter, including stretch processing. Diversity may be of special interest to electronic warfare and counter-measure experts, because it increases the number of permutations that a signal can have. This chapter contains some original material published recently by the authors.

Merrill Skolnik decided to remove CW signals from the 3rd edition of his classic text "Introduction to radar systems". "Radar Signals" takes the opposite view. CW signals receive considerable attention, including the entire Chapter 10. The analytical tool to analyze periodic signals is the periodic ambiguity function, defined and developed by Levanon and his students in the mid nineties and revisited in chapter 10. Periodic signals are of special theoretical interest because only they can produce ideal autocorrelation (zero sidelobes). Both phase-coded and frequency-modulated periodic signals are studied. CW signals are gaining renewed interest because of their low peak power, and are sometimes referred to as low probability of intercept

(LPI) signals. Although with a matched filter they are as detectable as any other signal. The authors do not take sides in this controversy, but offer excellent tools for analyzing CW signals.

Multicarrier signals were introduced to radar by the authors in a series of five papers published between 2000 and 2003. Chapter 11 covers the main results of these papers and more. It offers design rules and tables that yield multicarrier signals with good autocorrelation, while maintaining low peak-to-average power ratio.

The book chapters are embedded with MATLAB programs and each one of the 11 chapters is followed by a set of problems. The problems range from simple to extremely complex. Some problems could be considered as small research projects.

Especially commendable is the aesthetic look of the book with its many drawings and 3-D plots. The clarity and precision of the drawings provides instant intuition, teaches the signal's performances in a glance, and also attracts the reader to investigate deeper. In July 2002 the IEEE Transactions on AES found it worthwhile to publish a MATLAB code for plotting ambiguity functions, by Mozeson and Levanon. The book contains a more elaborate version of it, with a convenient graphic user interface (GUI). The authors use that program to plot ambiguity functions, autocorrelations and spectrums of the various signals. All the MATLAB programs in the book can be downloaded from Levanon's website at Tel Aviv University.

R & D in radar signals is likely to be affected by this book. Radar designers need to read it if they wish to find out what signals are currently known. Researchers will have to read it in order to avoid reinventing.

Frequency-Modulated Pulse

Phase-Coded Pulse

Coherent Train of LFM Pulses

Coherent Train of Diverse Pulses

Continuous-Wave Signals

Multicarrier phase-coded signals

Orthogonal frequency-division multiplexing
Multicarrier phase-coded signals with low PMEPR
PMEPR of an IS MCPC signal
Closed-form multicarrier bit phasing with low PMEPR
PMEPR of an MCPC signal based on COCS of a CLS
Single MCPC pulse
Identical sequence
MCPC pulse based on COCS of a CLS
CW (periodic) multicarrier signal
Train of diverse multicarrier pulses
ICS MCPC diverse pulse train
COCS of a CLS MCPC diverse pulse train
MOCS MCPC pulse train
Frequency spectra of MCPC diverse pulse train

NADAV LEVANON is a professor in the Department of Electrical Engineering-Systems at Tel-Aviv University, and head of its Weinstein Research Institute for Signal Processing. He is an IEEE Fellow, cited for "contributions to radar signal analysis and detection." He is the author of Radar Principles (Wiley).

ELI MOZESON, a former student of Dr. Levanon, is a practicing radar engineer.