Tutorial – Digital Signal Processing for Communications

PRIMARY AREA: Digital Circuits and Computer Arithmetic
RELATED AREA: Communications and Wireless Systems

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INSTRUCTOR BIO:

Michael Alan Soderstrand: Offering 40-years of experience including 11 years industry experience in computer-based design for telemetry, control systems and automatic test (Sandia National Laboratories) with 36 years of teaching and research including 26 years teaching Electrical and Computer Engineering at University of California, Davis, 5 years as Head of the Electrical and Computer Engineering Department at Oklahoma State University, 4 years as Adjunct Professor of Electrical Engineering and Computer Science at the DeVry University Oklahoma City Center and Adjunct Professor of Math, Statistics and Computer Science at Southern Nazarene University. Dr. Soderstrand is currently Adjunct Professor of Electrical Engineering at Yonsei University in Seoul, Republic of Korea. Dr. Soderstrand was General Co-Chair of last year’s IEEE International Midwest Symposium on Circuits and Systems (MWSCAS) and previously Co-Chaired the 2002 MWSCAS and chaired the 1997 MWSCAS. He is a member of the MWSCAS Steering Committee and maintains the MWSCAS web. He was elected Fellow of the IEEE in January 1999 and Life Fellow of the IEEE in January 2012.

This tutorial was presented at the International Conference on Electronics, Information and Communications (ICEIC 2012) held at the High-One Resort, Jeongseon, Republic of Korea, February 1-3, 2012. The tutorial drew an audience of approximately 60 and was very well received (http://iceic2012.org/sub/tutorial.html).

Learning Objectives: Provide an overview of DSP for communications appropriate for novices at the same time as providing several specific advanced techniques aimed at hardware/software improvement and adaptive filtering appropriate for those working in DSP for communications.

Target Audience: Graduate students, researchers and practicing engineers in DSP for communications.

ABSTRACT: This tutorial covers digital signal processing techniques for wireless communications. It consists of three 50-minute lectures. Lecture 1 covers basic DSP fundamentals, such as DFT, FFT, IIR and FIR filters and DSP algorithms. Lecture 2 covers DSP applications in wireless communications. Lecture 3 covers adaptive DSP. Various physical layer issues in wireless communications are addressed, including channel estimation, adaptive equalization, interference cancellation, pipelining for high-speed applications and adaptive heterodyne filters.

Modern telecommunications systems such as PSK and ASK, and sometimes FSK, are based on the principle of QAM. The I and Q signals can be combined into a complex-valued signal I+jQ (where j is the square root of -1). The resulting equivalent low-pass signal (baseband signal) is a representation of the real-valued modulated physical signal (called pass-band signal or RF signal). Digital Signal Processing (DSP) is key to both modulation and demodulation. In modulation (transmitter) DSP is used for pulse shaping needed to limit the bandwidth and form the spectrum of the equivalent low-pass signal, in the digital-to-analog conversion of the I and Q signals, in the generation of the high-frequency sine/cosine wave carrier waveform quadrature components, and modulation by multiplying the sine and cosine wave form with the I and Q signals resulting in the equivalent low pass signal with direct digital synthesis using waveform tables. In demodulation (receiver) DSP is used for channel equalization and attenuation of narrow-band interference as well as wave shaping. In this tutorial the novice will learn the basic concepts of DSP used in modern wireless systems while the expert will learn some specific techniques reduction of hardware using Canonical Sign-Digit CSD-based hardware, speeding up processing through pipelining and new techniques for narrow-band interference attenuation in the broadband receiver using adaptive heterodyne filters.
Introduction

This tutorial on DSP for Communications provides an overview of the major digital signal processing techniques commonly applied to modern wireless communication systems. The focus is on practical applications rather than theory. The tutorial is appropriate both for the novice and for the expert as major topics are summarized in a manner that should be very useful to the novice yet each of the three hour lectures has at least one detailed description of an advanced concept that can be used in practice to enhance speed, reduce power, optimize performance or provide DSP functions in a novel manner.

Part 1 – DSP Overview and Hardware Optimization with CSD

Part 1 starts with an overview of DSP techniques including the DFT, FFT, FIR digital filter design and IIR digital filter design. It then moves into a more detailed discussion of software implementation of DSP in practical communications systems and implementation issues for DSP in FPGA and ASIC hardware. Part 1 ends with a discussion of how hardware can be optimized using Canonic Sign Digit (CSD) hardware including a novel four quadrant multiplier based on CSD.

Part 2 – Pipelining to Dramatically Increase Throughput in DSP Systems

Part 2 starts with the introduction of the concept of pipelining and its application to individual hardware components such as adders and multipliers. It then moves into a brief look at the typical DSP structures for FIR and IIR filters and how each of these structures might be pipelined. The presentation is aimed at practical aspects of pipelining and includes detailed descriptions of how to pipeline IIR filters using four different techniques (scattered look-ahead, clustered look-ahead, minimum-denominator multiplier, and hybrid techniques). Part 2 ends with a survey of typical DSP applications in wireless communication systems including A/D conversion, symbol encoding, DSP issues in transmitters and receivers, frequency sources, squelch systems, harmonic sampling receivers, direct sampling receivers and modulation schemes such as FSK, PSK and QPSK.

Part 3 – Adaptive Digital Filtering

Part 3 starts with a brief overview of various adaptive filter applications in wireless communication systems. It then moves on to discuss in some detail the narrow-band interference problem in broad-band receivers and the use of adaptive filters for narrow-band signal attenuation. Details for the design of three novel techniques for Adaptive Heterodyne Filters are discussed with an aim at practical implementation in FPGA hardware and comparisons are made to alternative adaptive narrow-band signal attenuation using lattice structures, variable coefficient filters and switched filter banks.

Summary and Conclusions

The tutorial provides both and overview of DSP for communications and several practical applications discussed in sufficient detail for the tutorial attendee to design practical DSP systems based on what is presented in the tutorial. As currently designed, the three parts would be presented in three fifty-minute sessions. This could be structured with two 15-minute breaks, one coinciding with the 15-minute coffee break. The result would be a 3-hour tutorial with sufficient break time for individual questions and the scheduled 15-minute coffee break.