EE/TE 4385 DSP-Based Design Project I

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TA: TBA

http://www.utdallas.edu/~torlak/courses/DSPproject

Why Senior Design Project?

<table>
<thead>
<tr>
<th>Ideal World</th>
<th>Real World</th>
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<td>supposes that there is one right answer to a given question.</td>
<td>supposes that there are many workable solutions but that, among workable solutions, some are much better than others.</td>
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<td>involves only one disciplinary perspective or discrete body of knowledge.</td>
<td>is broadly multidisciplinary.</td>
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<td>is bounded more than it is constrained, largely because it is abstracted from context.</td>
<td>is unbounded and fully embedded in context.</td>
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<td>deals with components rather than with systems.</td>
<td>deals with systems rather than components.</td>
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<td>typically requires great powers of imagination to develop an understanding of the social and ethical context of the work in question.</td>
<td>provides direct experience of the social and ethical impacts of technology and of the human and organizational dynamics that characterize the context of engineering practice.</td>
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- Thus, the major design experience needs to introduce students to the messiness of “the real world.”

How?

- **Overview of EE/TE 4385**
  - Objectives
    - Learn real-time signal processing concepts and build a digital radio on a digital signal processor
  - Course components
    - **Lectures** (includes a Midterm and homework assignments)
    - **Laboratory** experiments (groups of two)
      - Labs are conducted by Teaching Assistant
      - Overview of hardware and software tools in ECSN 3.114
      - Sinusoidal generation: sinusoidal modulation
      - Finite impulse response filter
      - Pseudo-noise sequence generation
      - Pulse amplitude modulation and demodulation
    - **Project**: Digital Radio (or Software-Defined Radio)
      - Designed and built by each group on TI TMS320C6711DSK

Student Responsibilities

- “Students must be able to integrate previous coursework and exhibit technical competence, apply the design process and project management skills to a realistic problem, and demonstrate teamwork and communication skills.”

From “Processes For Ensuring Quality Capstone Design Projects”, Ralph M. Ford and William C. Lasher
Prerequisites

- EE 2310 Computer Organization and Design
  - Assembly

- EE 3350 Communications Systems, or
  - Modulation and demodulation

- EE 4350 Digital Communications, or
  - Digital transmission

- EE 4361 Intro. To Digital Signal Processing
  - Sampling, filters, quantization, etc

Course Materials

- Course Web Site: [http://www.utdallas.edu/~torlak/course/DSProject](http://www.utdallas.edu/~torlak/course/DSProject)

- Textbooks (Optional)

Supplemental Texts

- S. A. Tretter, *Comm. system design using DSP algorithms: with lab experiments for the TMS320C601 and TMS320C6711*,
  - Assumes DSP theory, algorithm, and processor knowledge
  - DSP theory and algorithms at sophomore level
  - DSP processor tutorial with source code examples

Grading

- **Calculation of numeric grades**
  - 10% homework (four assignments)
  - 10% Midterm
  - 30% Laboratory (five lab reports)
  - 50% Project: Demonstration, Implementation, and report
- **No late homework assignments/lab reports accepted**
- **Laboratory**
  - Lab team members assigned same lab report grade
  - Can drop lowest HW or Lab grade
- **Deliverable: Project Demo and Report**
- **No final exam**
Lectures

- Review of Complex Numbers
- Digital signal processing
  - Signals, sampling, filtering, and quantization
  - Oversampling and data converters
- Digital signal processor (DSP) architectures
  - Harvard architecture, special addressing modes
  - Parallel instructions, pipelining, real-time programming
- Digital communications
  - Analog/digital, modulation/demodulation
  - Pulse shaping and pseudo-noise sequences

Laboratory Experiments

- Laboratory
  - Ends at the half of the semester with lectures
  - Groups of two
- Labs are conducted by Teaching Assistant
  - TA: TBA
  - Wednesday and additional day labs
- Five experiments
  1. Overview of hardware and software tools in EC 3.120
  2. Sinusoidal generation: sinusoidal modulation
  3. Finite impulse response (FIR) filter
  4. Pseudo-noise (PN) sequence generation
  5. Pulse amplitude modulation (PAM) and demodulation
Deliverable: Project

- After completing five laboratory experiments,
  - Each lab group will build a complete digital radio (or a software-defined radio) that includes each part of a typical digital communication system.
  - You will build your digital radio based on QAM digital modem within voiceband (remember dialup modems?) using TI TMS320C6711 DSK.
- You will have to complete
  - Labview simulation of digital radio based on QAM modulation and demodulation and a 4-page description of your simulation (due: Wednesday lab, 10/25/06)
  - Project demonstration based on TMS320C6711 DSK (Labview, C, and Assembly) and presentations are scheduled for Monday 11/27/06.
- A project report will be due at 5PM, Friday, 12/1/06.

TMS320C67 Manuals

- You need to refer to various TMS320C6000 manuals, which are only available electronically:
  - Code Composer User’s Guide (328B)
  - Optimizing C Compiler (187K)
  - Programmer’s Guide (198G)
    - http://www-s.ti.com/sc/psheets/spru198g/spru198g.pdf
  - CPU and Instruction Set Reference Guide (189F)
Lab Ex: Sine Wave Generation

- Make your sine wave in DSP
- Evaluation procedure: Validate sine wave frequency on scope, and test for various sampling rates

Test your algorithm in LabVIEW
Code Composer Studio 2.2

LabView QAM Modem
Communication Systems

- **Transmitter**
  - Signal processing conditions the message signal
  - Lowpass filtering to make sure that the message signal occupies a specific bandwidth, e.g. in AM and FM radio
  - Add redundancy to the message bit stream $m[n]$ to assist in error detection (and possibly correction) in the receiver

- **Receiver**
  - Carrier circuits undo effects of carrier circuits in transmitter, e.g. demodulation
  - Signal processing subsystem extracts and enhances the baseband signal

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Example: Faster Than Dial-Up?

- Multicarrier modulation divides broadband (wideband) channel into narrowband subchannels
  - Uses Fourier series computed by fast Fourier transform (FFT)
  - Standardized for IEEE 802.11a/g wireless LAN & 802.16a

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Each ADSL/VDSL subchannel is 4.3 kHz wide (about a voice channel) and carries a QAM signal

Slide by Prof. Evans
Signal Processing Systems

- Speech synthesis and speech recognition
- Audio CD players
- Audio compression (MP3, AC3)
- Image compression (JPEG, JPEG 2000)
- Optical character recognition
- Video CDs (MPEG 1)
- DVD, digital cable, and HDTV (MPEG 2)
- Wireless video (MPEG 4/H.263)

Audio Compact Discs

- Human hearing is from about 20 Hz to 20 kHz
- Sampling theorem: sample analog signal at rate of more than twice highest analog frequency
  - Apply a lowpass filter to pass frequencies up to 20 kHz; e.g., a coffee filter passes water (small particles) through but not coffee grounds (large particles)
  - Lowpass filter needs 10% of maximum passband frequency to roll off to zero (2 kHz rolloff in this case)
  - Sampling at 44.1 kHz captures analog frequencies that are less than 22.05 kHz
- Other examples of signal processing systems?
Communication Systems

- Voiceband Dialup/Fax modems
- Digital subscriber line (DSL) modems
  - ISDN: 144 kilobits per second (kbps)
  - Business/symmetric: HDSL and HDSL2
  - Home/asymmetric: ADSL and VDSL
- Cable modems
- Cell phones
  - First generation (1G): AMPS
  - Second generation (2G): GSM, IS-95 (CDMA)
  - Third generation (3G): cdma2000, WCDMA

What is a DSP?

- Digital Signal Processor (DSP) process digital signals
- An alternative method to process analog world signals
- Digital technology offers tremendous processing power

```plaintext
ADC → DSP → DAC
```

- Convert analog signals into electrical signals
- Digitize these signals using an analog-to-digital converter (ADC)
- Once the signal is in digital form, digital signal processor (DSP) can easily process it.
- The DSP specializes in processing these signals, thus, it is slightly different from microprocessors and microcontrollers.
- After the DSP has processed the signal, the output signal must be converted back to analog so that we can sense it
Why Digital Signal Processing?

- Advantages of digital signal processing
  - Programmability – one hardware many tasks
  - Flexibility and upgradeability – develop a new code
  - Repeatability – A CD player always plays the same music quality
  - Specific functions – compression and digital filtering
- Advantages of Analog signal processing
  - low cost in some applications – attenuators, amplifiers
  - wide bandwidth (GHz)
  - Infinite resolution (no quantization error) and low signal levels

Characteristics of DSP processors

- Mostly designed with the same few basic operations in mind
- They share the same set of basic characteristics
- These characteristics fall into three categories:
  - specialized high speed arithmetic
  - data transfer to and from the real world
  - multiple access memory architectures
A DSP System

- DSP chip
  - Arithmetic logic Unit
  - TMS320C6X
- Memory
- Converters
  - Analog-to-digital
  - Digital-to-analog
- Communication Ports
  - Serial
  - Parallel

Review: Signals

- Continuous-time signals are functions of a real argument
  - $x(t)$ where $t$ can take any real value
  - $x(t)$ may be 0 for a given range of values of $t$
- Discrete-time signals are functions of an argument that takes values from a discrete set $x[n]$
  - $n \in \{-3, -2, -1, 0, 1, 2, 3, \ldots\}$
  - Integer index $n$ instead of time $t$ for discrete-time systems
- Values for $x$ may be real or complex
Analog and Digital Signals

- Amplitude of an analog signal can take any real or complex value at each time/sample

- Amplitude of a digital signal takes values from a discrete set

Review: Systems

- A system is a transformation from one signal (called the input) to another signal (called the output or the response).

- Continuous-time systems with input signal $x$ and output signal $y$ (a.k.a. the response):
  
  \[ y(t) = x(t) + x(t-1) \]
  
  \[ y(t) = x^2(t) \]

- Discrete-time system examples
  
  \[ y[n] = x[n] + x[n-1] \]
  
  \[ y[n] = x^2[n] \]
Review of Sinusoidal Signals

- Make the angle a function of t
  \[ x(t) = A \cos(\omega_0 t + \phi) = A \cos(2\pi f_0 t + \phi) \]
  - A: amplitude, \( \phi \): phase shift, \( \omega_0 \): radian frequency, and \( f_0 \): cyclic frequency
- Relation to the period, \( x(t) = x(t + T_0) \)
- Phase shift and time shift
  \[ \text{if } x_0 = A \cos(\omega_0 t), \quad x_0(t-t_1) = ? \]
  - Express the phase shift in terms of \( t_1, f_0 \) or \( T_0 \)
- Discrete time representations

Review of Complex Numbers

- Cartesian and polar representations
  - \( z = x + jy \) or \( z = re^{j\theta} \)
  - \( x = \Re\{z\} \) and \( y = \Im\{z\} \)
  - \( e^{j\theta} = \cos(\theta) + j\sin(\theta) \)
- Complex number multiplication
  - \( z = r_1 e^{j\theta_1} \) and \( z = r_2 e^{j\theta_2} \)
  - \( z = z_1 z_2 = ? \)
  - Phasor = complex amplitude
Review of Complex Exp. Signals

- Complex exponential signals
  - $z(t) = Ae^{j(w_0t + \phi)}$, find $|z(t)|$ and $\arg z(t)$

- Any sinusoid can be written
  
  $$A \cos(w_0t + \phi) = \Re \{ Ae^{j(w_0t + \phi)} \} = \Re \{ Ae^{j\phi}e^{jw_0t} \}$$

- Phasor addition rule

$$x(t) = \sum_{k=1}^{N} A_k \cos(w_0t + \phi_k) = A \cos(w_0t + \phi)$$

- Instead use the following addition of complex numbers

$$\sum_{k=1}^{N} A_k \cos(w_0t + \phi_k) = \sum_{k=1}^{N} \Re \{ A_k e^{j(w_0t + \phi_k)} \}$$