Telecommunications and Signal Processing at UT Austin

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http://www.ece.utexas.edu
Outline

• Introduction
• Wireline Communications speaker phones, ADSL modems
• Wireless Communications base stations, video cell phones
• Raster Image Processing printers, copiers, next-generation fax
• Power Quality Assessment next-generation power meters
• Computer Architecture high-performance processors
• Conclusion
Telecommunications & Signal Processing Faculty

- **Signal and Image Processing**
  - J. K. Aggarwal  *image, vision, ATR*
  - Alan Bovik  *image, video, vision*
  - Brian Evans  *real-time DSP software*
  - Joydeep Ghosh  *neural networks*
  - Margarida Jacome  *DSP architecture*
  - Lizy John  *DSP architecture*
  - Thomas Milner  *biomedical imaging*
  - John Pearce  *biomedical imaging*
  - Irwin Sandberg  *nonlinear systems*
  - Earl Swartzlander  *VLSI DSP*

- **Networking**
  - Ross Baldick  *Internet pricing*
  - Bill Bard  *(adjunct) security, TCP/IP*
  - Gustavo de Veciana  *performance*
  - Takis Konstantopoulos  *analysis*
  - San-qi Li  *ATM networks/switches*
  - Scott Nettles  *active networks*

- **Systems and Controls**
  - Aristotle Araposthatis  *stochastic*
  - Robert Flake  *manufacturing*
  - Baxter Womack  *machine learning*

- **Wireless Communications**
  - Hao Ling  *propagation, E911*
  - Edward Powers  *satellite*
  - Guanghan Xu  *smart antennas*

- **Speech and Audio Processing**
  - Mark Hamilton  *(ME) audio/acoustics*
  - Randy Diehl  *(Psychology) speech*
  - Russell Pinkston  *(Music) synthesis*

[http://www.ece.utexas.edu/telecom/faculty.html](http://www.ece.utexas.edu/telecom/faculty.html)
<table>
<thead>
<tr>
<th>Area</th>
<th>Graduate Courses</th>
<th>Undergraduate Courses</th>
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<td>Audio and Acoustics</td>
<td>• Acoustics I</td>
<td>• Noise and Vibration Control</td>
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<td>• Digital Signal Processing</td>
<td>• Linear Systems and Signals</td>
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<td>• Advanced Signal Processing</td>
<td>• Digital Signal Processing</td>
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<td>• Signal Compression</td>
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<td>Digital Signal Processing</td>
<td>• Digital Communications</td>
<td>• Probability, Statistics, Random Processes</td>
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<td>• Wireless Communications</td>
<td>• Communication Systems</td>
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<td>• Advanced Probability and Random Processes</td>
<td>• Intro. to Digital Communications</td>
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<tr>
<td>Communications</td>
<td>• Communication Networks: Tech., Arch., Protocols</td>
<td>• Intro. to Telecommunication Networks</td>
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<td>• Communication Networks: Analysis &amp; Design</td>
<td>• Networking Engineering Laboratory</td>
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<td>• Advanced Telecommunication Networks</td>
<td>• Distributed Information Security</td>
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<td>Networking</td>
<td>• Multidimensional Digital Signal Processing</td>
<td>• Digital Image Processing</td>
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<td>• Biomedical Image Processing</td>
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<td>Image and Multidimensional Signal Processing</td>
<td>• Application-Specific Processing</td>
<td>• Microprocessor Programming</td>
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<td>• <strong>Superscalar Microprocessor Architecture</strong></td>
<td>• Microprocessor Applications/Organization</td>
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<td>• <strong>High-Level Synthesis</strong></td>
<td>• Microprocessor Interfacing Lab</td>
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<td>• <strong>Embedded Software Systems</strong></td>
<td>• Real-Time DSP Laboratory</td>
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<td>• Hardware/Software Codesign</td>
<td>• Computer Architecture</td>
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<td>• Data Mining</td>
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<td>• Neural Networks</td>
<td>• Introduction to Neural Networks</td>
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Yellow underlined: four courses using TI DSPs  
Green italics: three courses using Motorola microcontrollers
Undergraduate Telecommunications Laboratories

• Three Microprocessor Laboratories (Lipovski and Valvano)
  – *Topics*: microcomputer organization, modular programming in C and assembly, interfacing, real-time software, data acquisition, communication, control
  – *Laboratory*: develop software on and interface hardware to Motorola MC68HC11 and MC68HC12 microcontroller boards
  – *Enrollment*: 500 per year

• Real-time Digital Signal Processing Laboratory (Evans)
  – *Topics*: digital signal processing, data conversion, digital communications, DSP architecture, real-time software, ADSL modems
  – *Laboratory*: build a voiceband modem on TMS320C30 EVM in C and DSP assembly language using Code Composer
  – *Enrollment*: 100 per year

• Network Engineering Laboratory (Bard)
  – *Topics*: ATM, TCP/IP, Ethernet, routers, switches, firewalls, servers, security
  – *Laboratory*: configure Cisco equipment and PCs to create/analyze network services
  – *Enrollment*: 20 per year (limited by space)
Touchtone Decoding for Speaker Phones

- **Problem:** Algorithms based on the Fourier transform cannot meet ITU Q.24 specifications.
- **Goal:** Develop first ITU-compliant touchtone detector using 8-bit arithmetic.
- **Solution:** Nonlinear frequency estimation by zero crossings using Friedman interpolator.
- **Implementation:** 5-MIP 8-bit PIC16C711, 64 bytes data, 800 bytes program memory (1998).
- **Funding:** Nat. Sci. Foundation.

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<th>Frequency (Hz)</th>
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<th>1477 Hz</th>
<th>1633 Hz</th>
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<td>697 Hz</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>A</td>
</tr>
<tr>
<td>770 Hz</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>B</td>
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<tr>
<td>852 Hz</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>C</td>
</tr>
<tr>
<td>941 Hz</td>
<td>*</td>
<td>0</td>
<td>#</td>
<td>D</td>
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**ITU DTMF Specifications**

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<tr>
<th>Frequency Tolerance</th>
<th>Low Group</th>
<th>≤ 1.5%</th>
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<tr>
<td>High Group</td>
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<td>≥ 3.5%</td>
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<tr>
<td>Signal Duration</td>
<td>Operation</td>
<td>40 ms min</td>
</tr>
<tr>
<td></td>
<td>Non-operation</td>
<td>23 ms max</td>
</tr>
<tr>
<td>Signal Exceptions</td>
<td>Pause Duration</td>
<td>40 ms max</td>
</tr>
<tr>
<td></td>
<td>Signal Interruption</td>
<td>10 ms min</td>
</tr>
<tr>
<td>Twist</td>
<td>Forward</td>
<td>8 dB</td>
</tr>
<tr>
<td></td>
<td>Reverse</td>
<td>4 dB</td>
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</table>

WIRELINE COMMUNICATIONS (EVANS)
Touchtone Decoding for Central Offices

**Problem:** Algorithms based on the Fourier transform cannot meet ITU Q.24 specifications

**Goal:** Develop first ITU-compliant touchtone decoder on a single DSP for a T1/E1 line

**Solution:** Multiresolution algorithm (1997)
- Sliding windows of 106 and 212 samples to meet both ITU frequency and timing specs (106 samples = 13.3 ms)
- Signal analysis to provide power level and talk-off checks
- Finite state machine (FSM) to enforce ITU specifications
- UT Austin filed a patent application on April 3, 1998, on the detector (30 claims)

**Implementation:** To decode 24 (32) voice channels of a T1 (E1) line: 17 (22) DSP MIPS, 800 data words, 1100 (1500) program words: **30-MIP TI C54, 16 kw RAM, 4 kw ROM** (1998)

**Funding:** UT Austin

*Wireline Communications (Evans)*
Improving Performance of ADSL Modems

- **Problem:** Equalizer design
  - Is computationally complex
  - Does not maximize bit rate
- **Goal:** Design time-domain equalizer to maximize bit rate
- **Solution:** Model signal, noise, ISI paths in equalized channel
  - Derive cost function for ISI power as a function of equalizer taps
  - Solve constrained quadratic optimization problem to minimize ISI power
- **Implementation:** Suboptimal method weights ISI power in freq.
  - Achieves 98% of channel capacity with 2 taps not 17 (500x complexity reduction)
  - Achieves up to 18% more bit rate for same number of taps for ADSL channels
- **Funding:** None (worked performed 1999–present)

*Wireline Communications (Evans)*
Wireless Base Station Design

- **Problem:** Mobile wireless services hampered by cochannel interference, multipath effects, fading, and noise
- **Goal:** Increase system quality and capacity through spatial diversity
- **Solution:** Base station smart antennas
- **Implementation #1:** First university smart antenna testbed (1993)
  - Characterize wireless channels & test smart antenna algorithms: 1.5 GHz, 900 MHz
- **Implementation #2:** Real-time narrow band testbed (1997)
  - Mobile: 2 30-MIP DSPs for speech codec
  - Base: 16 A/Ds, D/A's, DSPs; 2 33-MIP DSPs baseband
  - Funding: GE, Motorola, Raytheon TI, DoD (ONR/JSEP)
- **Implementation #3:** Wide band testbed (now)
  - Analog/IF baseband goes from 0.5 to 5 MHz
  - Funding: SBC, State of Texas, Nat. Science Foundation

Wireless Communications (Xu & Ling)
H.263 Video Cell Phone Implementation

- **Problem:** Motion compensation takes 80% of computation in H.263 encoder
- **Goal:** Real-time H.263 codec on DSPs
- **Solution:** Handcode sum-of-absolute differences for two 16 x 16 subblocks
  - 9.2 : 1 speedup on C62x over C implementation with all compiler optimizations enabled
- **Implementation:** Modify H.263 codec in C from Univ. of British Columbia
  - TI’s DCT/IDCT gives speedup of 2.7/2.3
  - Overall speedup of 4:1 – 10 QCIF (176 x 142) frames/s on 300 MHz C67x
- **Funding:** TI DSP R&D Fund, State of Texas (started 1/15/00)
  - TI Contacts: Raj Talluri, Raja Rajasekaran, and Bob Hewes

*Wireless Communications (Bovik & Evans)*
Improving H.263 Video Cell Phone Performance

- **Problem**: Controlling transmission rate, buffer size, and subjective quality
- **Goal**: Use nonuniform sampling of fovea
  - Resolution on retina falls off $1/r^2$ away from fovea
  - Need point(s) of focus for observer(s)
- **Solutions**: Foveation points are estimated or obtained by eye tracker
  - Preprocessing: apply spatially-varying linear filter with cutoff freq. proportional to local bandwidth
  - Modify encoder: foveation simplifies motion est.
- **Implementation**: Demo available at http://pineapple.ece.utexas.edu/class/Video/demo.html (presented at TI DSP Systems Fest ‘99, Houston, TX)
- **Funding**: Same project as previous slide

\[ e_x = \tan^{-1}\left( \frac{i_d \cdot d_x}{i_p \cdot V_d} \right) \]
Improving Image Quality in Printers and Copiers

- **Problem:** Halftoning (binarizing images for printing) introduces linear distortion, nonlinear distortion, and additive noise.
- **Goal:** Develop low-complexity high-quality halftoning algorithms.
- **Solution:** Model quantizer as gain plus noise (1997-present)
  - Halftone quality: edge sharpness (quantizer gain) and noise (noise transfer function)
  - Inverse halftones: blurring and spatially-varying noise
- **Funding:** HP, National Science Foundation, UT Austin
  - TI Contacts: Jim Bearss, Eric Brandom, Frank Minich
Next-Generation Fax Machines

- **Problem:** Fast algorithms for high-quality JBIG2 compression of halftones (JBIG2 standard adopted in April 2000 by ITU-T)
- **Goal:** Develop low-complexity encoding algorithms with good rate-distortion tradeoffs
- **Solution:** Filter, descreen, error diffuse, quantize (1999-present)
  - Use small symmetric FIR prefilter to reduce noise before descreening
  - Modify error diffusion: reduce gray levels & sharpening and trade off rate-distortion
  - Measures of subjective quality based to rank encoding methods
- **Funding:** National Science Foundation, UT Austin

*Raster Image Processing (Evans)*
Next-Generation Power Meters

**Problem:** A power quality disturbance can result in a loss of $0.5M to $2.0M in semiconductor industry (Dennis Johnson, TI, 5/3/2000, Texas Electrical Power Quality Workshop, UT Austin)
- Disturbance: deviation from constant amplitude, freq. and phase in voltage/current
- Deregulation: different providers of power generation, transmission, and distribution

**Goal:** Detect/classify transient power quality disturbances

**Solution:** Methods (1993-present)
- Detect voltage sag, capacitance switching, and impulsive events in presence of noise
- Characterize statistics by constant false alarm rate detectors to set thresholds

**Implementation:** DSPs for future power meters and fault recorders
- TI contacts: Joe Childs, Dennis Johnson, and Mike Masten

**Funding:** Electric Power Research Institute, State of Texas, TXU

*Power Quality (Powers & Grady)*
High-Performance Microarchitecture

• **Problem:** How to harness larger and larger numbers of transistors on a chip on behalf of higher performance processing

• **Goal:** Develop microarchitectures to improve performance

• **Solution #1:** Four-wide issue general-purpose processor (1984)
  – 1984: everyone laughed at it
  – 1996: everyone is doing it

• **Solution #2:** Two-level branch predictor (1991)
  – 1995: Intel first to adopt it (PentiumPro)
  – 2000: widely used as top-of-line predictor

• **Funding:** AMD, HAL Computer, IBM, Intel, Motorola

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**Current Research**

- Trace cache optimization
- Subordinate simultaneous microthreading
- Low-power implementations
- Application-specific high-performance coprocessors
Conclusion

• UT ECE Department
  62 full-time faculty, 1730 undergraduates, 570 graduate students

• UT ECE R&D in telecommunications and signal processing
  22 full-time faculty, 300 undergraduates, 200 graduate students

• Leader in several telecommunication and signal processing R&D areas for high-volume products using digital signal processors
  – Wireline communications (touchtone detectors)
  – Wireless communications (wireless base stations and video cell phones)
  – Raster image processing (printers, copiers, and fax machines)
  – Power quality assessment (next-generation power meters and fault recorders)
  – Computer architecture (high-performance processors and coprocessors)
ADSL Modems

- **Multicarrier modulation**: Decompose channel into subchannels
  - Standardized for ADSL (ANSI 1.413) and proposed for VDSL
  - Implemented by the fast Fourier transform (FFT): efficient DSP implementation

- **Cyclic prefix**: Append guard period to each symbol
  - Receiver has a **time-domain equalizer** to shorten effective channel length to be less than the cyclic prefix length to reduce intersymbol interference (ISI)
  - Helps receiver perform symbol synchronization
ITU-T H.263 Video Encoder

Coding control

2-D DCT

Q

Q⁻¹

2-D IDCT

MCP

VLC

Control info

Quantizer index for transform coefficient

Motion vectors

DCT = Discrete Cosine Transform
MCP = Motion Compensation
VLC = Variable Length Coding

Appendix: Wireless Communications
Model Based Image Quality Assessment

• **Problem:** Develop quality measures to quantify the performance of image restoration algorithms
• **Goal:** Decouple linear distortion and noise injection
• **Solution:**
  – Modeled degradation as spatially varying blur and additive noise
  – Developed distortion measure to quantify linear distortion
  – Developed Non-linear Quality Measure (NQM) for additive uncorrelated noise

**Appendix: Raster Image Processing (Evans)**

- White noise added
  - SNR = 10.00 dB
  - NQM = 20.47 dB

- Filtered white noise added
  - SNR = 10.00 dB
  - NQM = 32.65 dB
Adaptive Algorithms for Image Halftoning

- **Problem:** Low-complexity adaptive algorithm to minimize nonlinear and linear distortion in digital halftoning
- **Goal:** Threshold modulation method to preserve sharpness of original (a.k.a. what-you-see-is-what-you-get halftone)
- **Solution:**
  - Minimize linear distortion: develop a framework for adaptive threshold modulation
  - Reduce nonlinear distortion: use a deterministic bit flipping (DBF) quantizer to eliminate limit cycles

Appendix: Raster Image Processing (Evans)
Speaker Localization Using Neural Networks

- **Problem:** Estimate speaker location (applications in videoconferencing and acoustic echo cancellation)

- **Goal:** Develop low-cost speaker location estimator for microphone array that works in far and near fields

- **Solution:** Neural network
  - Train multilayer perceptron off-line with normalized instantaneous cross-power spectrum samples as feature vectors (4 input nodes, 10 hidden nodes, and 1 output node)
  - Using more than four microphones gives diminishing returns
  - Less than 6° average error for modeled speech
  - Massively parallel with possible fixed-point implementation

- **Implementation:** 1 MFLOPS/s for 4 microphones at 8 kHz, 16 bits

*Appendix: Speech Processing (Evans)*
Multi-Criteria Analog/Digital IIR Filter Design

- **Problem:** Optimize multiple filter behavioral and implementation characteristics simultaneously for analog and digital IIR filters
- **Goal:** Develop an extensible, automated framework
- **Solution:** Filter optimization packages for Mathematica
  - Solve constrained nonlinear optimization using Sequential Quadratic Programming: converges to global optimum and robust when closed-form gradients provided
  - Program *Mathematica* to derive formulas for cost function, constraints, and gradients, and synthesize formulas as Matlab programs to run optimization
- **Analog example:** linearize phase, minimize overshoot, max Q \( \leq 10 \)

Appendix: Filter Optimization (Evans)

http://www.ece.utexas.edu/~bevans/projects/syn_filter_software.html