# Telecommunications and Signal Processing at UT Austin

*Prof. Brian L. Evans*

http://www.ece.utexas.edu/~bevans

**Department of Electrical and Computer Engineering**
**The University of Texas at Austin, Austin, TX 78712-1084**

**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*
- Wireless Communications
  - Hao Ling *propagation, E911*
  - Edward Powers *satellite*
  - Guanghan Xu *smart antennas*
- 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 Arapostathis *stochastic*
  - Robert Flake *manufacturing*
  - Baxter Womack *machine learning*
- 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*

# Telecommunications & Signal Processing Courses

| ***Area*** | ***Graduate Courses*** | ***Undergraduate Courses*** |
|---|---|---|
| ***Audio and Acoustics*** | • Acoustics I | • Noise and Vibration Control |
| ***Digital Signal Processing*** | • Digital Signal Processing<br>• Advanced Signal Processing<br>• Signal Compression | • Linear Systems and Signals<br>• Digital Signal Processing |
| ***Communications*** | • Digital Communications<br>• Wireless Communications<br>• Advanced Probability and Random Processes | • Probability, Statistics, Random Processes<br>• Communication Systems<br>• Intro. to Digital Communications |
| ***Networking*** | • Communication Networks: Tech., Arch., Protocols<br>• Communication Networks: Analysis & Design<br>• Advanced Telecommunication Networks | • Intro. to Telecommunication Networks<br>• Networking Engineering Laboratory<br>• Distributed Information Security |
| ***Image and Multidimensional Signal Processing*** | • Multidimensional Digital Signal Processing<br>• Biomedical Image Processing | • Digital Image Processing |
| ***Embedded Systems*** | • Application-Specific Processing<br>• Superscalar Microprocessor Architecture<br>• High-Level Synthesis<br>• Embedded Software Systems<br>• Hardware/Software Codesign | • *Microprocessor Programming*<br>• *Microprocessor Applications/Organization*<br>• *Microprocessor Interfacing Lab*<br>• Real-Time DSP Laboratory<br>• Computer Architecture |
| ***Neural Networks*** | • Data Mining | • Introduction to Neural Networks |

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

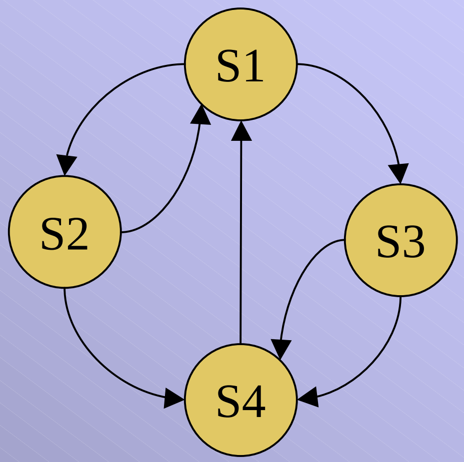
| | **1209 Hz** | **1336 Hz** | **1477 Hz** | **1633 Hz** |
|---|---|---|---|---|
| **697 Hz** | 1 | 2 | 3 | A |
| **770 Hz** | 4 | 5 | 6 | B |
| **852 Hz** | 7 | 8 | 9 | C |
| **941 Hz** | * | 0 | # | D |

**ITU DTMF Specifications**

| | | |
|---|---|---|
| *Frequency Tolerance* | Low Group | $\leq 1.5\%$ |
| | High Group | $\geq 3.5\%$ |
| *Signal Duration* | Operation | 40 ms min |
| | Non-operation | 23 ms max |
| *Signal Exceptions* | Pause Duration | 40 ms max |
| | Signal Interruption | 10 ms min |
| *Twist* | Forward | 8 dB |
| | Reverse | 4 dB |

# Touchtone Decoding for Central Offices

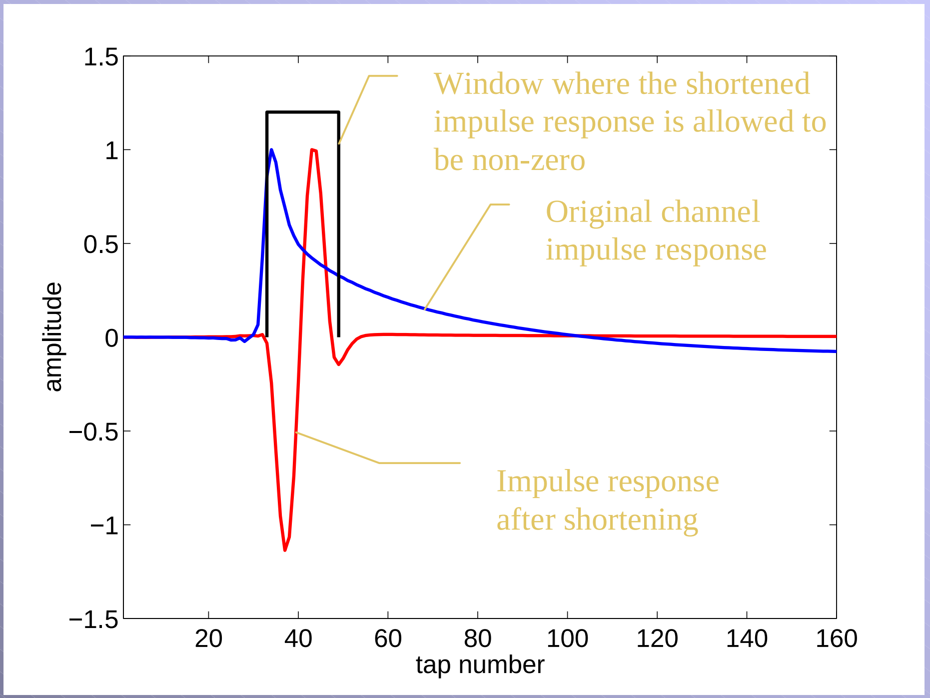
- *Problem:* Algorithms based on the Fourier transform cannot meet ITU Q.24 specifications
- *Goal:* Develop first ITU-compliant touchtone decoder on a single DSP for a T1/E1 line
- *Solution:* Multiresolution algorithm (1997)
  - Sliding windows of 106 and 212 samples to meet both ITU frequency and 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



FSM

# 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



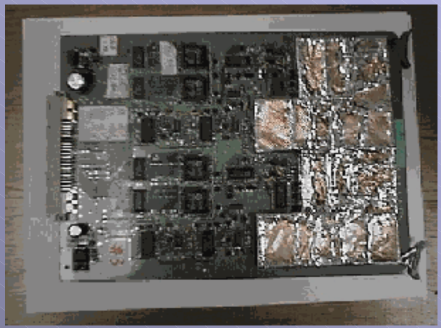

- *Implementation:* Suboptimal method weights ISI power in freq.
  - Achieves 98% of channel capacity with 2 taps not 17 (*500x complexity reduction*)
  - Achieves up to 18% more bit rate for same number of taps for ADSL channels
- *Funding:* None (Motorola contacts: Sayfe Kiaei, Jim Kosmach)

# 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

Narrow Band Testbed (1.8 GHz)

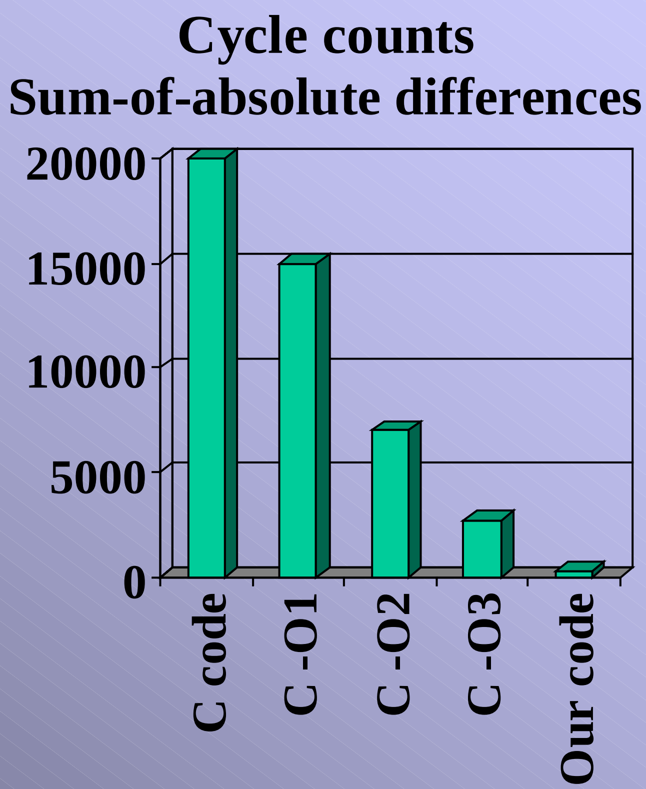
- *Implementation #1:* First university smart antenna testbed (1993)
  - Characterize wireless channels & test smart antenna algorithms: 1.5 GHz, 900 MHz
- *Implementation #2:* Real-time narrow band testbed (1997)
  - Mobile: 2 30-MIP DSPs for speech codec
  - Base: 16 A/Ds, D/As, DSPs; 2 33-MIP DSPs 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



TX/RX Circuit Board

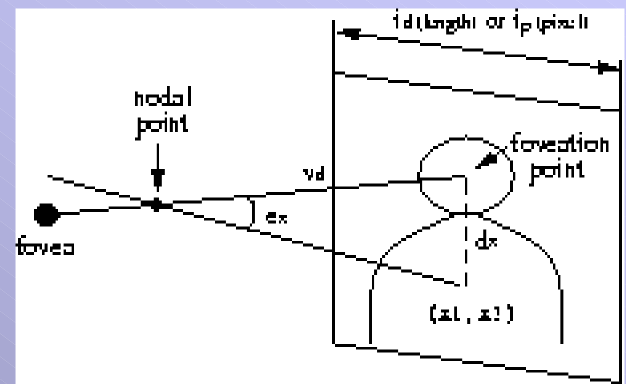
# H.263 Video Cell Phone Implementation

- *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, State of Texas (started 1/15/00)
  - Motorola contact: Dana Taipale

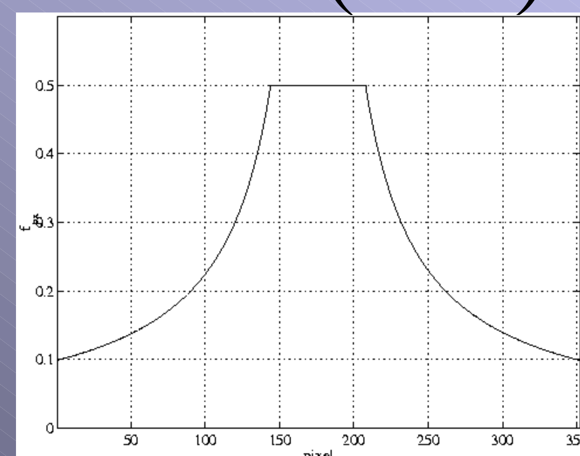


# Improving H.263 Video Cell Phone Performance

- *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
- *Funding:* Same project as previous slide




$$e_x = \tan^{-1}\left( \frac{i_d \, d_x}{i_p \, v_d} \right)$$



# 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

Original Image

Halftoned Image

Inverse Halftone

*Raster Image Processing (Evans)*

# 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

Original

Compressed (5:1)

# 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

| ***Signal Analysis Methods*** | ***Classification Methods*** |
| --- | --- |
| Linear prediction | Neural network |
| Wavelets (6 scales) | Rule-based |
| Teager operator | Hidden Markov |
| Wigner operator | models |

- *Implementation:* DSPs for future power meters and fault recorders
- *Funding:* Electric Power Research Institute, State of Texas, TXU

# 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

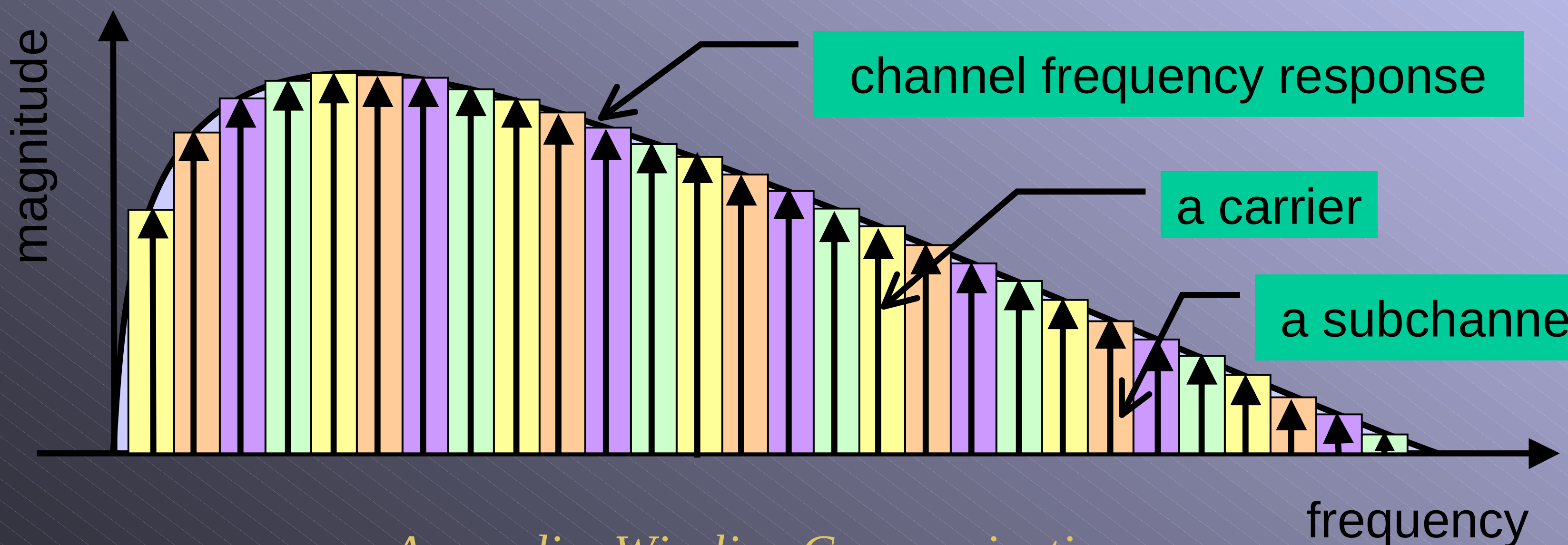
| ***Current Research*** |
| --- |
| Trace cache optimization |
| Subordinate simultaneous microthreading |
| Low-power implementations |
| Application-specific high-performance coprocessors |

# Conclusion

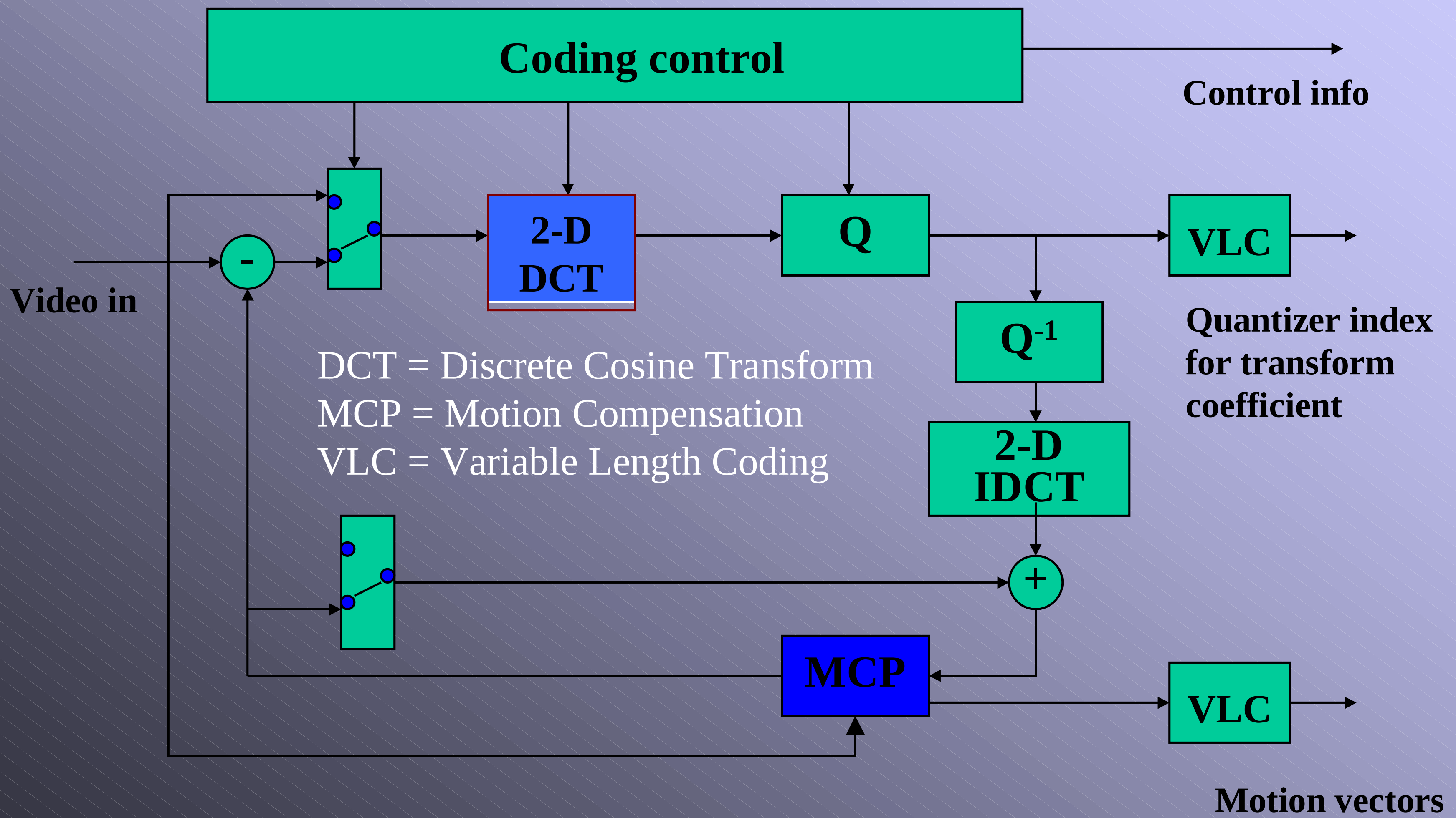
- UT ECE Department
  62 full-time faculty, 1730 undergraduates, 570 graduate students
- UT ECE R&D in telecommunications and signal processing
  22 full-time faculty, 300 undergraduates, 200 graduate students
- Leader in several telecommunication and signal processing R&D areas for high-volume products 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




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

# 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

White noise added

**SNR=10.00dB**

**NQM=20.47dB**

Filtered
white noise added

**SNR=10.00dB**

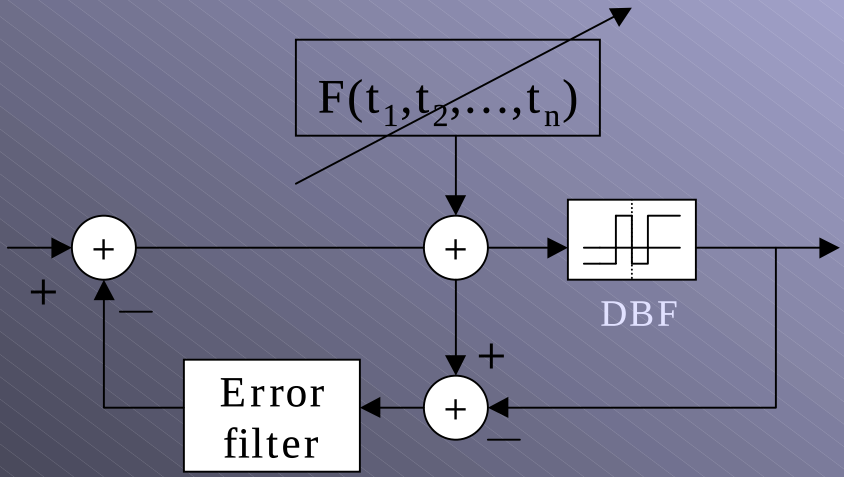
**NQM=32.65dB**

*Appendix: Raster Image Processing (Evans)*

# 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

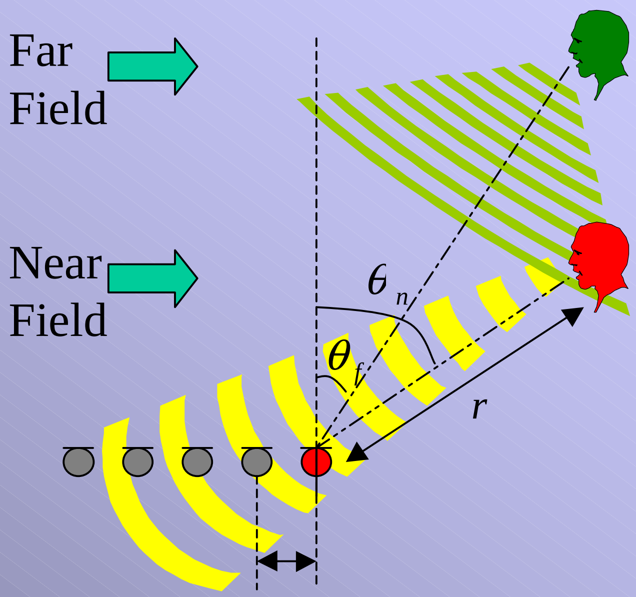
Greyscale image




WYSIWYG halftone

*Appendix: Raster Image Processing (Evans)*

# Speaker Localization Using Neural Networks

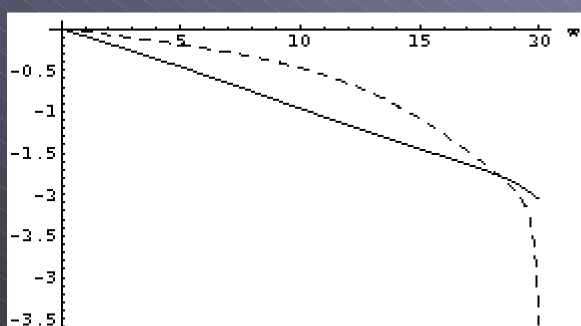



- *Problem:* Estimate speaker location (applications in videoconferencing and acoustic echo cancellation)
- *Goal:* Develop low-cost speaker location estimator for microphone array that works in far and near fields
- *Solution:* Neural network
  - Train multilayer perceptron off-line with normalized 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 $6^{o}$ average error for modeled speech
  - Massively parallel with possible fixed-point implementation
- *Implementation:* 1 MFLOPS/s for 4 microphones at 8 kHz, 16 bits

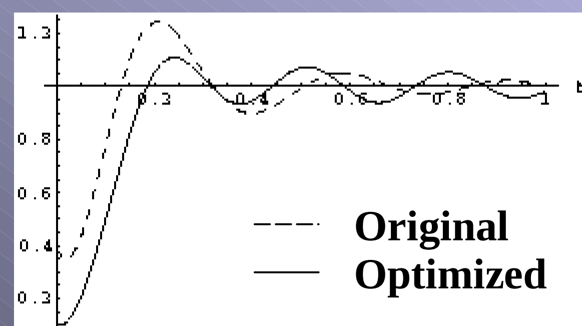
# Multi-Criteria Analog/Digital IIR Filter Design

- *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 ≤ 10

**Linearized phase in passband**




**Minimized peak overshoot**




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