Introduction

Prof. Güner Arslan

Dept. of Electrical and Computer Engineering

The University of Texas at Austin

Outline

- **Introduction**
- **Communication systems**
- **Single carrier transceiver**
  - Sinusoidal generation
  - Digital filters
- **Multicarrier transceiver**
- **Conclusion**
- **Optional slides**
  - Data scramblers
  - Modulation

Instructional Staff

- **Prof. Güner Arslan**

  Senior Systems Design Engineer at Silicon Labs

  Adjunct Faculty in ECE

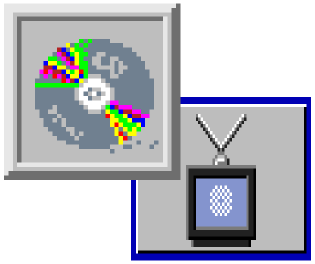
  Research Areas: digital signal processing, communication systems, embedded systems

  Office hours: W 5:00 – 7:00 PM ENS 620B

- **Teaching assistants**
  - Alex Olson – Head TA
  - Ahmad Sheikh
  - Daifeng Wang

Overview

- **Objectives**
  - Build intuition for signal processing concepts
  - Translate signal processing concepts into real-time digital communications software
- **Lecture: breadth (three hours/week)**
  - Digital signal processing algorithms
  - Digital communication systems
  - Digital signal processor architectures



- **Laboratory: depth (three hours/week)**
  - Deliver voiceband transceiver
  - "Design is the science of tradeoffs" (Prof. Yale Patt)
  - Test/validate implementation

Pre-Requisites

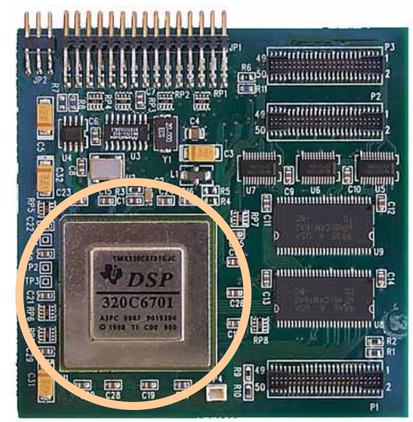
- **Pre-Requisites**
  - *EE 438 Electronics I:* test signal generation, measurement and analysis of transfer functions and frequency responses (pre-requisite is *EE 313 Linear Systems and Signals*)
  - *EE 319K Intro. to Microcontrollers:* assembly and C languages, microprocessor organization, quantization
- **Co-Requisites**
  - *EE 351K Probability, Statistics, and Random Processes:* Gaussian and uniform distributions, noise, autocorrelation, power spectrum, filtering noise, signal-to-noise ratio
  - *EE 333T Engineering Communication:* technical writing

Detailed Topics

- **Digital signal processing algorithms/applications**
  - Signals, sampling, and filtering (EE 313)
  - Transfer functions and frequency responses (EE 313/438)
  - Quantization (EE 319K), noise shaping, and data converters
- **Digital communication algorithms/applications**
  - Analog modulation/demodulation (EE 313)
  - Digital modulation/demod, pulse shaping, and pseudo-noise
  - Multicarrier modulation: ADSL and wireless LAN systems
- **Digital signal processor (DSP) architectures**
  - Assembly language, interfacing, and pipelining (EE 319K)
  - Harvard architecture and special addressing modes
  - Real-time programming and modern DSP architectures

Which Digital Signal Processor?

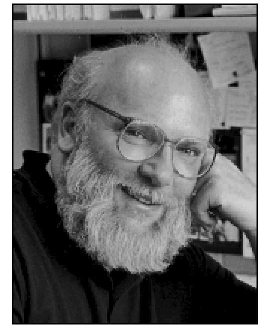
- **Fixed-point DSPs for high-volume products**
  - Battery-powered: cell phones, digital still cameras …
  - Wall-powered: ADSL modems, cellular basestations …
- **Fixed-point representations and calculations**
  - Fractional data ∈ [-1, 1) and integer data
  - Non-standard C extensions for fractional data
  - Converting floating-point to fixed-point
  - Manual tracking of binary point is tedious
- **Floating-point DSPs**
  - Shorter prototyping time
  - Feasibility for fixed-point DSP realization



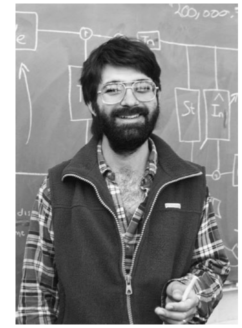
TI C6701 Floating-Point Digital Signal Processor

Required Textbooks

- **C. R. Johnson, Jr., and W. A. Sethares, *Telecommunication Breakdown*, Prentice Hall, 2004**
  - Introduction to digital communications systems and transceiver design
  - Tons of Matlab examples



Rick Johnson (Cornell)



Bill Sethares (Wisconsin)

- **S. A. Tretter, *Comm. System Design using DSP Algorithms with Lab Experiments for the TMS320C6701 & TMS320C6711*, 2003**
  - Assumes DSP theory and algorithms
  - Assumes access to C6000 reference manuals
  - Errata/code: http://www.ece.umd.edu/~tretter

Steven Tretter (Maryland)

Required C6000 Reference Manuals

- **Code Composer User's Guide (328B)**

  www-s.ti.com/sc/psheets/spru328b/spru328b.pdf
- **Optimizing C Compiler (187L)**

  www-s.ti.com/sc/psheets/spru187l/spru187l.pdf
- **Programmer's Guide (198G)**

  www-s.ti.com/sc/psheets/spru198g/spru198g.pdf
- **Evaluation Module Board User's Guide (269F)**

  www-s.ti.com/sc/psheets/spru269f/spru269f.pdf
- **CPU & Instruction Set Reference Guide (189F)**

  www-s.ti.com/sc/psheets/spru189f/spru189f.pdf

TI software development environment

Download for reference but read at your own risk

Supplemental (Optional) Textbooks

- **J. H. McClellan, R. W. Schafer, and M. A. Yoder, *DSP First: A Multimedia Approach*, 1998**
  - DSP theory and algorithms at sophomore level
  - Many in-class demonstrations are from *DSP First*
  - Demos: http://users.ece.gatech.edu/~dspfirst/

Ronald Schafer's 1975 book founded DSP field

- **B. P. Lathi, *Linear Systems & Signals*, either edition**
  - Introduction to signal processing theory
  - Textbook for EE 313 Linear Systems and Signals

Really Useful

- **R. Chassaing, *DSP Applications Using C and the TMS320C6x DSK*, 2002**
  - C6000 DSP Starter Kit (DSK) external board via serial port
  - DSP processor tutorial with source code examples

Related BS Degree Technical Areas

Communication/networking

EE345S Real-Time DSP Lab

EE360K Digital Comm. Spring

EE371M Comm. Systems Fall

EE372N Telecom. Networks Spring

NEW EE379K-15 Info. Theory Fall

EE379K-19 Net. Eng. Lab. Fall

EE379K Wireless Comm Lab Spring

Undergraduates may request permission to take grad courses

EE345S may be used for advanced laboratory pre-requisite for senior design project.

Signal/image processing

EE345S Real-Time DSP Lab

EE351M DSP Spring

EE371D Neural Nets Fall

EE371R Digital Image and Video Processing Spring

Embedded Systems

EE345M Embedded and Real-Time Systems Fall

EE345S Real-Time DSP Lab

EE360M Dig. Sys. Design

EE360N Comp. Arch.

EE360R VLSI CAD

UT Comm./DSP Graduate Courses

- **Communications theory**

  Spring EE381K-2 Digital Comm.   EE381K-11 Wireless Comm Fall

  EE381V Advanced Wireless: Modulation and Multiple Access

  EE381V Advanced Wireless: Space-Time Communications

  EE381V Channel Coding

Courses in italics are offered every other year

- **Signal processing theory**

  Fall EE381K-8 DSP   *EE381K-9 Advanced DSP*

  EE381K-14 Multidim. DSP   *EE381L Time Series Analysis*

- **Other related courses**

  EE380K System Theory   EE381K-7 Info. Theory Spring

  Fall EE381J Probability and Stochastic Processes I

  EE382C-9 Embedded Software   EE 382V VLSI Comm. Spring

Grading

- **Calculation of numeric grades**
  - 15% midterm #1
  - 15% midterm #2 (not cumulative)
  - 10% homework (four assignments)
  - 60% laboratory (6 pre-lab quizzes + 7 reports)
- **Laboratory component**
  - Each student takes pre-lab quiz on course Web site alone
  - Students work in teams of two on lab assignments/reports
  - TAs grade individual attendance and participation
  - TAs assign team members same lab report grade
  - TAs assign individual grades for attendance/participation
  - Lowest pre-lab quiz and lowest lab report dropped

Past average GPA is 3.1

www.UTLife.com

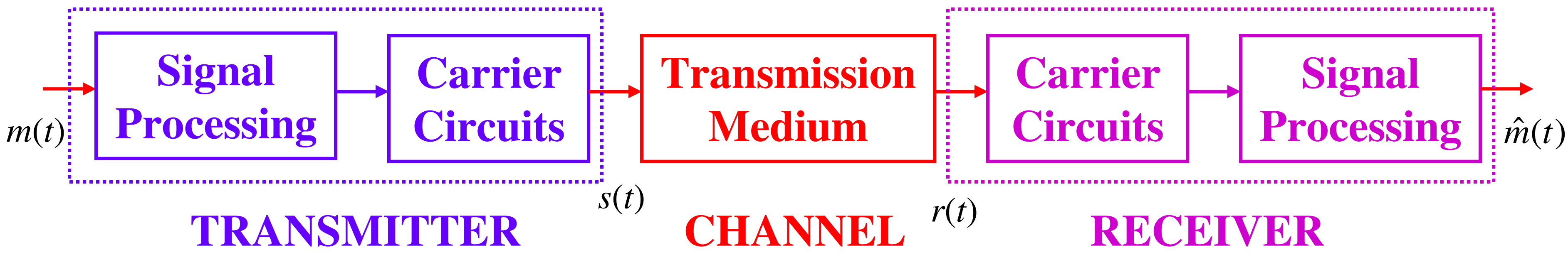
No final exam

Academic Integrity

- **Homework assignments**
  - Discuss homework questions with others
  - Be sure to submit your own *independent* solution
  - Turning in two identical (or nearly identical) homework sets is considered *academic dishonesty*
- **Laboratory reports**
  - Should only contain work of those named on report
  - If any other work is included, then reference source
  - Copying information from another source without giving proper reference and quotation is *plagiarism*
  - Source code must be original work
- **Why does academic integrity matter? *Enron!***

Communication Systems

- **Information sources**
  - Message signal $m(t)$ is the information source to be sent
  - Possible information sources include voice, music, images, video, and data, which are baseband signals
  - Baseband signals have power concentrated near DC
- **Basic structure of an analog communication system is shown below**



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, each station is assigned a slot in the frequency domain.
  - In a digital communications system, we might add redundancy to the message bit stream $m[n]$ to assist in error detection (and possibly correction) in the receiver

Transmitter

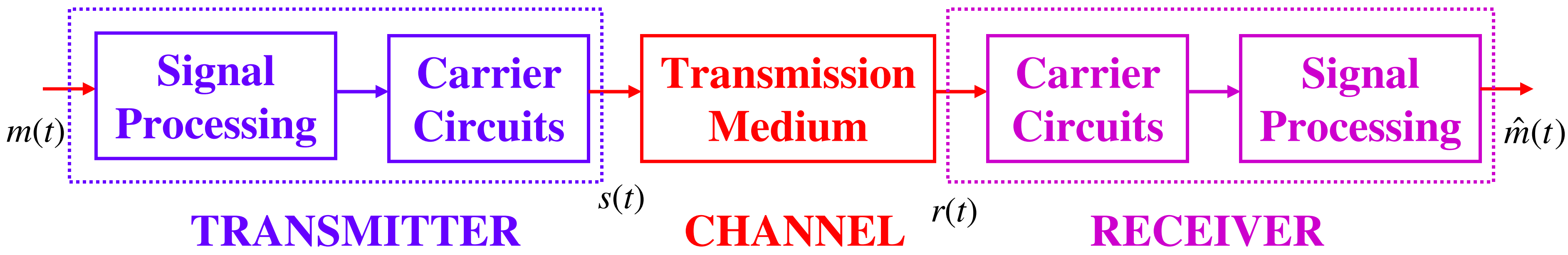
- **Carrier circuits**
  - Convert baseband signal into a frequency band appropriate for the channel
  - Uses analog and/or digital modulation

Communication Channel

- **Transmission medium**
  - Wireline (twisted pair, coaxial, fiber optics)
  - Wireless (indoor/air, outdoor/air, underwater, space)
- **Propagating signals experience a gradual degradation over distance**
- **Boosting improves signal and reduces noise, e.g. repeaters**

Receiver and Information Sinks

- **Receiver**
  – Carrier circuits undo effects of carrier circuits in transmitter, e.g. demodulate from a bandpass signal to a baseband signal
  – Signal processing subsystem extracts and enhances the baseband signal
- **Information sinks**
  – Output devices, e.g. computer screens, speakers, TV screens



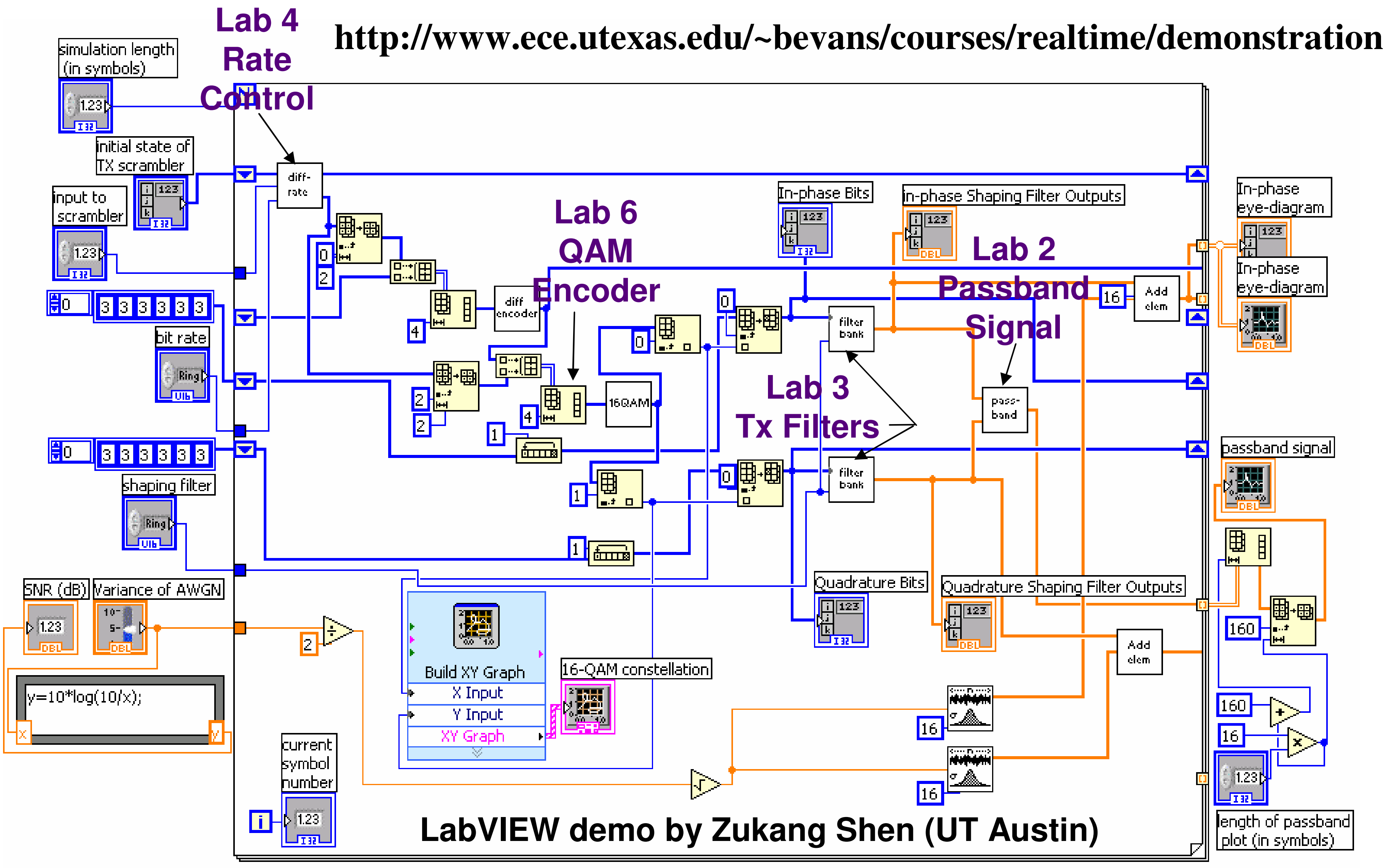
Single Carrier Transceiver Design

- **Design/implement dial-up (voiceband) transceiver**
  - Design different algorithms for each subsystem
  - Translate signal processing algorithms into real-time software
  - Test implementations using test equipment and LabVIEW

Laboratory	*Modem Subsystems*
1 introduction	block diagram of transmitter
2 sinusoidal generation	sinusoidal mod/demodulation
3(a) finite impulse response filter	pulse shaping, 90^{o} phase shift
3(b) infinite impulse response filter	transmit and receive filters, carrier detection, clock recovery
4 pseudo-noise generation	training sequences
5 pulse amplitude mod/demodulation	training during modem startup
6 quadrature amplitude mod (QAM)	data transmission
7 QAM demodulation	data reception

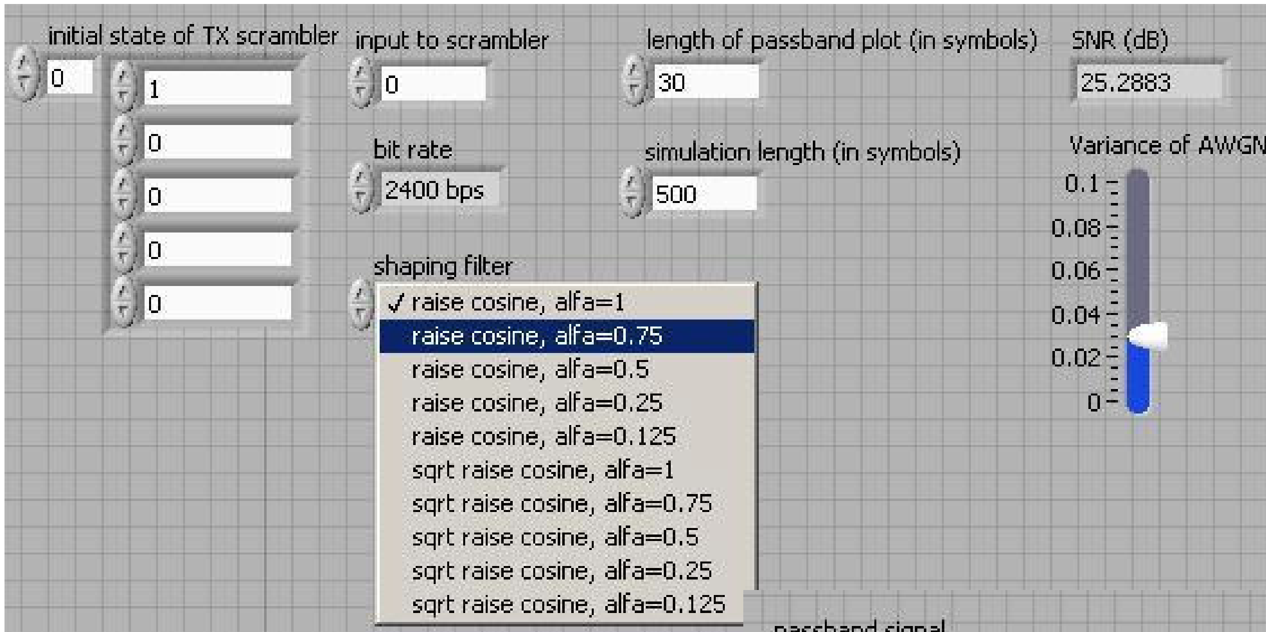
Lab 1: QAM Transmitter Demo

http://www.ece.utexas.edu/~bevans/courses/realtime/demonstration



Lab 1: QAM Transmitter Demo

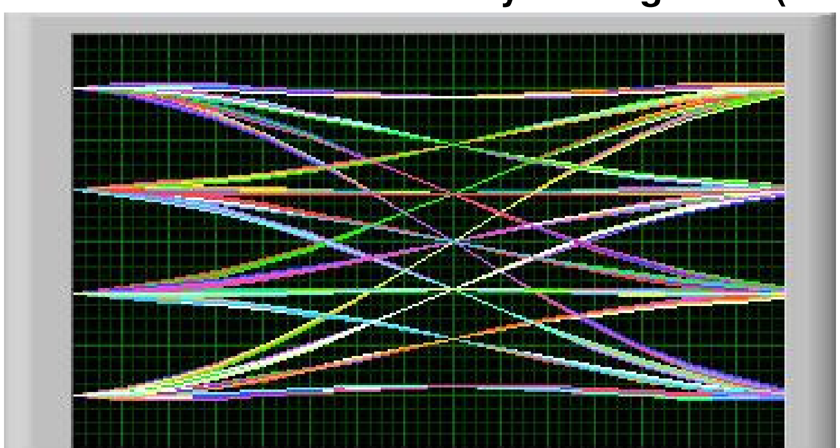
LabVIEW Control Panel

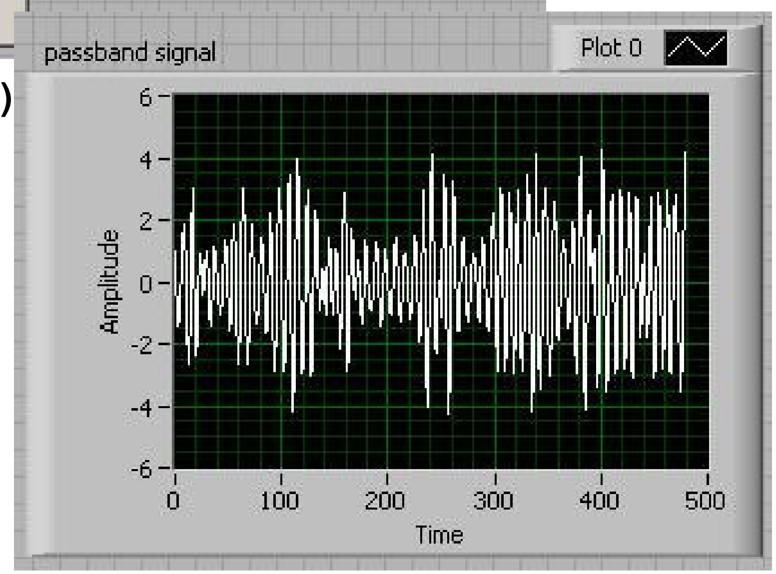


QAM Passband Signal

Eye Diagram

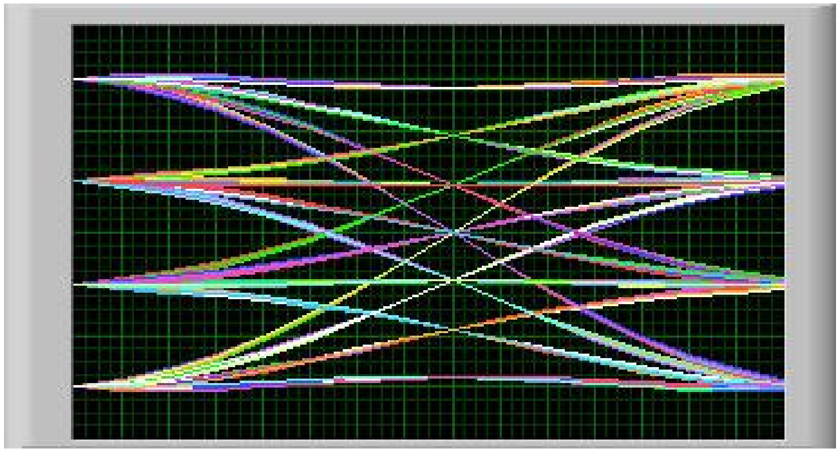
LabVIEW demo by Zukang Shen (UT Austin)



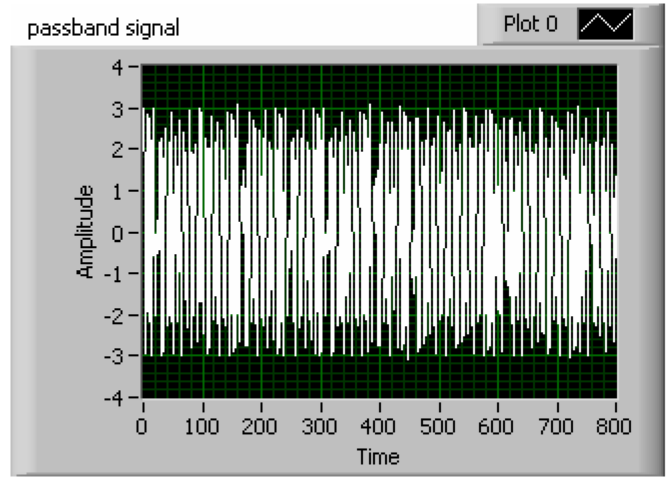


Lab 1: QAM Transmitter Demo

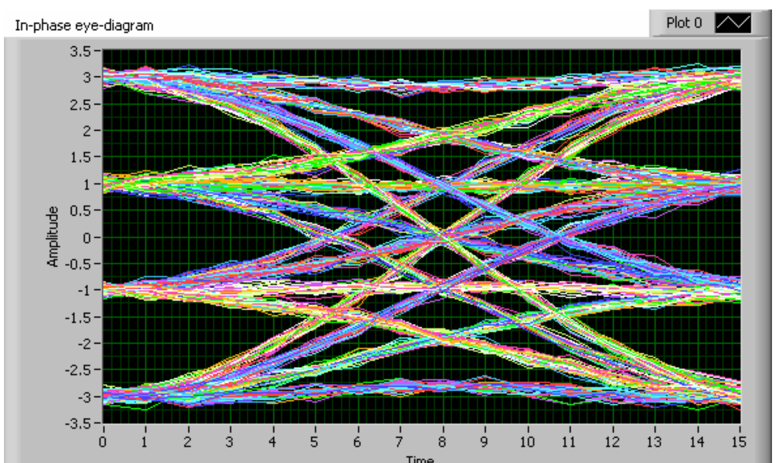
square root raise cosine, roll-off = 1, SNR = ∞



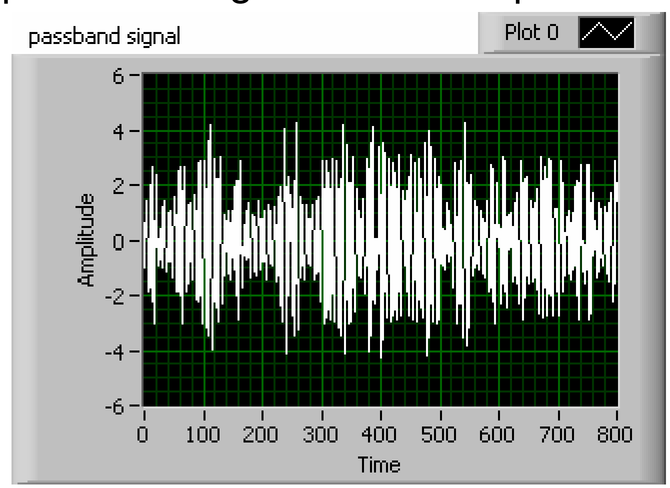
passband signal for 1200 bps mode



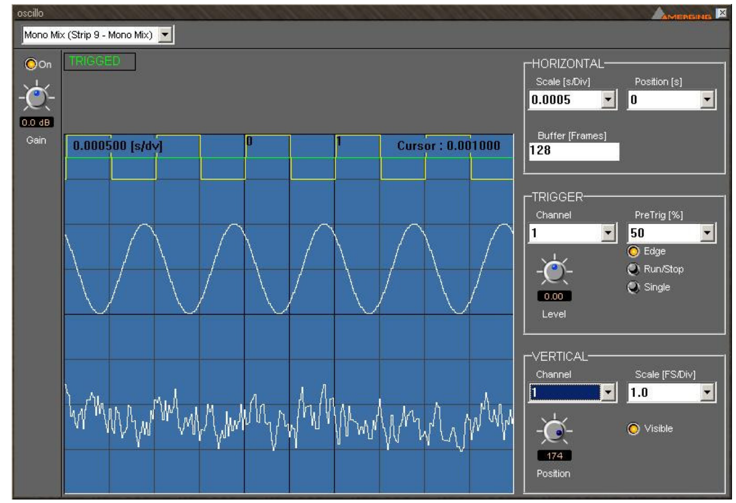
raise cosine, roll-off = 1, SNR = 30 dB



passband signal for 2400 bps mode



Lab 2: Sine Wave Generation



- **There must be three ways to make your sine waves**
  - Function call
  - Lookup table
  - Difference equation
- **Three output methods**
  - Polling data transmit register
  - Software interrupts
  - Direct memory access (DMA) transfers
- **Expected outcomes are to understand**
  - Signal quality vs. implementation complexity tradeoff
  - Interrupt mechanisms and DMA transfers

Lab 2: Sine Wave Generation

- **Evaluation procedure**

  Validate sine wave frequency on scope, and test for various sampling rates (14 sampling rates on board)

  Method 1 with interrupt priorities

  Method 1 with different DMA initialization(s)

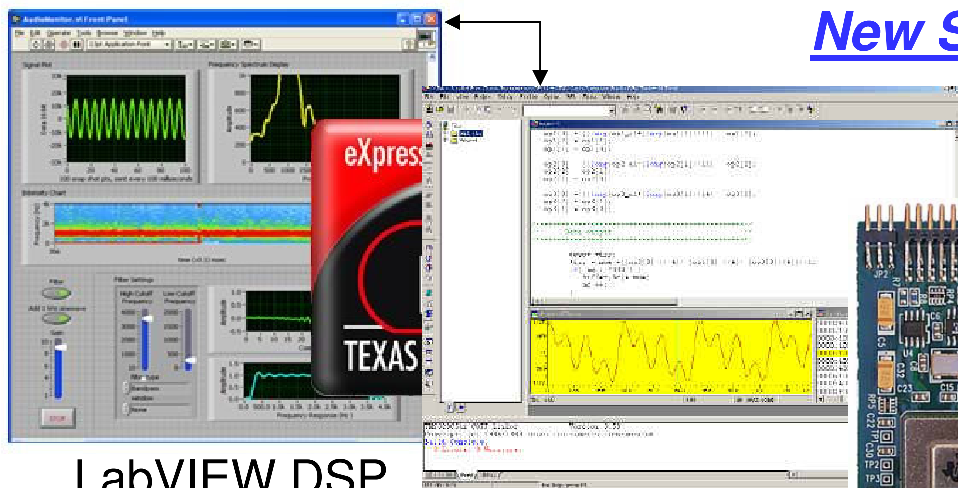
Old School

HP 60 MHz

Digital Storage

Oscilloscope

New School



LabVIEW DSP Test Integration Toolkit 2.0

Code Composer Studio 2.2

C6701

Lab 3: Digital Filters

- **Aim: Evaluate four ways to implement discrete-time linear time-invariant filters**
  - FIR filter: convolution in C and assembly
  - IIR Filter: direct form and cascade of biquads, both in C
- **IIR filter design gotchas: oscillation & instability**
  - In classical designs, poles sensitive to perturbation
  - Quality factor measures sensitivity of pole pair:
    $Q \in [\ ½\ ,\ \infty\ )$ where $Q = ½$ dampens and $Q = \infty$ oscillates
- **Elliptic analog lowpass IIR filter $\delta_p = 0.21$ at $\omega_p = 20$ rad/s and $\delta_s = 0.31$ at $\omega_s = 30$ rad/s** [Evans 1999]

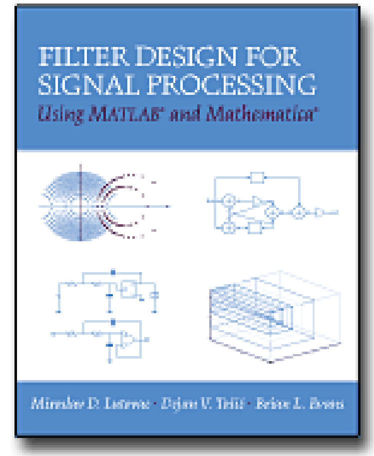
classical

Q	poles	zeros
1.7	$-5.3533 \pm j16.9547$	$0.0 \pm j20.2479$
61.0	$-0.1636 \pm j19.9899$	$0.0 \pm j28.0184$

optimized

Q	poles	zeros
0.68	$-11.4343 \pm j10.5092$	$-3.4232 \pm j28.6856$
10.00	$-1.0926 \pm j21.8241$	$-1.2725 \pm j35.5476$

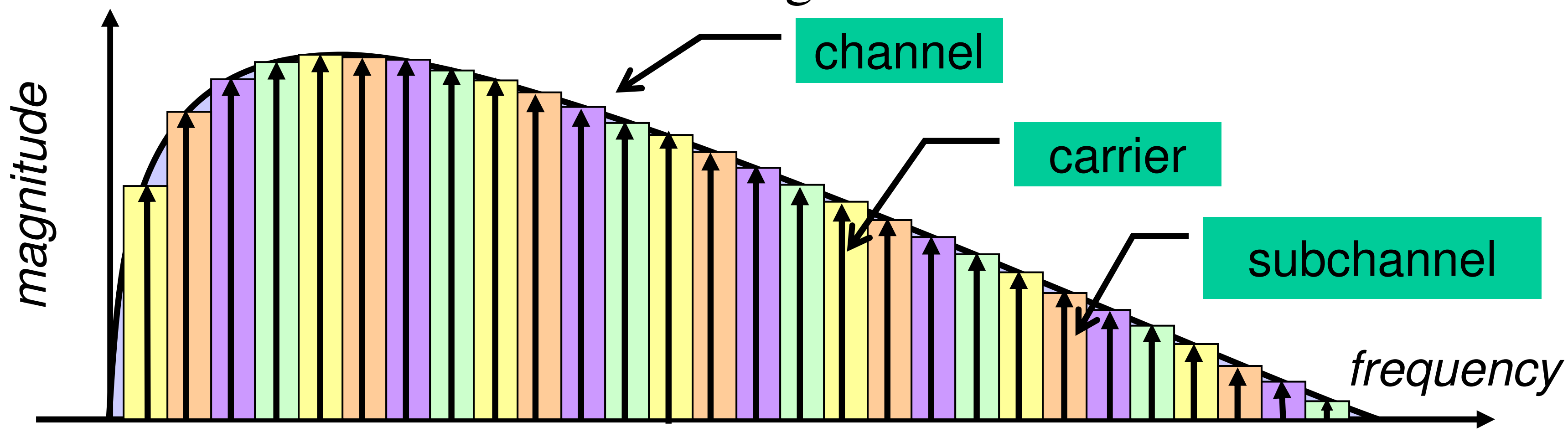
Lab 3: Digital Filters



- **IIR filter design for implementation**
  - Butterworth/Chebyshev filters special cases of elliptic filters
  - Minimum order not always most efficient
- **Filter design gotcha: polynomial inflation**
  - Polynomial deflation (rooting) reliable in floating-point
  - Polynomial inflation (expansion) may degrade roots
  - Keep native form computed by filter design algorithm
- **Expected outcomes are to understand**
  - Speedups from convolution assembly routine vs. C
  - Quantization effects on filter stability (IIR)
  - FIR vs. IIR: how to decide which one to use

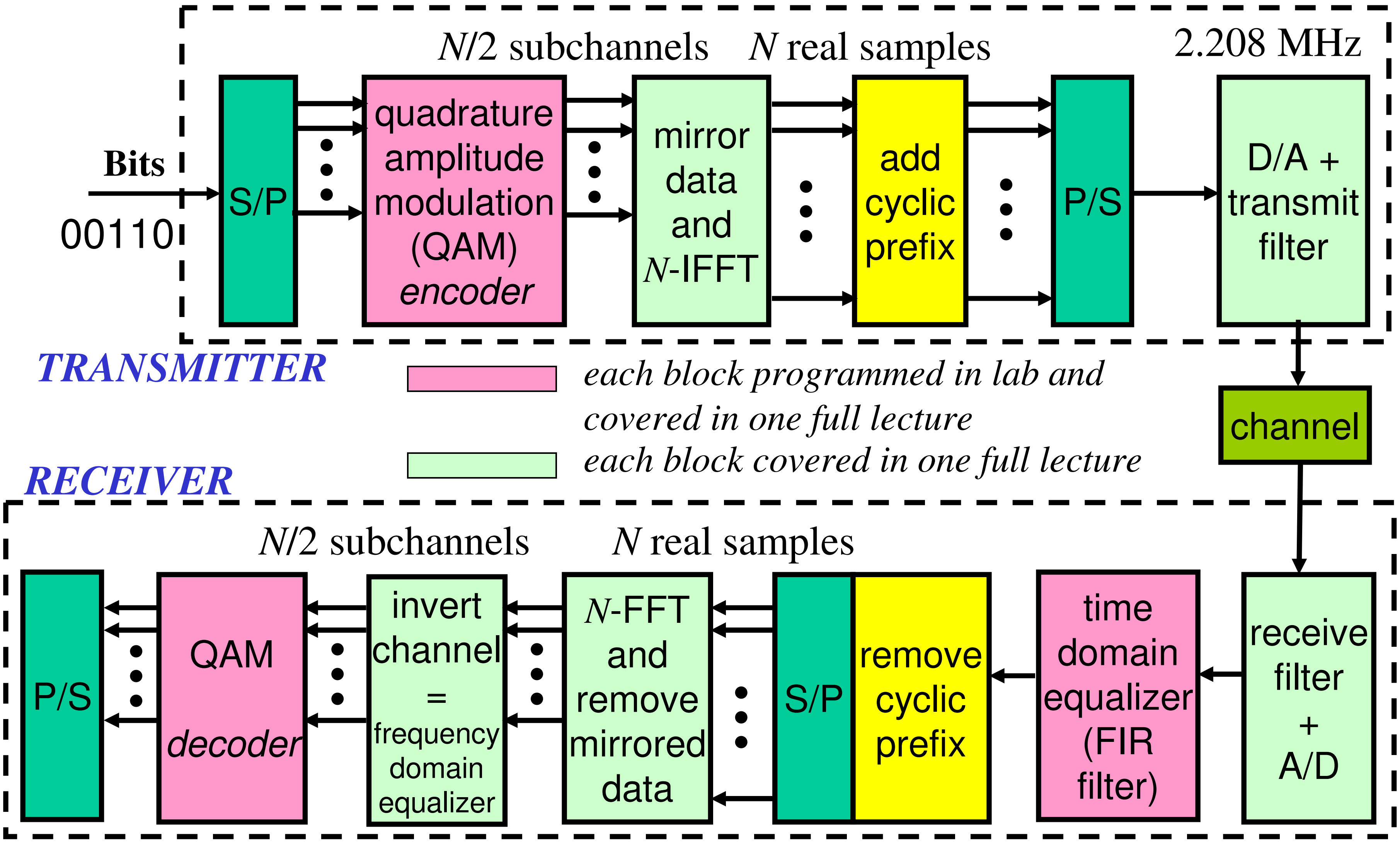
Got Anything Faster Than Dial-Up?

- **Multicarrier modulation divides broadband (wideband) channel into narrowband subchannels**
  - Uses Fourier series computed by fast Fourier transform (FFT)
  - Standardized for Digital Audio Broadcast (1995)
  - Standardized for ADSL (1995) & VDSL (2003) wired modems
  - Standardized for IEEE 802.11a/g wireless LAN & 802.16a



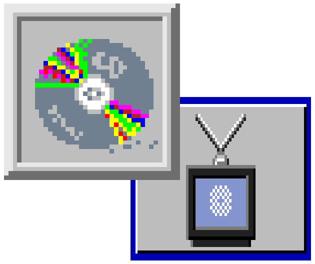
Each ADSL/VDSL subchannel is 4.3 kHz wide
(about a voice channel) and carries a QAM signal

ADSL Transceiver: Data Xmission



P/S parallel-to-serial S/P serial-to-parallel FFT fast Fourier transform

Conclusion



- **Objectives**

  Build intuition for signal processing concepts

  Translate signal processing concepts into real-time digital communications software

- **Deliverables and takeaways**

  Deliver voiceband transceiver

  Tradeoffs in signal quality vs. implementation complexity

  Test/validate implementation

  Extend hands-on experience to broadband modems

- **Role of technology**

  TI DSPs and Code Composer Studio

  NI LabVIEW and DSP Test Integration Toolkit

Lab 4: Data Scramblers

- ***Aim*: Generate pseudo-random bit sequences**

  Build data scrambler for given connection polynomial

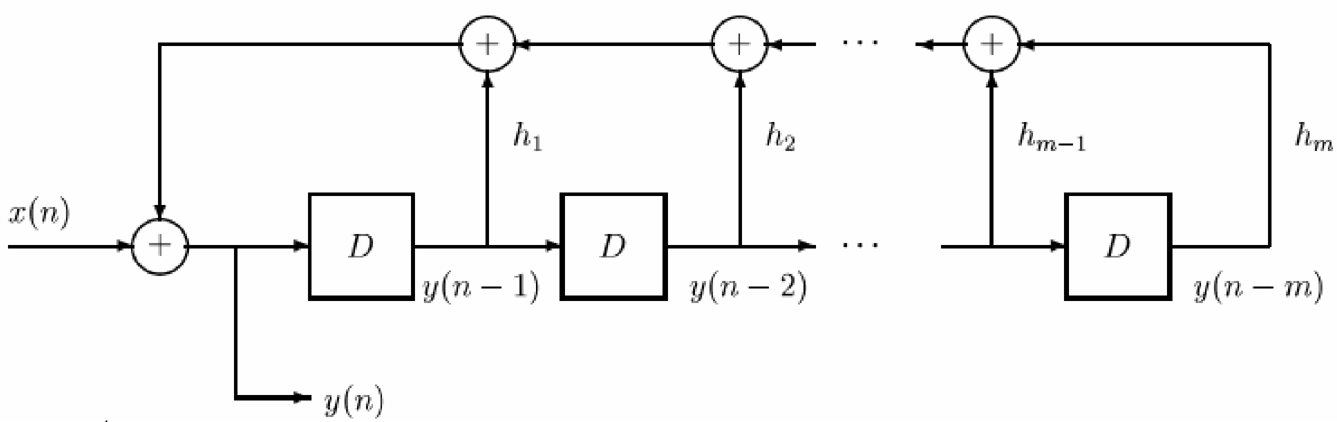
  Descramble data via descrambler

  Obtain statistics of scrambled binary sequence

- **Expected outcomes are to understand**

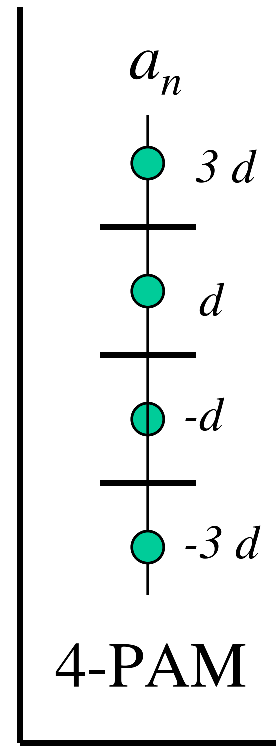
  Principles of pseudo-noise (PN) sequence generation

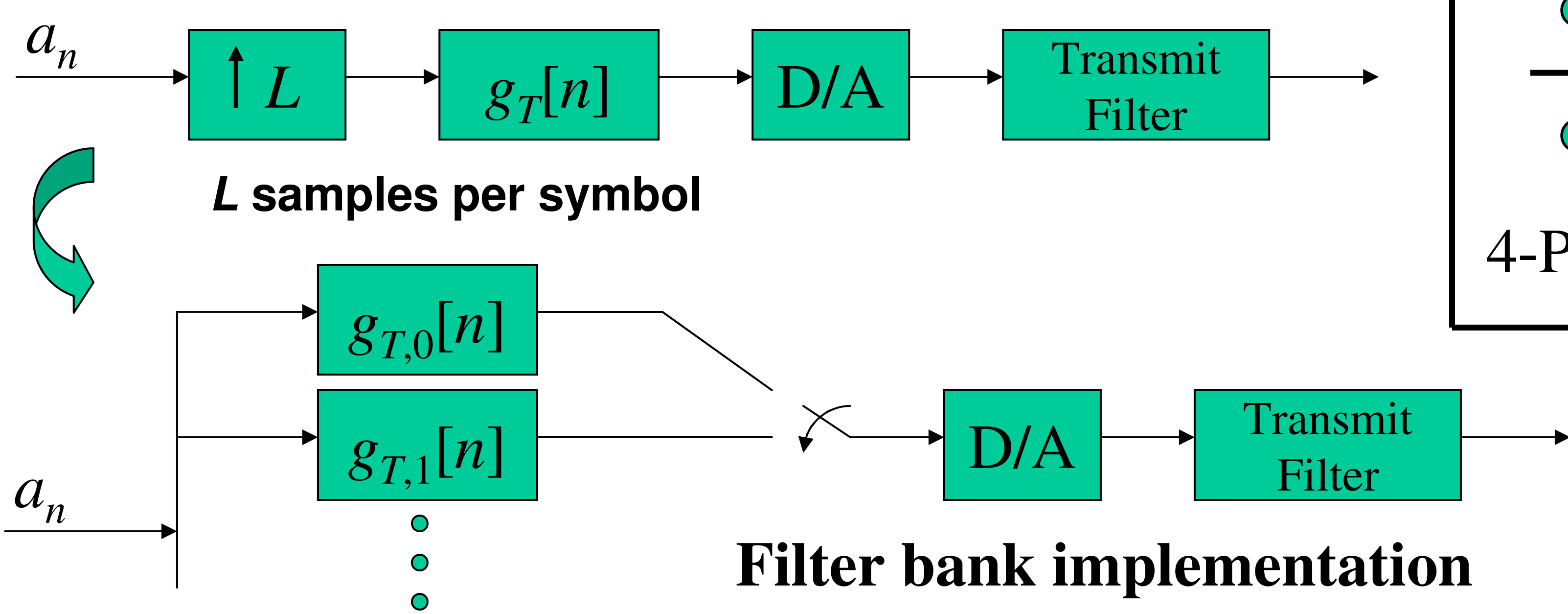
  Identify applications in communication systems



Lab 5: Digital PAM Transceiver

- ***Aim*: Develop PAM transceiver blocks in C**
  - Amplitude mapping to PAM levels
  - Interpolation filter bank for pulse shaping filter
  - Clock recovery via phase locked loops

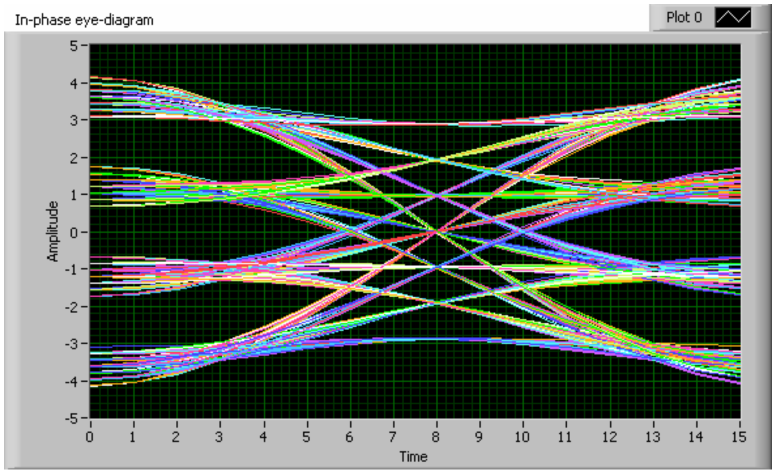




Optional

Lab 5: Digital PAM Transceiver

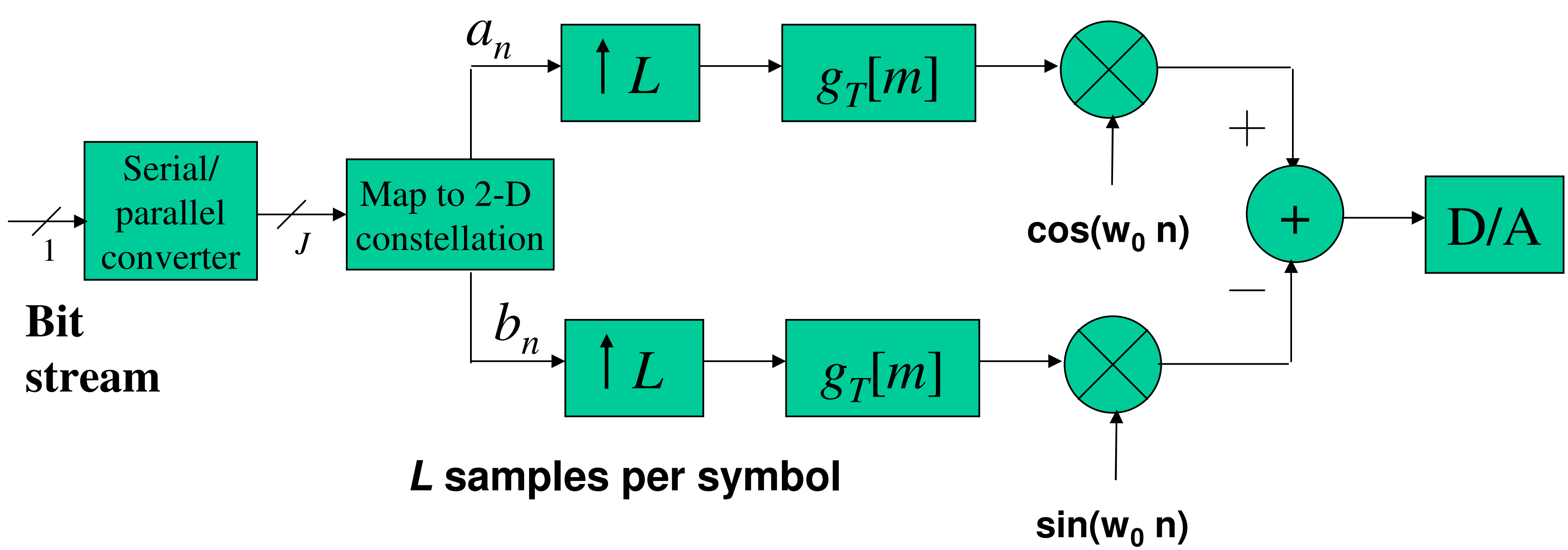
- **Expected outcomes are to understand**
  - Basics of PAM modulation
  - Zero inter-symbol interference condition
  - Clock synchronization issues
- **Evaluation procedure**
  - Generate eye diagram to visualize PAM signal quality
  - Observe modulated spectrum
  - Prepare DSP modules to test symbol clock frequency recovery subsystem



4-PAM Eye Diagram

Lab 6: Digital QAM Transmitter

- ***Aim*: Develop QAM transmitter blocks in C**
  - Differential encoding of digital data
  - Constellation mapping to QAM levels
  - Interpolation filter bank for pulse shaping filter



Lab 7: Digital QAM Receiver

- ***Aim*: Develop QAM receiver blocks in C**
  - Carrier recovery
  - Coherent demodulation
  - Decoding of QAM levels to digital data
- **Expected outcomes are to understand**
  - Carrier detection and phase adjustment
  - Design of receive filter
  - Probability of error analysis to evaluate decoder
- **Evaluation procedure**
  - Recover and display carrier on scope
  - Regenerate eye diagram and QAM constellation
  - Observe signal spectra at each decoding stage