EE345S Real-Time Digital Signal Processing Lab Spring 2006

Quadrature Amplitude Modulation (QAM) Receiver

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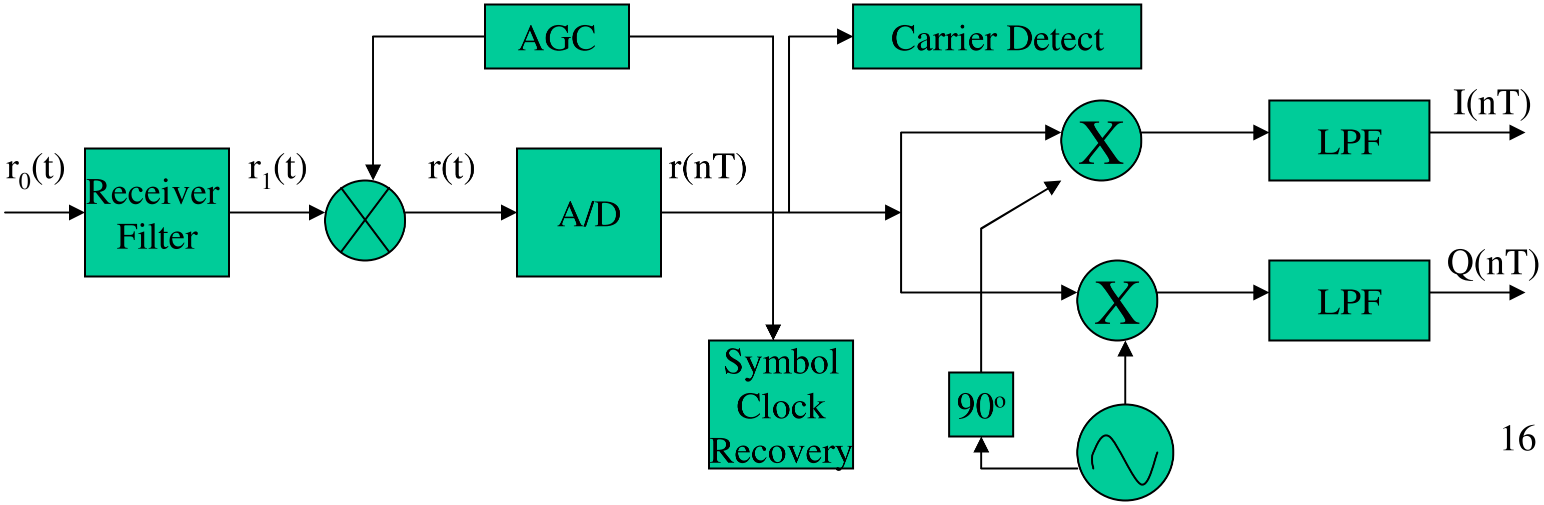
Lecture 16

Introduction

- **Channel has linear distortion, additive noise, and nonlinear distortion**
- **Adaptive digital FIR filter used to equalize linear distortion (magnitude/phase distortion in channel)**

Channel equalizer coefficients adapted during modem startup

At startup, transmitter sends known PN training sequence



QAM Receiver

- **Automatic gain control**
  - Scales analog input voltage to appropriate level for A/D
  - Increase gain when received signal level is low
- **Carrier detection**
  - Determines whether or not a QAM signal is present
- **Symbol clock recovery**
  - Track clock frequency
- **In-phase/quadrature (I/Q) demodulation**
  - Recover baseband in-phase/quadrature signal

Carrier Detection

- **If receiver is not currently receiving a signal, then it listens for known training sequence**
- **Detect energy of received signal**

  $$p[n] = c\ p[n-1] + (1-c)\ r^2[n]$$

  Transfer function?

  - c is a constant where $0 < c < 1$
  - $r[n]$ is received signal
- **Check if received energy is larger than threshold**
- **If receiver is currently receiving signal, then it detects when transmission has stopped**
  - Detect energy of received signal
  - Check whether it is smaller than a smaller threshold

Symbol Clock Recovery

- **Two single-pole bandpass filters in parallel**
  - One tuned to upper Nyquist frequency $\omega_u = \omega_c + 0.5\ \omega_{sym}$
  - Other tuned to lower Nyquist frequency $\omega_l = \omega_c - 0.5\ \omega_{sym}$
  - Bandwidth is *B*/2 (100 Hz for 2400 baud modem)

Pole locations?

- **A recovery method**
  - Multiply upper bandpass filter output with conjugate of lower bandpass filter output and take the imaginary value
  - Sample at symbol rate to estimate timing error τ

    $v[n] = \sin(\omega_{sym}\ \tau) \approx \omega_{sym}\ \tau$ when $|\omega_{sym}\ \tau| << 1$
  - Smooth timing error estimate to compute phase advancement

    $p[n] = \beta\ p[n-1] + \alpha\ v[n]$

See Reader handout M

Lowpass IIR filter

In-Phase/Quadrature Demodulation

- **QAM transmit signal** $x(t) = a(t)\cos(\omega_c\, t) + b(t)\sin(\omega_c\, t)$
- **QAM demodulation by modulation then filtering**
  - Construct in-phase $i(t)$ and quadrature $q(t)$ signals
  - Lowpass filter them to obtain baseband signals $a(t)$ and $b(t)$

$$i(t) = 2x(t)\cos(\omega_c t) = 2a(t)\cos^2(\omega_c t) + 2b(t)\sin(\omega_c t)\cos(\omega_c t)$$

$$= \underbrace{a(t)}_{\textit{baseband}} + \underbrace{a(t)\cos(2\omega_c t) + b(t)\sin(2\omega_c t)}_{\textit{high frequency component centered at 2 } \omega_c}$$

$$q(t) = 2x(t)\sin(\omega_c t) = 2a(t)\cos(\omega_c t)\sin(\omega_c t) + 2b(t)\sin^2(\omega_c t)$$

$$= \underbrace{b(t)}_{\textit{baseband}} + \underbrace{a(t)\sin(2\omega_c t) - b(t)\cos(2\omega_c t)}_{\textit{high frequency component centered at 2 } \omega_c}$$

$\cos^2\theta = \frac{1}{2}(1+\cos 2\theta)$ $\quad 2\cos\theta\sin\theta = \sin 2\theta$ $\quad \sin^2\theta = \frac{1}{2}(1-\cos 2\theta)$