

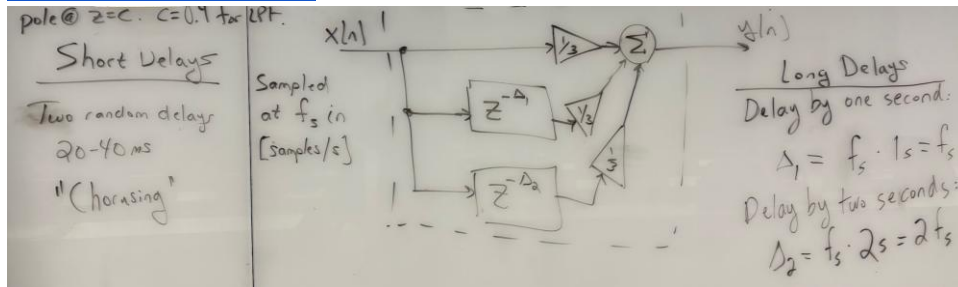
## Lecture 16 QAM Receivers Part 2

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Notes by Jenna May

### Delay and Reverb Demo (Preview of Lab 7)

- [Reverb and Delay Explained – Sound Basics with Stella Episode 4](#) (YouTube)
- Delay implemented as an FIR filter (see marker board picture below)
  - Long delays ~ delay by 1 or 2 seconds
  - Short delays randomized between 20-40ms makes one instrument/voice sounds like many playing/singing at the same time (called “chorusing”)
  - Might need to scale each delayed channel so that the addition of the channels does not exceed the range of minimum and maximum amplitude values either represented in the number system (e.g. 16-bit integer) or D/A converter
- [FIR and IIR comb filters](#) in lab 7

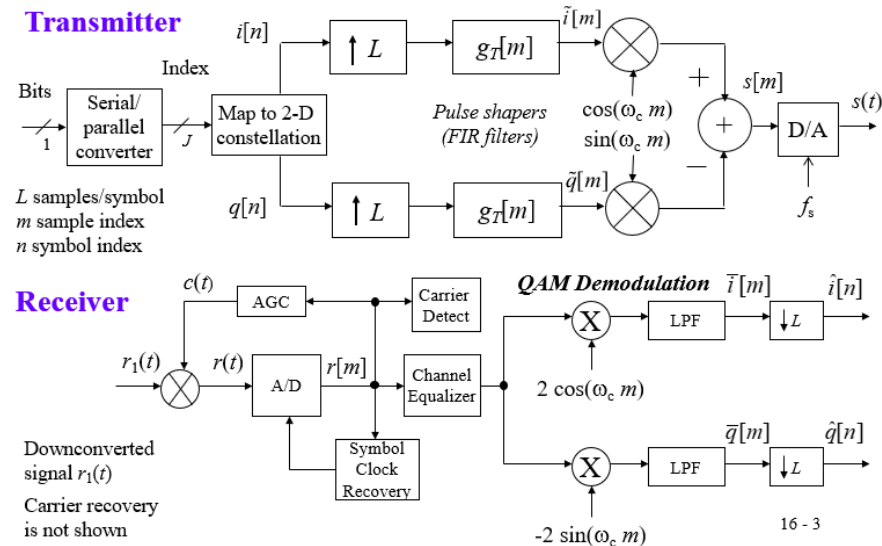


### QAM Receiver Part 1 Review

- Receiver has a subsystem to compensate each impairment experienced by the baseband signal as it travels through the Tx analog/RF front end, the communication channel, and the Rx analog/RF front end
- Fading
  - Changes in received signal amplitude in time due to changes in the electromagnetic propagation environment in the channel
  - Compensation: automatic gain control (*today's lecture*)
- Additive noise
  - Thermal noise due to random motion of electrons in the analog/RF front end
  - Compensation: matched filter (*labs 5 and 6; homework assignments 4-6*)
- Linear distortion
  - Delay, multipath, scattering due to trees, etc., in the communication channel
  - Analog RF front end at both tx and rx will also introduce linear distortion
  - Compensation: channel equalizer (*previous lecture*)
- Carrier mismatch
  - Circuits in rx for downconversion don't match circuits in tx for upconversion
  - Carrier frequency and phase differ in rx vs. tx
  - Lump into one parameter: phase offset
  - Compensation: carrier recovery
  - Lab 5 week 2 and homework problem 6.1

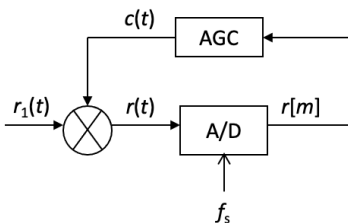
- Symbol timing mismatch
  - Can use Costas loop or another phase locked loop (PLL) algorithm
  - Rx tracks start of symbol time (timing offset) and symbol time (symbol rate)
  - Lump into one parameter: phase offset (time delay)
  - Track offset in time and compensate in phase
  - Compensation: symbol clock recovery
  - Homework problems 6.1 and 7.3
- Steepest descent algorithms for adaptive carrier recovery, channel equalizer, and symbol clock recovery subsystems

## Baseband QAM



## Automatic Gain Control (AGC)

- Common A/D converter input voltage ranges: [-1, 1], [-1.8, 1.8], [-3.3, 3.3], [-5, 5]
  - A/D converter on the STM ARM board in lab has a configurable upper voltage range between 1.6V to 3.4V and its negative counterpart
- Scales input voltage in the received baseband signal  $r_1(t)$  to the A/D converter



- Example: A/D converter with 8-bit signed output (values from -128 to 127)
  - Let  $f_i$  measure how frequently output  $i$  occurs in last  $N$  samples
  - $f_i = c_i/N$ , where  $c_i$  is count of times  $i$  occurs in last  $N$  samples
- Intuition: if  $f_0$  occurs often, increase gain. If  $f_{-128}$  and  $f_{127}$  occur often, decrease gain

- Update gain by
  - Update #1:  $c(t) = (1 + 2f_0 - f_{128} - f_{127}) c(t - \tau)$
  - Update #2:  $c(t) = \frac{2f_0 + \varepsilon}{f_{-128} + f_{127} + \varepsilon} c(t - \tau) = \frac{2c_0 + \varepsilon N}{c_{-128} + c_{127} + \varepsilon N} c(t - \tau)$
  - Constant  $\varepsilon > 0$  prevents division by zero
- Choice of how often the gain is updated, tau, is dependent on the application
- Both update algorithms require one integer division and three integer additions
- Update #2 is more volatile in the change in the gain c(t) over time

### Carrier Detection

- Detect energy of received signal using a first-order IIR filter
  - $p[m] = c p[m-1] + (1-c) r^2[m]$
  - c is a constant where  $0 < c < 1$  and  $r[m]$  is received signal
    - $r[m]$  is the discrete-time received baseband signal (a voltage)
    - $r^2[m]$  is the instantaneous power at discrete-time sample m
    - Initial condition  $p[-1]$  must be zero as a necessary condition for LTI to hold
    - For  $x[m] = r^2[m]$ , the transfer function of the energy detection

Slide  $x[m] \rightarrow p[m]$

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$$p[m] = c p[m-1] + (1-c)x[m]$$

$$P(z) = c z^{-1} P(z) + (1-c) X(z)$$

$$P(z) - c z^{-1} P(z) = (1-c) X(z) \Rightarrow \frac{P(z)}{X(z)} = \frac{1-c}{1 - c z^{-1}}$$

pole @  $z=c$ .  $c=0.9$  for LPF.  $x[n]!$

- If receiver is not currently receiving a signal, detect when transmission starts
  - If energy detector is larger than a large threshold, assume receiving transmission
- If receiver is currently receiving, detect when transmission stopped
  - If energy detector output is smaller than small threshold, assume transmission has stopped