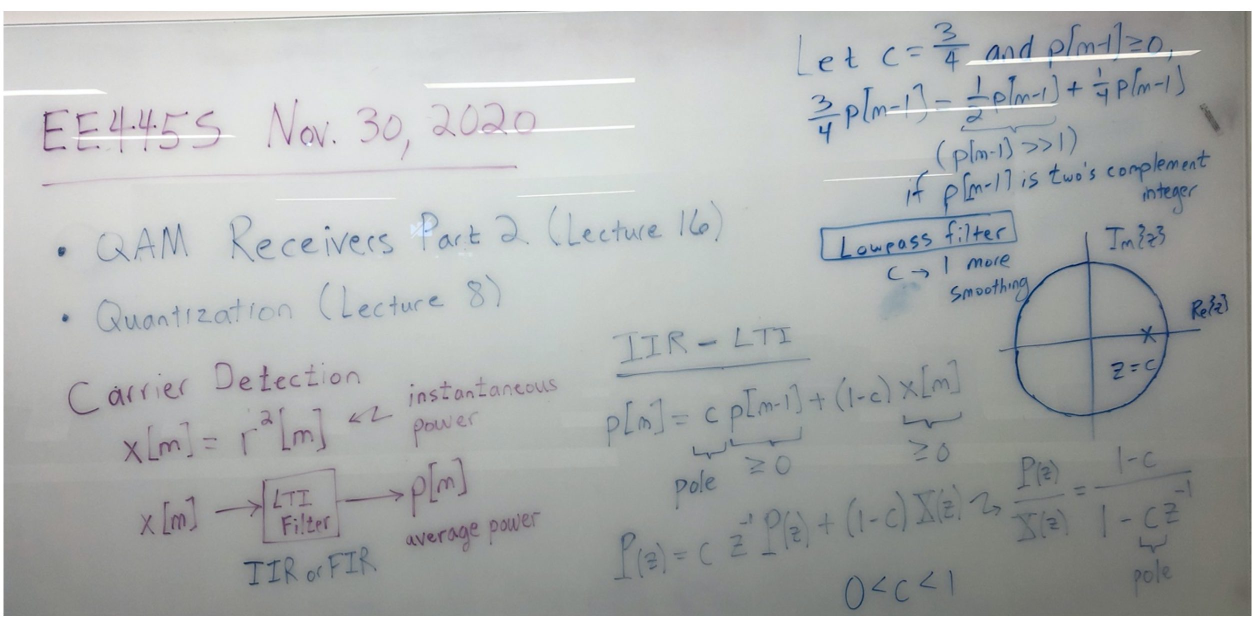
[10:30] Quadrature Amplitude Modulation (QAM) Receivers Part 2 (Review)

- A baseband signal in the transmitter experiences impairments as it passes through the transmitter analog/RF front end, channel, and receiver analog/RF front end
- A receiver would have subsystems to compensate impairments (Lecture Slide 16-3)
  - Fading: Automatic gain control
  - Additive noise: Matched filtering
  - Linear distortion: Channel equalizer
  - Carrier mismatch: Carrier recovery
  - Symbol timing mismatch: Symbol clock recovery (a.k.a. symbol timing recovery)

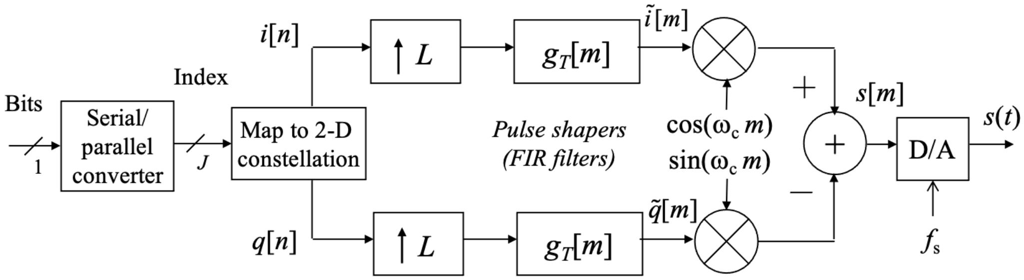
[10:40] Carrier Detection (Lecture Slide 16-9)

- Detect energy in the received signal
- Turn off subsystems when no transmission is occurring to save power
- Input: $x[m] = r^2[m]$ = instantaneous power
- Output: $p[m] = LPF\{x[m]\}$ = time-averaged power
- Low-complexity first-order IIR lowpass filter: $p[m] = c\, p[m-1] + (1-c)\, x[m]$
  - Since $p[m] \geq 0$ and $x[m] \geq 0$, $0 < c < 1$
  - Transfer function: $P(z) = c\, z^{-1} P(z) + (1-c)\, X(z) \Rightarrow \frac{P(z)}{X(z)} = \frac{1-c}{1-c\, z^{-1}}$
    - Pole location c : larger c -> more selective lowpass filter (more smoothing)
  - Choice of c can improve run-time efficiency
    - Example: $c = 3/4 \Rightarrow \frac{3}{4} p[m-1] = \frac{1}{2} p[m-1] + \frac{1}{4} p[m-1]$
    - Since $p[m-1] \geq 0$, multiplying $p[m$-1] by 2^{-n} can be replaced by right shift by n if $p[m-1]$ is in two's complement integer format



[11:00] Symbol clock recovery (Lecture Slide 16-10)

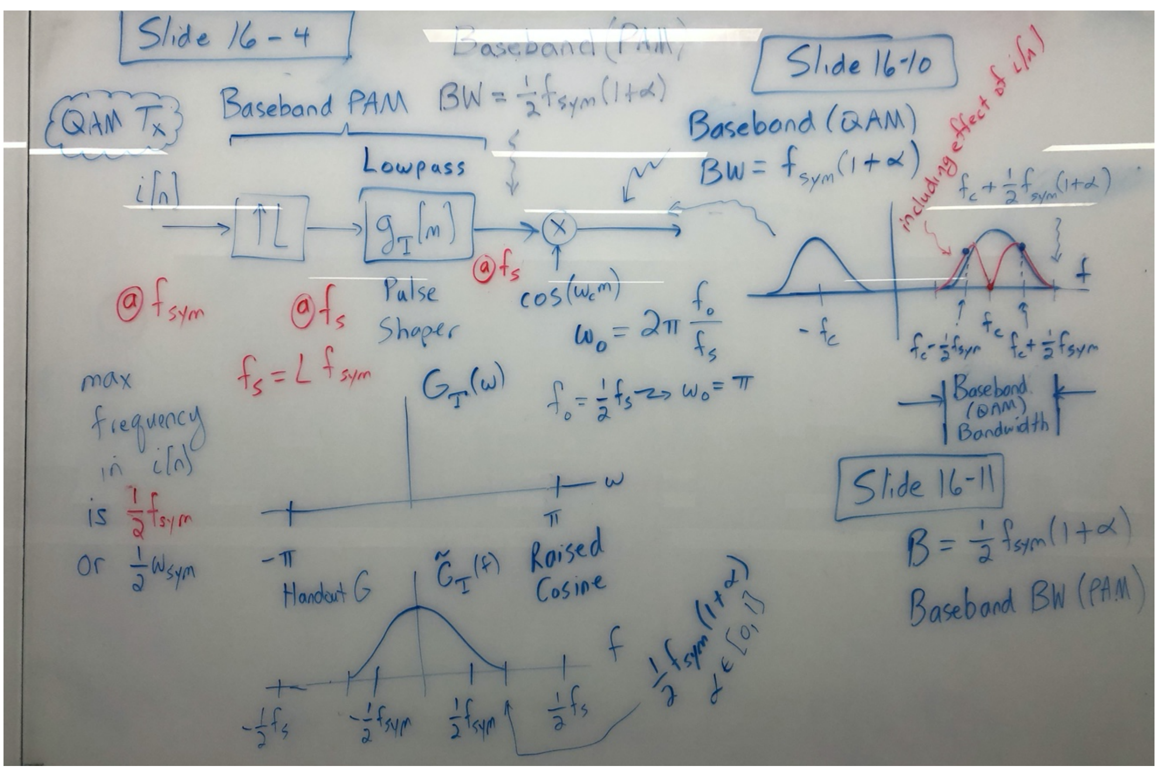
- QAM baseband transmitter consists of two upconverted Pulse Amplitude Modulation (PAM) transmitters that are 90 degrees out of phase (Lecture Slide 16-4)



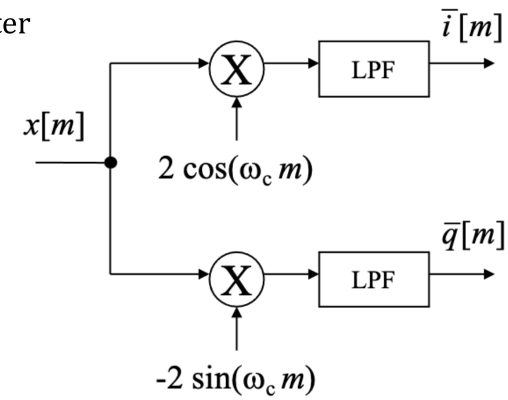
- Recall structure of baseband PAM for in-phase part of baseband QAM transmitter:

$$i[n] \underset{@f_{sym}}{\rightarrow} \uparrow L \underset{@f_s}{\rightarrow} \underbrace{g_T[m]}_{pulse\ shaper} \underset{@f_s}{\rightarrow} \tilde{i}[m]$$

  - Lowpass pulse shaping filter should pass frequencies up to $f_{sym}/2$
  - Raised cosine pulse shaping filter will expand bandwidth by factor $(1+\alpha)$
  - Baseband PAM bandwidth $B = \frac{1}{2} f_{sym} (1+\alpha)$
  - Upconversion by sinusoidal modulation doubles bandwidth to $f_{sym}(1+\alpha)$
  - $i[n]$ are symbol amplitudes with an average value of 0 (hence DC component is 0)
- One approach for symbol timing recovery (Handout M)
  - Use symmetry of received signal about f_c
  - Use two complex single-pole bandpass IIR filters with center frequencies $f_c - B$ and $f_c + B$ in parallel and combine outputs nonlinearly to estimate symbol timing offset



[11:25] Baseband QAM demodulation (Lecture Slides 16-11 and 16-12)



- Demodulation: multiply by sinusoid and lowpass filter
  - In phase: $\bar{\imath}[m] = LPF\{2\,x[m]\cos(\omega_c m)\}$
  - Quadrature: $\bar{q}[m] = LPF\{-2\,x[m]\sin(\omega_c m)\}$
- Lowpass filter serves multiple purposes
  - Matched filter
  - Anti-aliasing
  - Demodulation filter
- Downsample by L to return to symbol rate