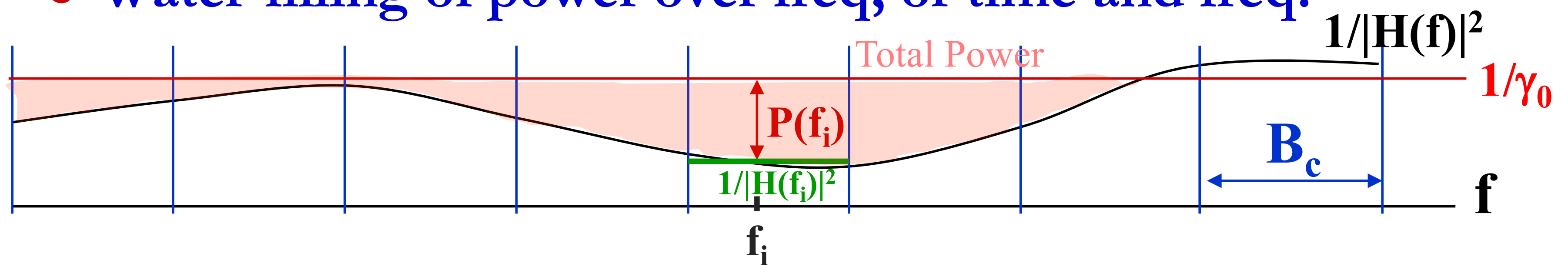
EE359 – Lecture 9 Outline

- Announcements:
  - Tom's email OHs today 1-2pm
  - New discussion section and OH times starting next week
    - Wednesdays 5-6pm Discussion session (Packard 361), Tom's OHs afterwards
  - Project proposals due midnight 10/27; get early feedback
  - Midterm Nov. 9, 6-8pm (pizza after), more details next week
    - Email me/TAs if you have a conflict
    - Open book/notes. Covers through diversity. No HW that week.
    - Over next week: propose dates for MT review, post practice MTs.
- Linear Modulation Review
- Linear Modulation Performance in AWGN
- Q-Function representations
- Probability of error in fading
- Outage probability
- Average P_s (P_b)

Review of Last Lecture

- Capacity in Flat-Fading: γ known at TX/RX
  - Optimal Adaptation: Power: $1/\gamma_0 - 1/\gamma$, Rate: $B\log_2(\gamma/\gamma_0)$; Depend on $p(\gamma)$ only through γ_0
  - Channel Inversion and Truncated Inversion
    - Received SNR constant; Capacity is $B\log_2(1+\sigma)$ above an outage level associated with truncation
- Capacity of ISI channels
  - Divide wideband channel into narrowband flat-fading subchannels of bandwidth B approximately equal to B_c
    - Each subchannel has NB fading approx. independent from others
  - Water-filling of power over freq; or time and freq.



Linear Digital Modulation

- **Signal over *i*th symbol period:**

$$s(t) = s_{i1} g(t)\cos(2\pi f_c t + \phi_0) - s_{i2} g(t)\sin(2\pi f_c t + \phi_0)$$

  - **Pulse g(t) typically Nyquist, assumed square**
  - **Signal constellation defined by (s_{i1},s_{i2}) pairs**
    - **M values for $(s_{i1},s_{i2}) \Rightarrow \log_2 M$ bits per symbol**
    - **We focus on MPSK and MQAM**
    - **MPSK can be differentially encoded**

- **P_s depends on**
  - **Minimum distance d_{min} *(depends on γ_s)***
  - **# of nearest neighbors α_M**
  - **Approximate expression:**
    - **Standard/alternate Q function**

$$P_s \approx \alpha_M Q\left(\sqrt{\beta_M \gamma_s}\right)$$

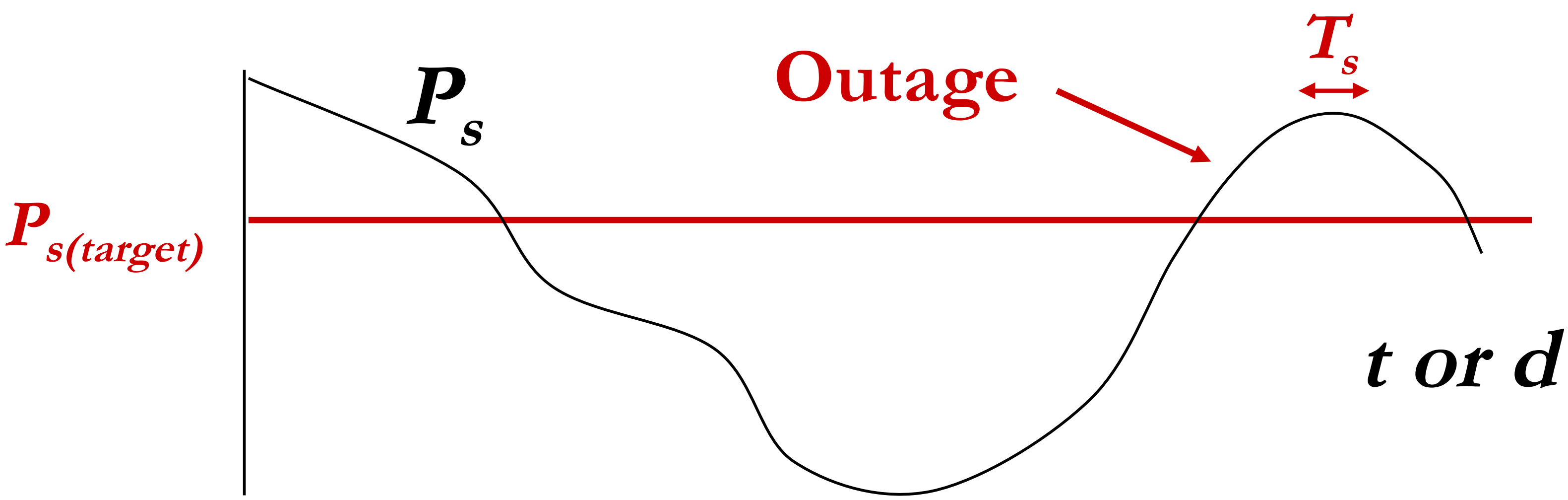
Linear Modulation in Fading

- In fading γ_s and therefore P_s random
- Performance metrics:
  - Outage probability: $p(P_s>P_{target})=p(\gamma<\gamma_{target})$
  - Average P_s , $\overline{P}_s$:

$$\overline{P}_s=\int_0^\infty P_s(\gamma)p(\gamma)d\gamma$$

  - Combined outage and average P_s

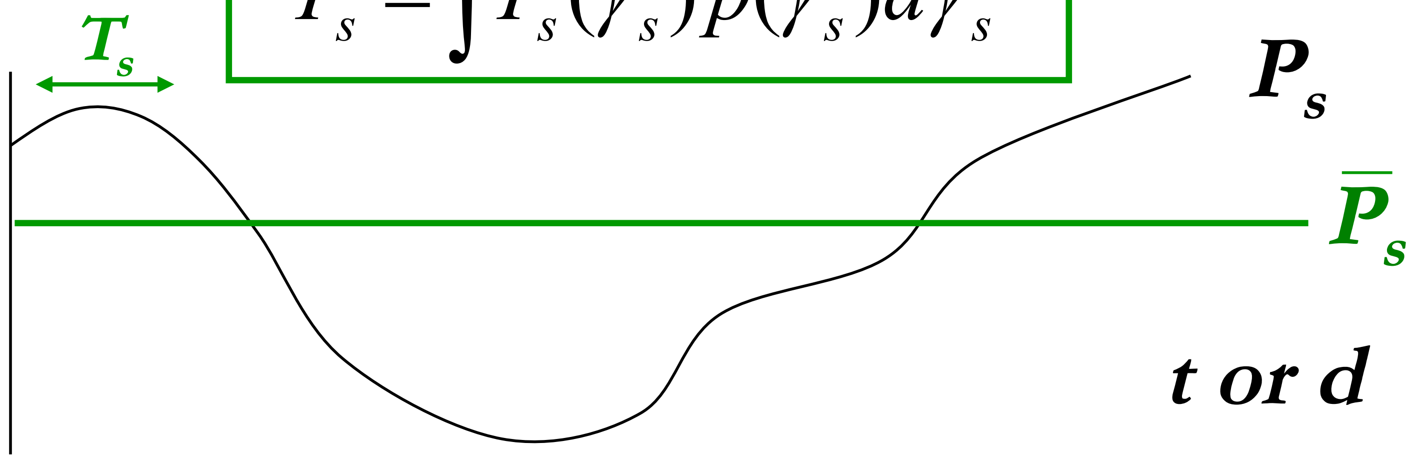
Outage Probability



- Probability that P_s is above target
- Equivalently, probability γ_s below target
- Used when $T_c >> T_s$

Average P_s

$$\overline{P}_s = \int P_s(\gamma_s)\, p(\gamma_s)\, d\gamma_s$$



- Expected value of random variable P_s
- Used when $T_c \sim T_s$
- Error probability much higher than in AWGN alone
- Rarely obtain average error probability in closed form
  - Probability in AWGN is Q-function, double infinite integral

Main Points

- P_s approximation in AWGN: $P_s \approx \alpha_M Q\left(\sqrt{\beta_M \gamma_s}\right)$
  - Alternate Q function useful in fading/diversity analysis
- In fading P_s is a random variable, characterized by average value, outage, or combined outage/average
- Fading greatly increases average P_s or required power for a given target P_s with some outage
  - Outage probability based on target SNR in AWGN.
- Need to combat flat fading or waste lots of power