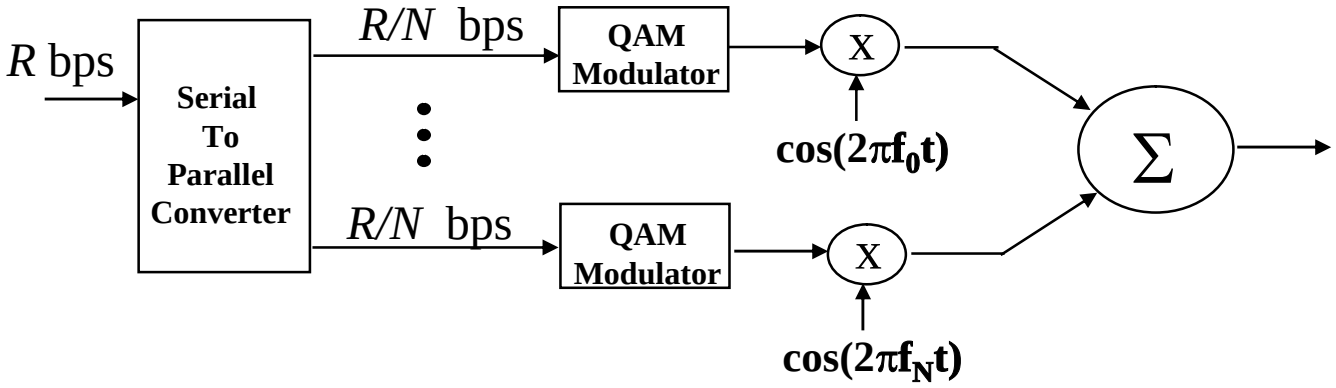
EE359 – Lecture 17 Outline

- Announcements
  - HW due Fri. 5pm, no HW next week, 1 more HW due 12/4
  - Bonus lecture 11/30, 5:15-7:15, 204 Packard
  - Final info (coverage, review, extra OHs, etc) given 11/30
  - Extra credit for Axess online evals
- Review of Last Lecture
- Overlapping subcarriers
- Fading across subcarriers
- OFDM FFT Implementation
- OFDM Challenges
- Introduction to Spread Spectrum

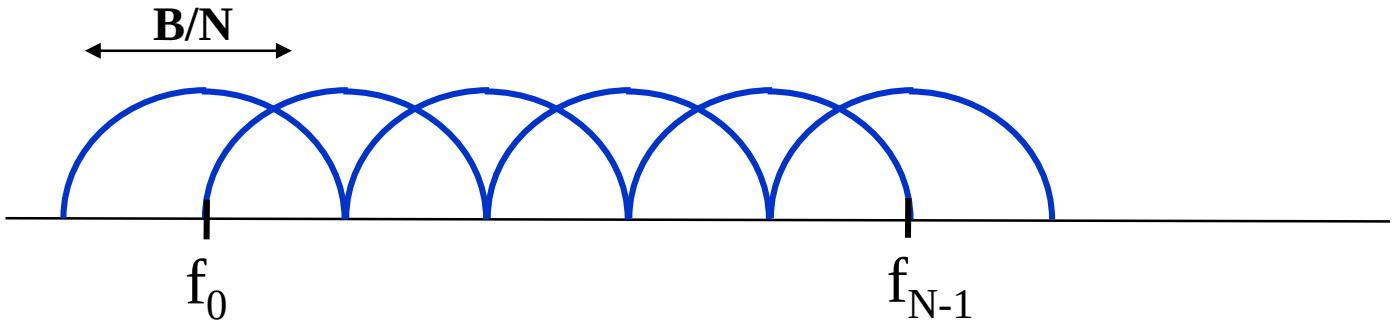
Review of Last Lecture

- MIMO Beamforming
  - Transmit along dominant spatial mode of channel matrix
- Diversity vs. Multiplexing Tradeoffs in MIMO
  - Optimal operating point depends on application
- MIMO system design issues
- Multicarrier modulation mitigates ISI
  - Splits data stream into NB flat fading substreams
  - Flat fading on each subcarrier



Overlapping Substreams

- Can have completely separate subchannels
  - Required passband bandwidth is B.
- OFDM overlaps substreams
  - Substreams (symbol time T_N) separated in RX
  - Minimum substream separation is $B_N/(1+\beta)$.
  - Total required bandwidth is $B/2$ (for $T_N=1/B_N$)

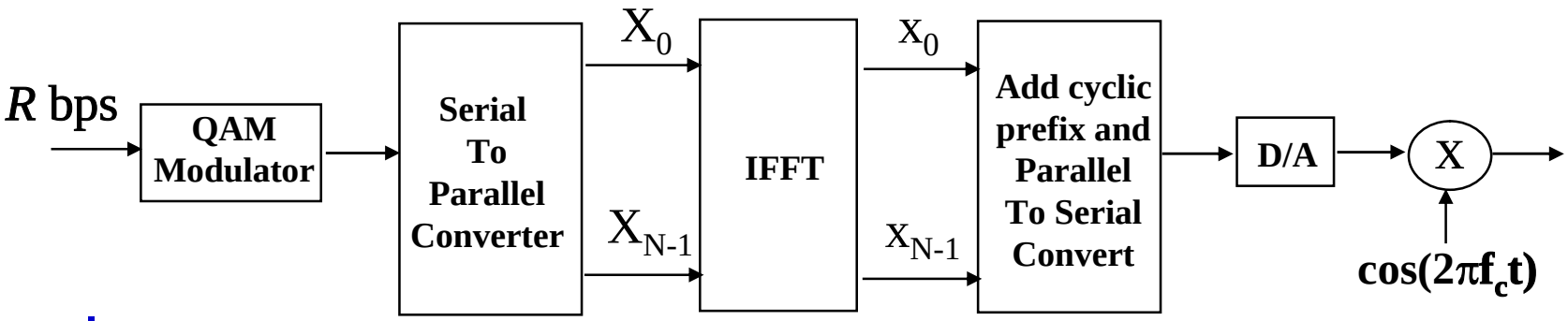


Fading Across Subcarriers

- Leads to different BERS
- Compensation techniques
  - Frequency equalization (noise enhancement)
  - Precoding
  - Coding across subcarriers
  - Adaptive loading (power and rate)

FFT Implementation of OFDM

- Efficient IFFT structure at transmitter
  - Reverse structure (with FFT) at receiver
  - Cyclic prefix makes linear convolution circular, so there is no interference between input blocks



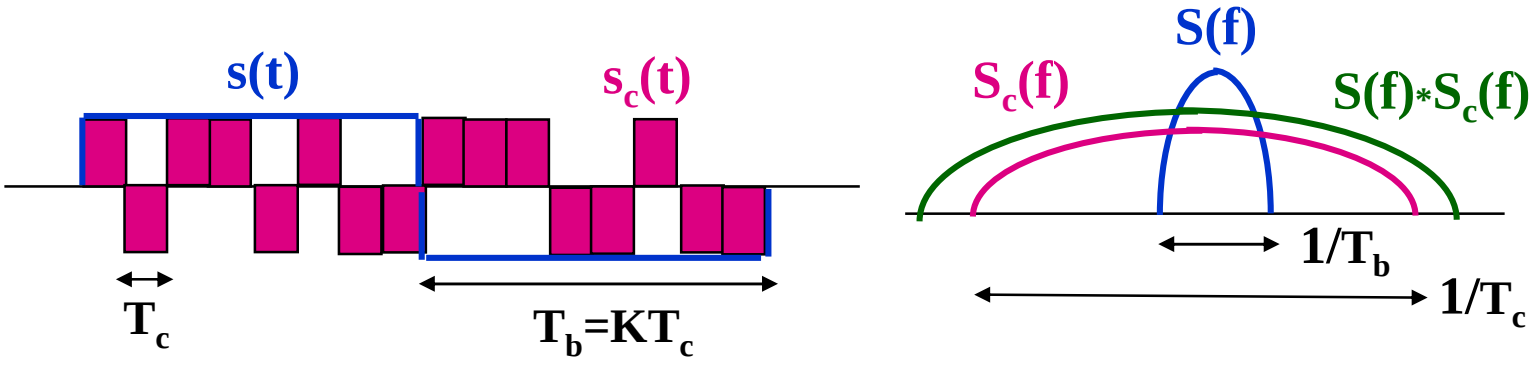
- Issues
  - Timing/frequency offset impacts subcarrier orthogonality
  - Adding signals creates large signal peaks (large PAPR)
  - Fading across subcarriers impacts performance

Introduction to Spread Spectrum

- Modulation that increases signal BW
  - Mitigates or coherently combines ISI
  - Mitigates narrowband interference / jamming
  - Hides signal below noise (DSSS) or makes it hard to track (FH)
  - Also used as a multiple access technique
- Two types
  - Frequency Hopping:
    - Narrowband signal hopped over wide bandwidth
  - Direction Sequence:
    - Modulated signal multiplied by faster chip sequence

Direct Sequence Spread Spectrum

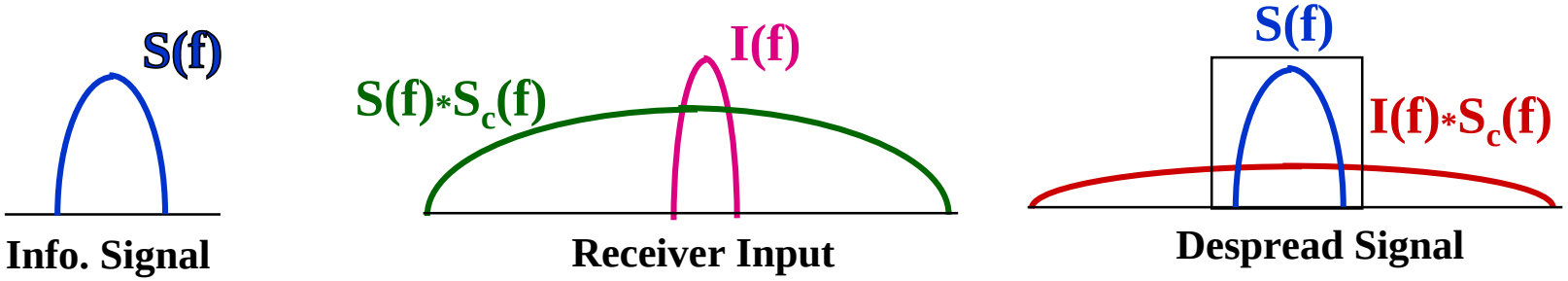
- Bit sequence modulated by chip sequence



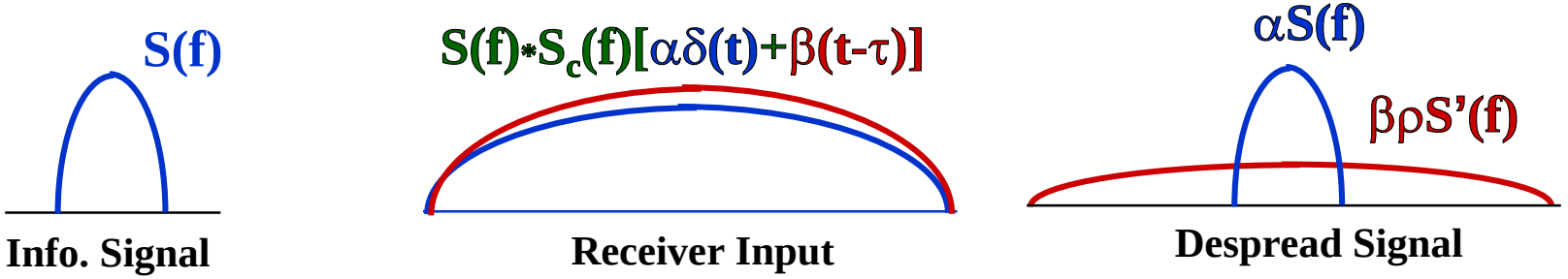
- Spreads bandwidth by large factor (K)
- Despread by multiplying by $s_c(t)$ again ($s_c^2(t)=1$)
- Mitigates ISI and narrowband interference

ISI and Interference Rejection

- Narrowband Interference Rejection (1/K)



- Multipath Rejection (Autocorrelation $\rho(\tau)$)



Main Points

- Subcarrier fading degrades MCM performance
  - Compensate through coding or adaptation
- OFDM efficiently implemented using FFTs
- OFDM challenges are PAPR, timing / frequency offset, and fading across subcarriers
- Spread spectrum spreads signal over wide bandwidth for ISI / interference rejection
- DSSS rejects interference by spreading gain
- DSSS rejects ISI by code autocorrelation