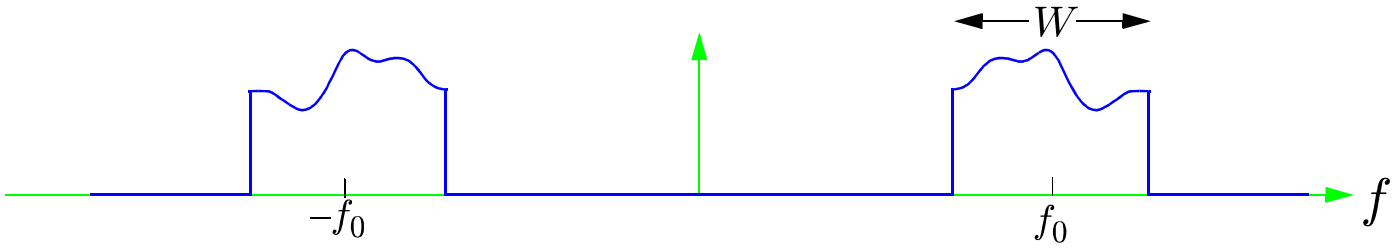
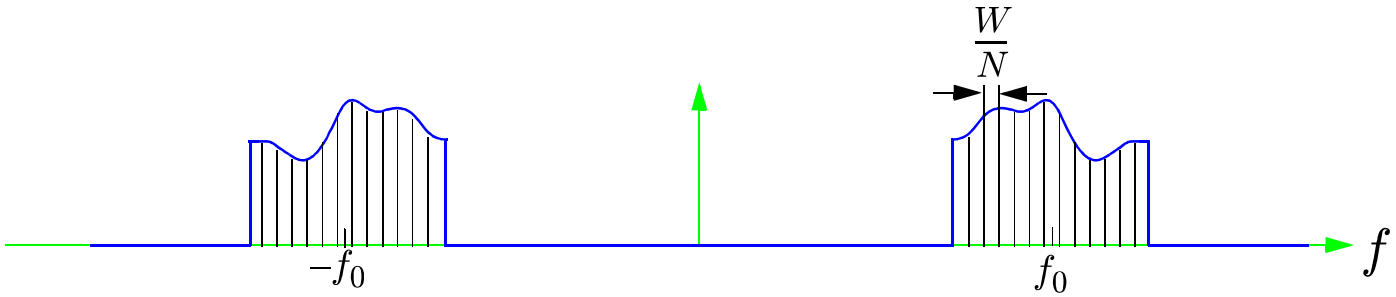
ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

Multi-Carrier Modulation

How to communicate across an ISI channel with bandwidth W?



2. Multicarrier



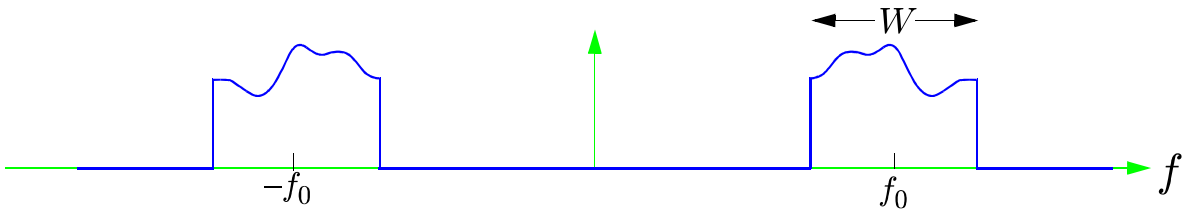
$\Rightarrow$ Carve band into N narrow subbands

$\Rightarrow$ *Transmit at rate* W/N *across each, independently*

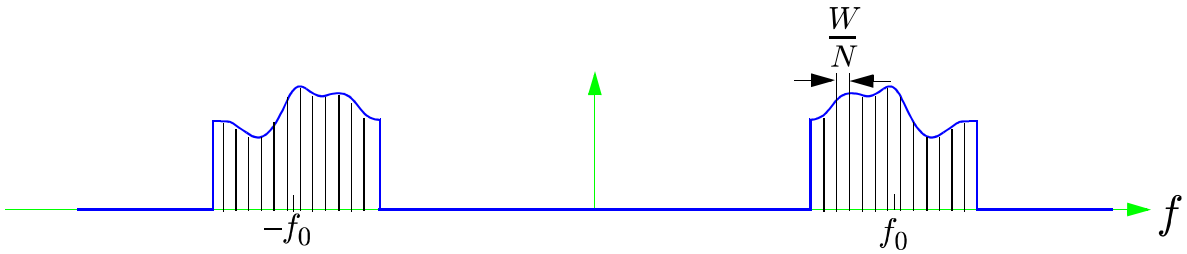
$\Rightarrow$ *Avoids* ISI when N is large

Identical Bit Rates

A single 64-QAM signal with symbol rate W:



N independent 64-QAM signals, each with rate W/N:



Both achieve the same bit rate, namely $R_b = 6W$.

Remark 2: Same power efficiency too.

$\Rightarrow$ The "point" in the SNR-v-BW plane is independent of N!

OFDM Widely Used

- Wireless LAN (WiFi 802.11a, 802.11g)
- Wireless MAN (WiMax, 802.16)
- Power line communications
- ADSL
- Digital Video Broadcast (DVB)
- Digital Audio Broadcast (DAB)
- Ultrawideband (UWB)
- Flarion OFDMA Mobile data

OFDM Advantages

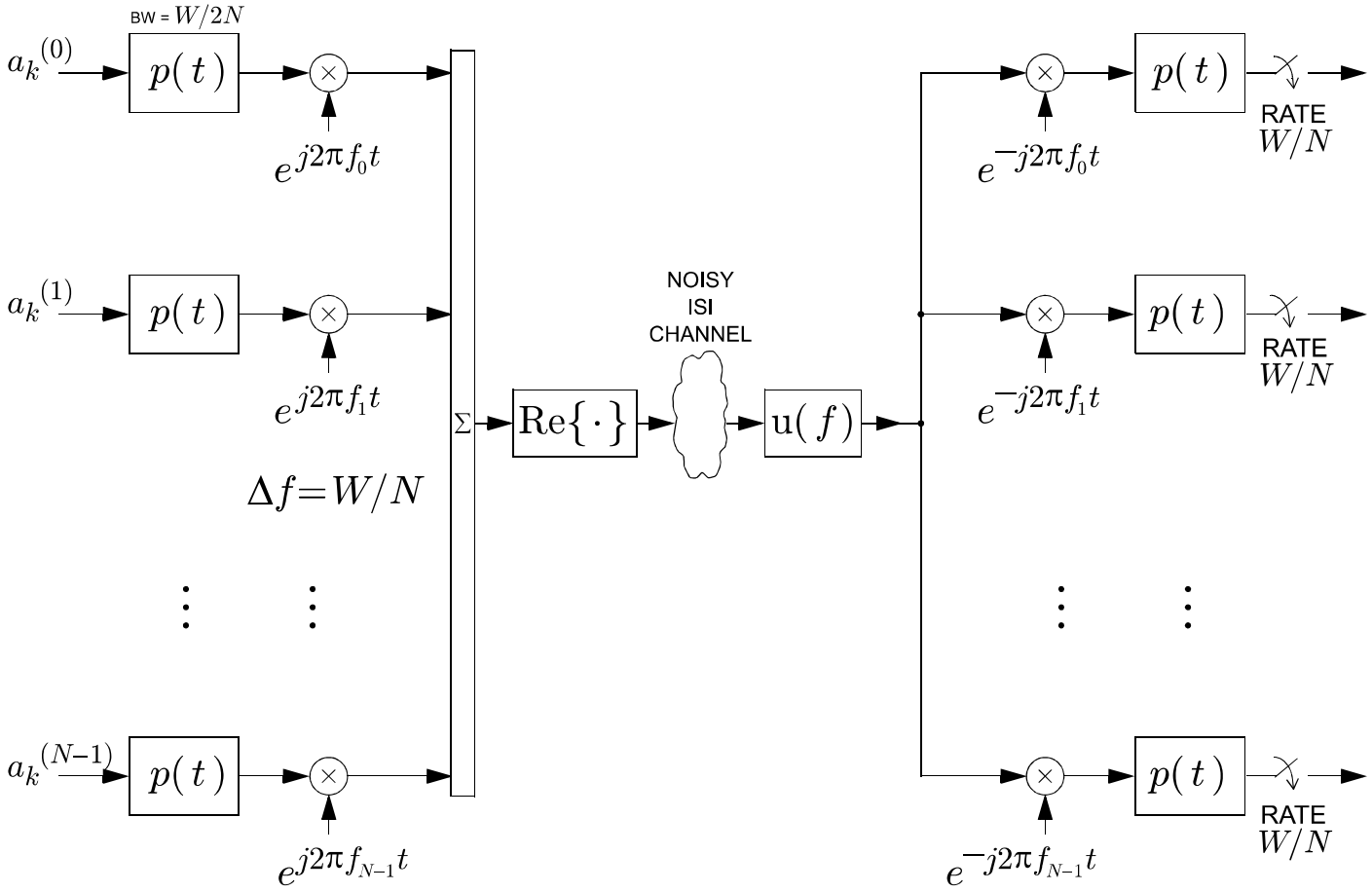
- OFDM is a spectrally efficient modulation technique
- It is conveniently implemented using IFFT and FFT operations
- It handles frequency selective channels well when combined with error correction coding

OFDM Disadvantages

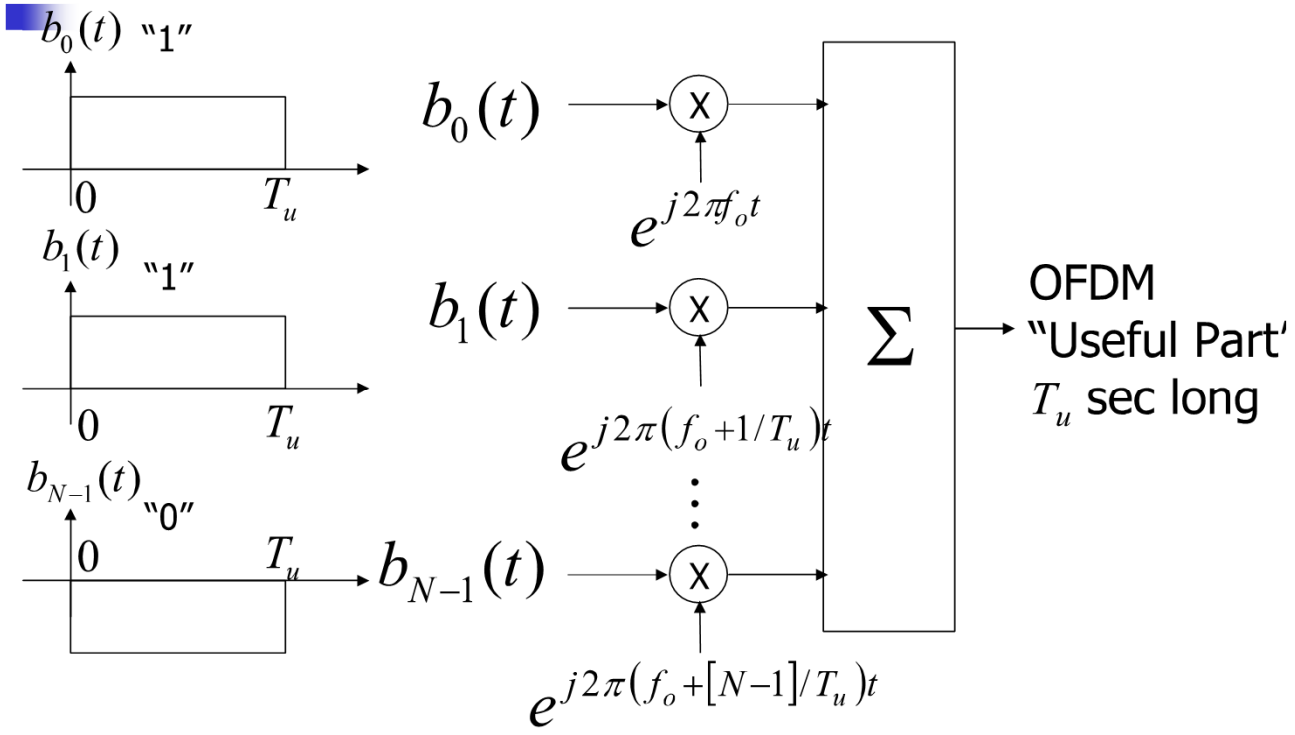
- More complex than single-carrier modulation
- Requires a more linear power amplifier

Naïve Implementation—Too Complex

Each symbol rate is $1/T = W/N$

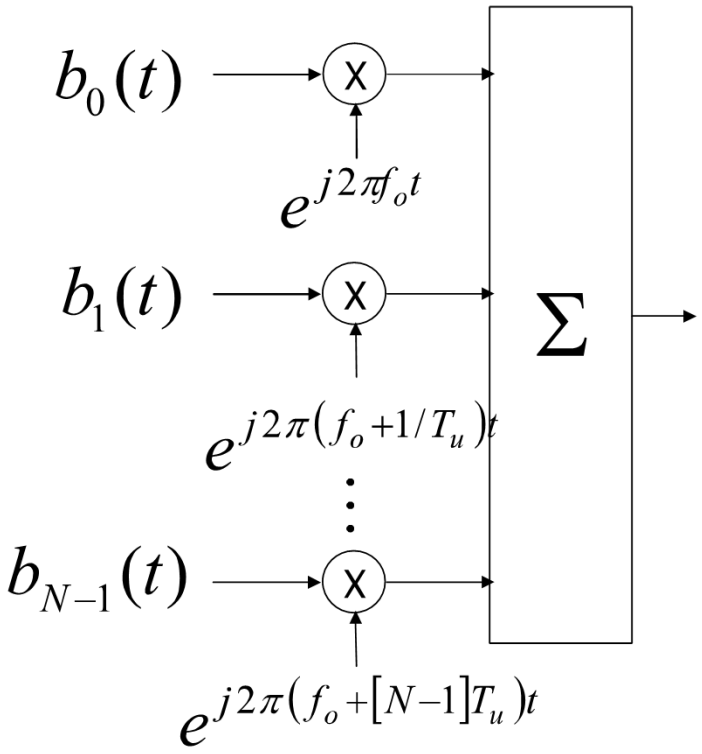


Transmitter Block Diagram



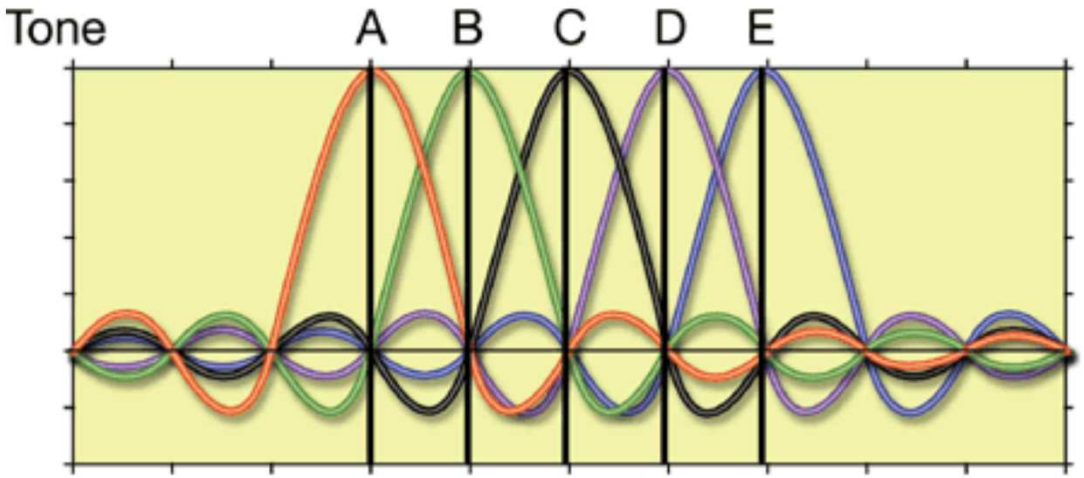
Sub-Carriers

- Each branch corresponds to a *subcarrier*
- Subcarriers are separated by $1/T_u$ Hz
- Each subcarrier modulates a different symbol
  - b_k can be QAM



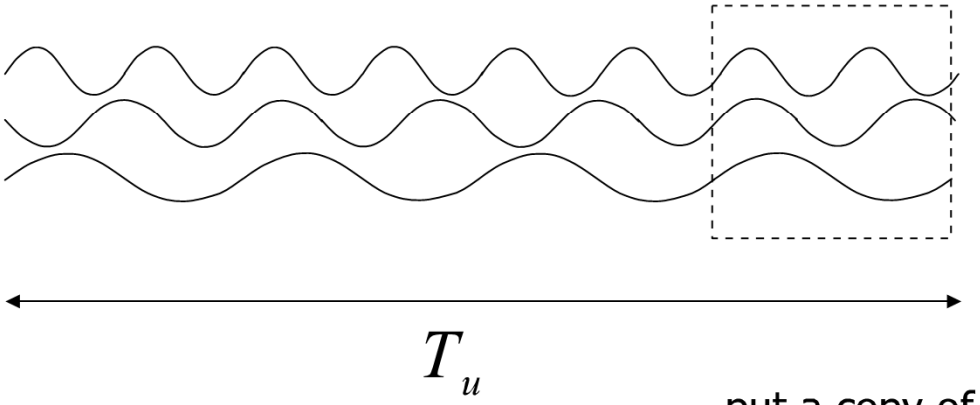
Sub-Carrier Spectra

- Each modulated subcarrier has a spectrum in the shape of a sinc squared function

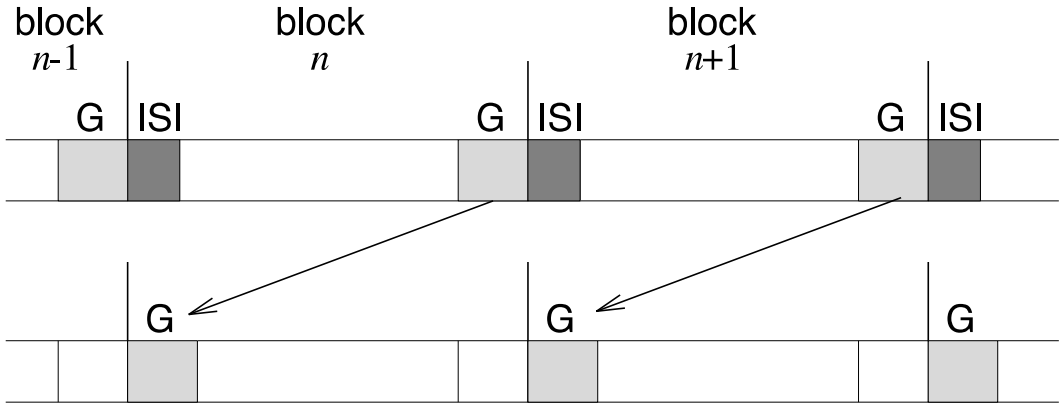


Cyclic Prefix

- To avoid losing the power from echoes, a copy of the end is appended to the beginning of the "useful" part



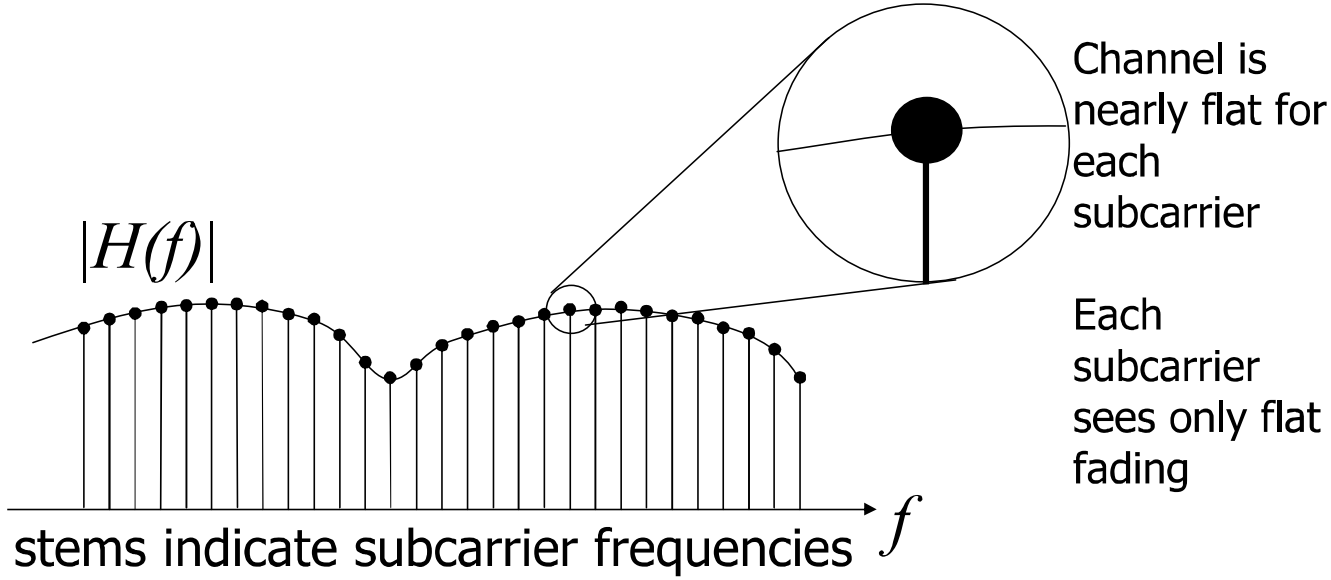
Cyclic Prefix



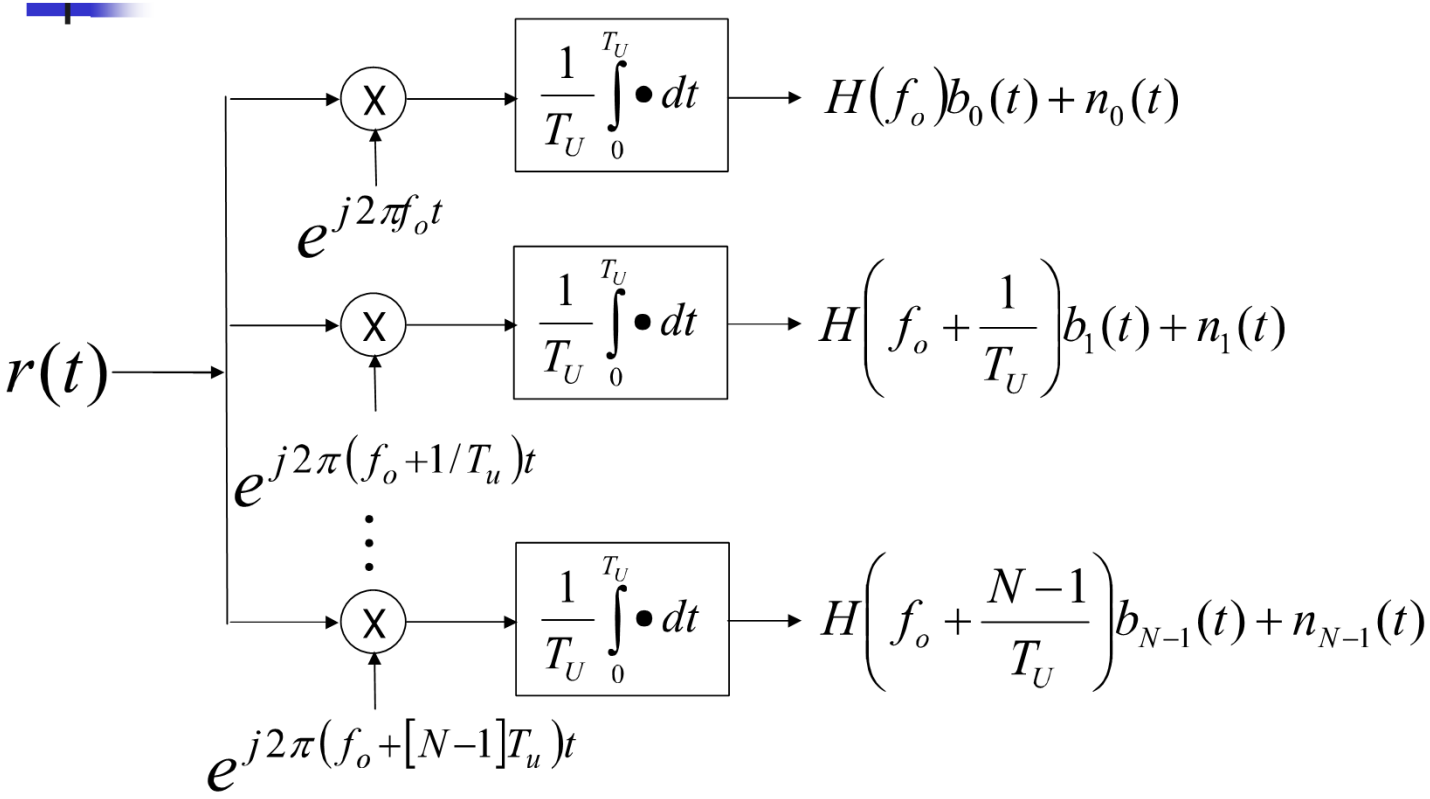
Removal of ISI using a cyclic suffix

Fading

- The subcarrier spacing is typically much less than the coherence bandwidth



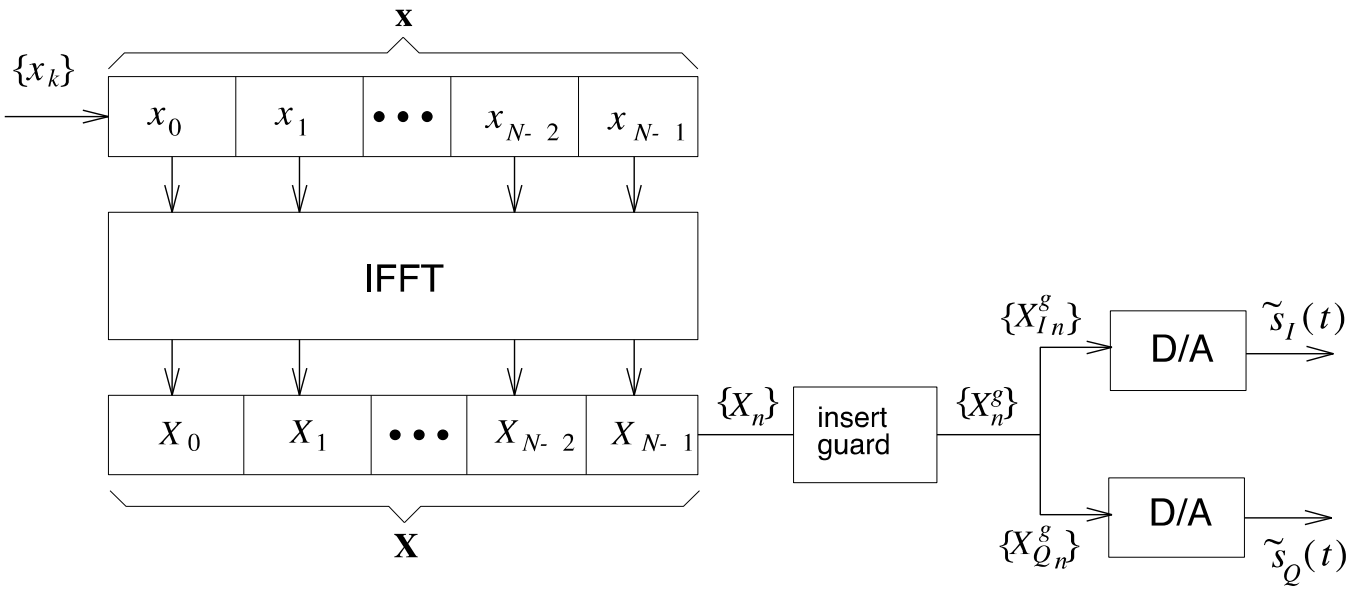
Correlator Block Diagram



FFT Based Implementation

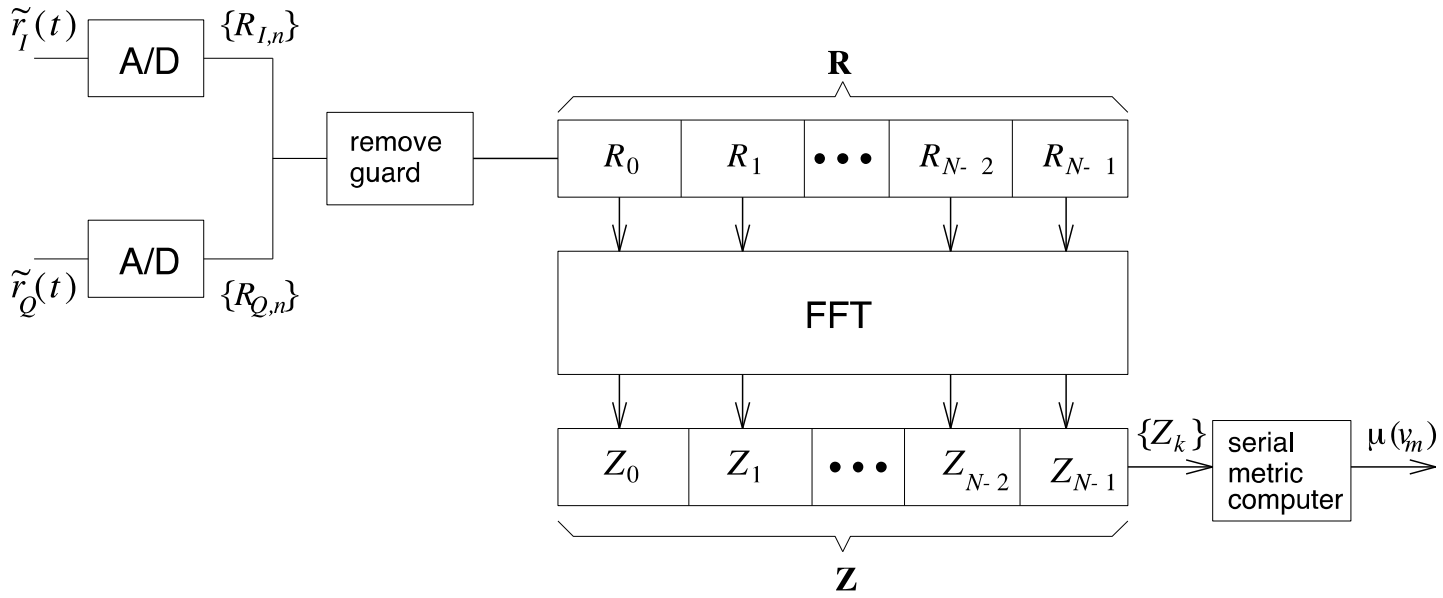
- These correlations are conveniently performed by the Fast Fourier Transform (FFT)
- The modulation is performed by the inverse FFT (IFFT)
- There are very fast and efficient implementations of the FFT and IFFT, which is a big reason for the popularity of OFDM

Modulator



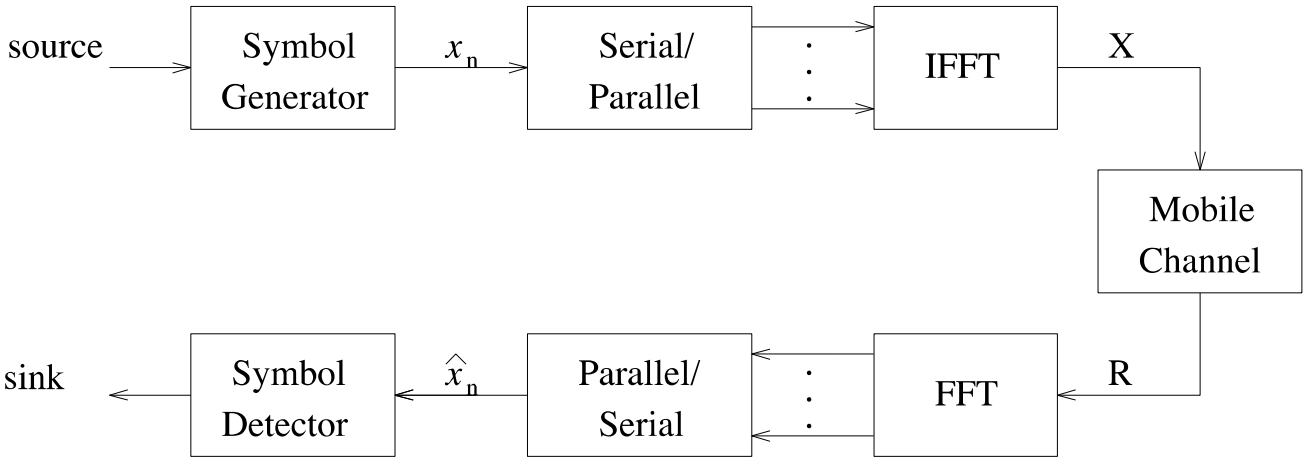
FFT-based OFDM Transmitter

Demodulator



FFT-based OFDM Receiver

OFDM System



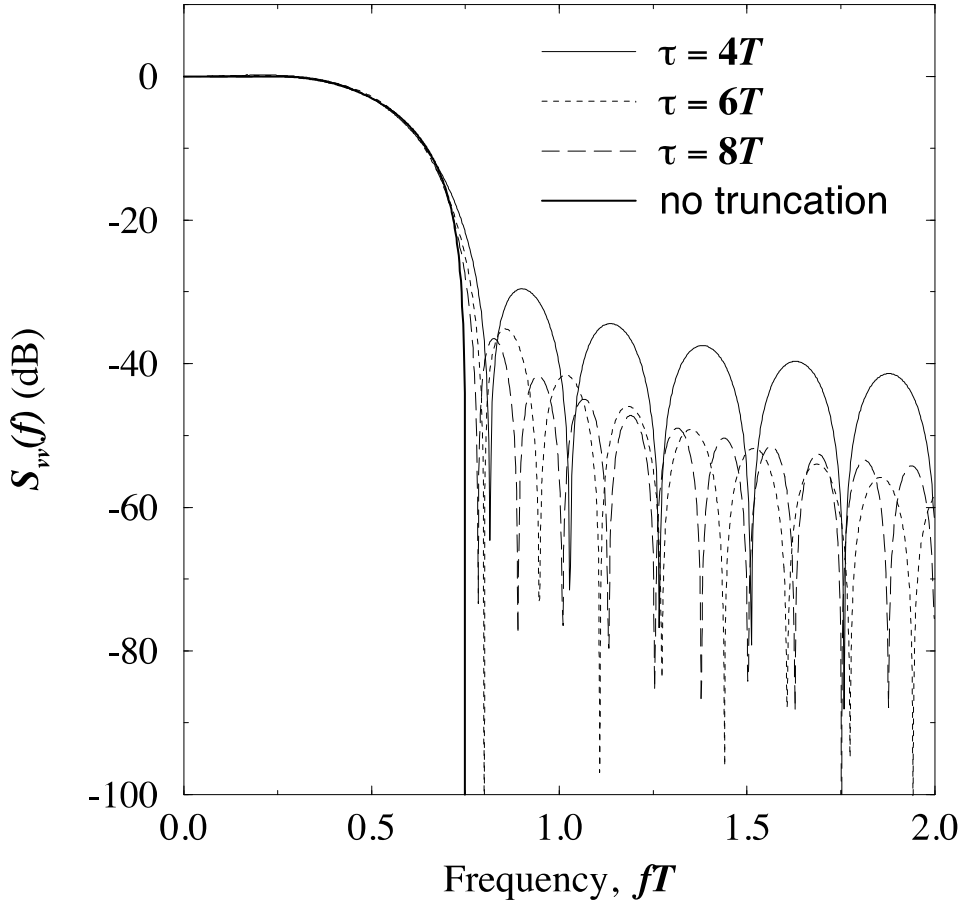
OFDM System

Summary

- OFDM is a multi-carrier modulation technique
- Each subcarrier carries BPSK, QPSK or QAM
- The subcarriers are so close, that each subcarrier sees a flat-faded channel
- The Guard Interval ensures that successive OFDM symbols do not interfere with each other
- FEC and interleaving provide frequency diversity
- OFDM modulation and demodulation is conveniently performed by fast DSP operations (FFT and IFFT)

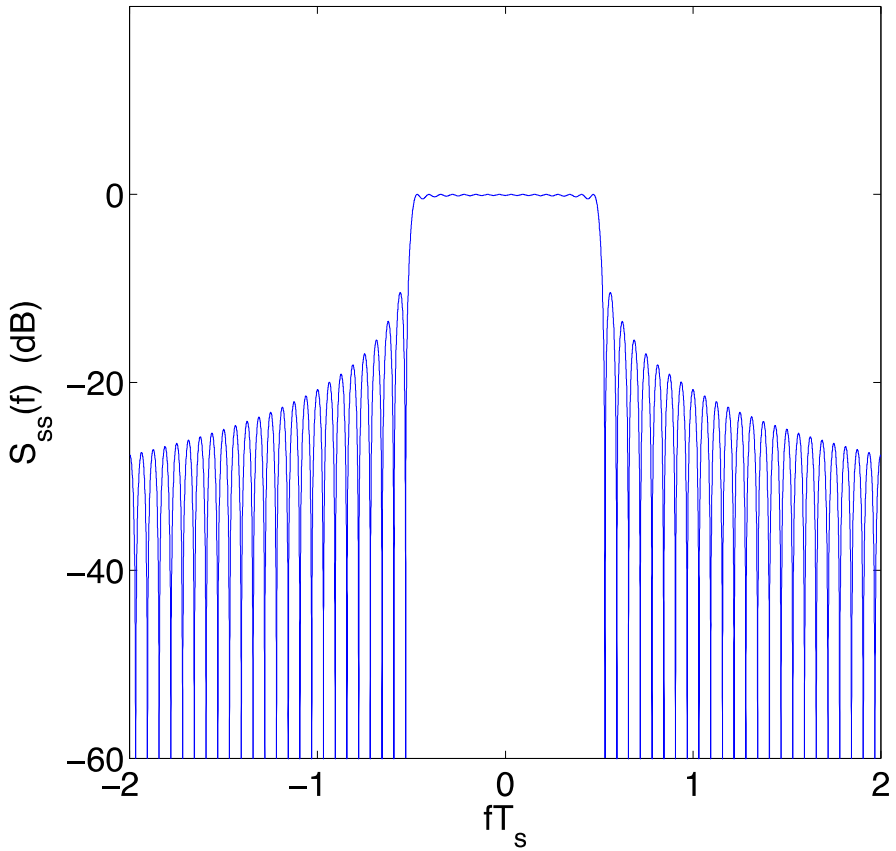
POWER SPECTRAL DENSITY (PSD)

PSD of ASK Signals

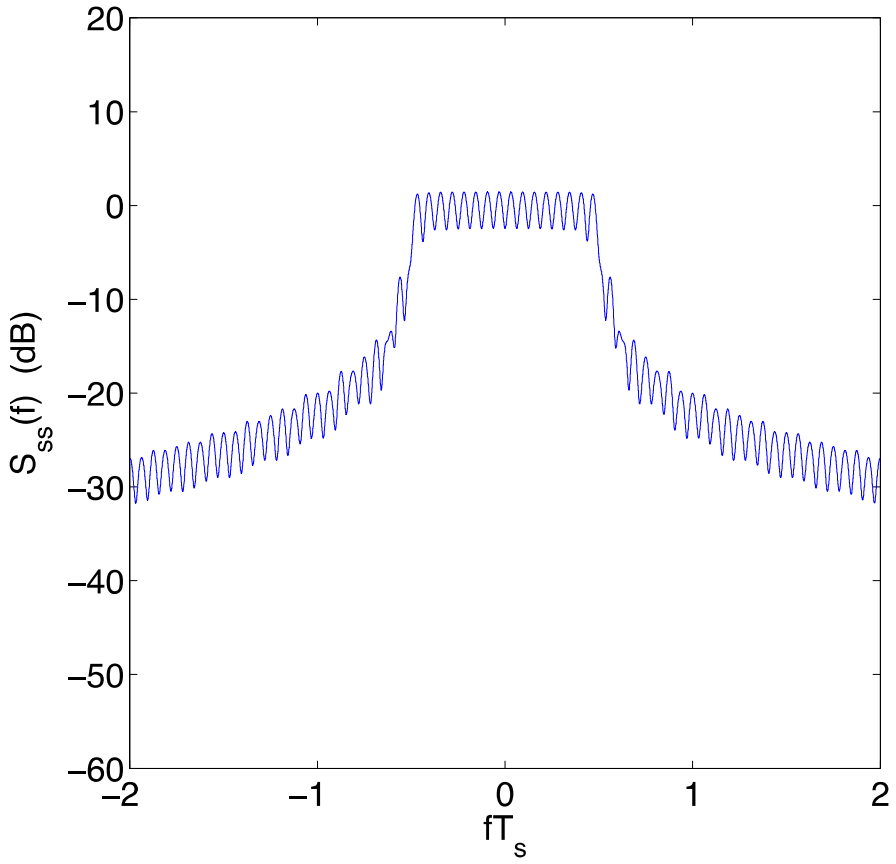


PSD of ASK with a root-raised cosine pulse

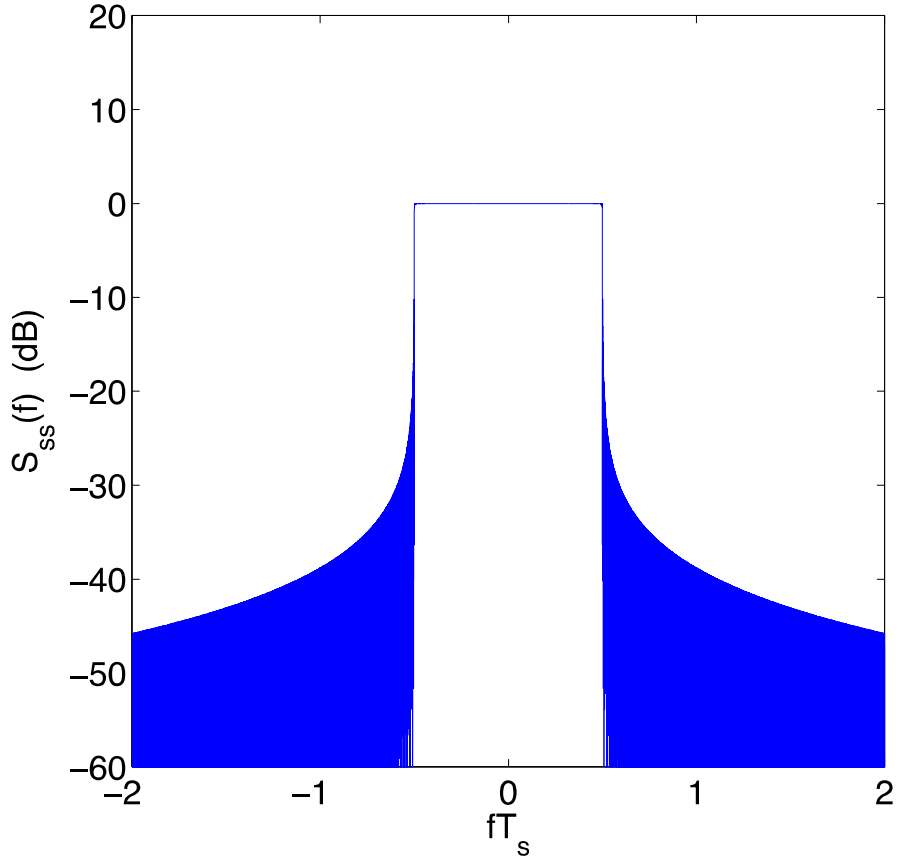
PSD of OFDM without prefix (N=16)



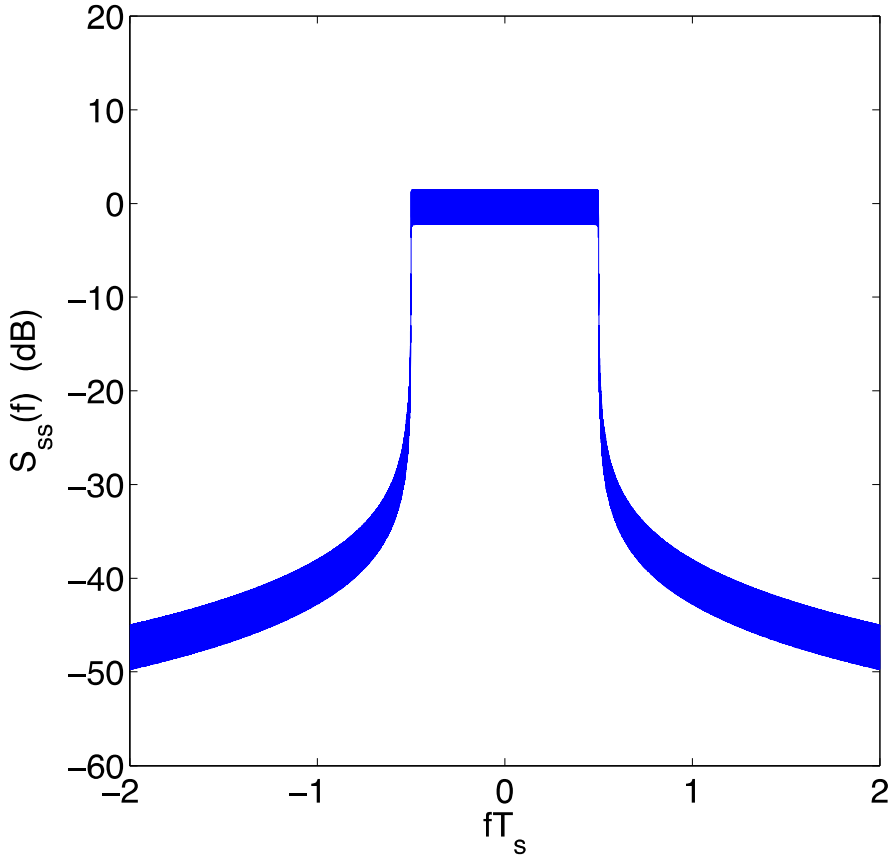
PSD OFDM with 25% Prefix (N=16)



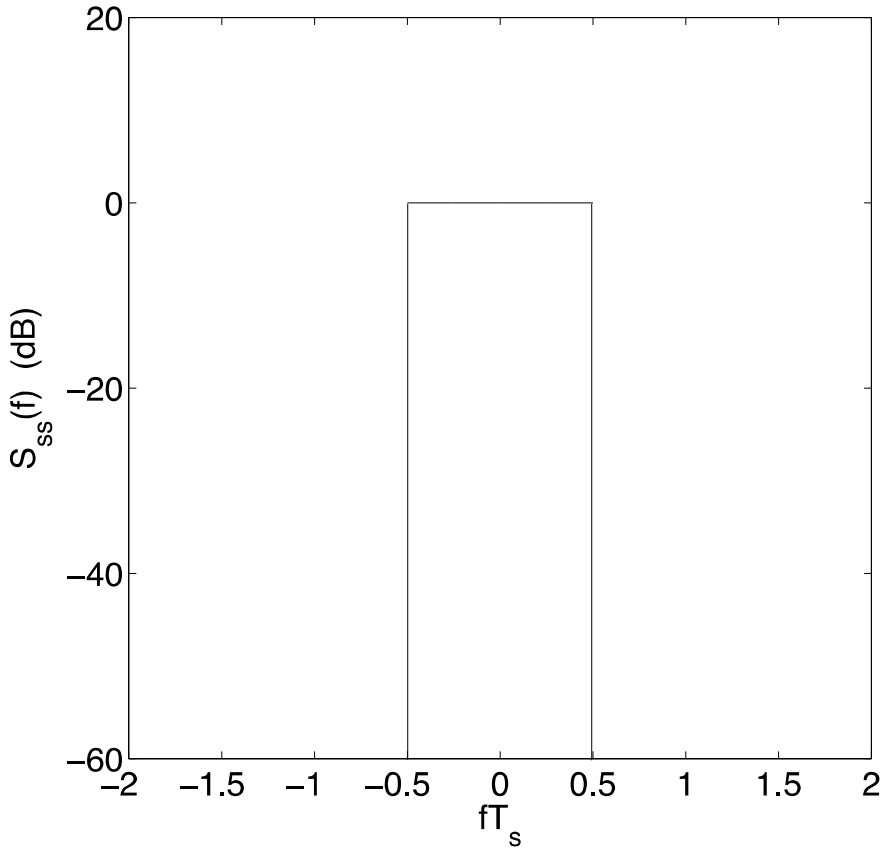
PSD of OFDM without prefix (N=256)



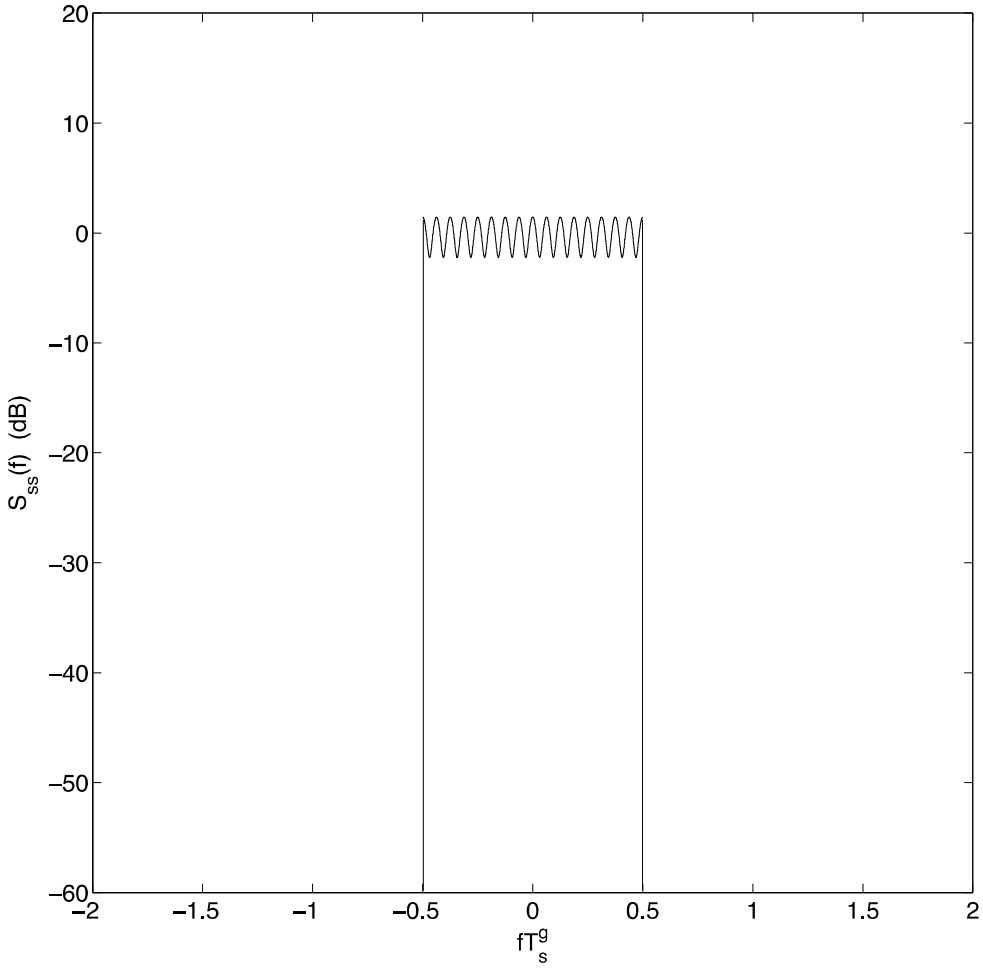
PSD OFDM with 25% Prefix (N=256)



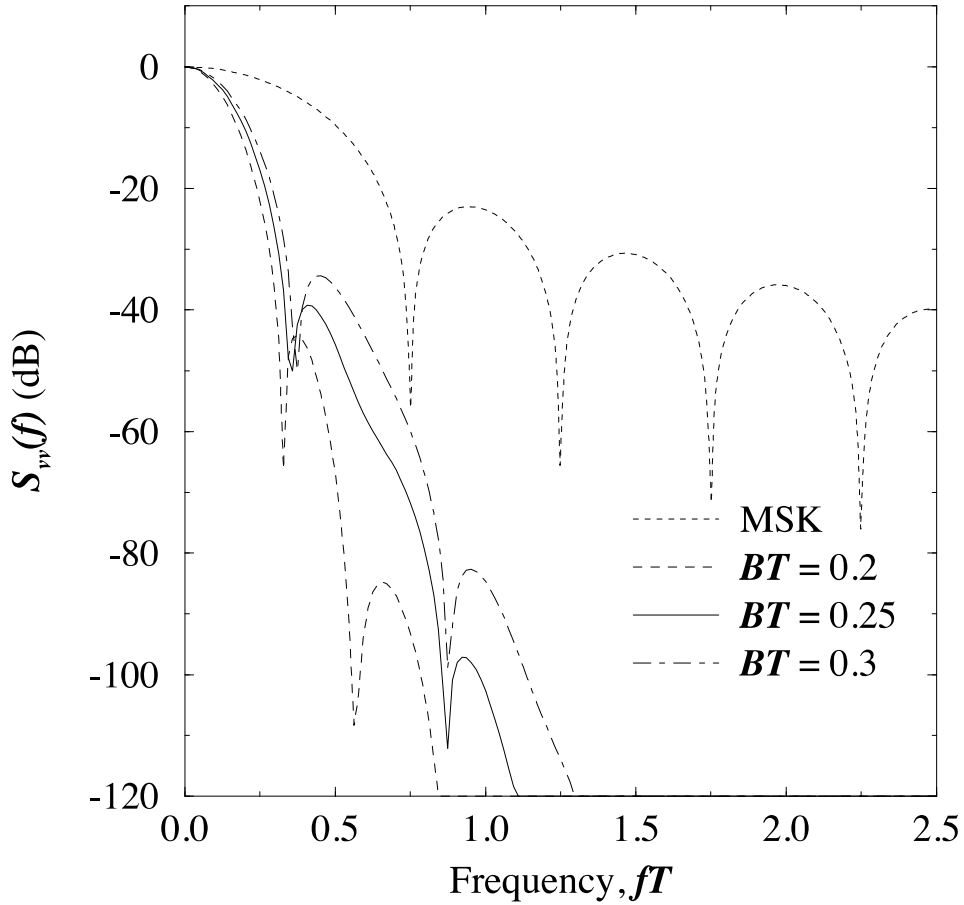
FFT Based OFDM Spectrum (N=16, No Prefix)



FFT Based OFDM Spectrum (N=16, 25% prefix)



PSD of MSK and GMSK



Summary

- OFDM is a multi-carrier modulation scheme
- Each subcarrier carries BPSK, QPSK, or QAM
- The subcarriers are so close, that each subcarrier sees a flat-faded channel
- Guard interval ensues low interference
- OFDM modulation and demoduation is conveniently performed by fast FFT/IFFT operations.