OFDM

Motivation…

- High transmission rates over wireline and wireless channels with protection from multipath fading

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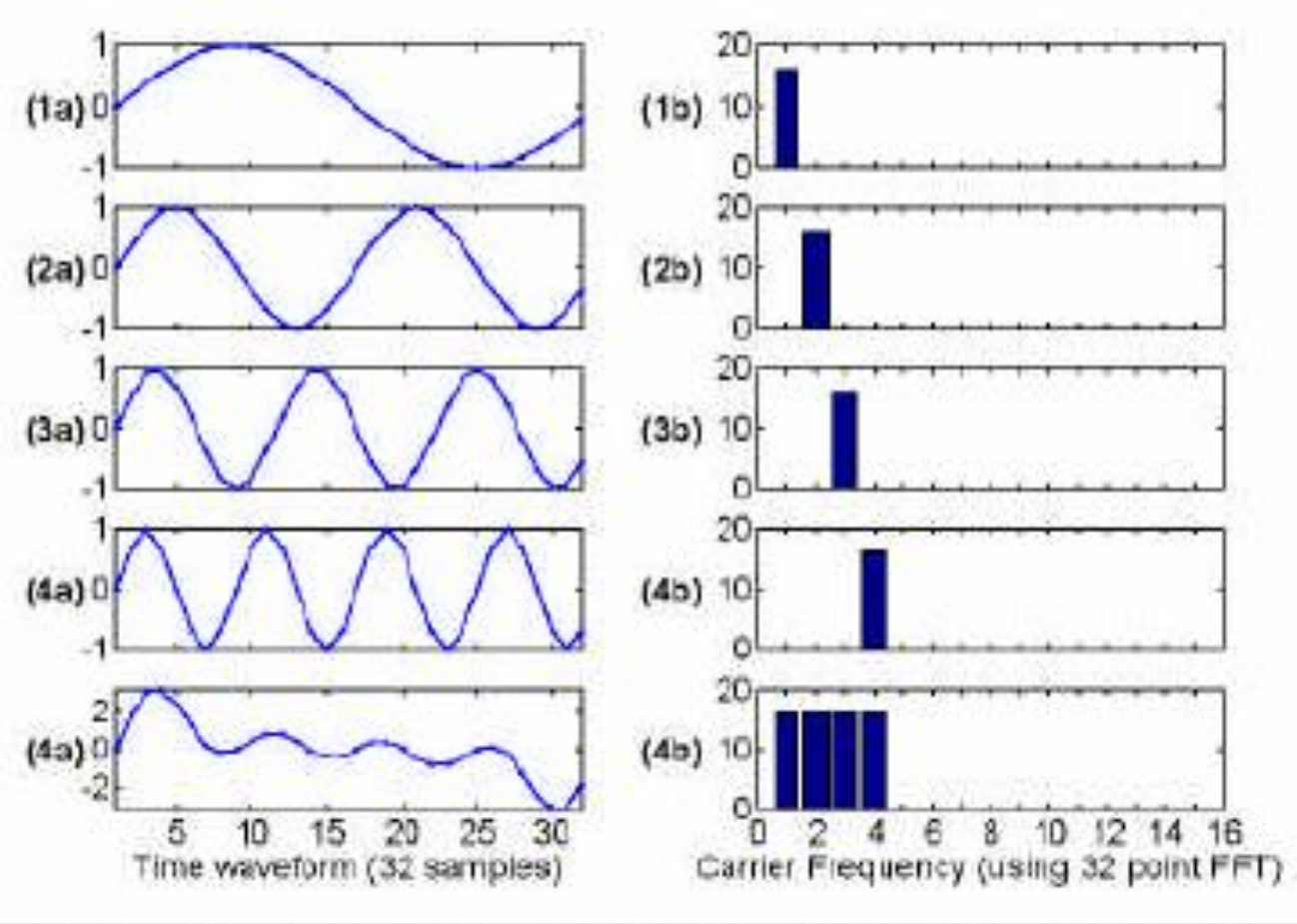
- Technique in fourth Generation (4G) mobile phones
- Ideal for bandwidth hogging applications like Video Conferencing, DAB, DVB, etc
- Multiuser capacity possible using MC-CDMA

Advantages of OFDM

- Allows carriers to overlap (no guard band), resulting in lesser wasted bandwidth without any Inter Carrier Interference (ICI)
- High data rate distributed over multiple carriers resulting in lower symbol rate (more immune to ISI)
- Permits higher data rate as compared to FDM
- Increased security and bandwidth efficiency possible using CDMA – OFDM (MC-CDMA)
- Simple guard intervals make the system more robust to multipath effects.

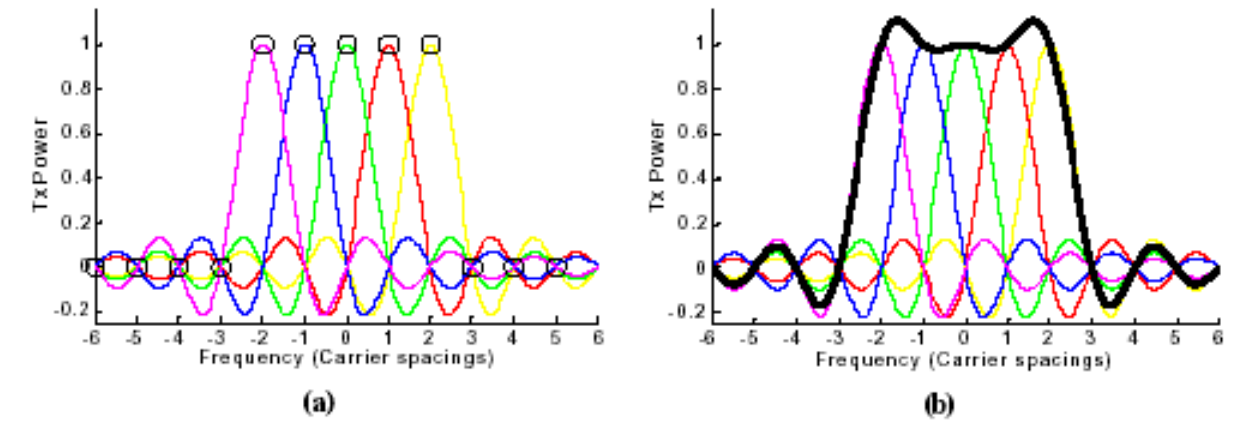
What is OFDM ??

Orthogonality in time domain…



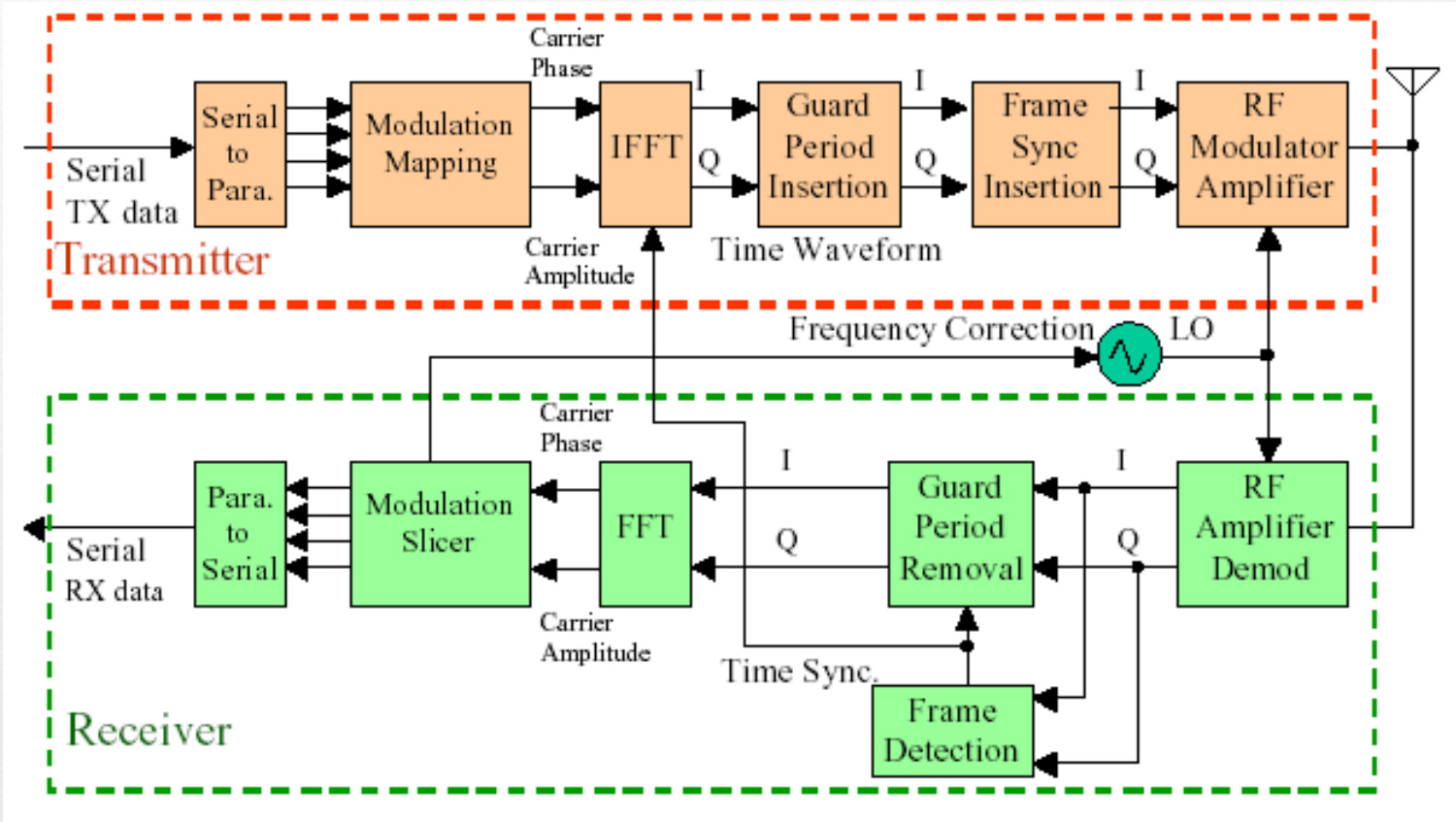
What is OFDM ??

Orthogonality in frequency domain…



- Each carrier is modulated using BPSK / QPSK / M-ary QAM
- Frequency response for each carrier is a Sinc(X)
- Overlap of frequency response is possible as against FDM where inter-carrier spacing is a must
- Frequency responses of the carriers overlap at zero crossings avoiding Inter Carrier Interference

OFDM Methodology



Fast Fourier Transform (FFT)

- FFT takes O(NlogN) time (assumption: $N=2^n$)

Table 3.1 A Comparison of N^2 versus $N \log_2 N$ for Various Values of N

N	N^2 (*Direct* FT)	$N \log_2 N$ (FFT)	*Computational Advantage* ($N/\log_2 N$)
2	4	2	2.00
4	16	8	2.00
8	64	24	2.67
16	256	64	4.00
32	1,024	160	6.40
64	4,096	384	10.67
128	16,384	896	18.29
256	65,536	2,048	32.00
512	262,144	4,608	56.89
1024	1,048,576	10,240	102.40
2048	4,194,304	22,528	186.18
4096	16,777,216	49,152	341.33
8192	67,108,864	106,496	630.15

Inverse FFT

Forward DFT

$$F(u) = \frac{1}{N} \sum_{x=0}^{N-1} f(x) e^{\frac{-j2\pi ux}{N}}$$

Inverse DFT

$$f(x) = \sum_{u=0}^{N-1} F(u) e^{\frac{j2\pi ux}{N}}$$

- The inverse FFT can be computed using the same implementation

Understanding Multipath

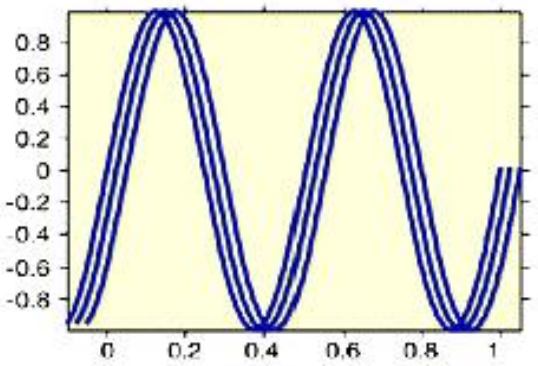


Figure Example of Time-Delayed Multipath Signals

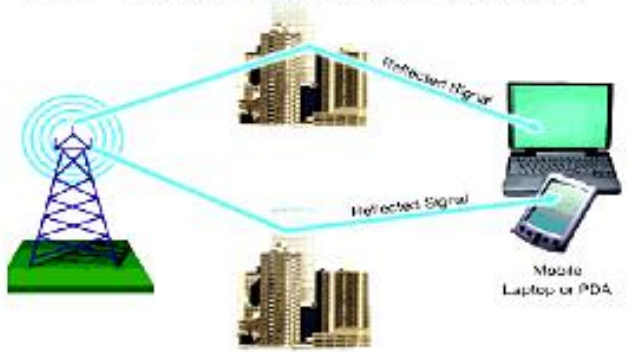


Figure Demonstration of Multipath Reflections

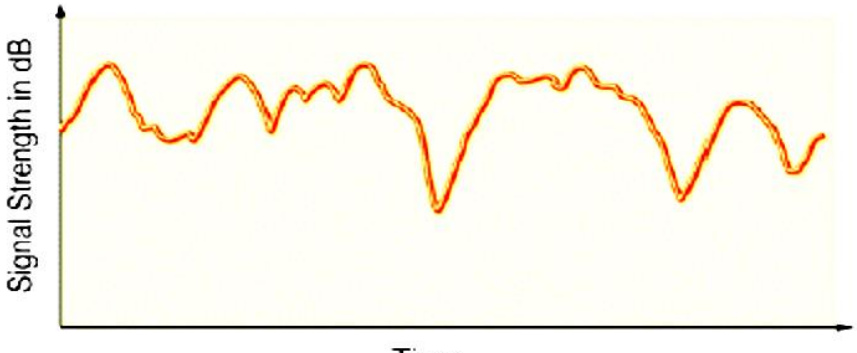
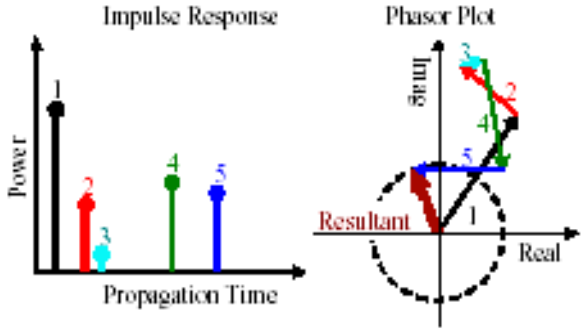


Figure Demonstration of Time-Varying Fading



Why we need the Guard Period…

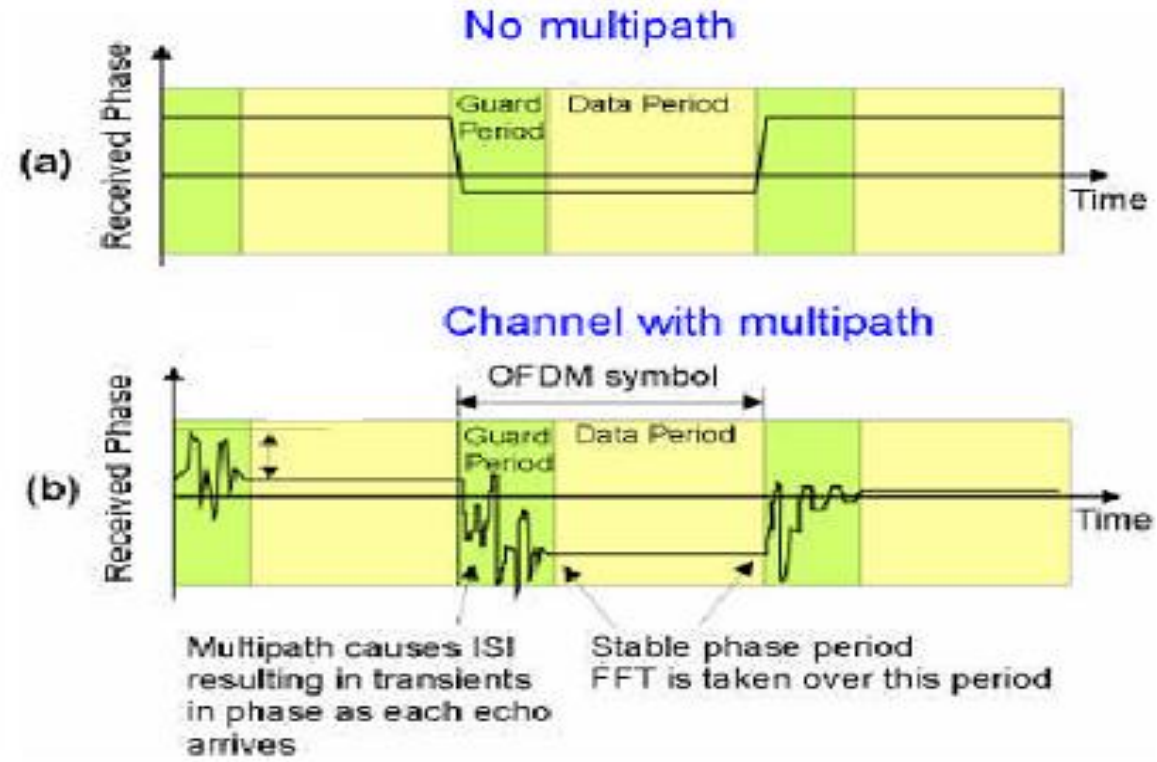
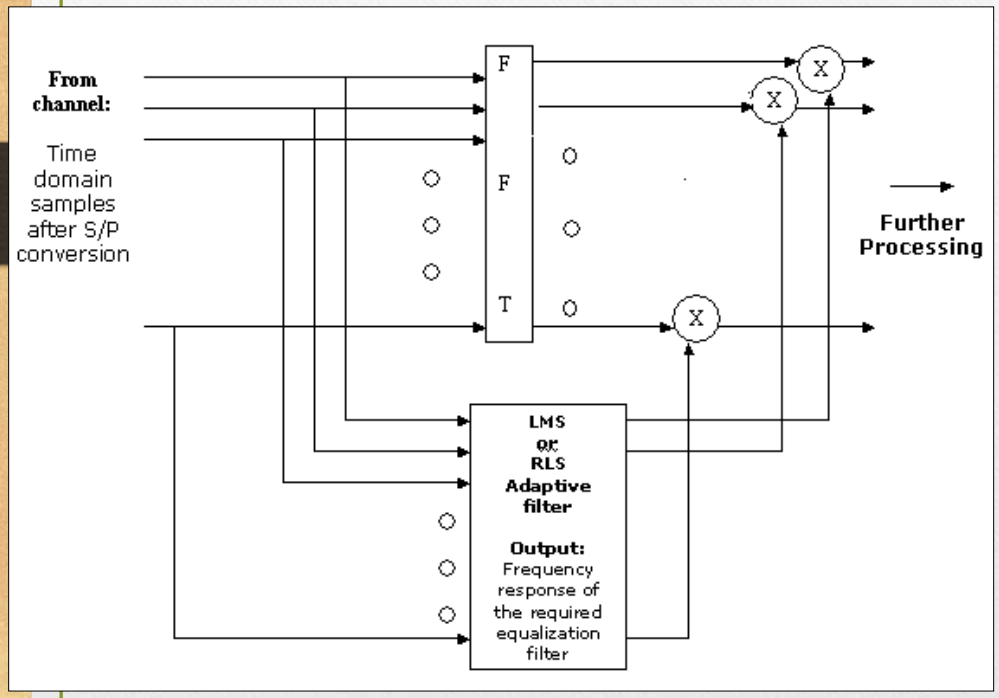


Figure Function of the guard period for protecting against ISI.

Equalization



- Performed in frequency domain
- FFT compulsorily performed in Receiver
- Time domain convolution replaced with frequency domain multiplication – computationally simpler code
- Adaptive filters used

The Modules

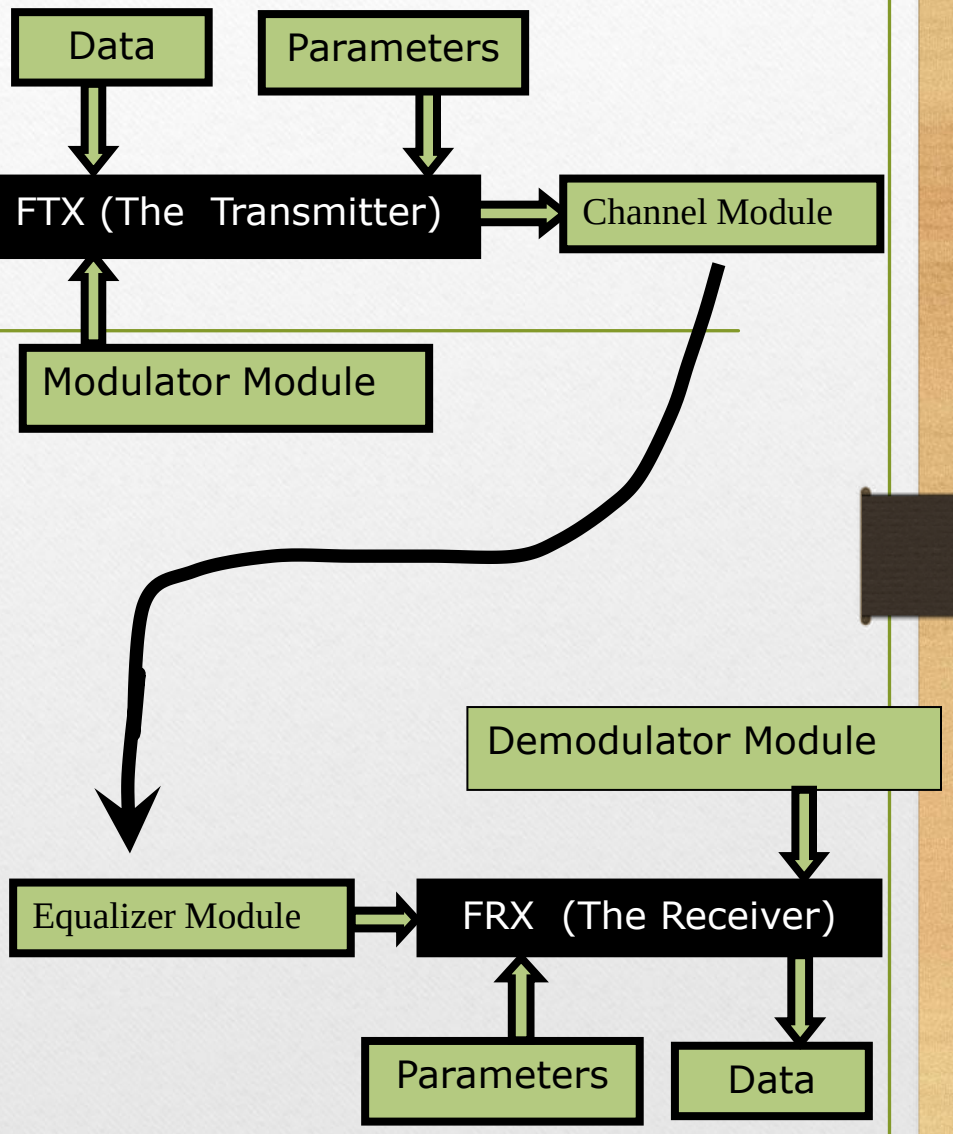
- **Modulator module:**

  BPSK, QPSK, 8QAM

- **Channel module:**

  AWGN, Fading, Physical

- **Equalizer module**



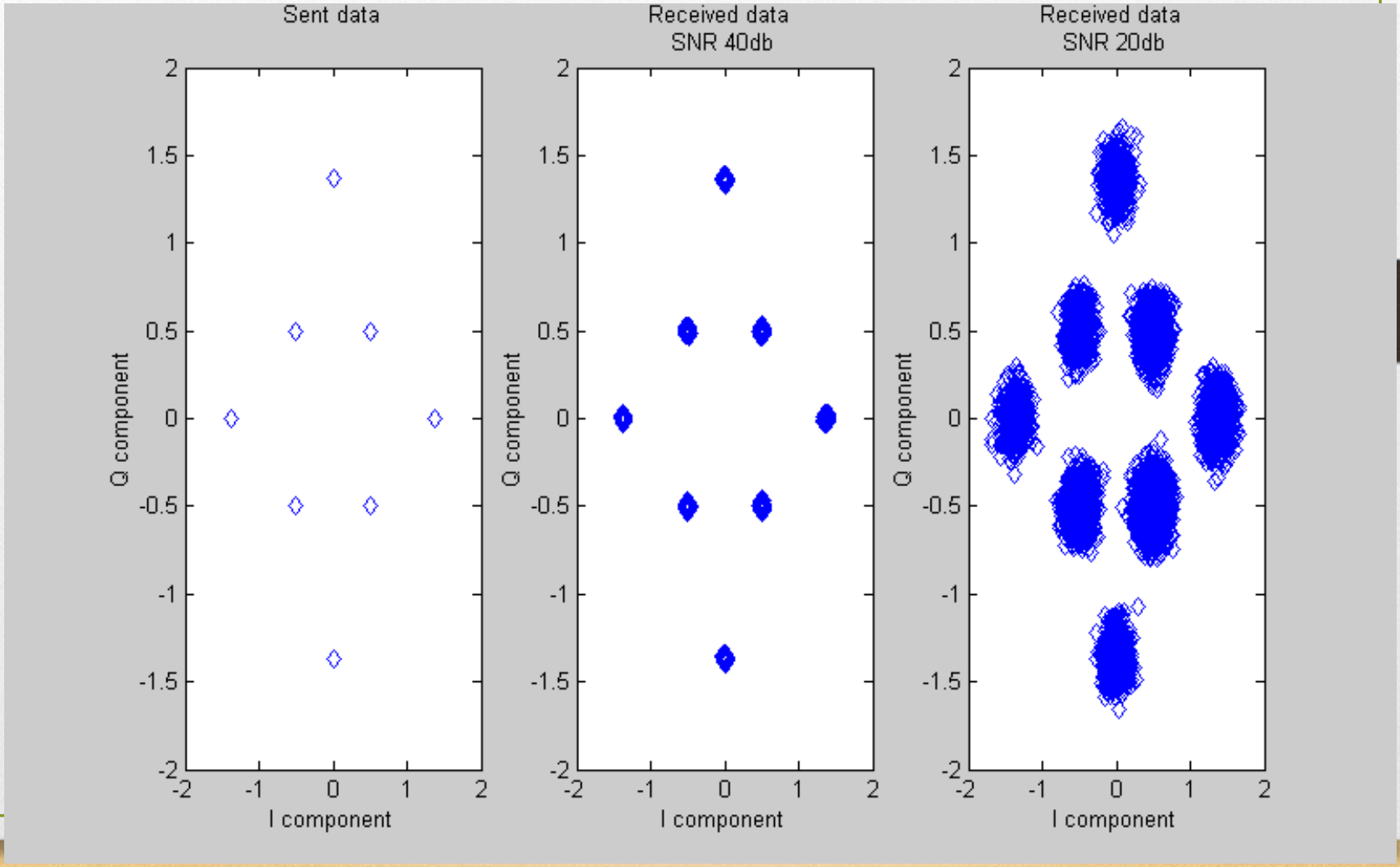
OFDM Advantages

- Makes efficient use of the spectrum by allowing overlap.
- By dividing the channel into narrowband flat fading subchannels, OFDM is more resistant to frequency selective fading than single carrier systems are.
- Eliminates ISI through use of a cyclic prefix.
- Using adequate channel coding and interleaving one can recover symbols lost due to the frequency selectivity of the channel.
- Channel equalization becomes simpler than by using adaptive equalization techniques with single carrier systems.
- It is possible to use maximum likelihood decoding with reasonable complexity.
- OFDM is computationally efficient by using FFT techniques to implement the modulation and demodulation functions.
- Is less sensitive to sample timing offsets than single carrier systems are.

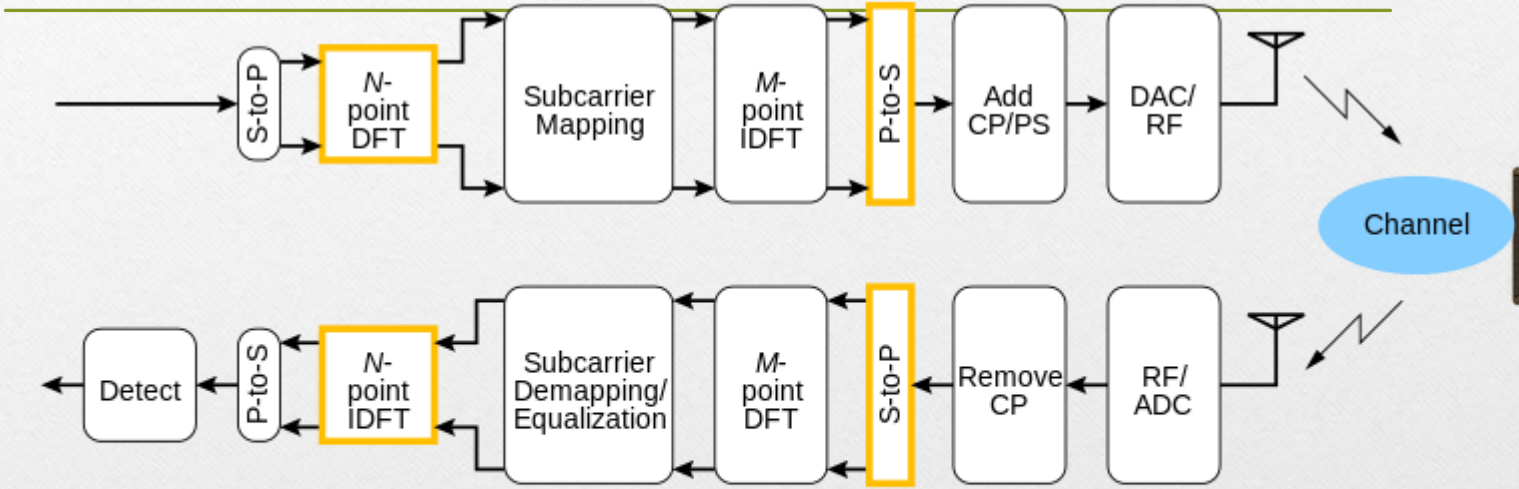
DISADVANTAGES OF OFDM

- Sensitive to Doppler shift
- Sensitive to frequency synchronization problems
- High peak-to-average-power ratio (PAPR), requiring linear transmitter circuitry, which suffers from poor power efficiency
- Loss of efficiency caused by cyclic prefix/guard interval

Constellation diagram



SC-FDMA



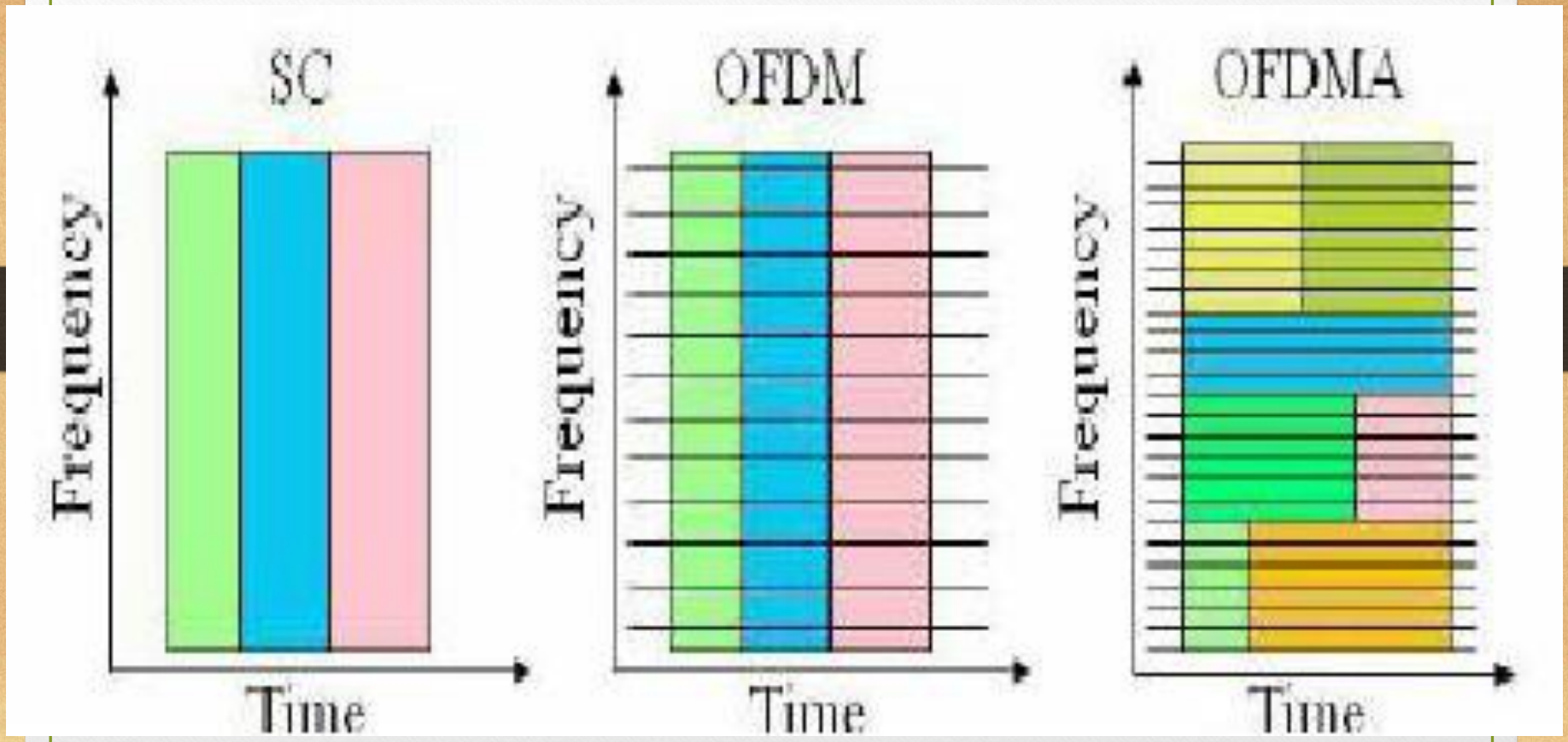
* $N < M$
* S-to-P: Serial-to-Parallel
* P-to-S: Parallel-to-Serial

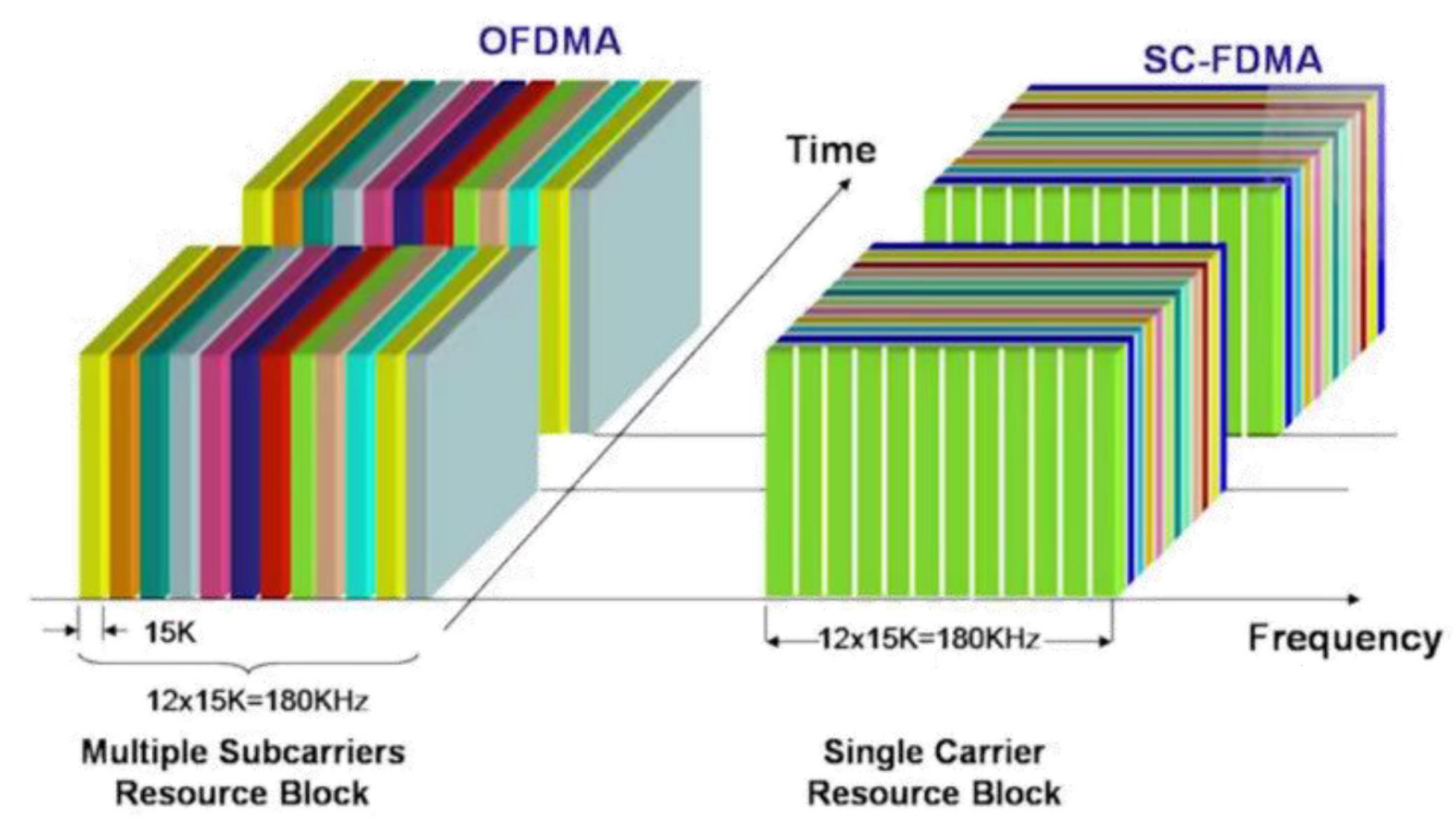
SC-FDMA: ▢ + ▢

OFDMA: ▢

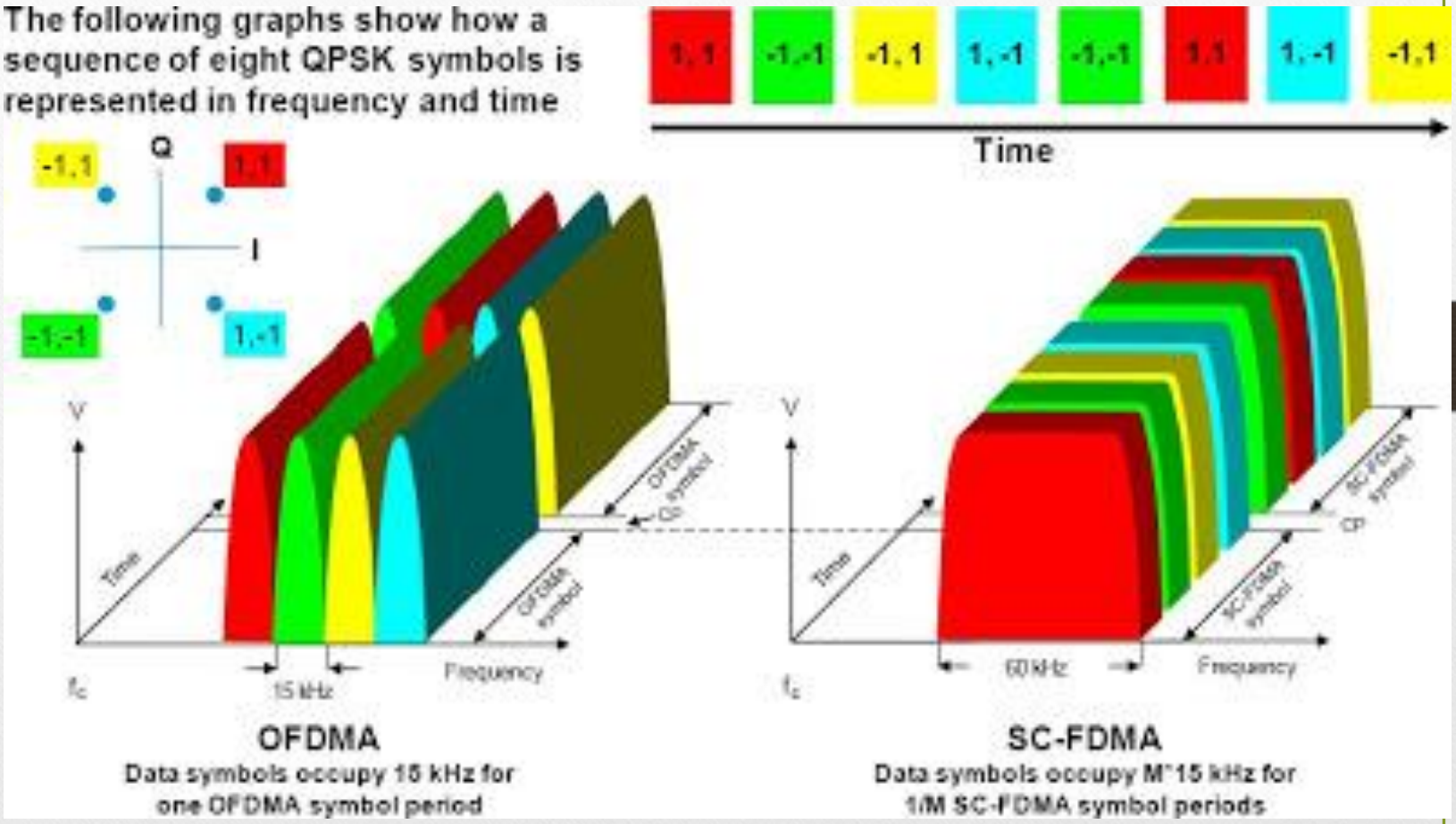
Advantages of SC-FDMA

1.Low PAPR
2.Low sensitivity to carrier frequency offset
3.Less sensitive to non-linear distortion and hence, it allows the use of low-cost power amplifiers
4.Greater robustness against spectral nulls


SC
Frequency
Time
OFDM
Frequency
Time
OFDMA
Frequency
Time


OFDMA
SC-FDMA
Time
15K
12x15K=180KHz
12x15K=180KHz
Frequency
Multiple Subcarriers
Resource Block
Single Carrier
Resource Block

The following graphs show how a sequence of eight QPSK symbols is represented in frequency and time



OFDMA

Data symbols occupy 15 kHz for one OFDMA symbol period

SC-FDMA

Data symbols occupy M*15 kHz for 1/M SC-FDMA symbol periods

MIMO-OFDM

- **MIMO**
  - High diversity gain (space-time coding)
  - High multiplexing gain (BLAST)
- **OFDM**
  - Bandwidth efficient
  - Robust to multipath fading thanks to cyclic prefix
  - Easy to implement thanks to the IFFT/FFT
  - Flexible in resource allocation

Diversity & Coding

- *Diversity in space, time and frequency*
  - Antenna diversity (space)
  - Delay diversity (time)
  - Multipath diversity (frequency)
- *Coding over space, time and frequency*
  - Space-time (**ST**) coding
  - Space-frequency (**SF**) coding
  - Space-time-frequency (**STF**) coding