Chapter 6

Digital transmission through band-limited AWGN channels

—— by Prof. XIAOFENG LI
SCIE, UESTC

Contents 5 Hrs

- ISI and zero-ISI condition

  (Ref p380-381, p393-394)

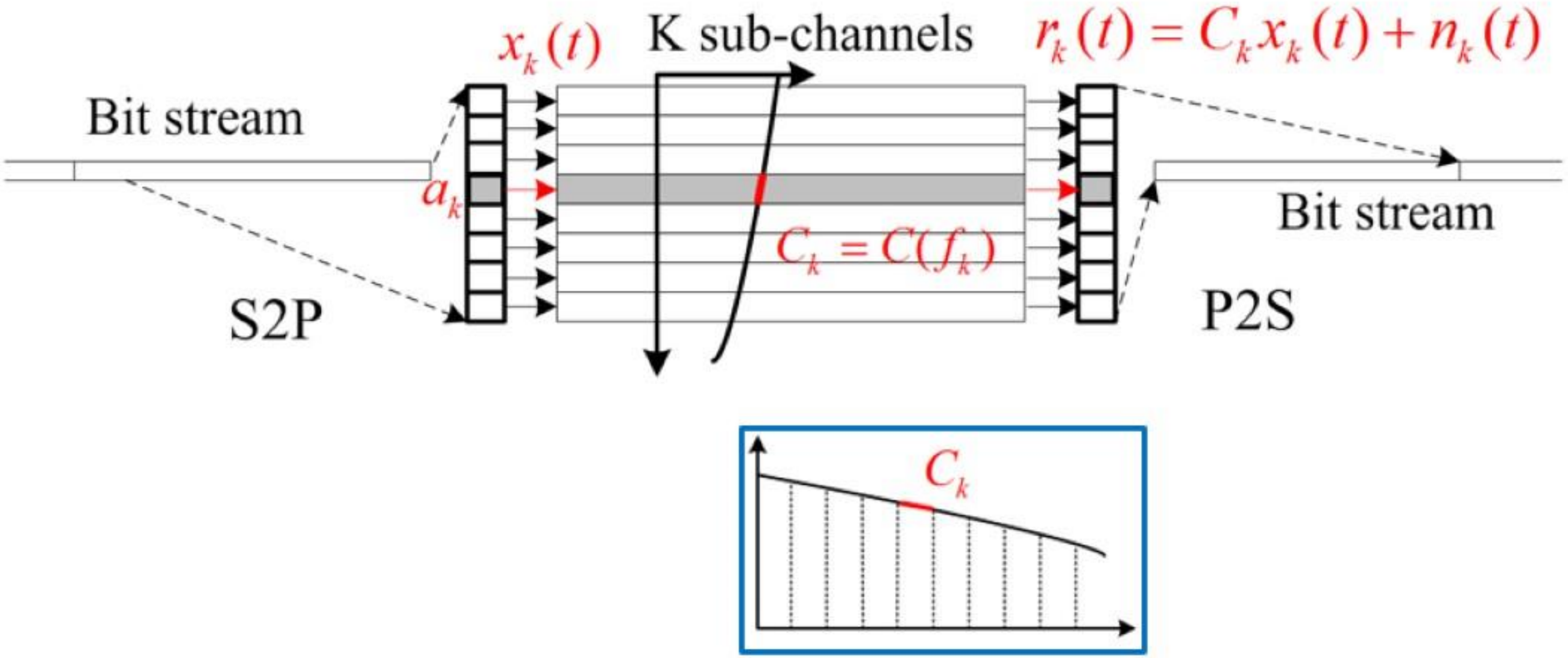
- Design of BL signals for zero-ISI

  (Ref p396-399)

- OFDM

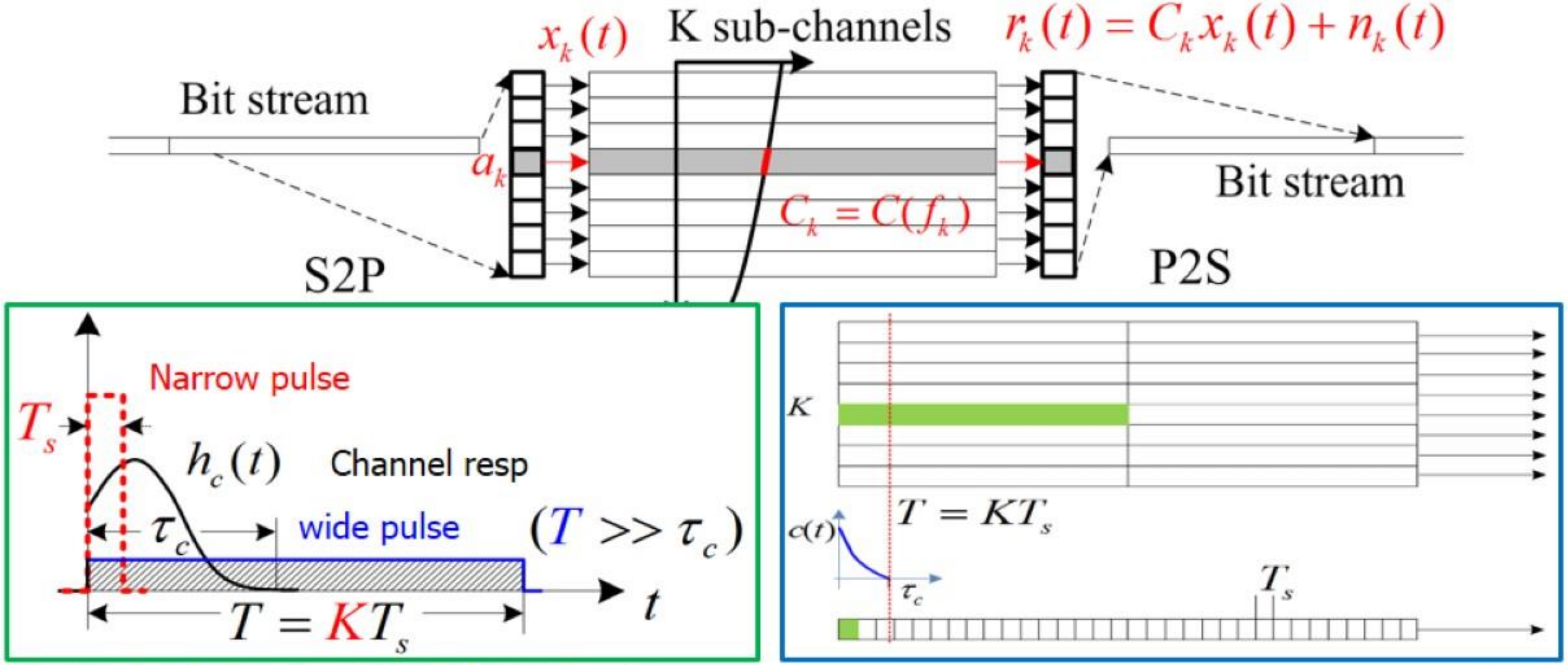
6.3.1 Basics

If the channel is not flat, an alternate approach to avoid ISI is to subdivide the channel into a number of narrow sub-channels, which are nearly **flat**. And the data is transmitted in a multicarrier or FDM manner.



6.3.1 Basics

Let R_s be the symbol rate and T_s the interval. Let **K** be the number of sub-channels, $T = KT_s$ the symbol interval of the parallel system.
Suppose that the channel time-dispersion is τ_c, which satisfies $\tau_c << KT_s$.
Thus ISI has very limited effect on the multicarrier system



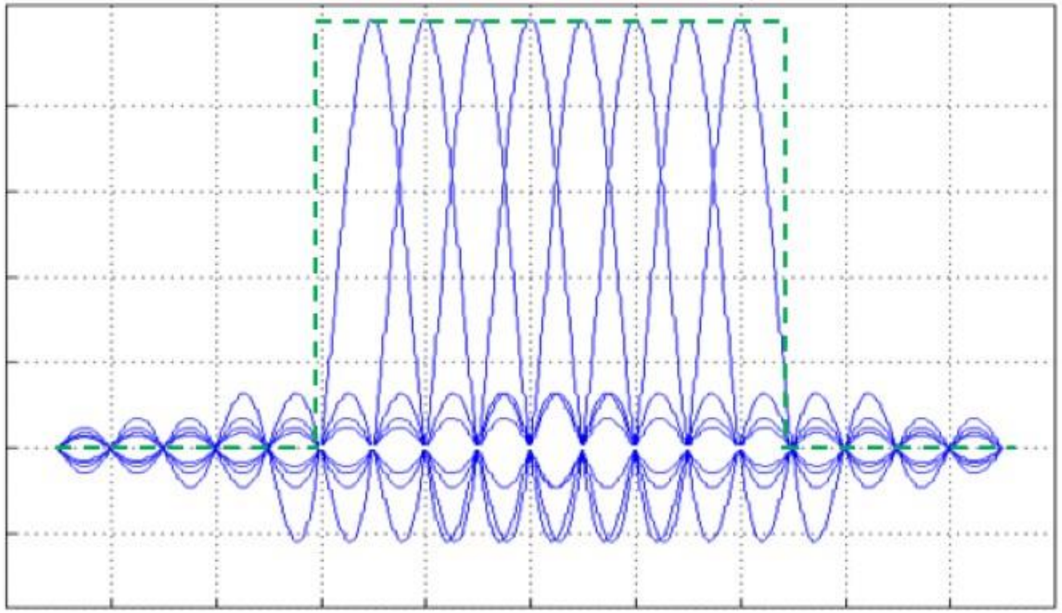
6.3.1 Basics

Let f_k be the carrier freq of the kth sub-channel and Δf the space of adjacent subcarriers, where $k = 0, 1, \ldots, K-1$. By selecting symbol interval, $T = 1/\Delta f$, the subcarriers are orthogonal regardless of the initial phases, that is,

$$\int_0^T \sin(2\pi f_i t + \phi_i)\sin(2\pi f_j t + \phi_j)dt = 0$$

where $i \neq j, 0 \leq i, j < K$.

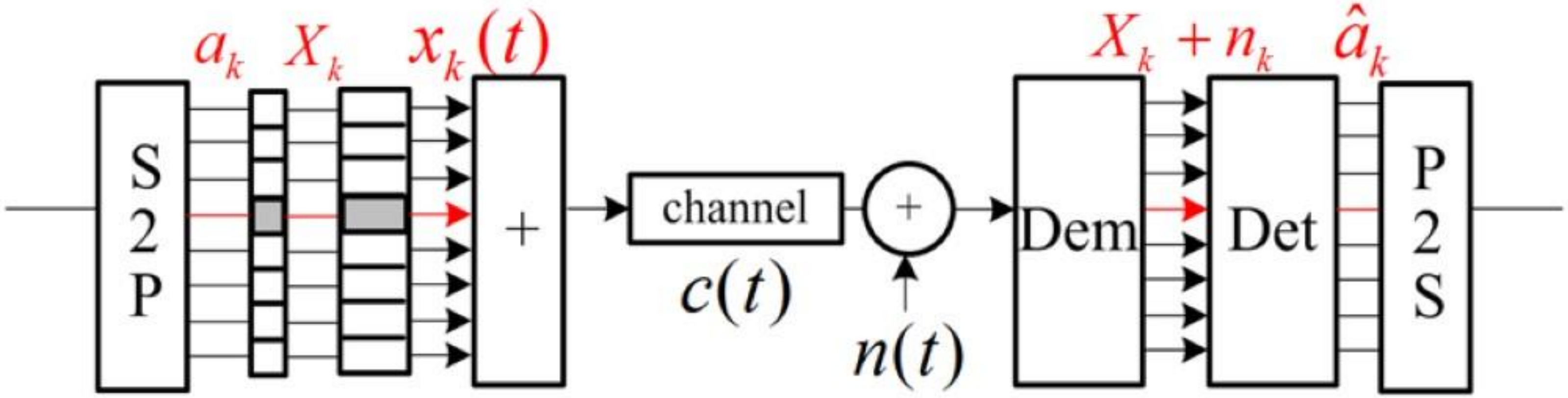
In this case, we refer the comm. system to as orthogonal freq-division multiplexing (**OFDM**) system. OFDM has highest spectral efficiency due to smallest Δf.



6.3.2 An OFDM system with FFT algorithms

1. Parallel-bank structure

The modulation and demodulation in an OFDM system can be implemented by use of a parallel bank of filters.



On each sub-channel, QAM is adopted in general.

Mapping: $a_k \Rightarrow \mathbf{s}_k = (s_{k1}, s_{k2})$, denoted as a complex $X_k = s_{k1} + js_{k2}$

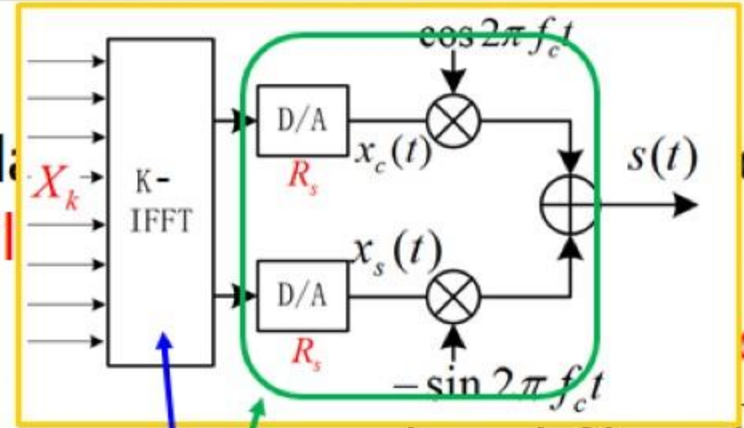
QAM: $x_k(t) = s_{k1}\cos 2\pi f_k t - s_{k2}\sin 2\pi f_k t = \mathrm{Re}(X_k e^{j2\pi f_k t})$

Overall signal: $s(t) = \sum_k x_k(t) = \mathrm{Re}\left(\sum_k X_k e^{j2\pi f_k t}\right)$

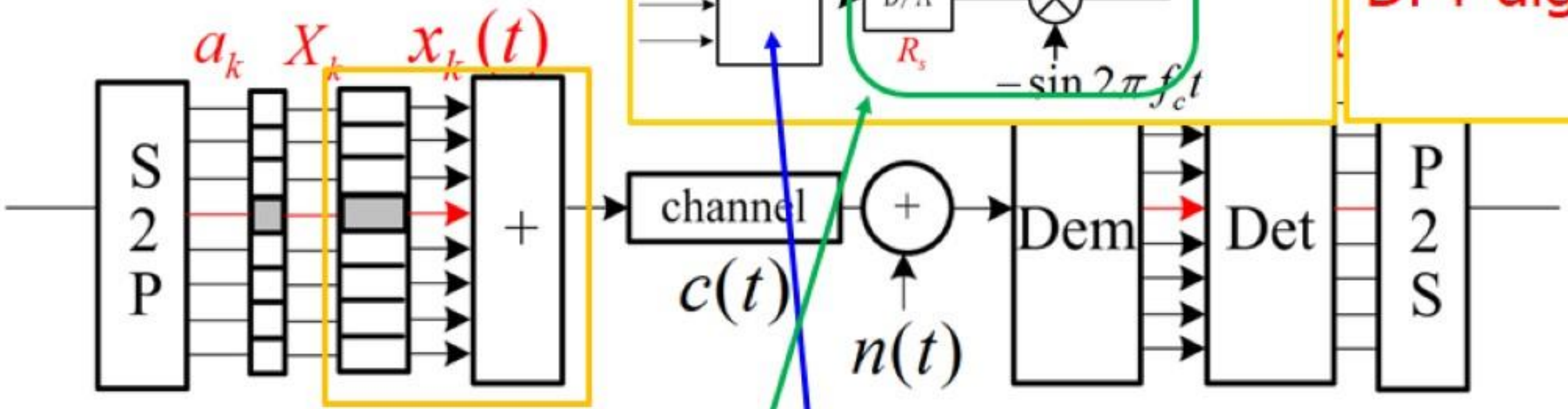
6.3.2 An OFDM system with FFT algorithms

2. Calculated by IFFT

The modulation and demodul
by use of a parallel bank of fil



It can be easily calculated with **IFFT**, the fast Inv-DFT algorithm.



On each sub-channel, QAM is adopted in general.

Mapping: $a_k \Rightarrow \mathbf{s}_k = (s_{k1}, s_{k2})$, denoted as a complex $X_k = s_{k1} + js_{k2}$

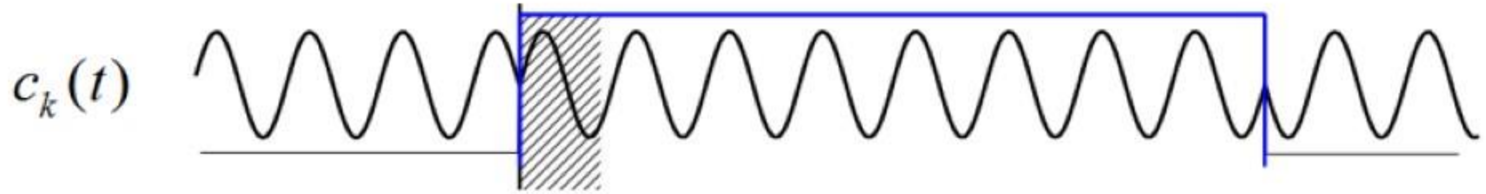
QAM: $x_k(t) = s_{k1}\cos 2\pi f_k t - s_{k2}\sin 2\pi f_k t = \mathrm{Re}(X_k e^{j2\pi f_k t})$

Overall signal: $s(t) = \sum_k x_k(t) = \boxed{\mathrm{Re}}\left(\boxed{\sum_k X_k e^{j2\pi f_k t}}\right)$

6.3.2 An OFDM system with FFT algorithms

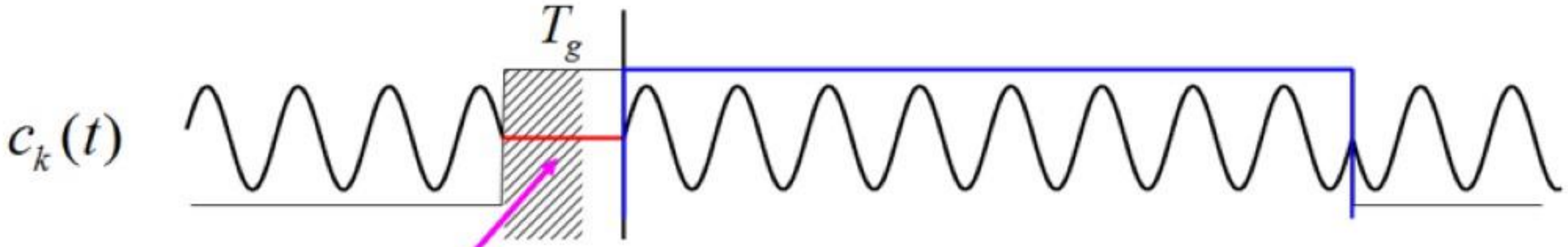
3. Cycle prefix

When transmit, there is ISI, through relatively small.



3. Cycle prefix

When transmit, there is ISI, through relatively small.



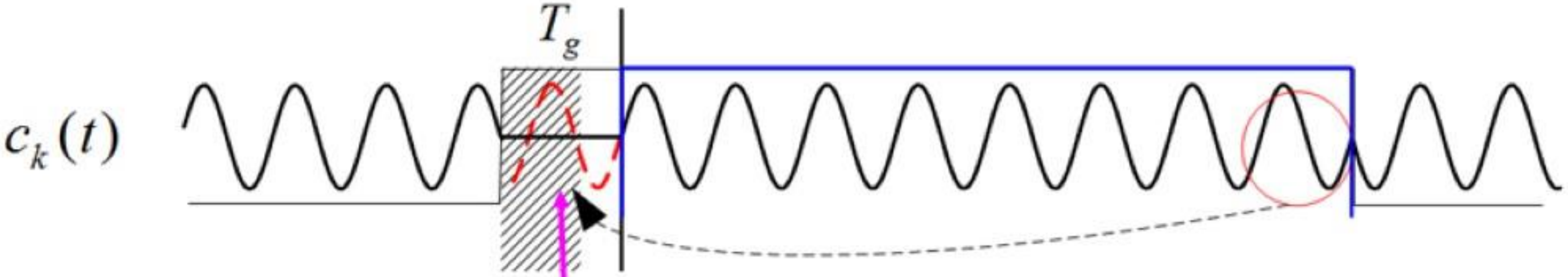
A simple way to completely avoid ISI is to insert a time guard of m points, then a slot is N+m points, of which N are for effective data.

On reception, we discard the guard before demodulation.

6.3.2 An OFDM system with FFT algorithms

3. Cycle prefix

When transmit, there is ISI, through relatively small.



A simple way to completely avoid ISI is to insert a time guard of m points, then a slot is N+m points, of which N are for effective data.

On reception, we discard the guard before demodulation.

More analysis finds that empty guard will cause other problem. A good way is to append a so-called cycle-prefix (**cp**) as time guard.

6.3.3 OFDM systems

3. The block diagram of a OFDM system

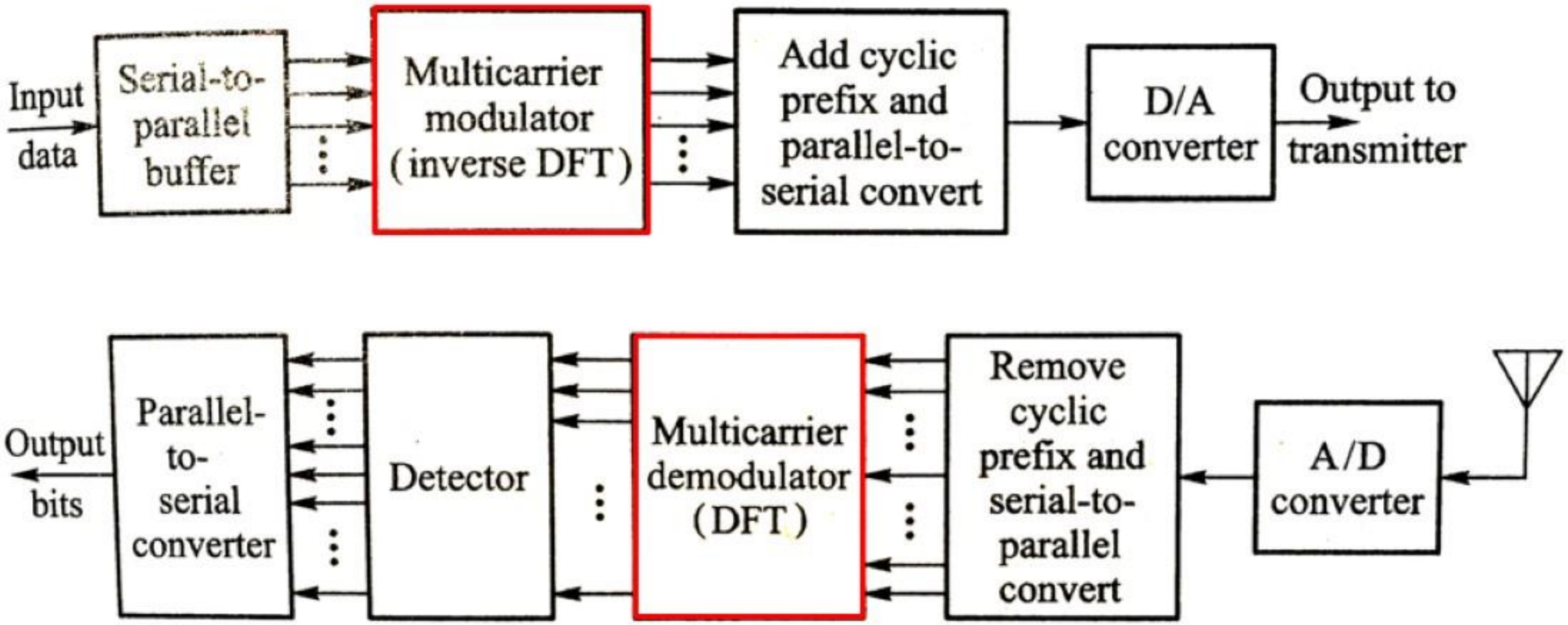


Fig 6.50 on p471

Note FFT (or DFT) serves as the demodulator.

3. The block diagram of a OFDM system

One of the major challenges of ODFM systems is to maintain the synchronization among subcarriers.

Another major problem with all multicarrier systems is the high peak-average-ratio (PAR) in their transmission signals. Large signals peaks occur when many signals of sub-channels add constructively in phase. Such large peaks may saturate the PA at TX and result in heavily distorted signals.

6.3.4 OFDM applications

OFDM technique is advanced and is largely used in various modern digital systems, such as the ADSL for high speed data transmission over telephone lines, 3G/4G wireless communications, wifi, DAB and DVB.

OFDM found wide applications from 1980s：

- ✓ Digital audio broadcasting（DAB，1995）
- ✓ Digital subscriber loop （DSL，1996）
- ✓ Digital video broadcasting （DVB-T，1997）
- ✓ Wireless LAN（WLAN-802.11a，1999；802.11g，2002）
- ✓ WiMAX（802.16d，2004）
- ✓ Long term evolution（LTE/B3G，2005）
- ✓ 4^{th} generation wireless(4G，2005)

End of this chapter

Thank you