OFDM introduction

ESPTR 2013

How to pack Mb/s?

- Single carrier: multipath → ISI, GI eating %
- Split to many carriers and slow down
- → getting ICI now....
- Make subcarriers orthogonal → „harmonics”

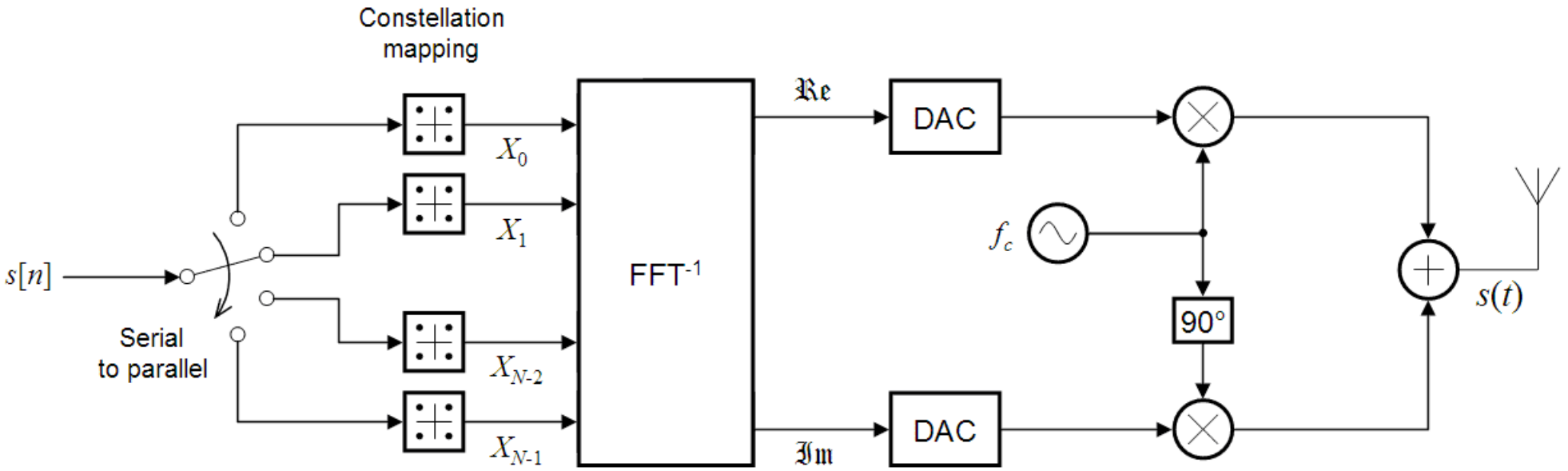
OFDM maths

$$\nu(t) = \sum_{k=0}^{N-1} X_k e^{i2\pi kt/T}, \quad 0 \leq t < T,$$

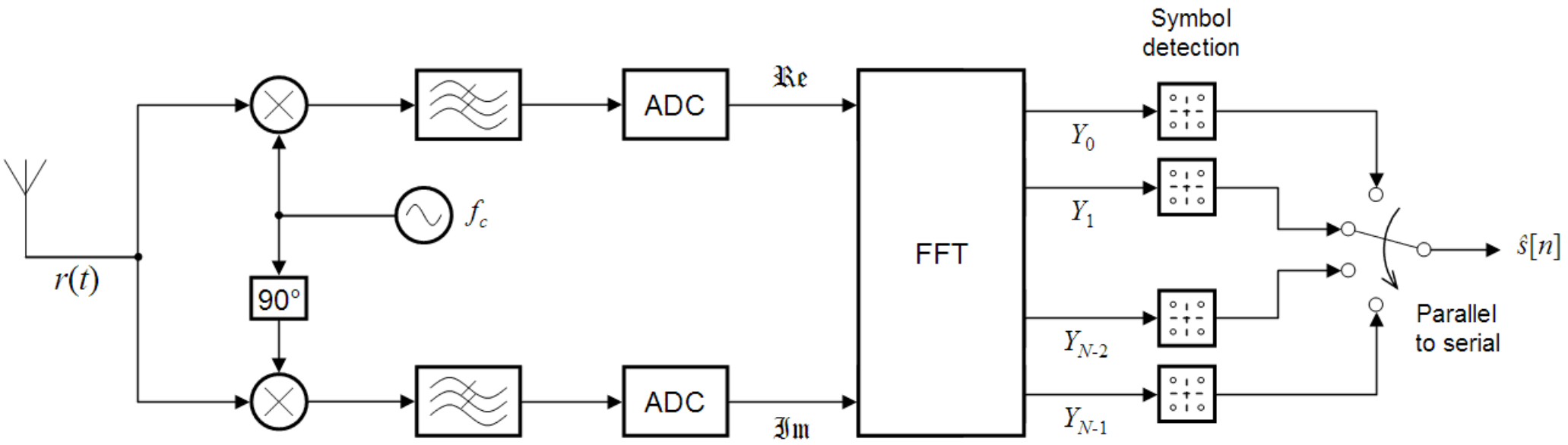
Xk – symbol
k – subcarrier index

- just a Discrete Fourier Transform....
- N orthogonal subcarriers (recall DFT...) - no interference between subchannels!
… provided that we get integer no. of periods (i.e. whole 0..T interval)

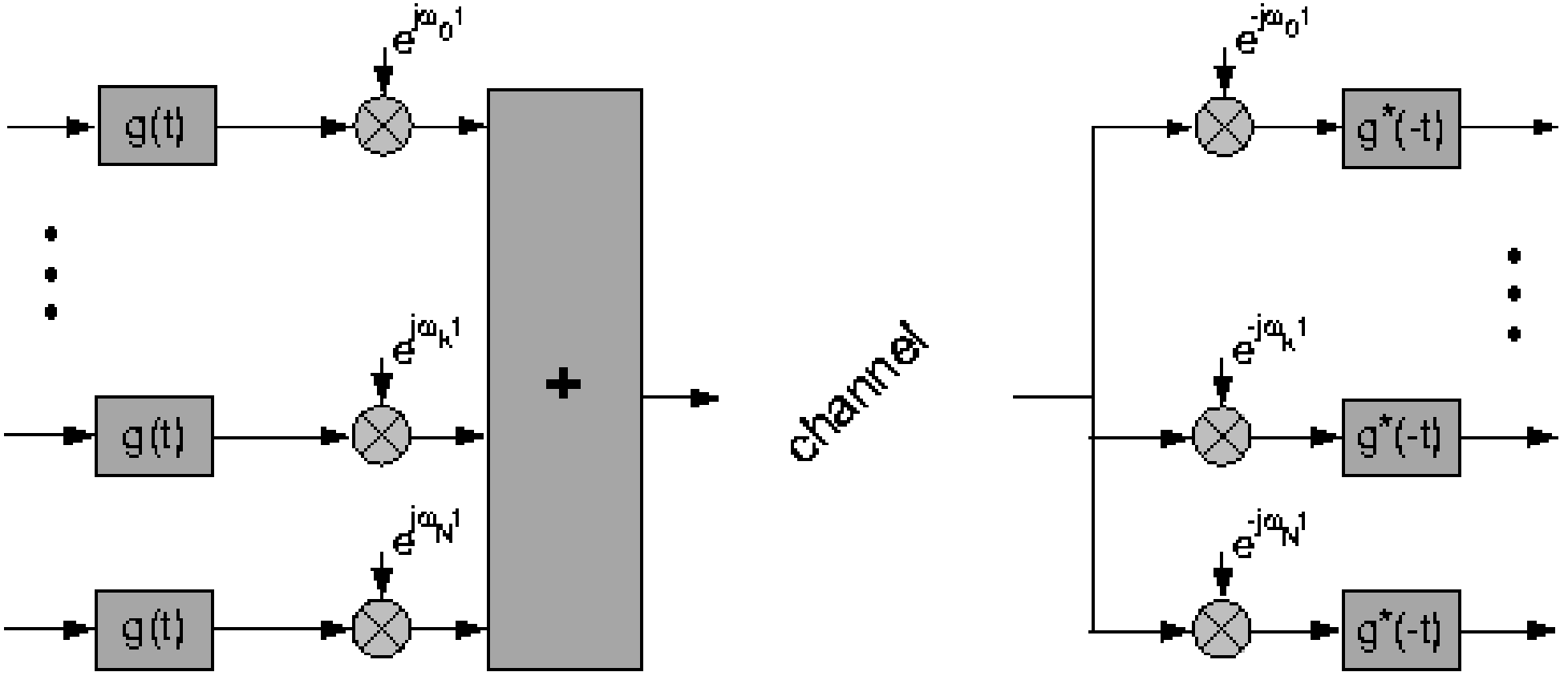
OFDM coder


Constellation mapping
$s[n]$
Serial to parallel
X_0
X_1
X_{N-2}
X_{N-1}
FFT^{-1}
$\Re e$
$\Im m$
DAC
DAC
f_c
90°
$s(t)$

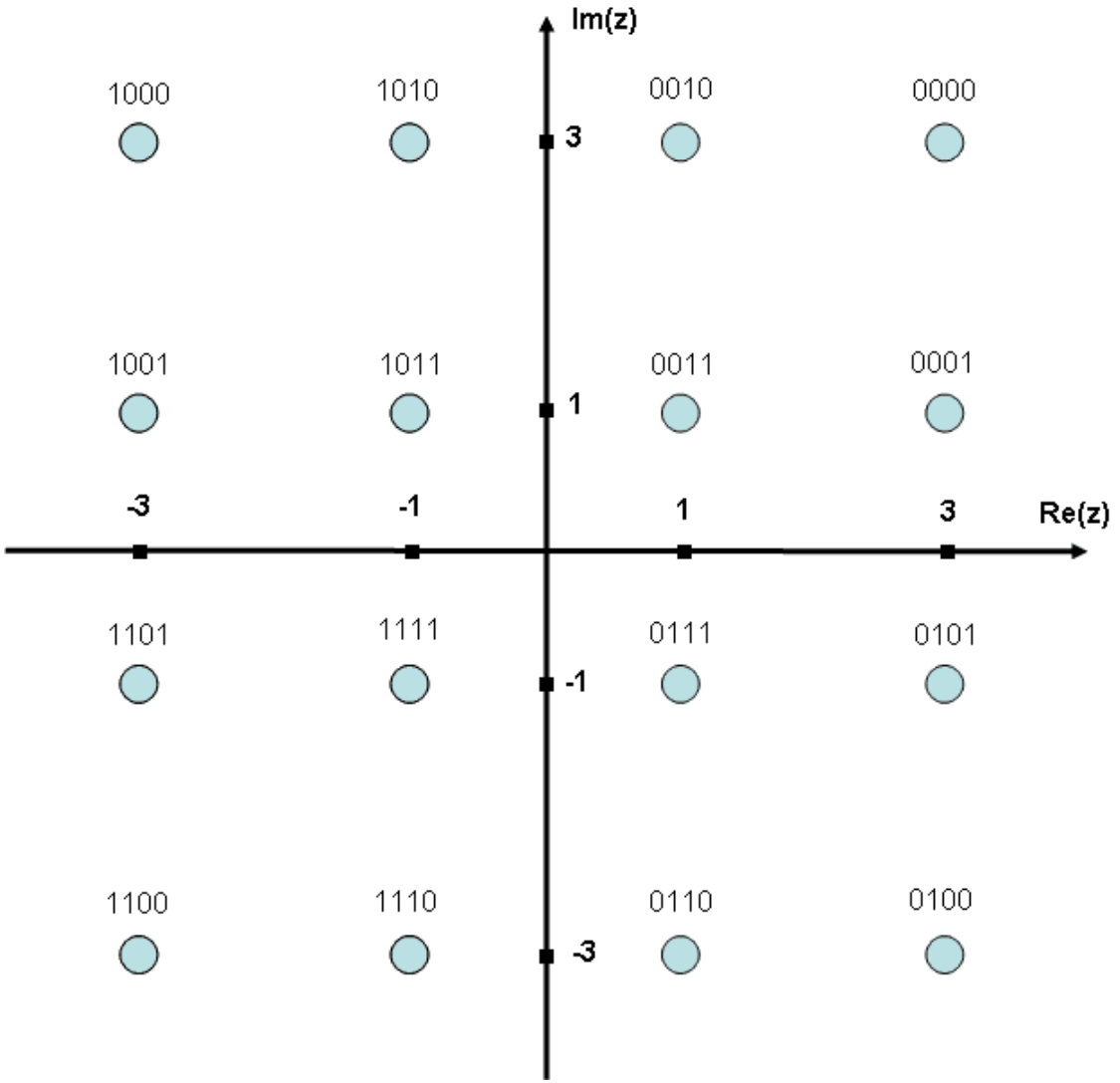
OFDM decoder



OFDM



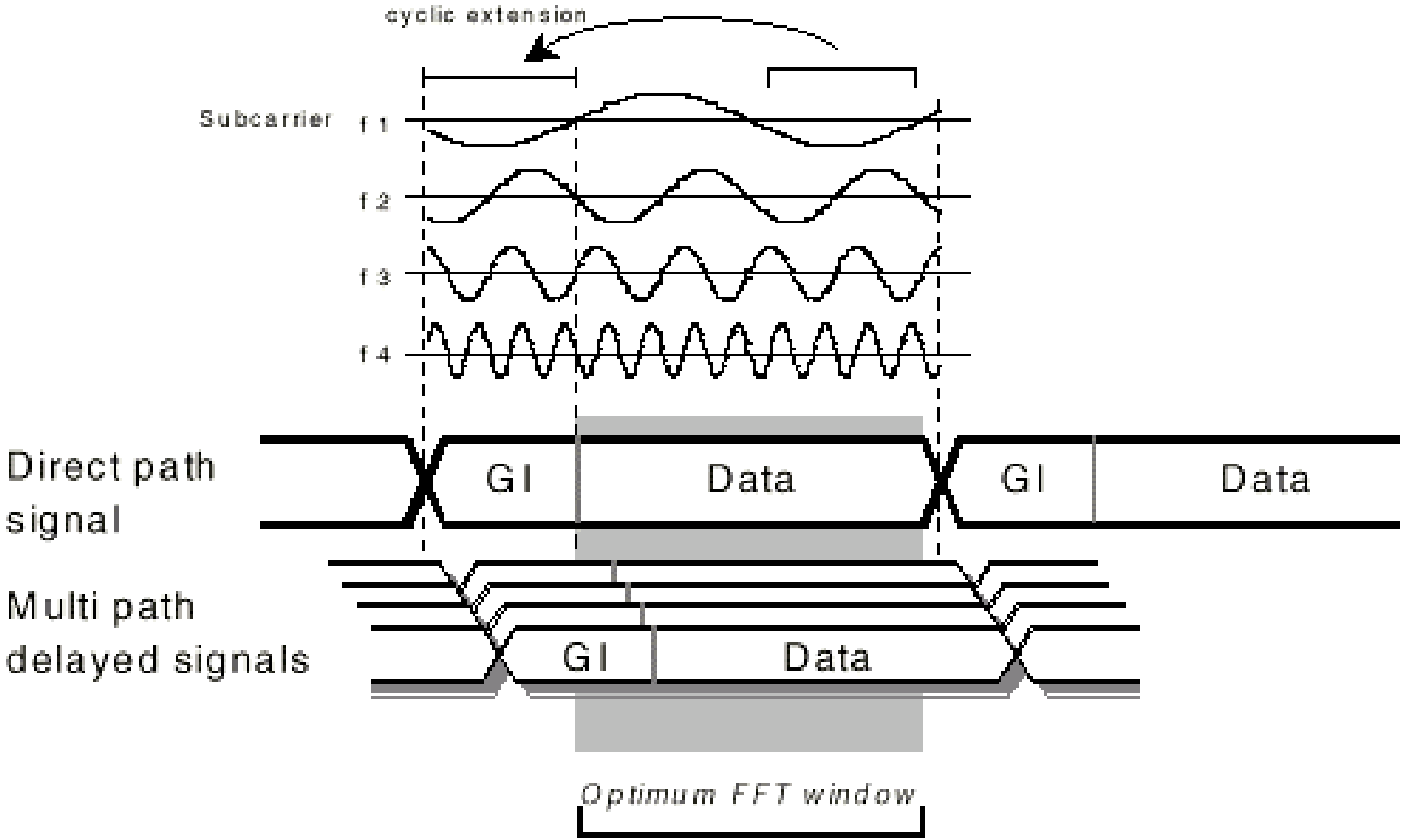
Mapper: e.g. 16-QAM



Guard Interval

- What to transmit?
  - Keep orthogonal after multipath
  - → cyclic prefix
    - Time: still a sinusoid (phase shifted)
    - Freq: window=int #periods, so orthogonal.

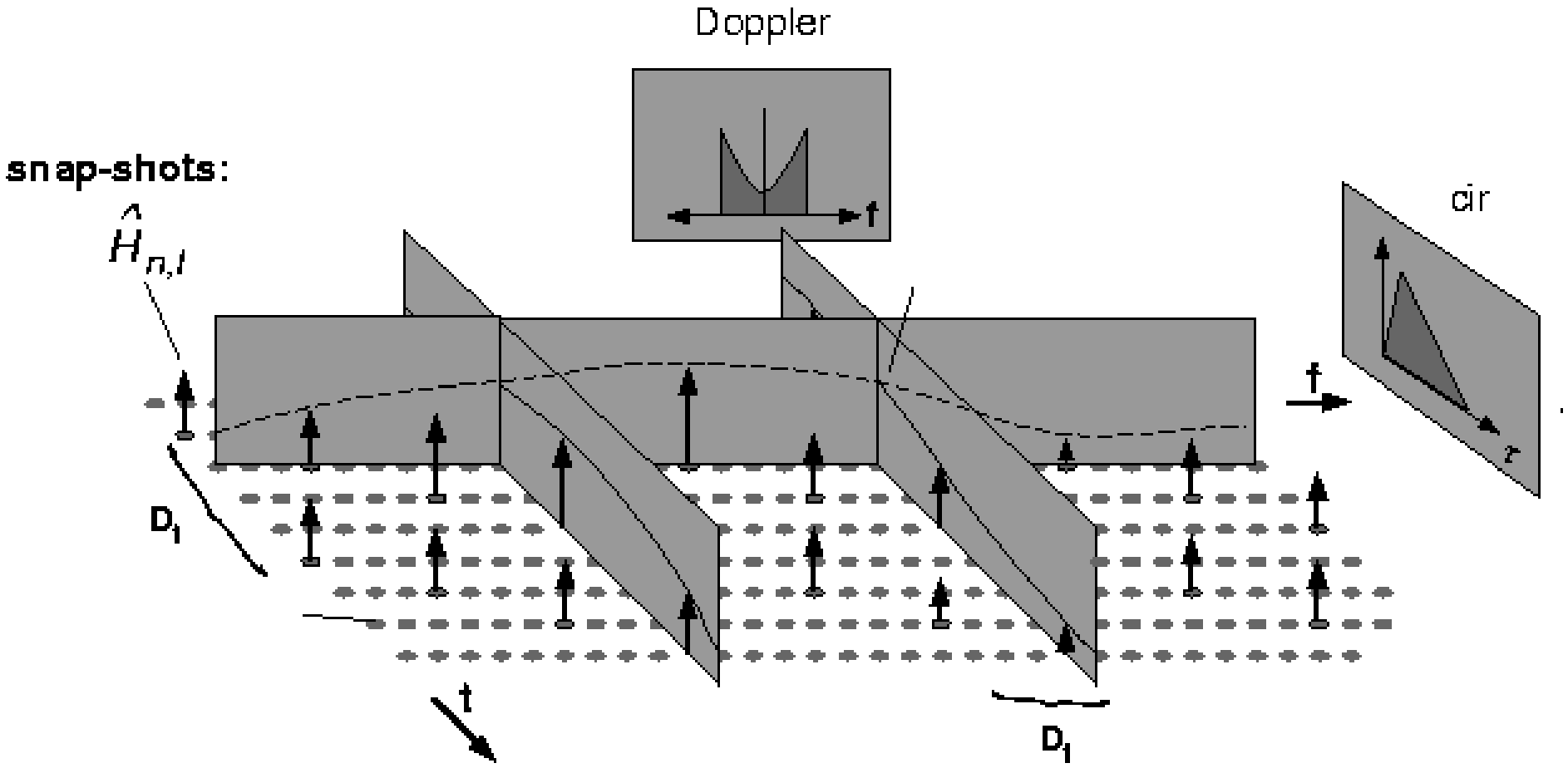
Guard interval



Multipath/fading

- Narrow subchannels → flat over channel equalizer = multiplier
- Some subchannels faded – ECC or allocation
- Diff QPSK → insensitive to slow changes
- Non-diff → channel estimation w/pilots
  - Block or comb or mixec
- Doppler (see few slides later)

Channel estimation



Can we go w/out phase estimation (differential coding)

- QPSK: look at the absolute phase of a symbol
(„but where is zero phase?" → phase reference needed)
- DQPSK: look at the phase change (→ previous symbol is reference now)
- Gain/loss:
  - [+] no pilot, preamble etc. needed, no phase estimation/correction
  - [+] self-adapts to slow changes of channel phase (small change in symbol time)
  - [-] first symbol is lost (has no previous symbol for reference...)
  - [-] DOUBLE sensitivity to uncorrelated noise

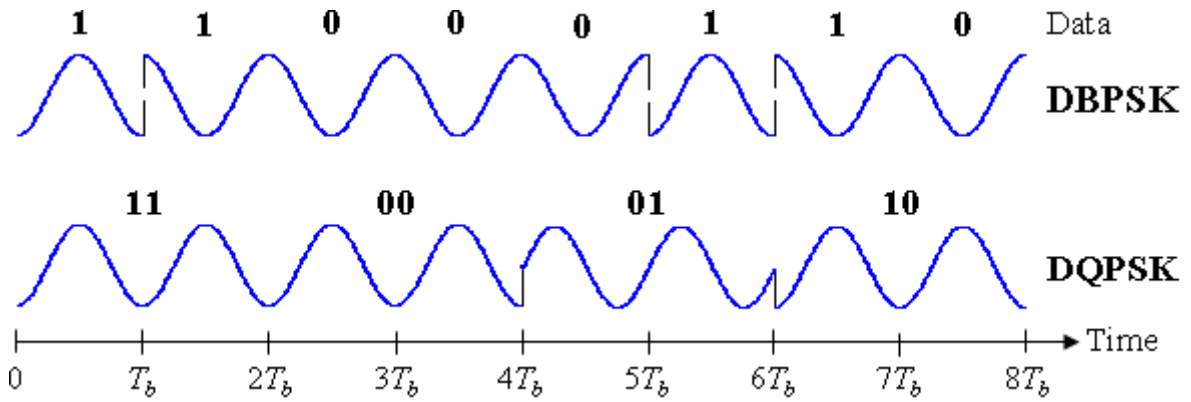
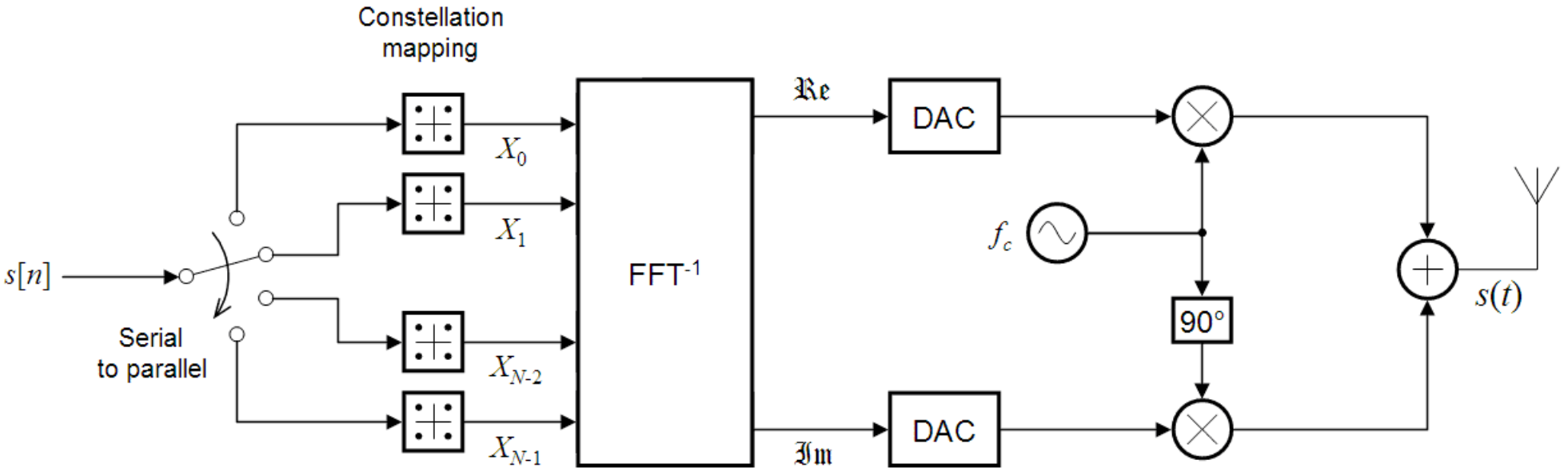


Image: http://en.wikipedia.org/wiki/File:DBQPSK_timing_diag.png (see GFDL there)

SFN

- FM reuse factor: ~15
- DAB reuse: ~4
- Another transmitter = „path”
  - Synchronization needed!
  - Freq reuse factor = 1

Front end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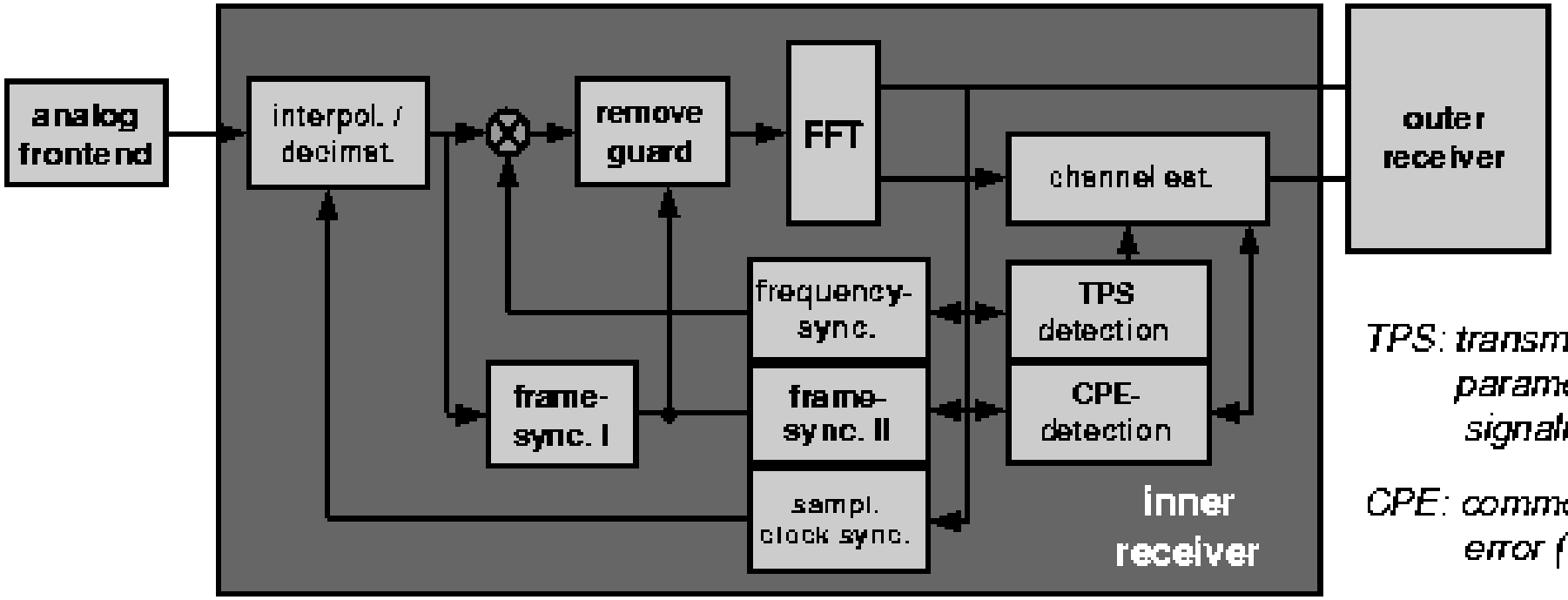
Receiver

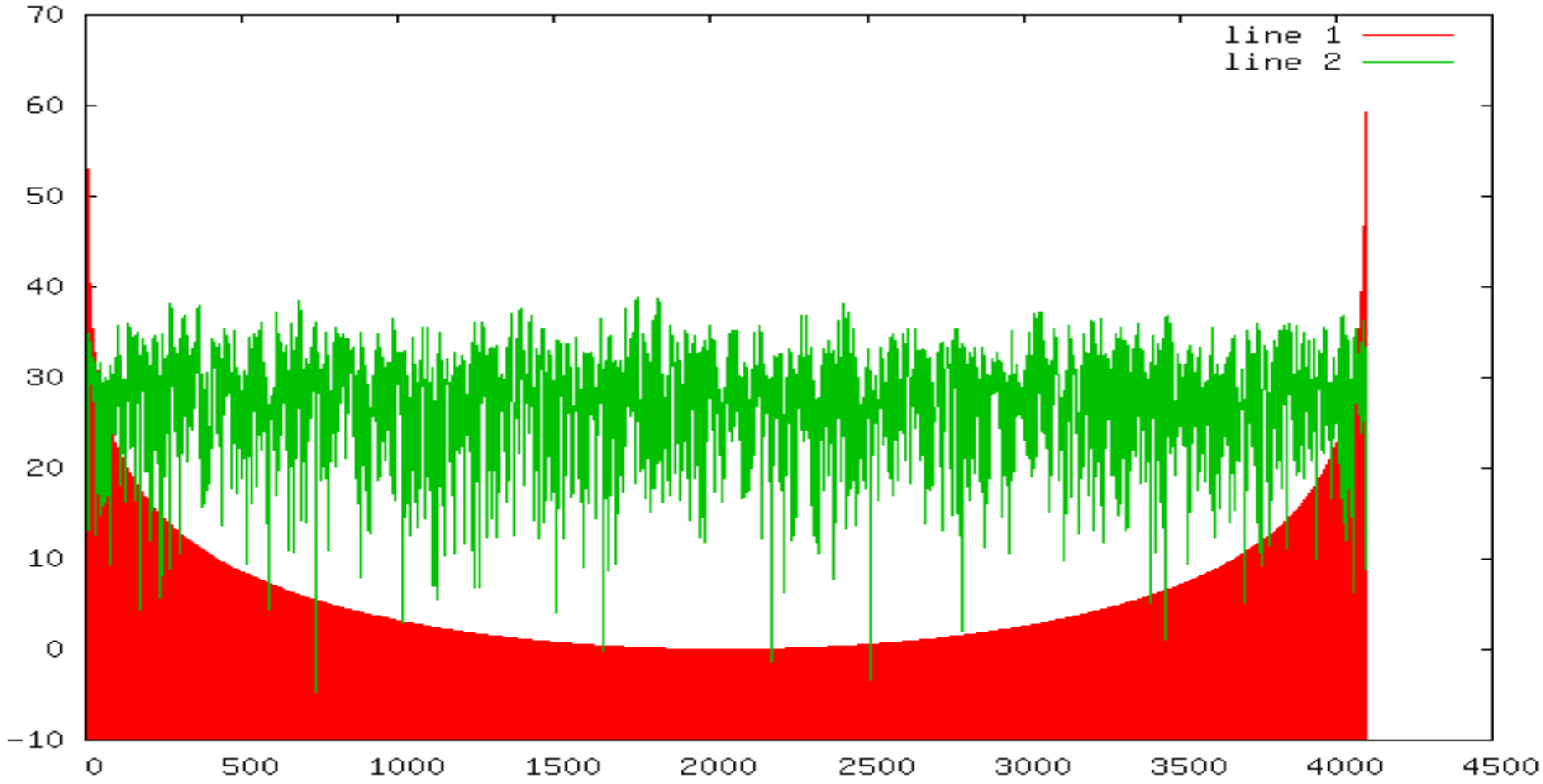


TPS: transmission parameter signaling

CPE: common phase error (oscillator)

Problem: PAPR

```
k=ones(1,1024);
plot(max(-10,20*log10(abs(fft(k,4096)))))
hold on
k1=k.*exp(2*pi*j*rand(1,1024));
plot(max(-10,20*log10(abs(fft(k1,4096)))))
```



PAPR fight

- Clipping and filtering
- Selective mapping (optimize spread before OFDM)
- Partial transmit sequence (optimize subcarriers after OFDM)
- Nonlinear coding (manipulate transmitted sequence so that peaks are avoided)

Doppler effect

- Multipath with different velocities
  → Doppler spread → ICI
- (uplink) different ME velocities → MUI
- Doppler effect limits „packing” of subcarriers into given bandwidth

ICI induces errors by:

- Direct influence on demapper decision: strong ICI
  → burst errors
- Increased noise sensitivity even with weaker ICI
  → demapper errors when ICI+noise crosses the line
    → increased SER (→ BER)

Calc example

Look at the blackboard :-)

- Multipath → guard interval
- Doppler etc. → subcarrier error → spacing
- Sync → pilots
- Next channel interference → silent subcarriers

How much guard interval? Depends on circumstances:
- Account for 1-2 kilometers for city propagation
- Much less for WiFi at home
- More for SFN broadcast...

How much frequency error acceptable?
- 25% w.r.t subcarrier spacing gives ~3 dB signal-to-interference
- 5% gives SER increase from 0.00018 to 0.03 (160x) at 16-QAM
- 0.4% giver SER increase from 0.00018 to 0.00036 (2x) at 16-QAM

(see IEEE Trans. Wireless Communications, June 2006, Wang et.al „Performance degradation of OFDM system due to Doppler spreading”

Where OFDM is used

- Cable: DVB-C2, ADSL etc.
- DVB-T
- DAB
- WiFi 802.11a, g, n
- Mobile-WiMax etc.
- Downlink of LTE
  - *Uplink: PAPR & problems in syncing mobile Tx's*
  - *→ SC-FDMA used in uplink*