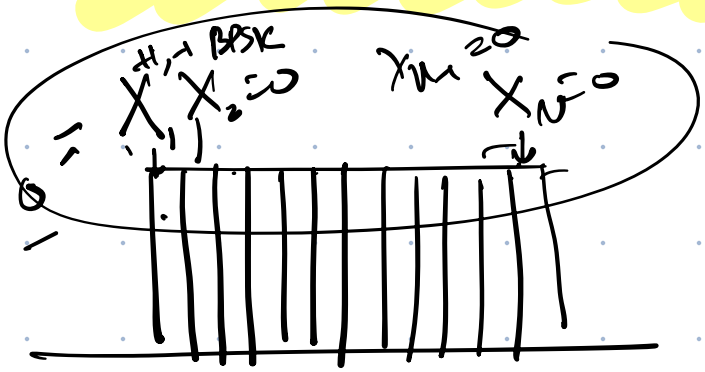
CSI 598 WSI, LECTURE 6

- OFDM
  - Pipeline
  - Packet Detection
  - Cyclic Prefix
  - CFO
  - Channel estimation
  - Residual CFO/SFO
  - Guard bands

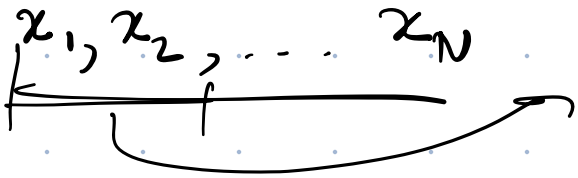
OFDM PIPELINE

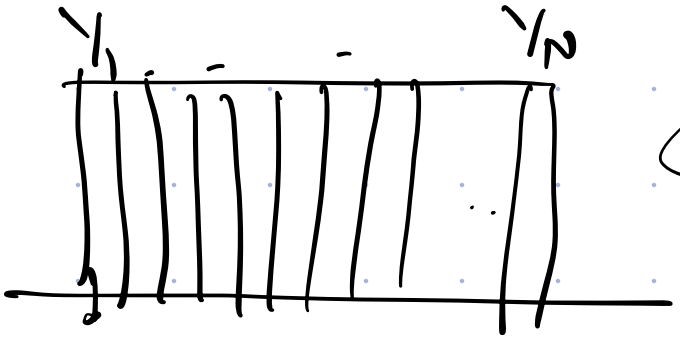
$N = 64, 128, 256$

LTE, $N = 1024$



IDFT ⟹

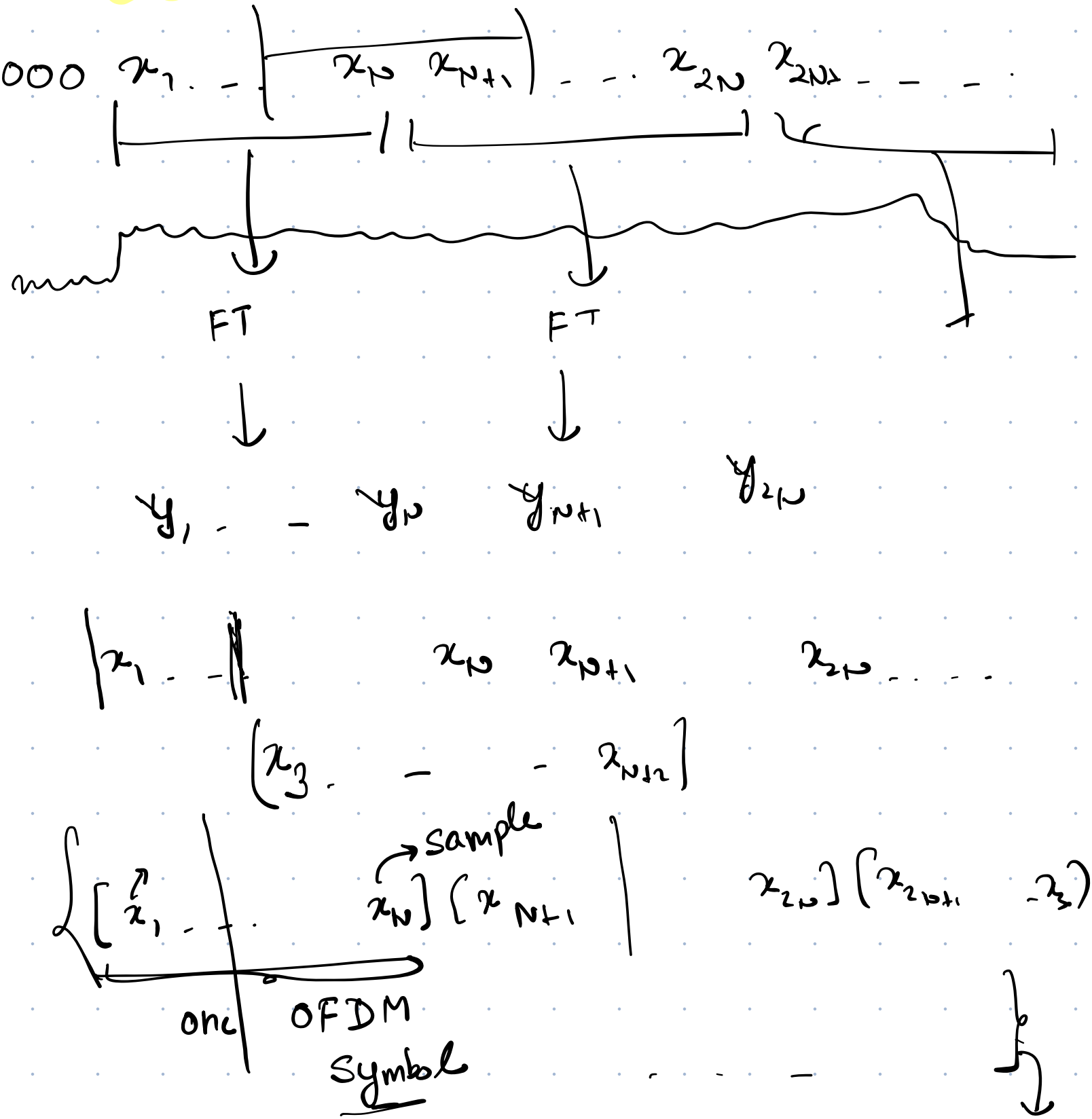




⟸ DFT/FFT $y_1, y_2 \ldots y_N$

$$Y_i = H_i X_i + n_i$$

PACKET DETECTION

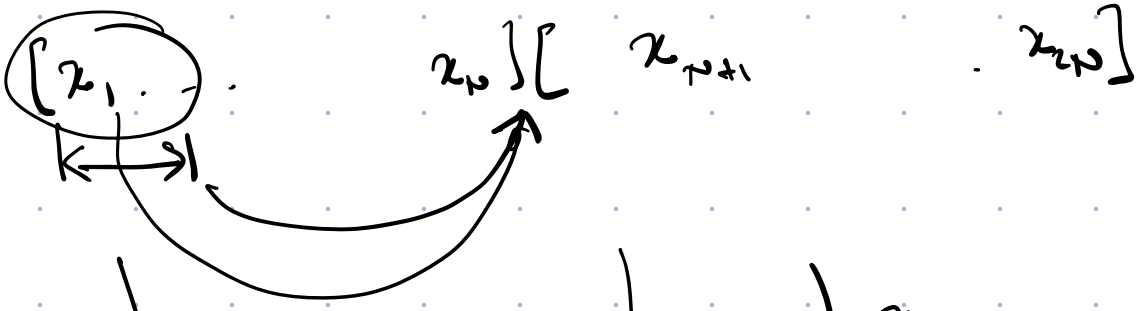


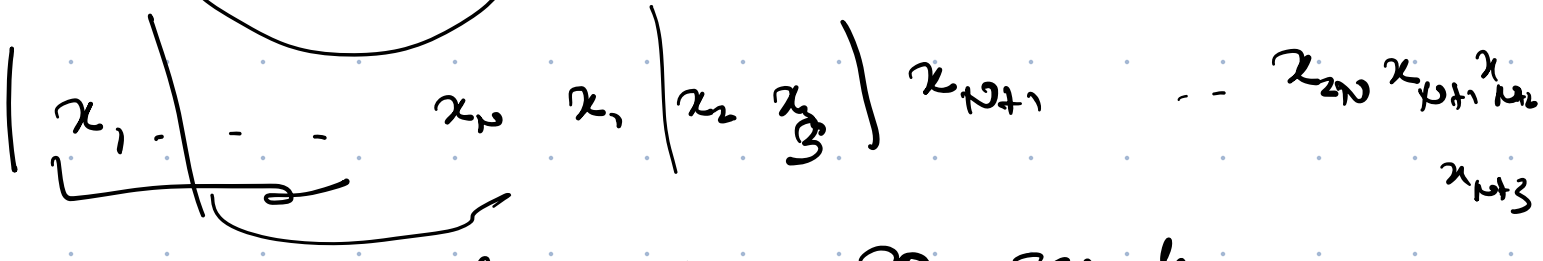
20MHz → 64

40MHz → 128

80MHz → 256

CYCLIC PREFIX





$N = 64$ samples $\Rightarrow$ 80 samples

16 CP (Cyclic prefix)

$y_1 \; . \; . \; y_N \xrightarrow{FFT} x_1 \; . \; . \; x_N$

$y_2 \; . \; . \; y_N \; y_{N+1} \xrightarrow{FFT} x_1 e^{j\phi} \; . \; . \; x_N e^{j\phi}$

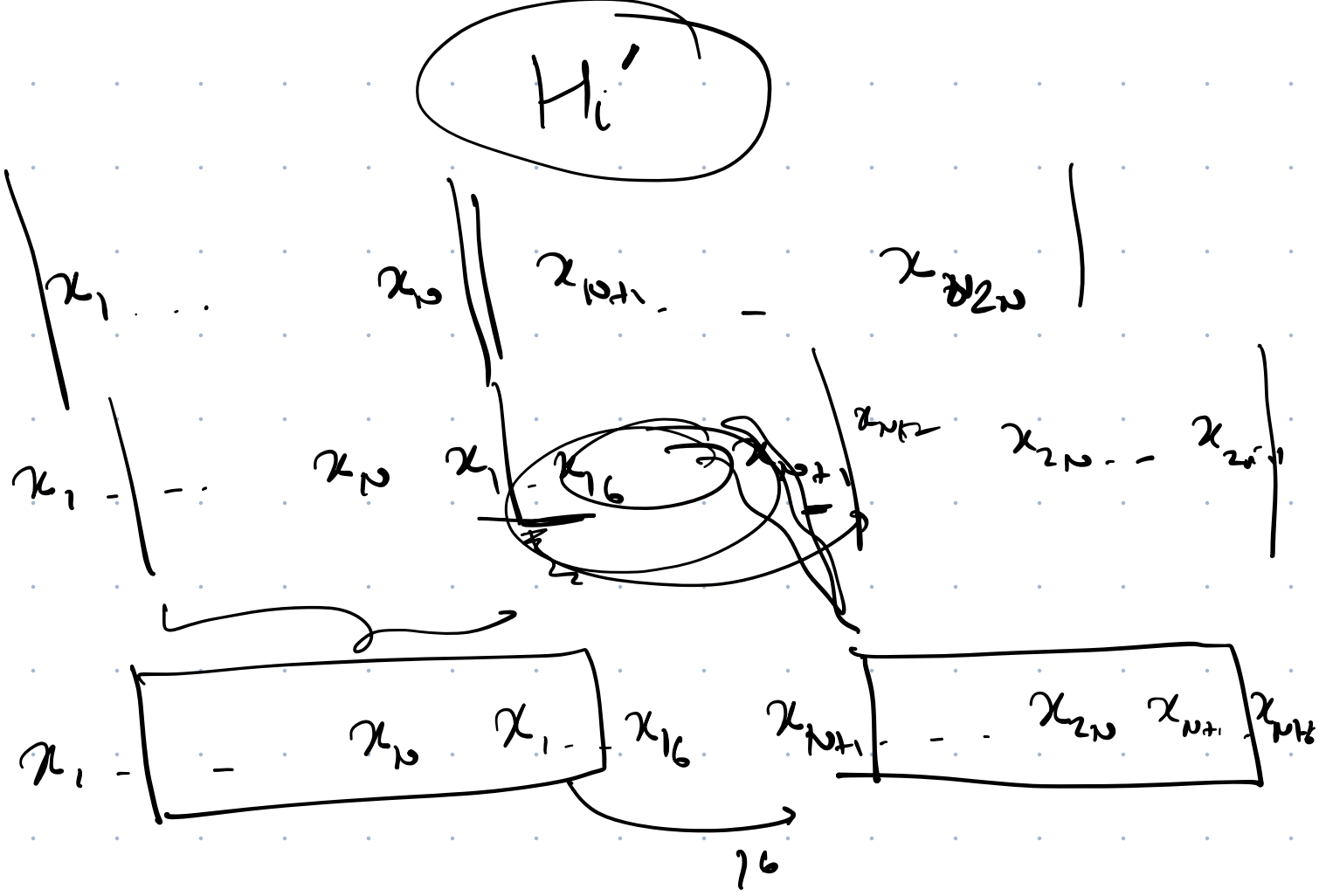
N

$\phi = -\frac{2\pi f \delta}{N} \bmod 2\pi$

$X_1 e^{-\frac{j 2\pi f \delta}{N}} \; . \; . \; X_N e^{-\frac{j 2\pi f \delta}{N}}$

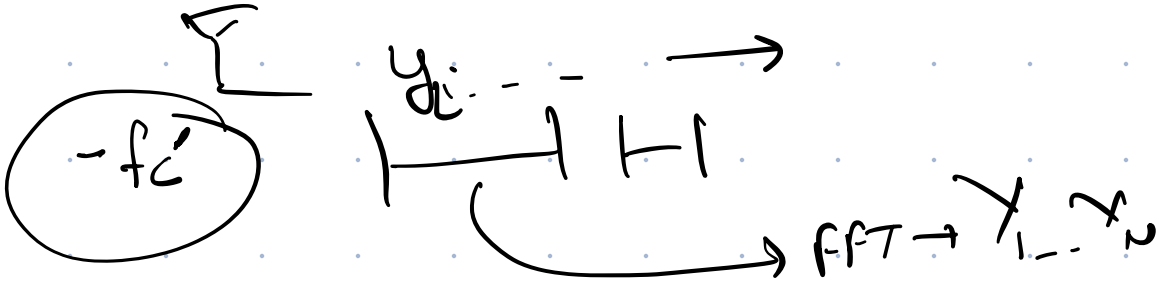
$Y_i = X_i H_i$

$Y_i = X_i H_i e^{-\frac{j 2\pi f_i \delta}{N}}$ ← error in packet detecta



CYCLE PREFIX
- Packet detection errors
- + Inter-symbol interference
- overhead.

CARRIER FREQUENCY OFFSET

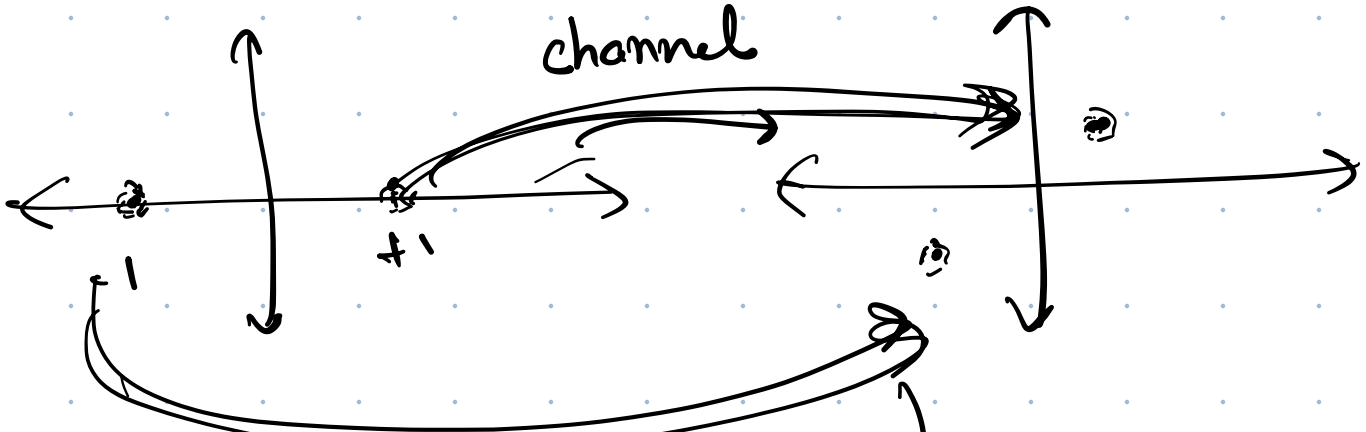


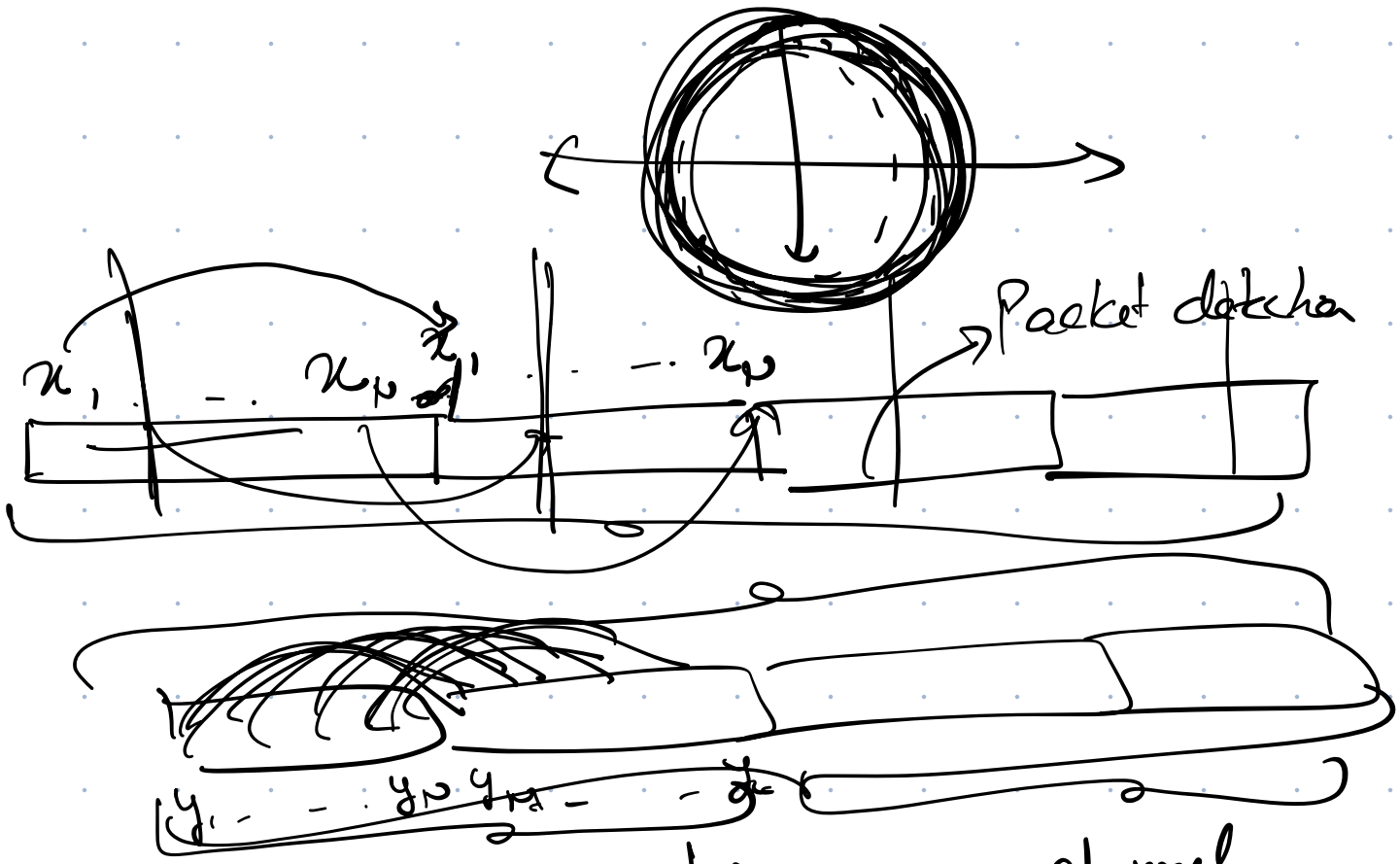
$f_c - f_c' = \Delta f$ ⟸ Carrier frequency offset.

$\Delta f \; (iT_s)$ → sampling distance

$x_i \, e^{j\{2\pi f_c (iT_s) - 2\pi f_c' (iT_s)\}}$

$y_i \longrightarrow y_i \, e^{j\, 2\pi (f_c - f_c')(iT_s)}$





64
128

$$y_n = x(n)\, e^{-j 2\pi \Delta f_c (n T_s)}$$

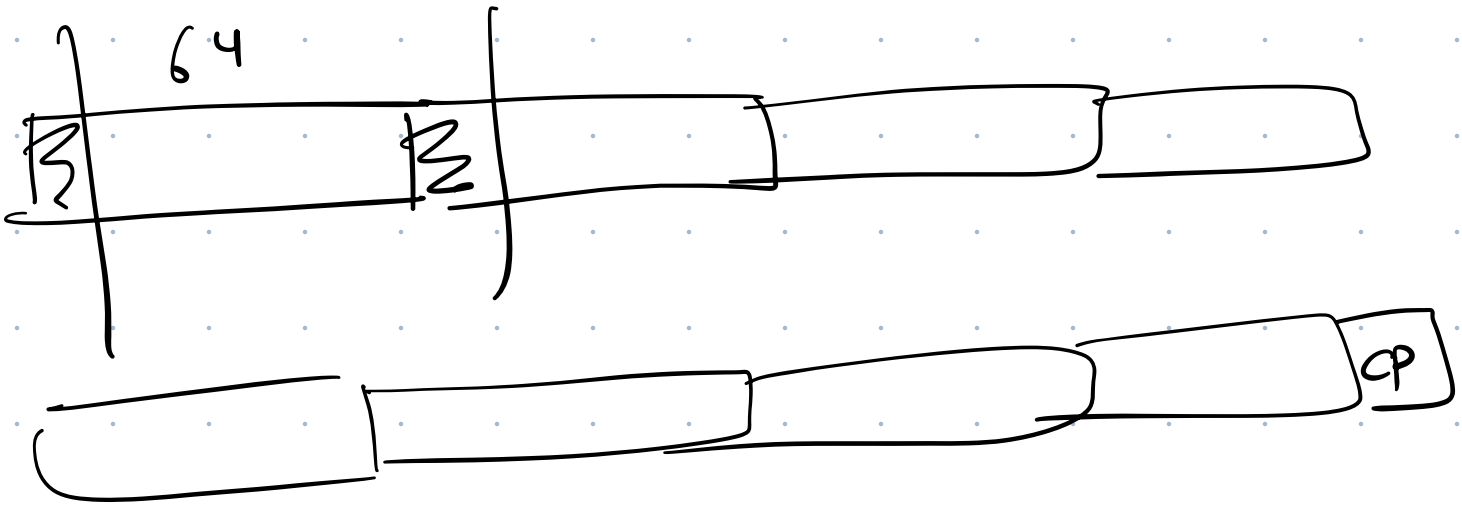
(error; time between samples)

$$y_{n+N} = x(n)\, e^{-j 2\pi \Delta f_c (n+N) T_s}$$

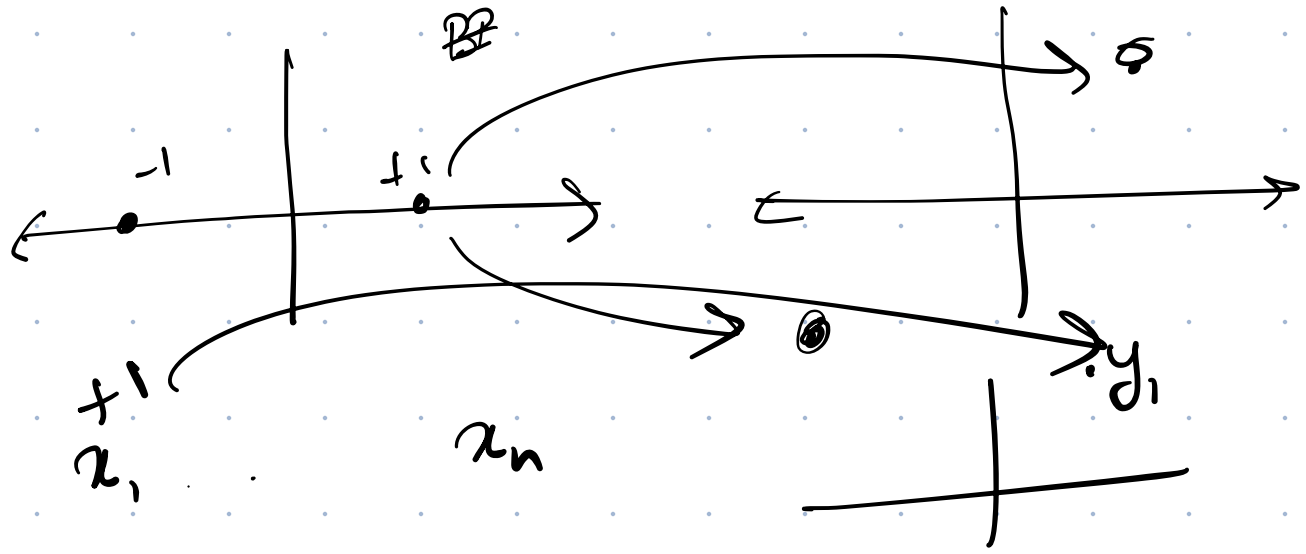
$$y_n \times y_{n+N}^{*} = x_n x_n^{*}\, e^{-j 2\pi \Delta f_c (-N) T_s}$$

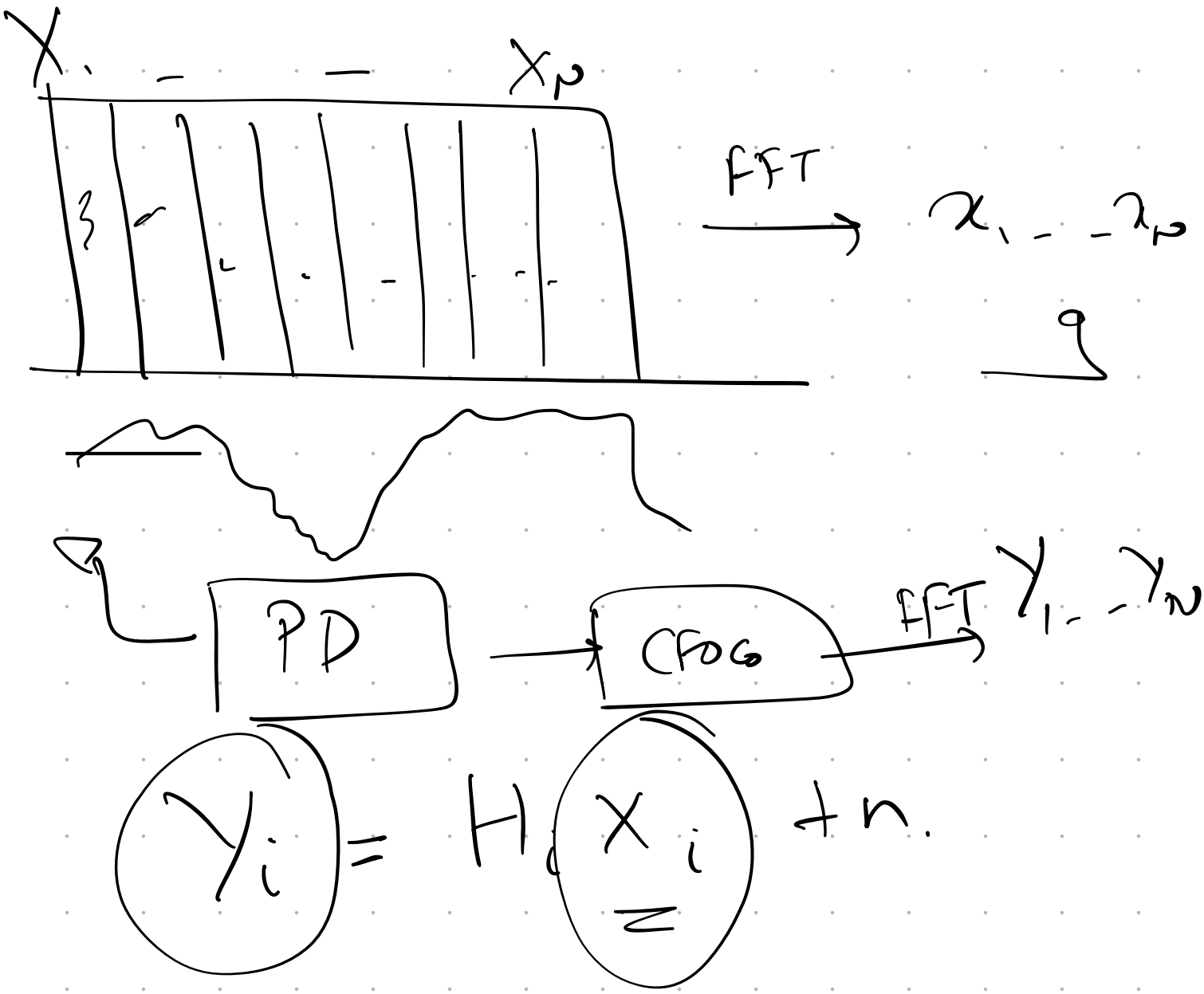
$$= x_n x_n^{*}\, e^{+j 2\pi \Delta f_c N T_s}$$

$$y_n \star y_{n+\nu}^{*} = 2\pi \leftrightarrow f_c N T_s$$

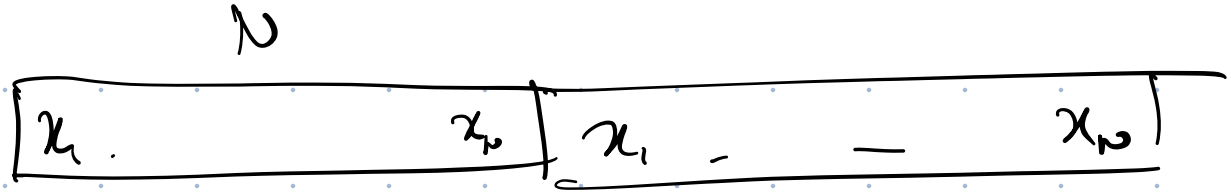


CHANNEL ESTIMATION





$$\widetilde{H}_i = \frac{Y_i}{X_i}$$



$$\widetilde{H}_i \quad \frac{\widetilde{H}_{i,1} + \widetilde{H}_{i,2}}{2}$$

$$\frac{Y_{N+1}}{\widetilde{H}_{N+1}} \quad \cdots \quad X_{2N} \Rightarrow \frac{X_{N+1} \cdots X_{2N}}{\widetilde{H}_N}$$

$1500\,B = 1500 \times 8$ bits $= 12000$ bits

$$\frac{12 \times 10^3}{20 \times 10^6 \text{ samples/s} \times 4 \text{ bit/s}}$$

$$\frac{12 \times 10^3}{8 \times 10^6} \simeq \frac{1}{6}\text{th of a second}$$

$\simeq$ 1 ms 200 µs + 1 ms

RESIDUAL CFO & SFO

Δf_c

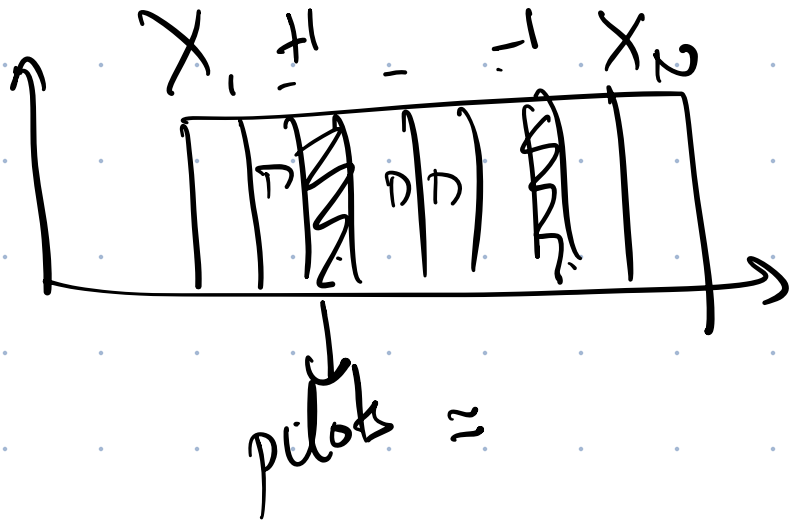
$x_1 \ldots x_N$

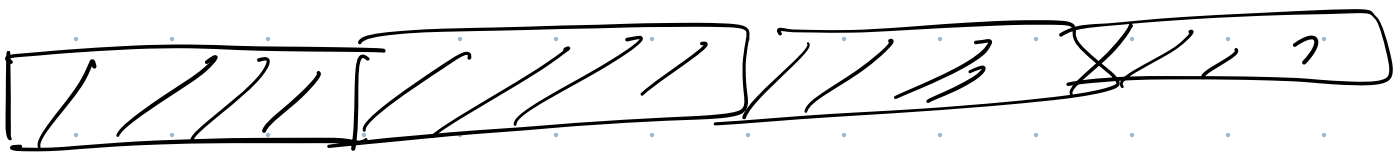
$1\mu s \; 2\mu s \; N\mu s$

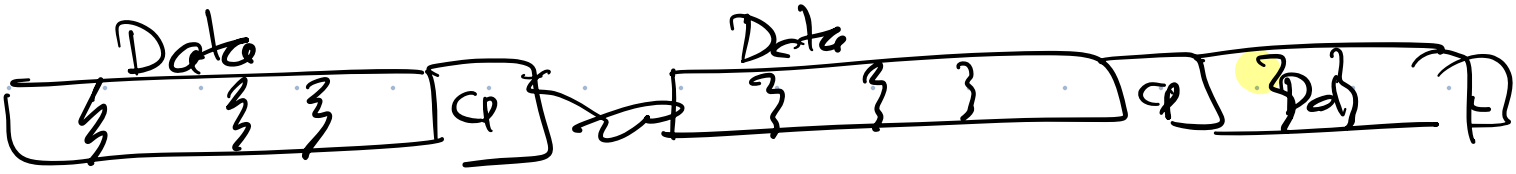
$y_1 \ldots y_N$

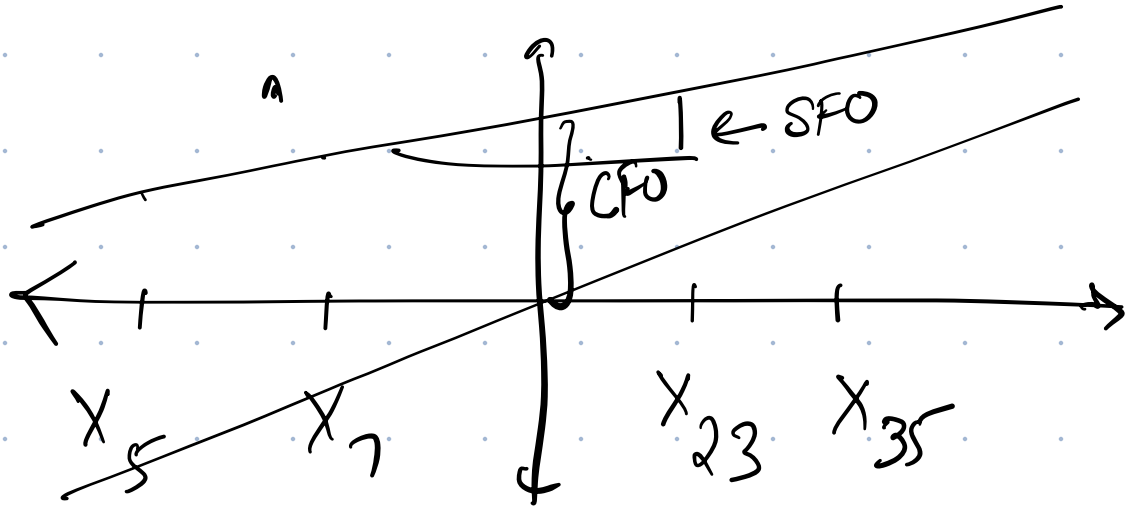
$1\mu s \; 2\mu s \ldots N\mu s$

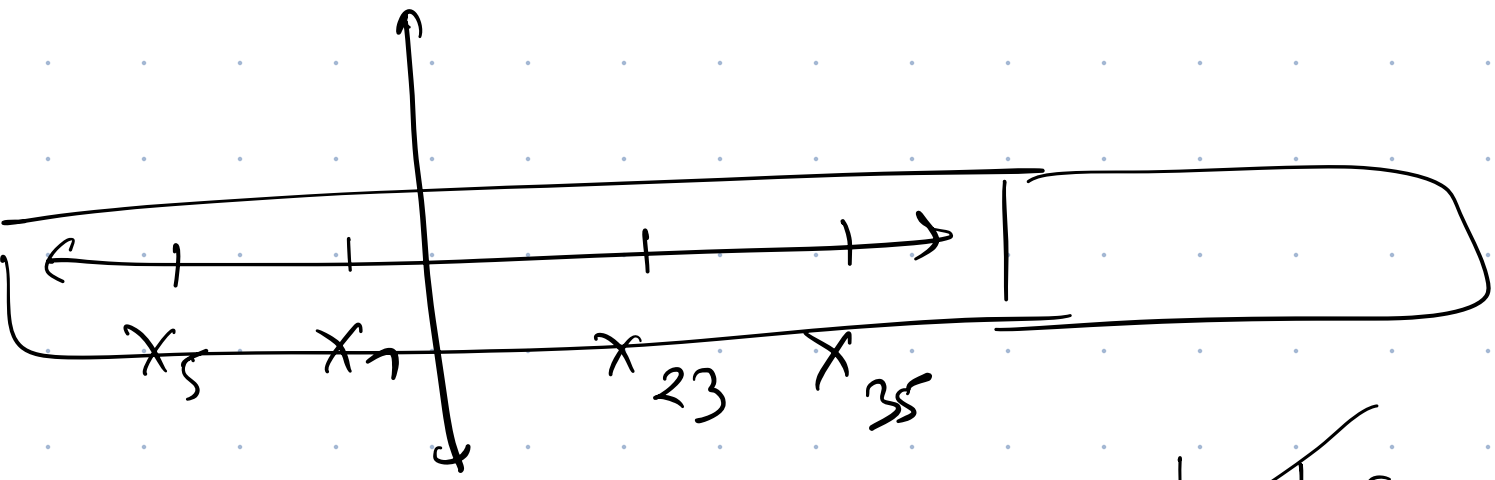
$3.2 \ldots N.N\mu s$

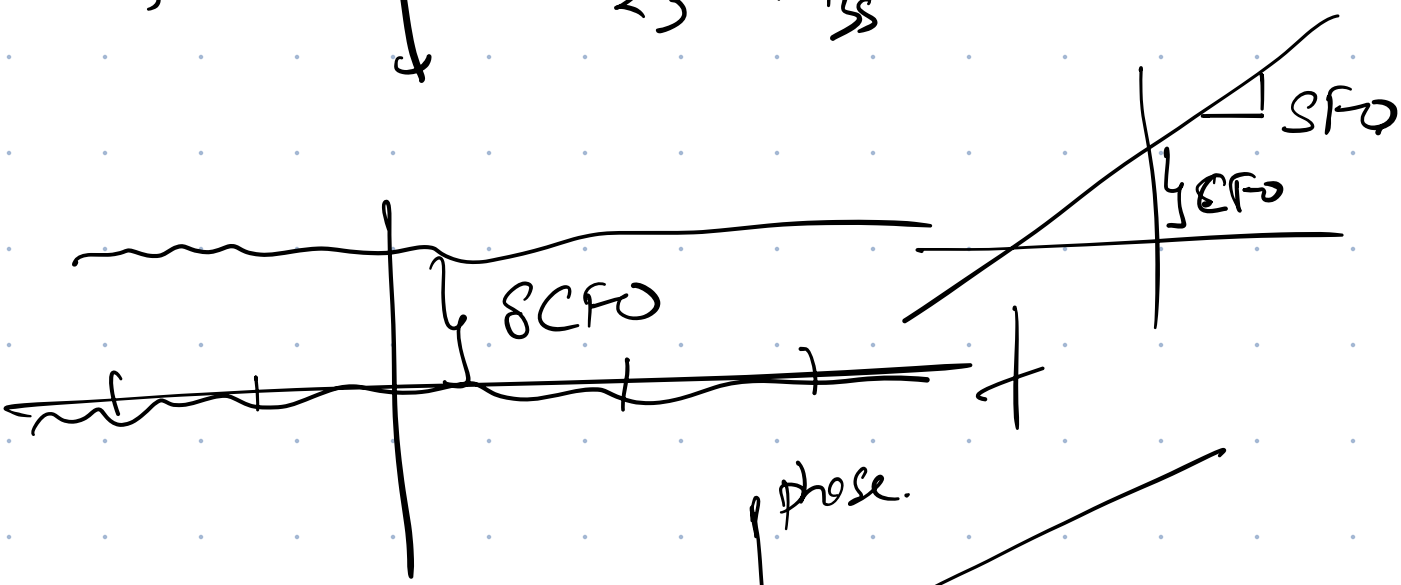


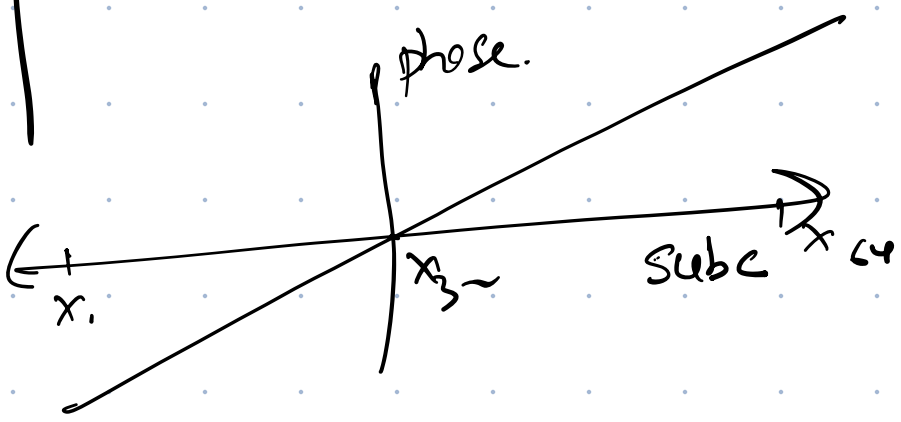



Data
CP
Data
CP

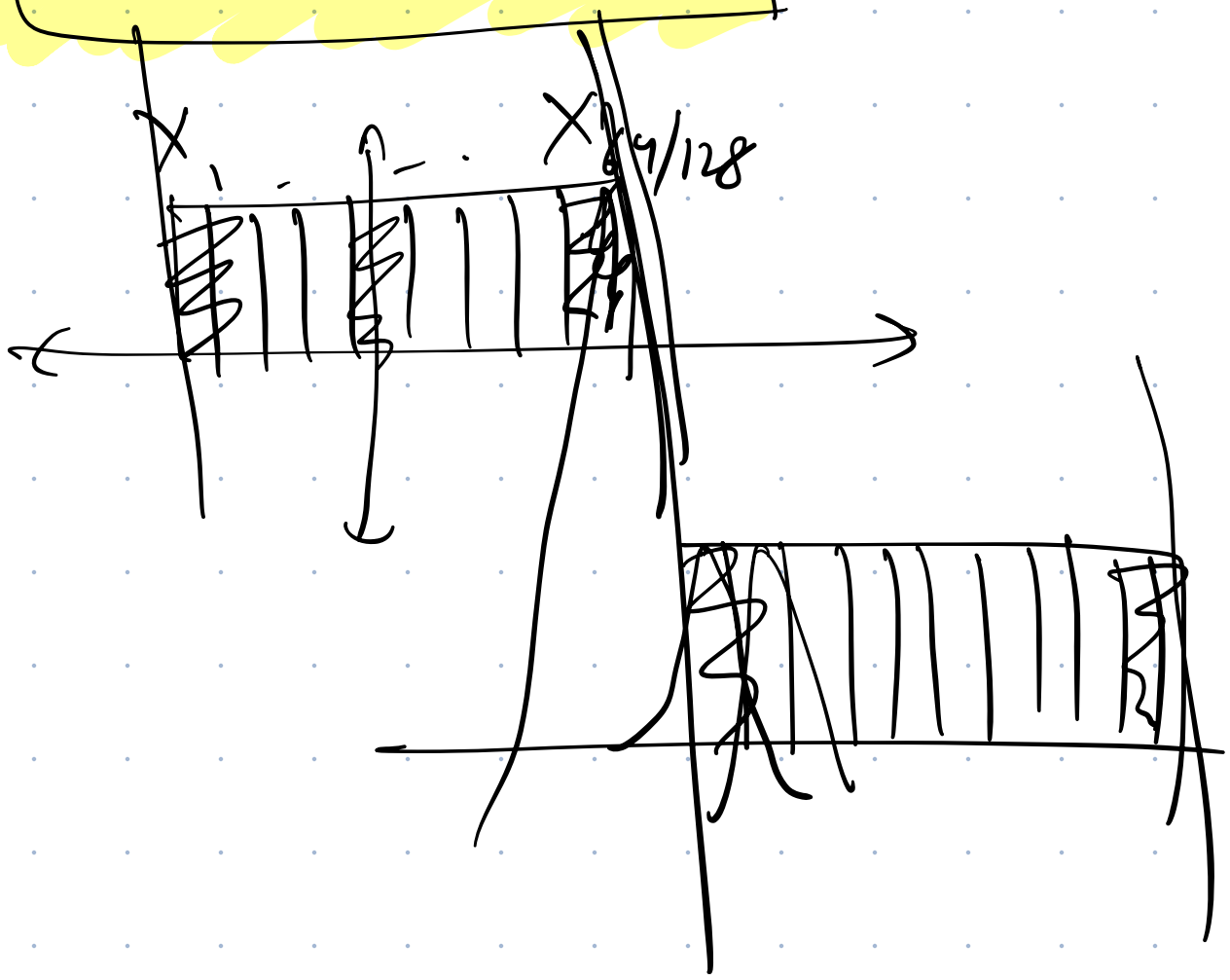

SFO
CFO
X5
X7
X23
X35


X5
X7
X23
X35


SFO
CFO
SCFO


phase.
X1
X3~
subc
X64

GUARD BANDS



2.4GHz

80MHz

At TX:

- Create preamble symbol from training sequence (Uses BPSK)
- Repeat preamble symbol:
  - 4 times for packet detection
  - 2 times for CFO estimation
  - 2 times for channel estimation
  - Add CP for the last preamble
- Create data symbol from:
  - Data bits (Uses BPSK, QPSK, M-QAM)
  - Pilot bits (Uses BPSK)
- Add cyclic prefix to data symbols.

At RX:

- Detect beginning of packet.
- Estimate & correct for CFO.
- Jump $\approx 0.75\ CP$ samples into symbol to avoid ISI
- Estimate the channel.
- For each subsequent data symbol:
  - Remove CP
  - Take FFT of Size N
  - Correct for channel by dividing with $\widetilde{H}(f)$
  - Use linear regression to estimate residual CFO and SFO
  - Estimate accumulated phase $\Delta\phi(f)$ for each frequency bin
  - Add $\Delta\phi(f)$ to channel estimate $\widetilde{H}(f)$
  - Decode Bits