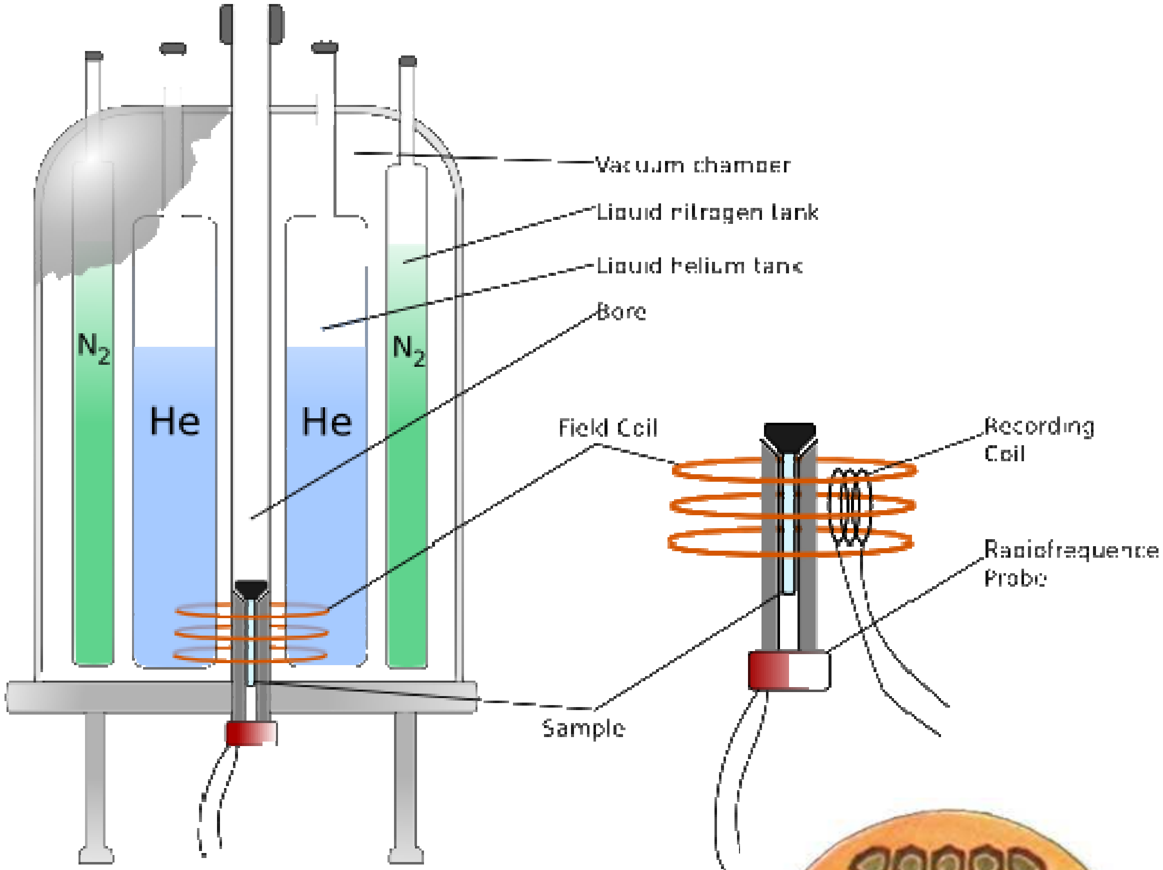
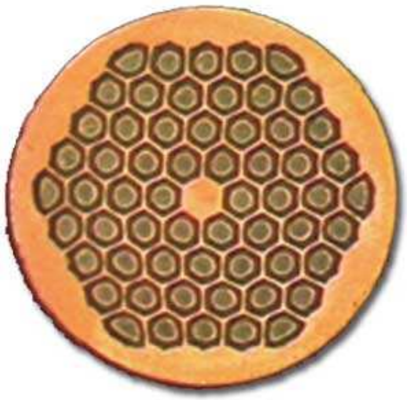
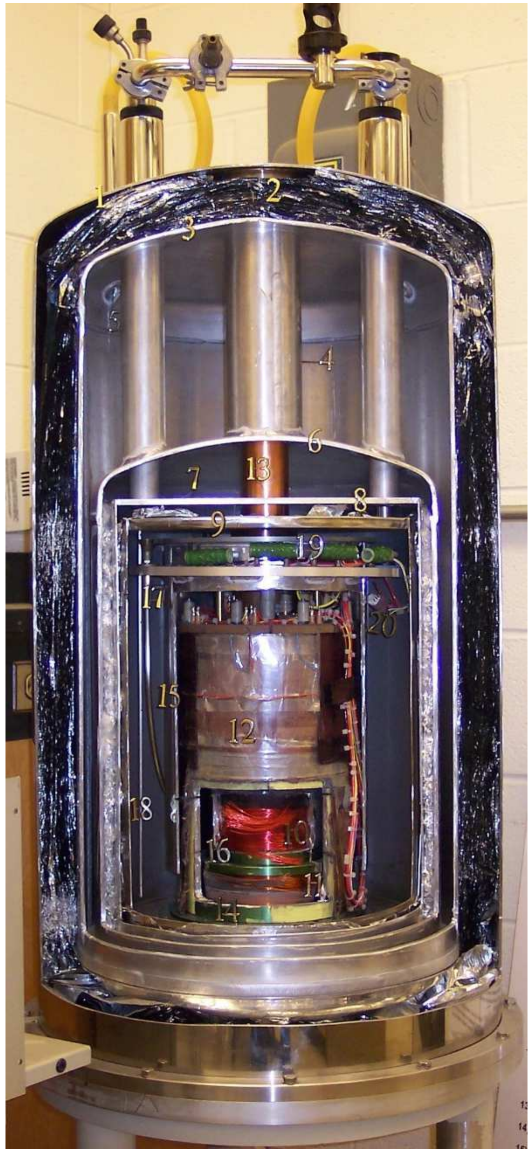
NMR hardware, pulses and signal processing

NMR spectrometer – magnet

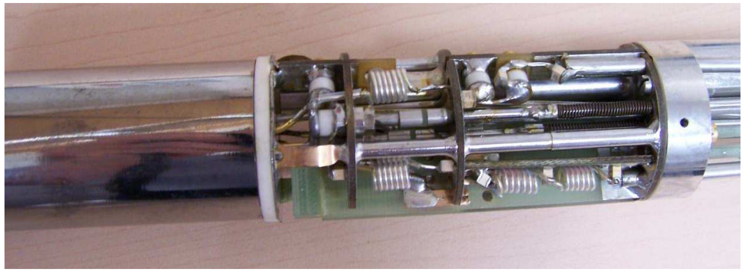




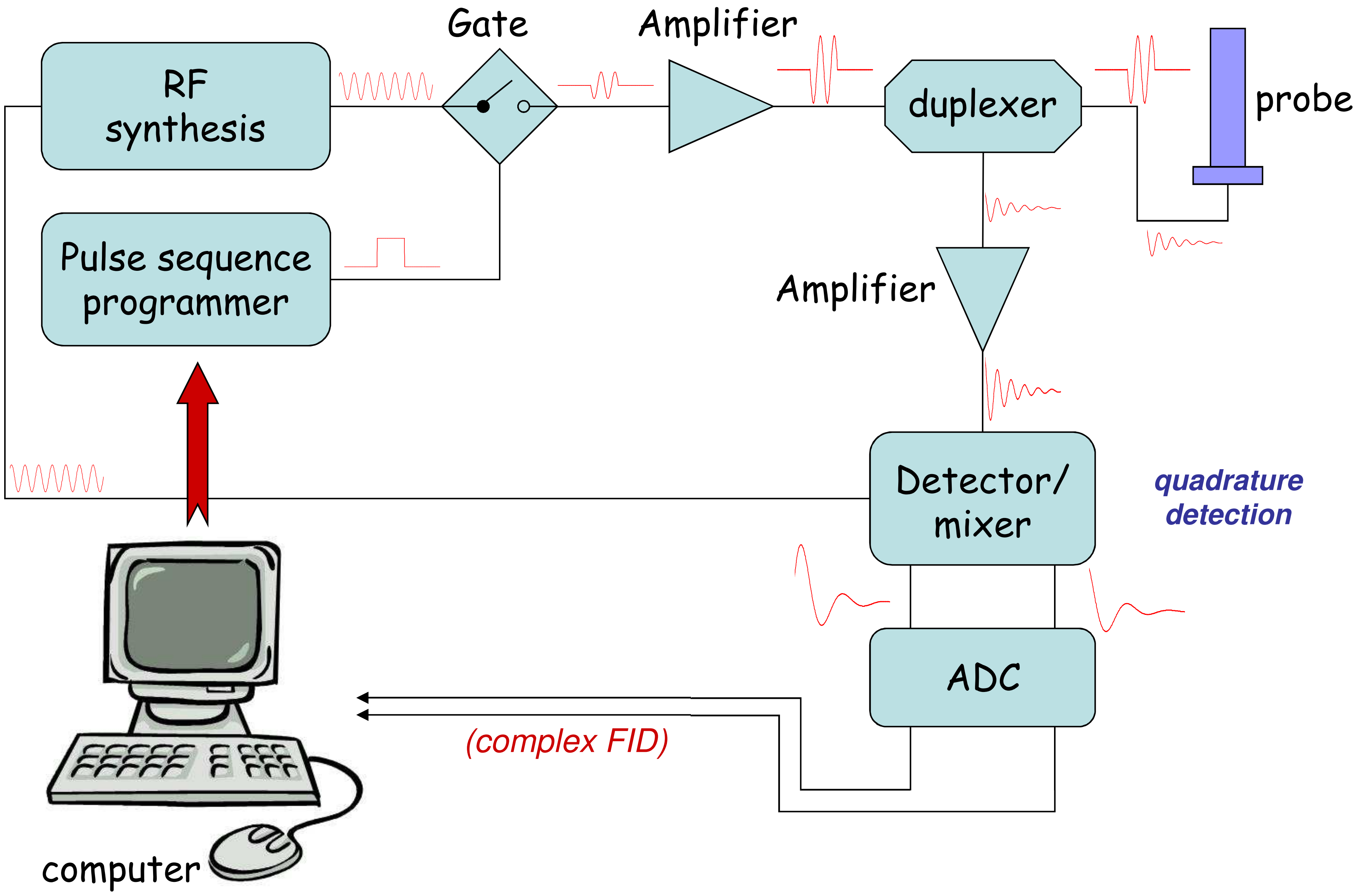
Superconductor cross-section



NMR spectrometer – probe

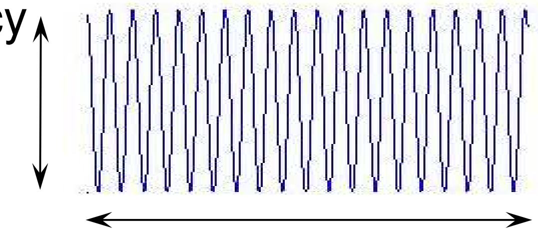


NMR spectrometer – schema



Radiofrequency pulses

nutation frequency
amplitude
ω_1

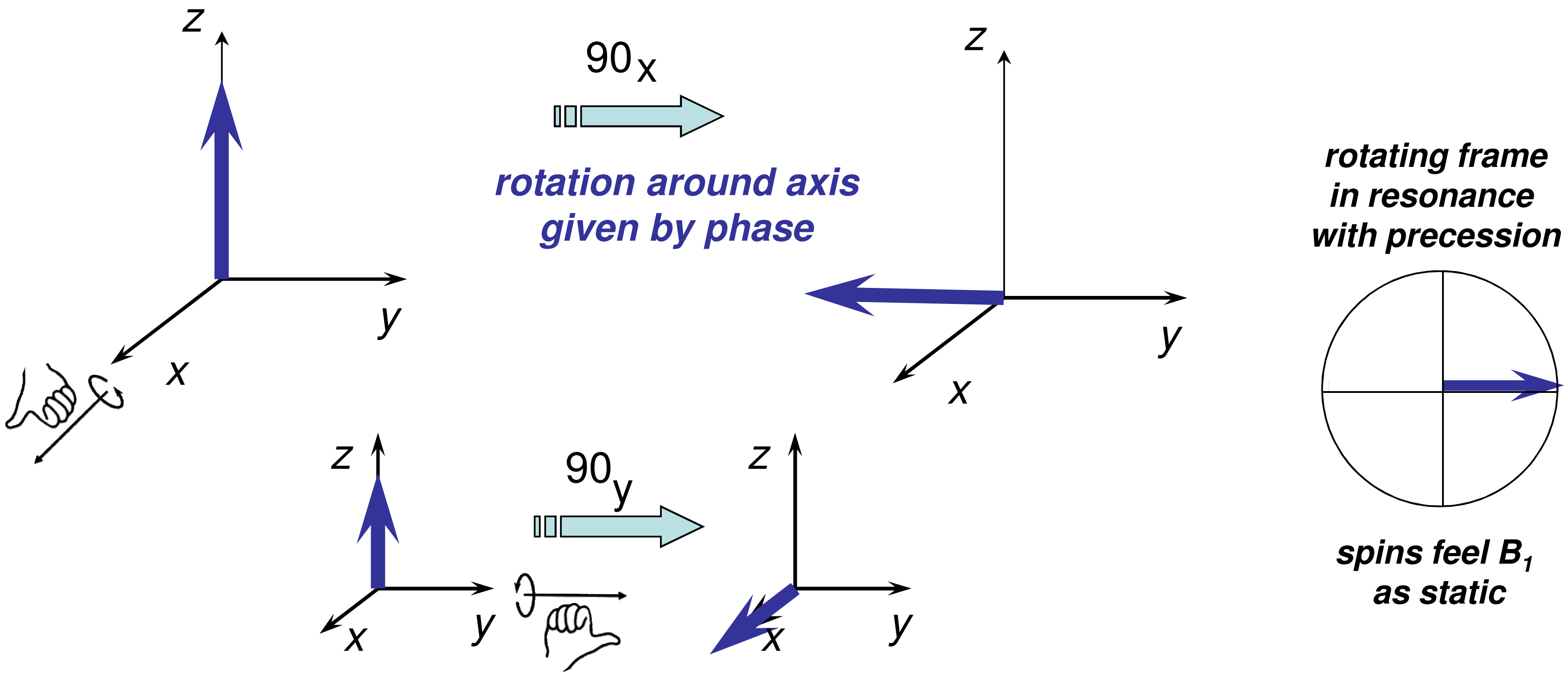


pulse length
τ_p

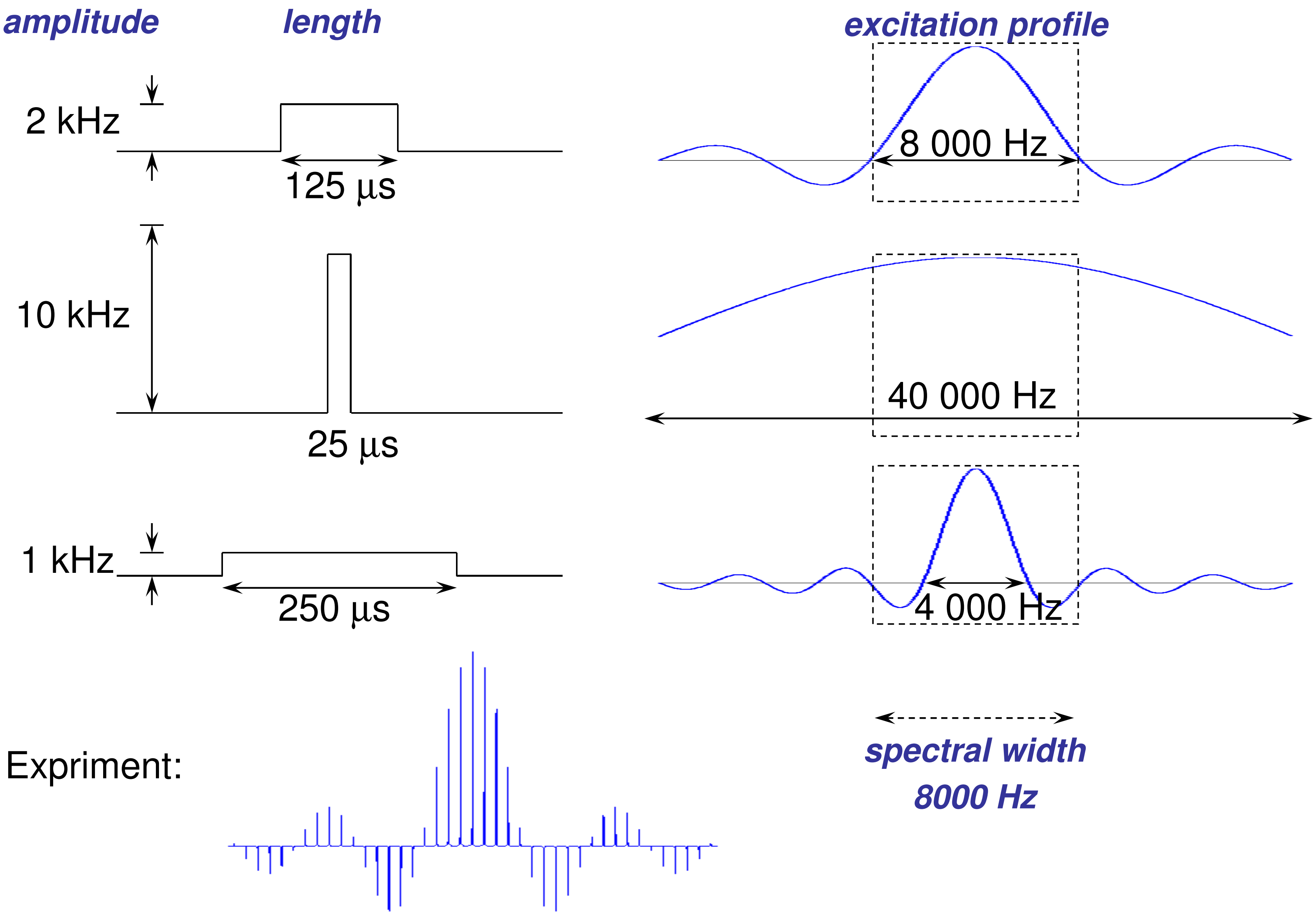
frequency
ω_{rf}

phase
x, y, -x, -y

Flip angle $\varphi = \omega_1 \tau_p$

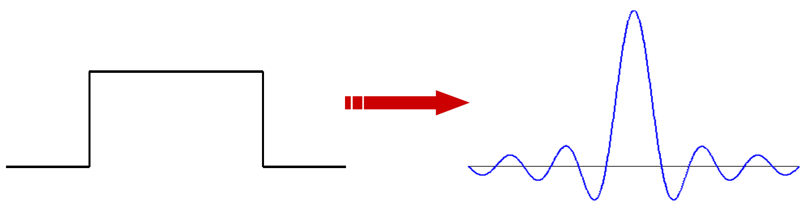


Pulse length and excitation profile

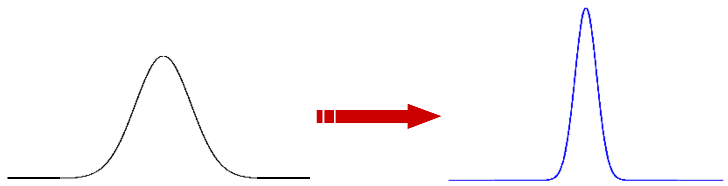


Selective and shaped pulses

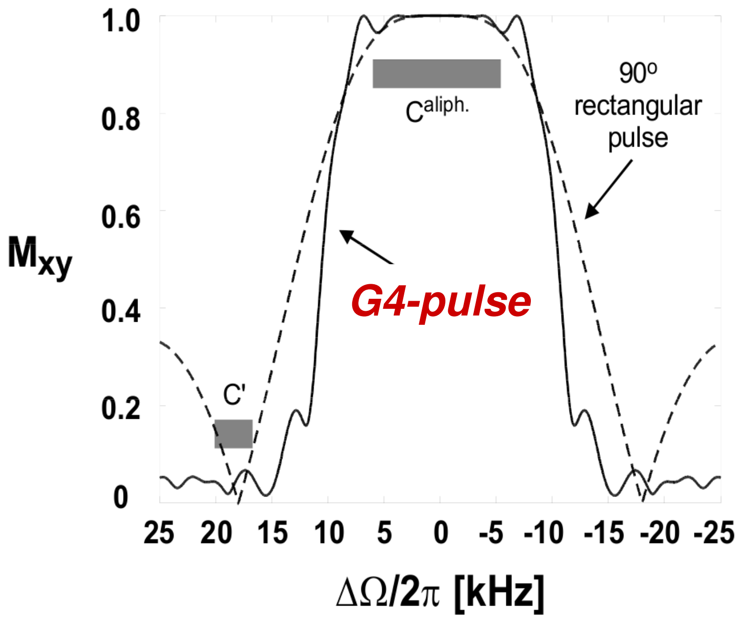
rectangular pulse ***excitation profile***



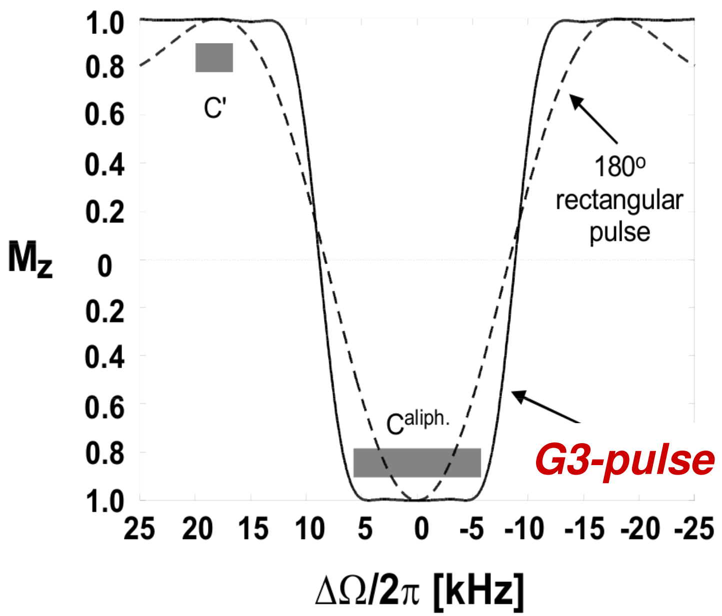
Gauss-shaped pulse ***excitation profile***



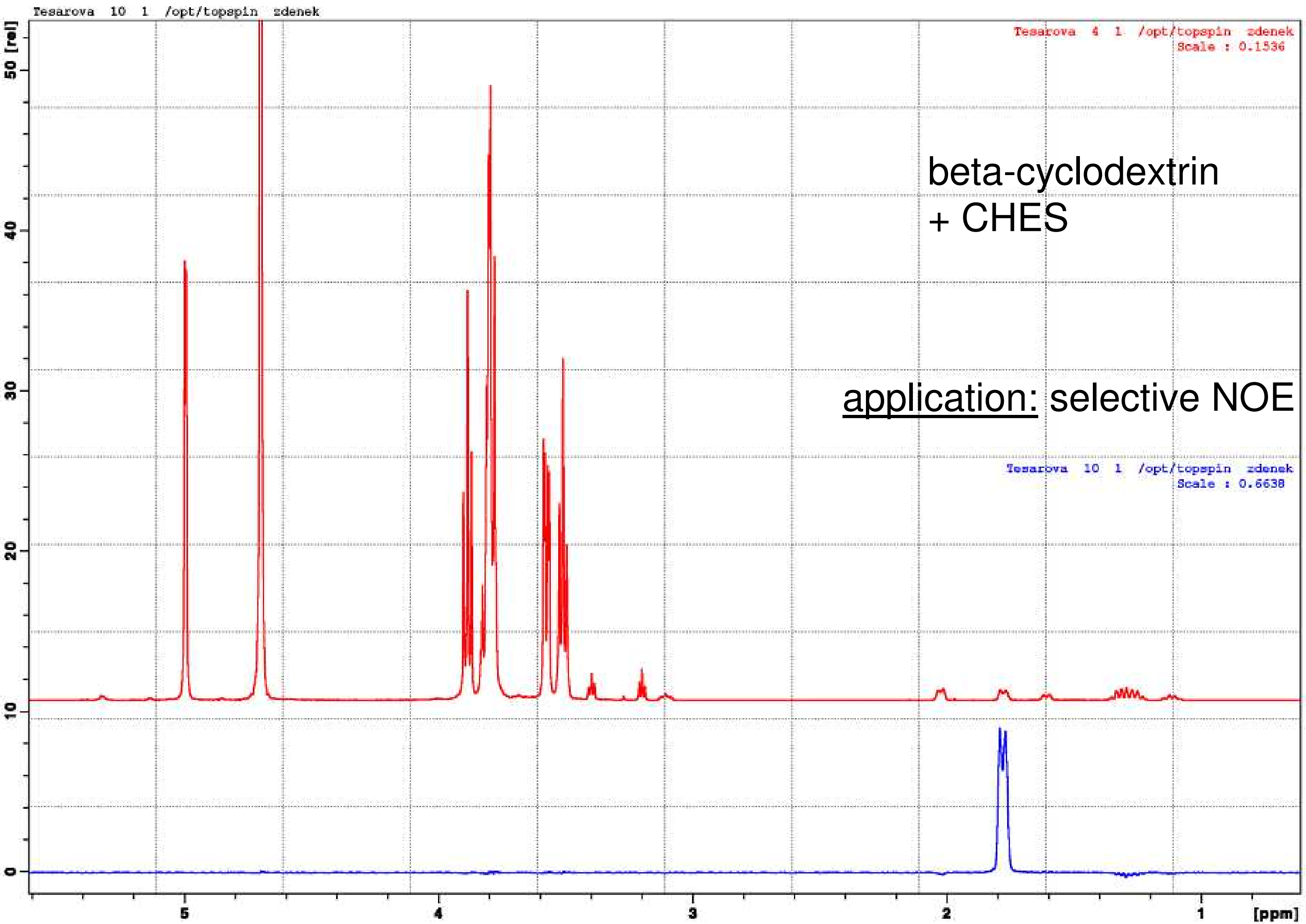
Selective excitation



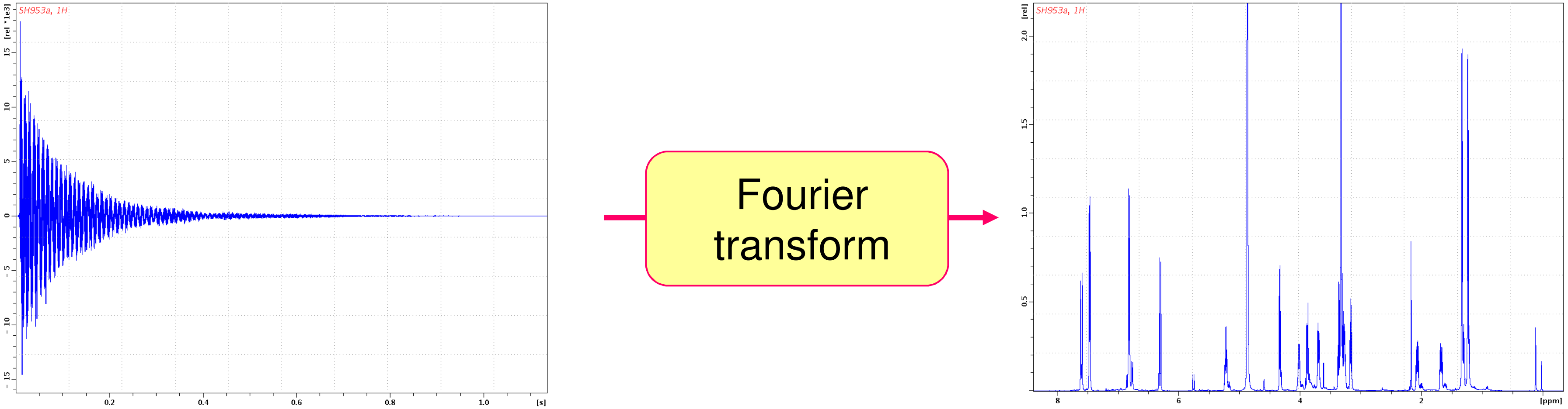
Selective inversion



Selective excitation



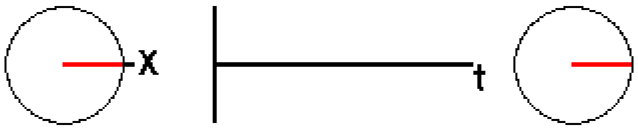
Fourier transform



analyzing periodicity
of time-domain signal

FTprincip.xls

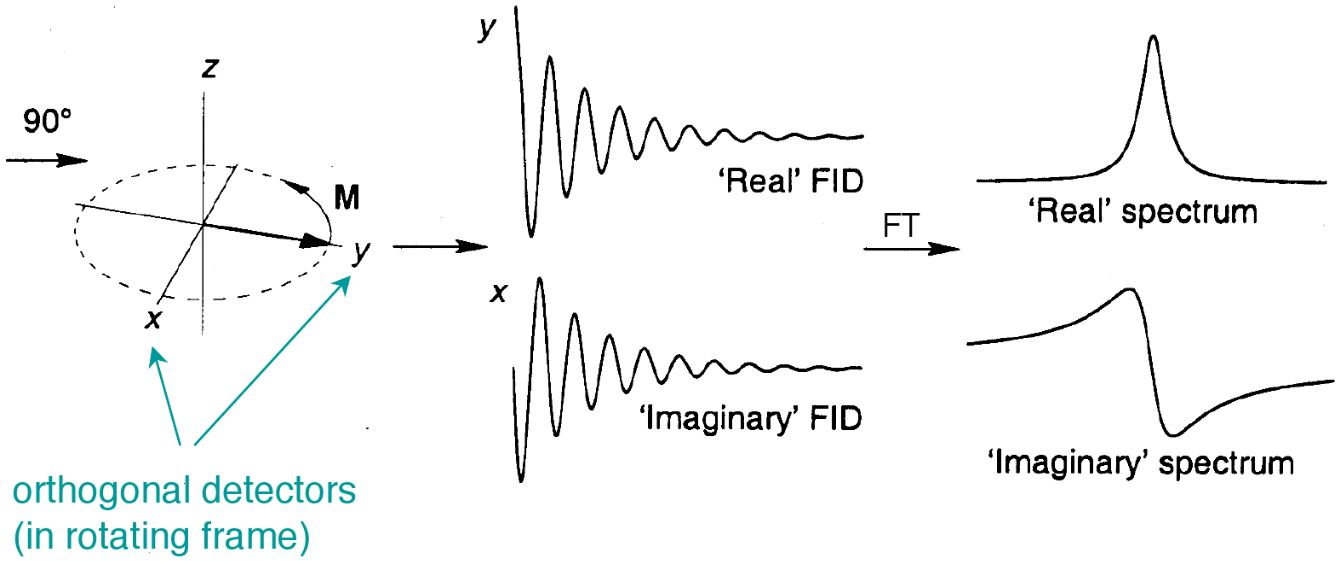
Quadrature detection



to decide on the sense of precession

to phase spectrum to absorption mode

receiver dead time

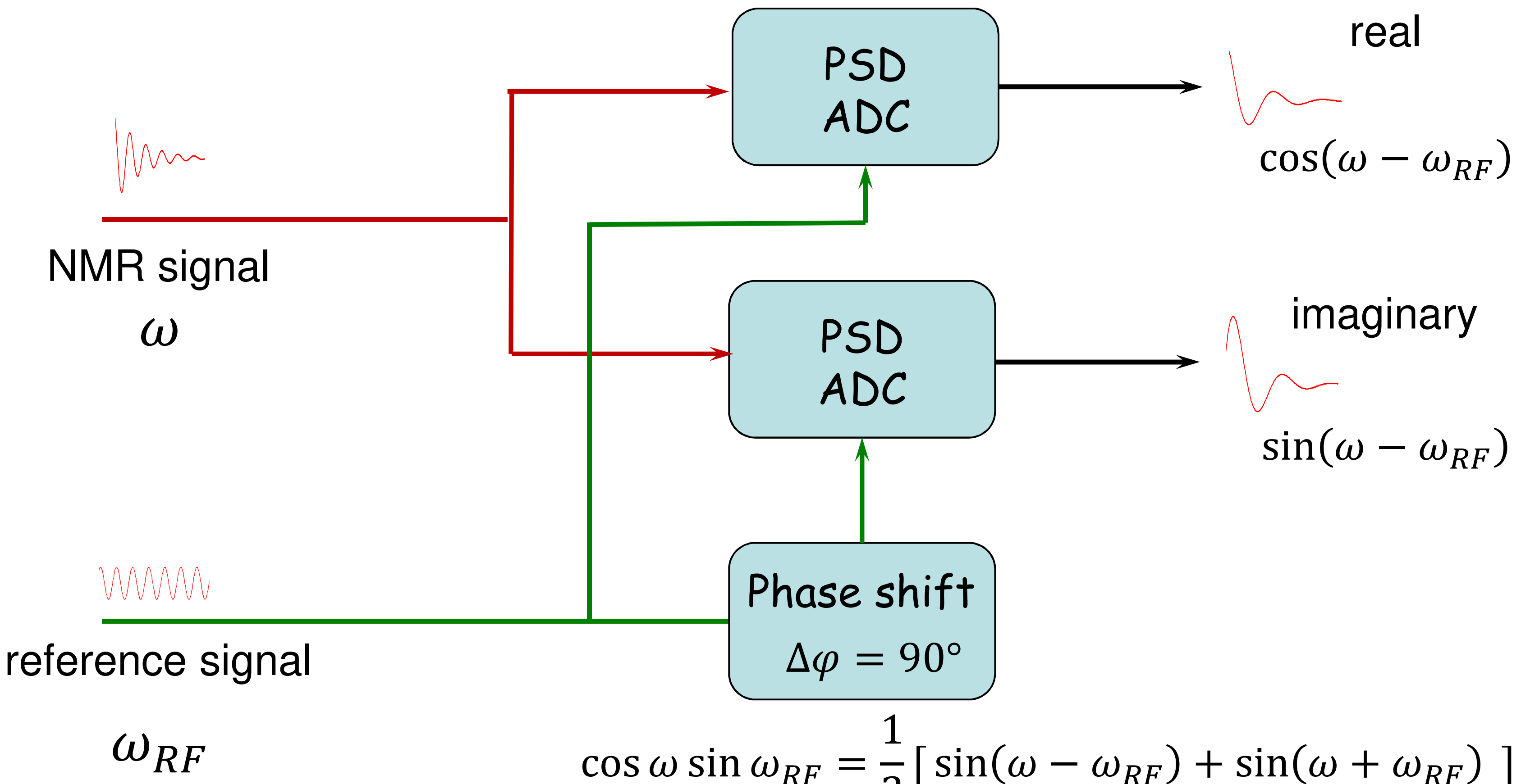


Quadrature detection

electronic "tricks"

Detector/ mixer

$$\cos\omega \cos\omega_{RF} = \frac{1}{2}[\cos(\omega - \omega_{RF}) + \cos(\omega + \omega_{RF})]$$

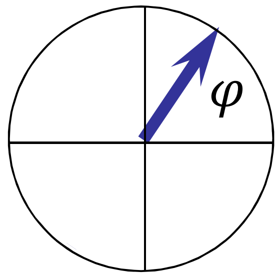


$$\cos\omega \sin\omega_{RF} = \frac{1}{2}[\sin(\omega - \omega_{RF}) + \sin(\omega + \omega_{RF})]$$

Spectrum phase

NMR signal

$$s(t) = \exp[i(\Omega t + \varphi)] \exp\left(-\frac{t}{T_2}\right)$$

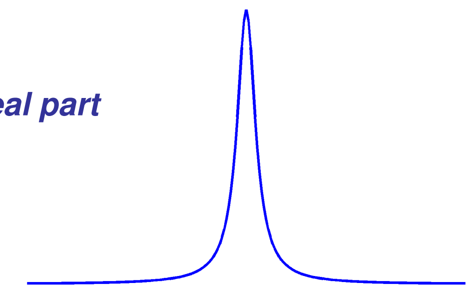


receiver dead time

Lorentzian lineshape

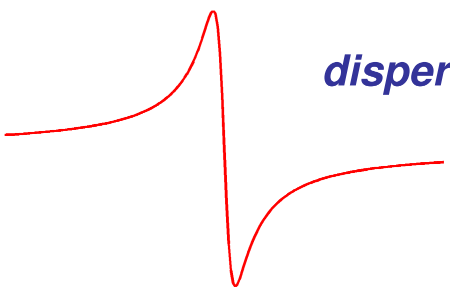
$$S(\omega) = \frac{\frac{1}{T_2} - i(\omega - \Omega)}{\left(\frac{1}{T_2}\right)^2 + (\omega - \Omega)^2} \exp(i\varphi)$$

Real part



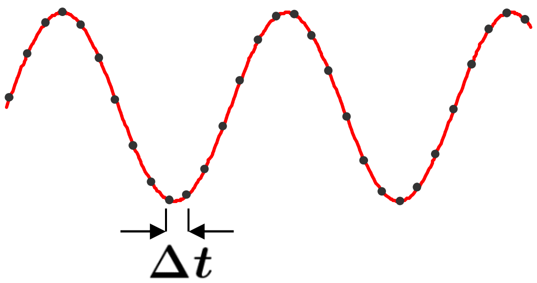
absorption signal

Imaginary part



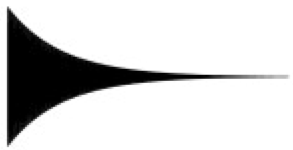
dispersion signal

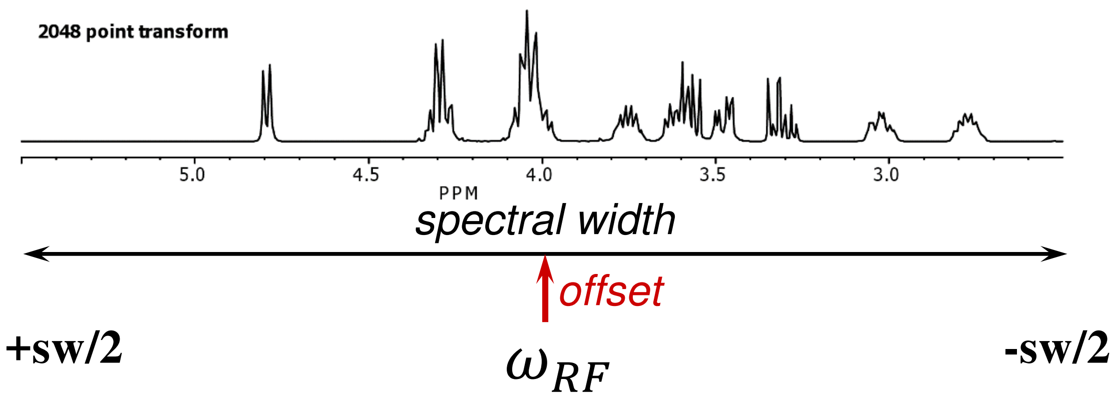
Digital detection



Nyquist theorem

$$\Delta t = \frac{1}{\mathrm{sw}}$$ *Spectral Width*



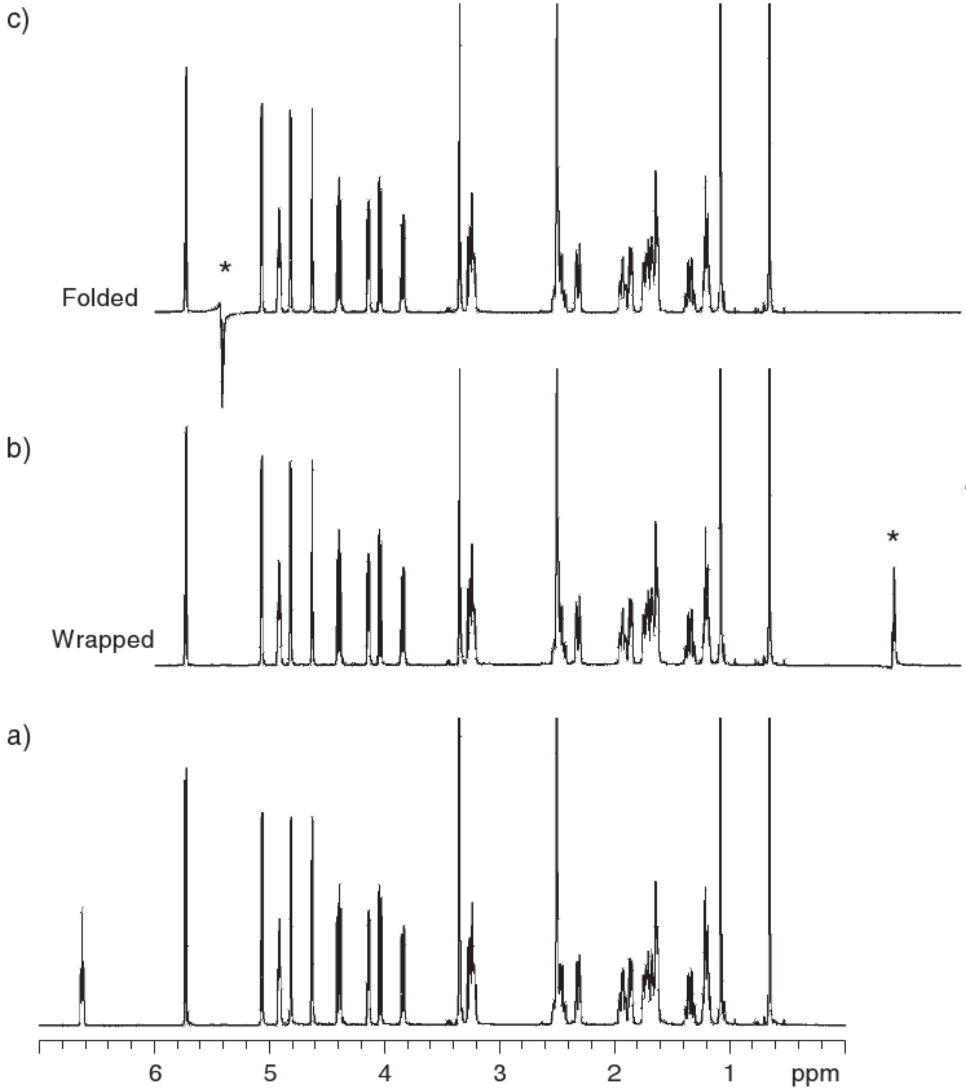


Number of points N_p

Acquisition time $t_{acq} = N_p \Delta t$

Nyquist.m

Spectral window



signal outside

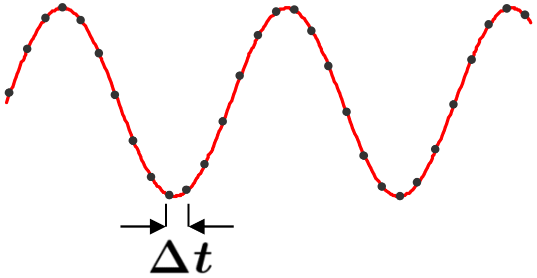
spectral window

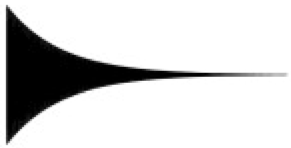
may appear at false positions

correct spectrum

Digital filters remove this…

Spectral resolution

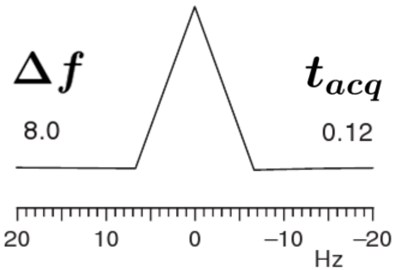


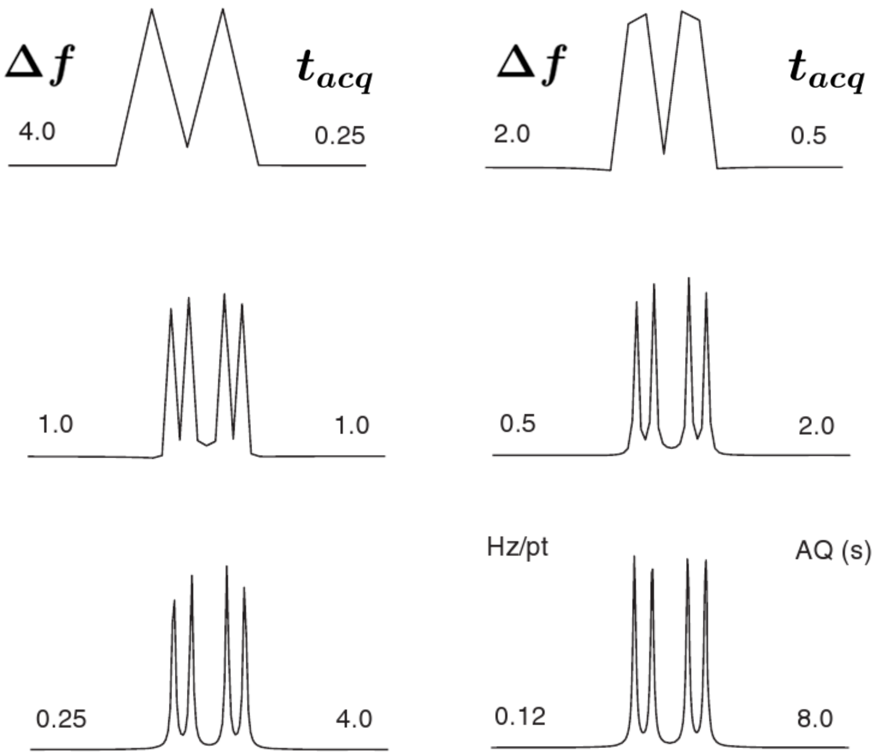


Number of points N_p

Acquisition time

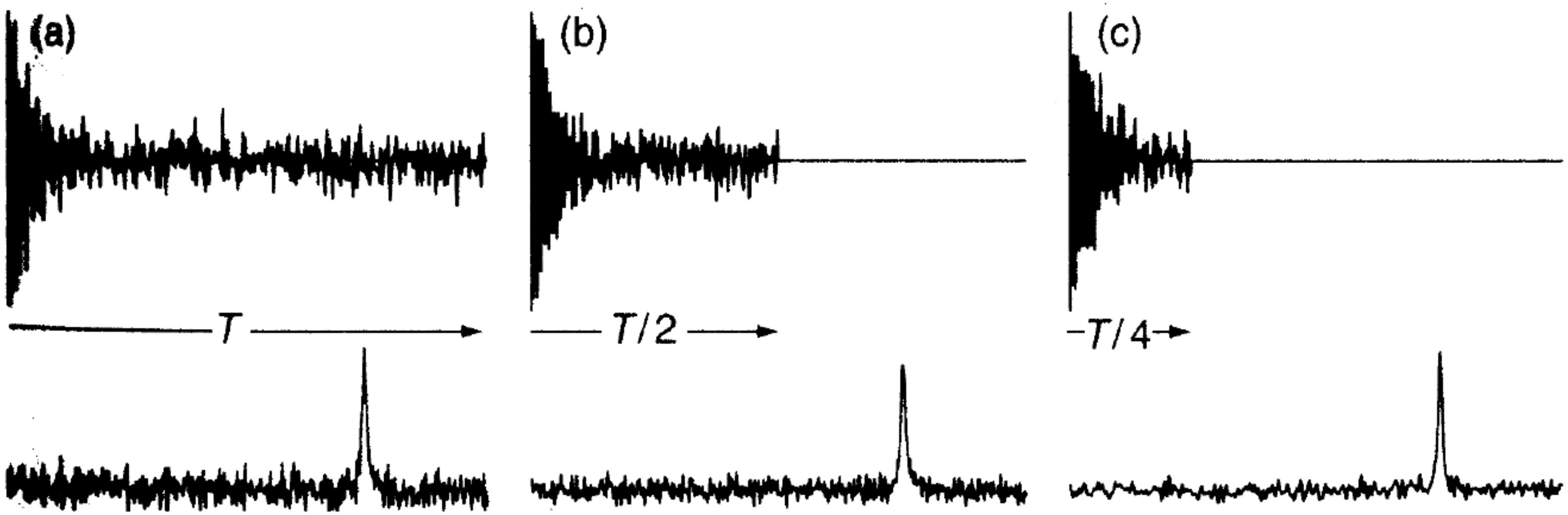
$$t_{acq} = N_p \Delta t$$





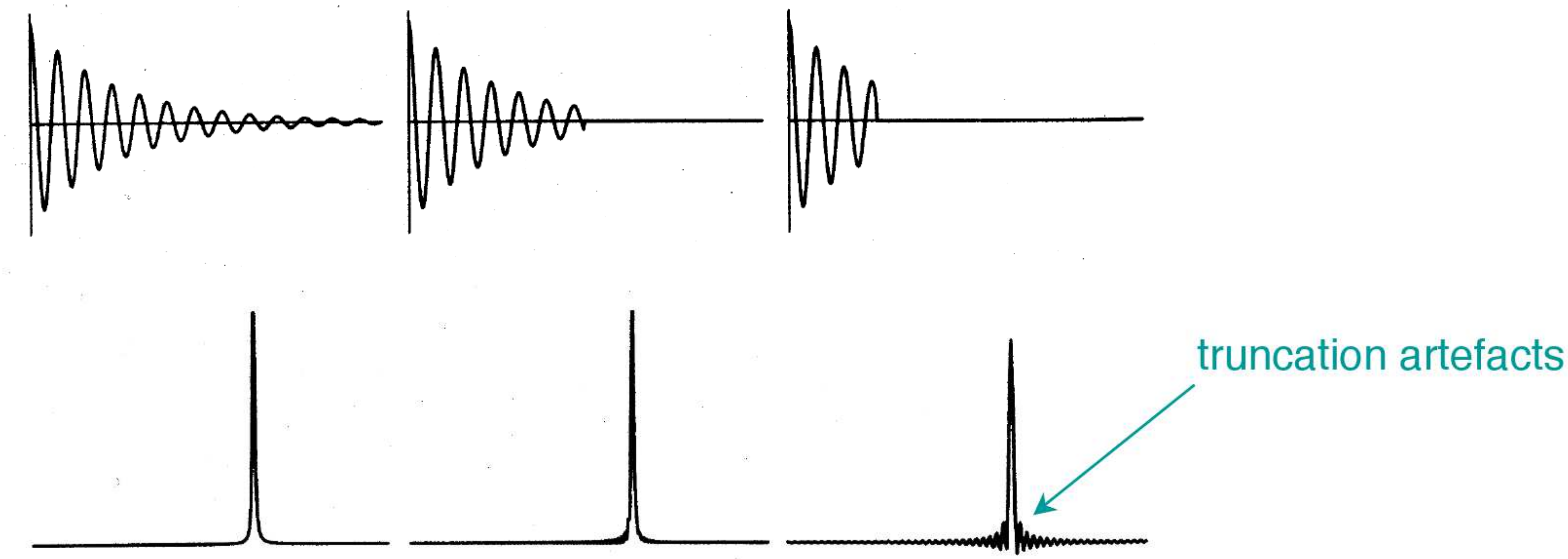
$$\Delta f = \frac{\mathrm{sw}}{N_p} = \frac{1}{\Delta t\ N_p} = \frac{1}{t_{acq}}$$

Acquisition time



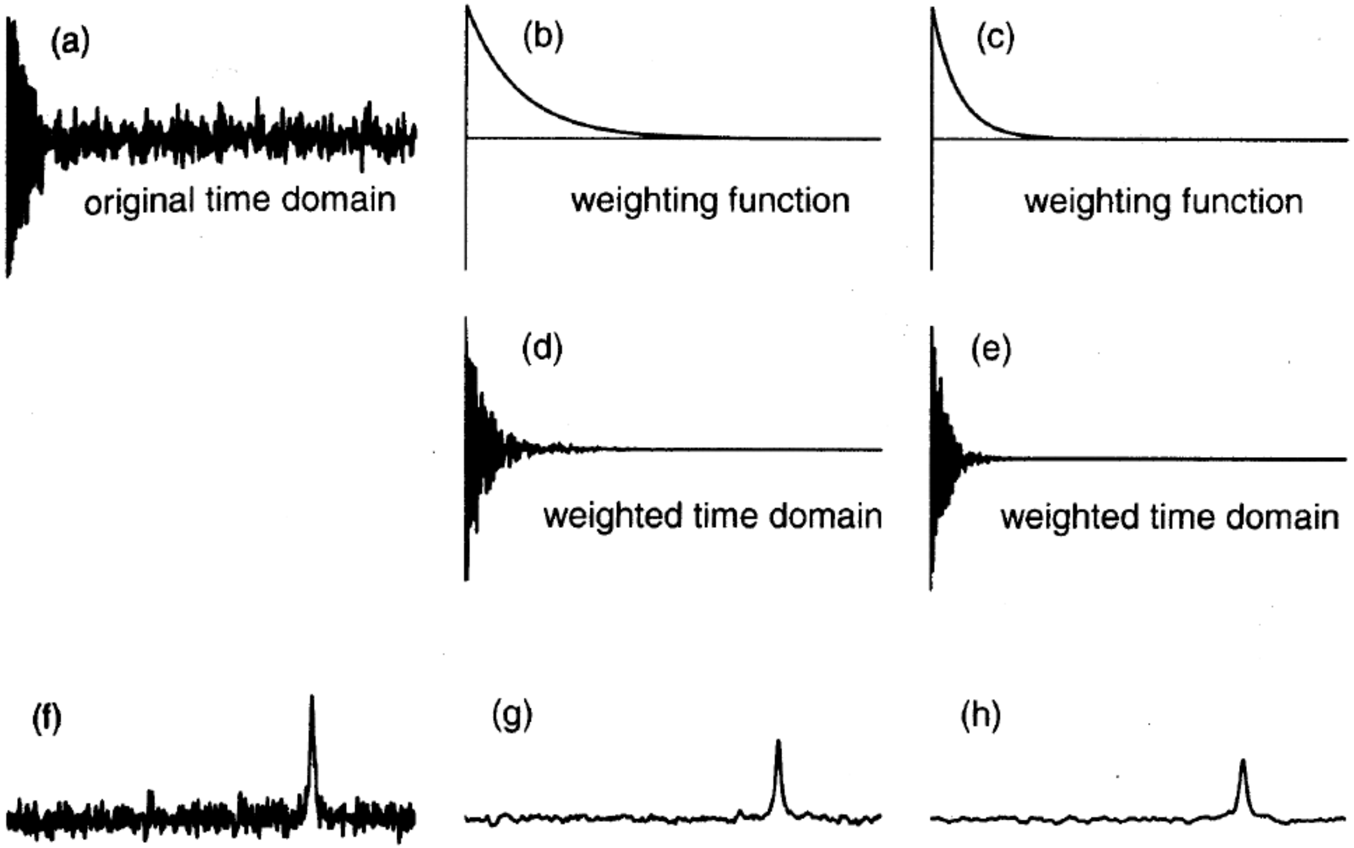
If too long → we get more noise

Acquisition time



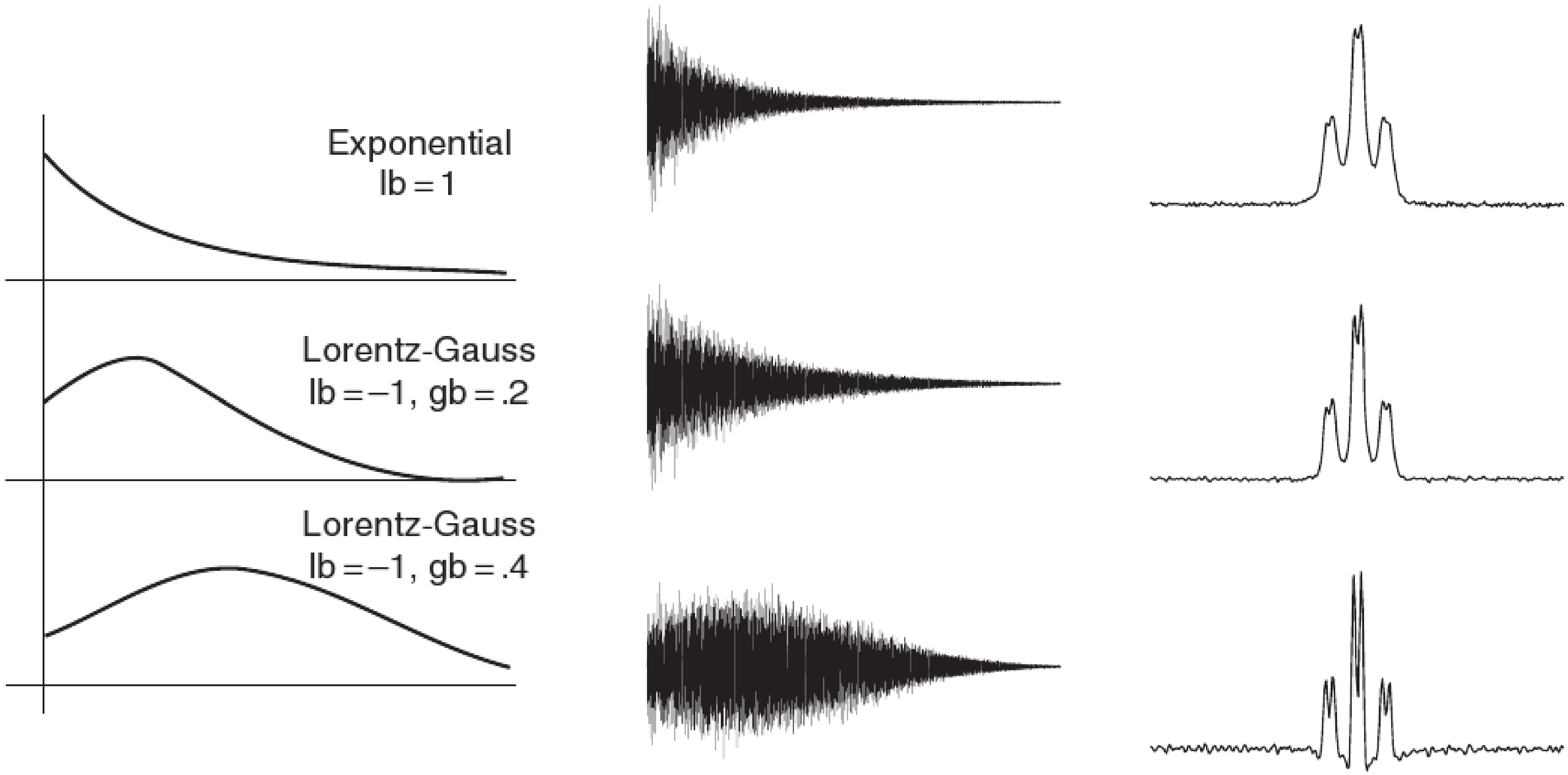
If too short → we get truncation artefacts

Apodization



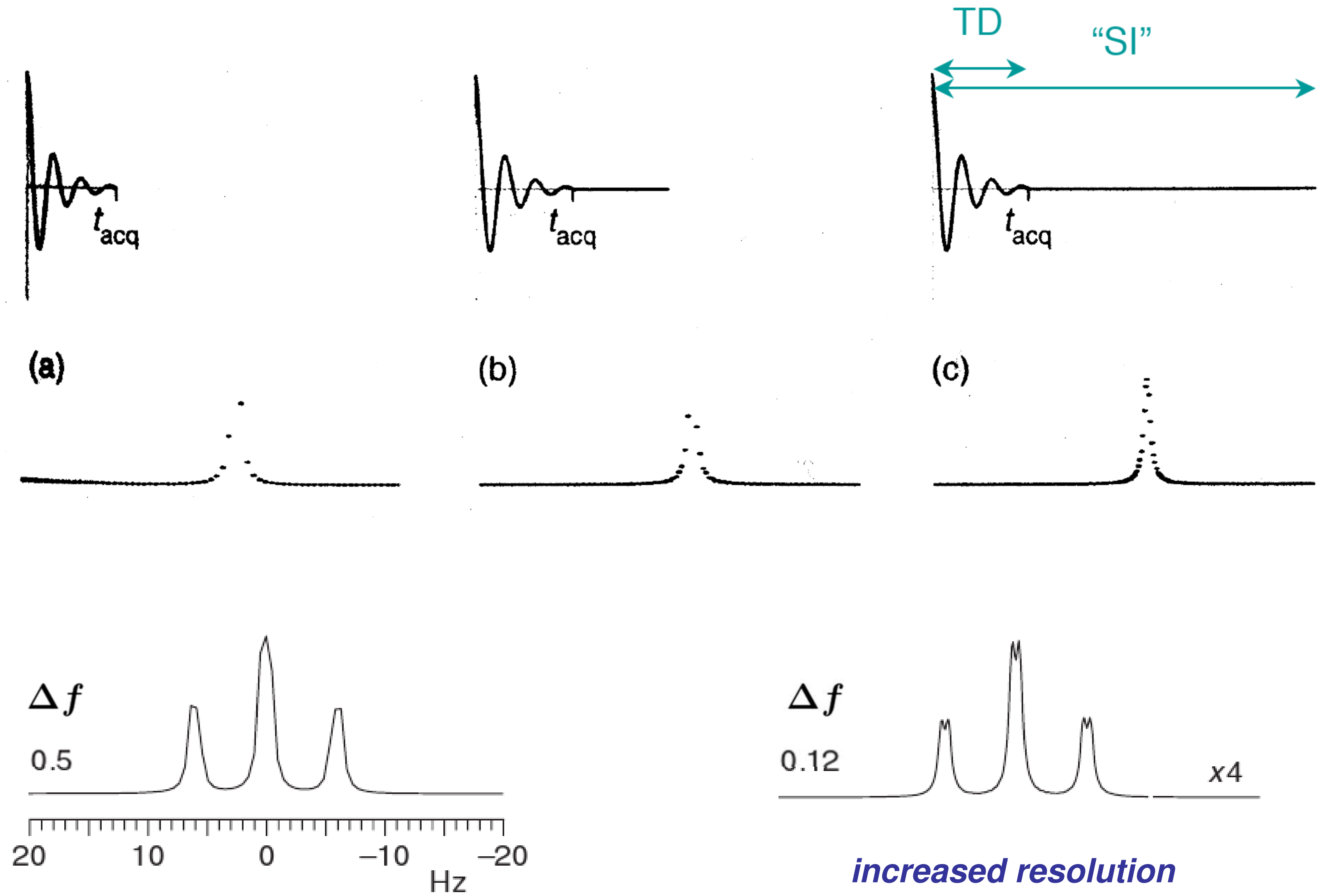
Exponential weight to suppress noise → *line broadening*

Apodization



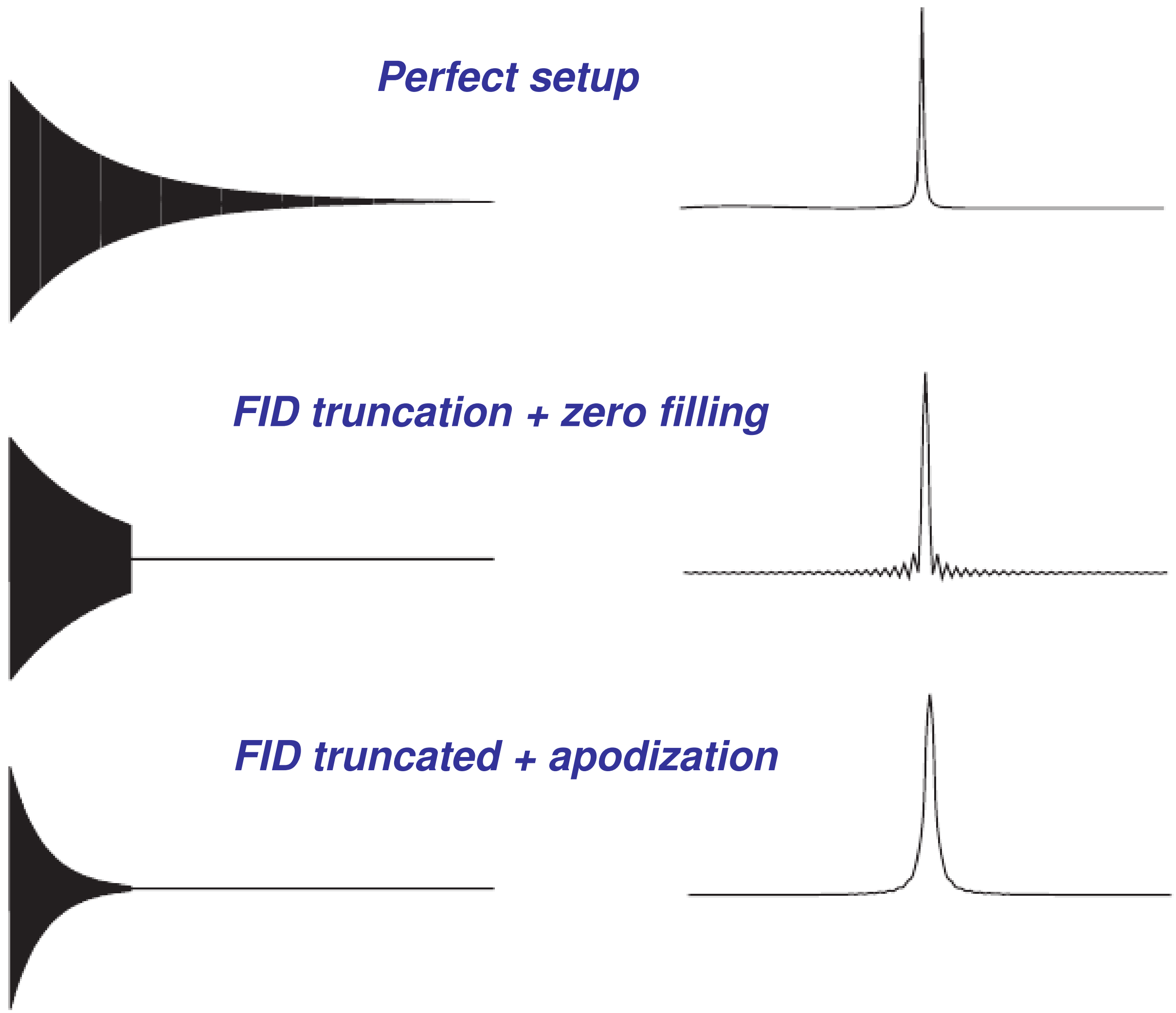
Artificial line narrowing → *increasing noise*

Zero filling



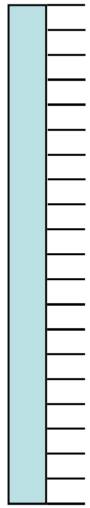
increased resolution

Apodization

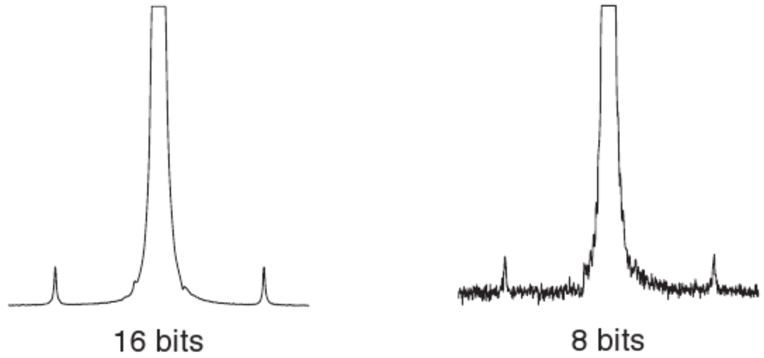


Receiver gain

ADC

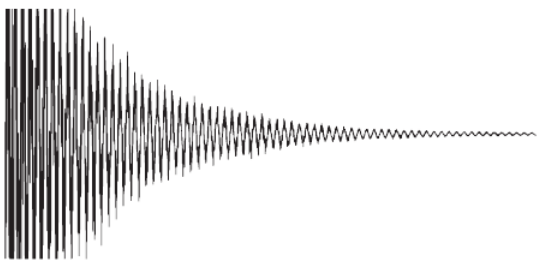


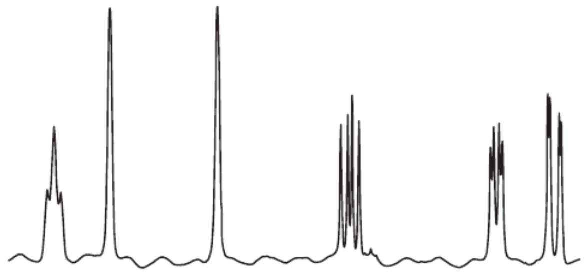
amplify before detection



Optimal usage of ADC dynamic range

strong and weak signals



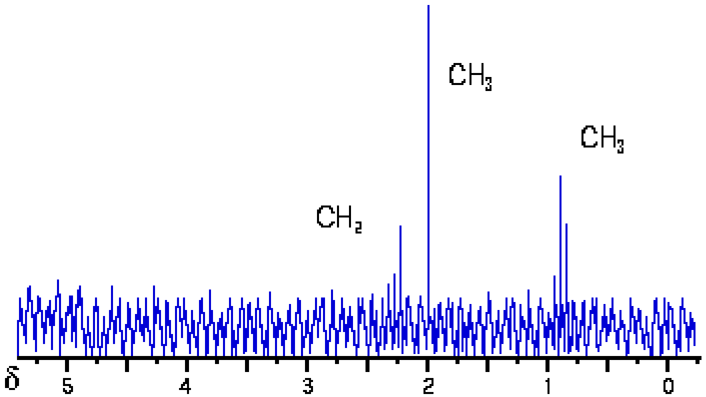


Receiver overflow → ***baseline artifacts***

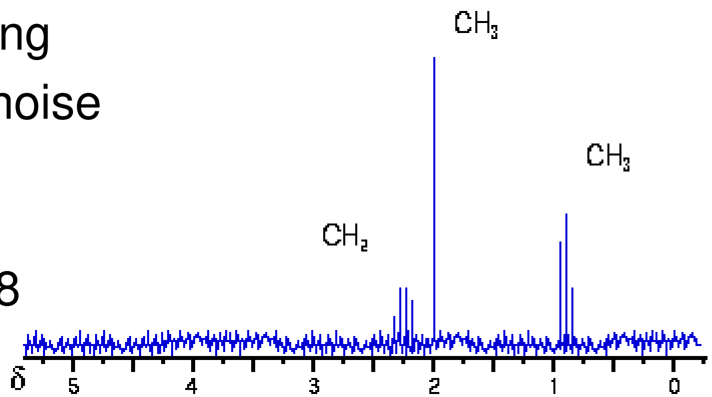
Signal averaging

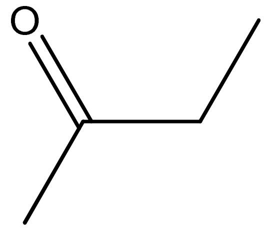
Improving signal-to-noise ratio

1



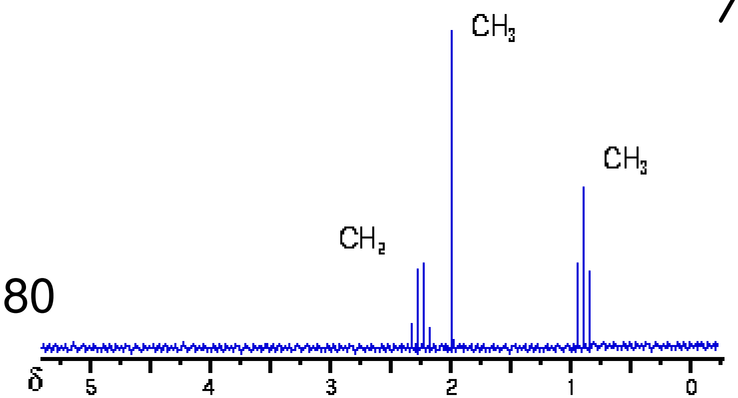
8



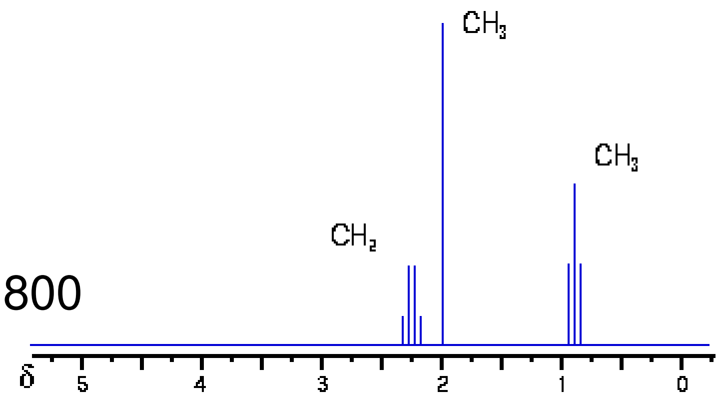


$$S/N = \sqrt{N_{rep}}$$

80



800

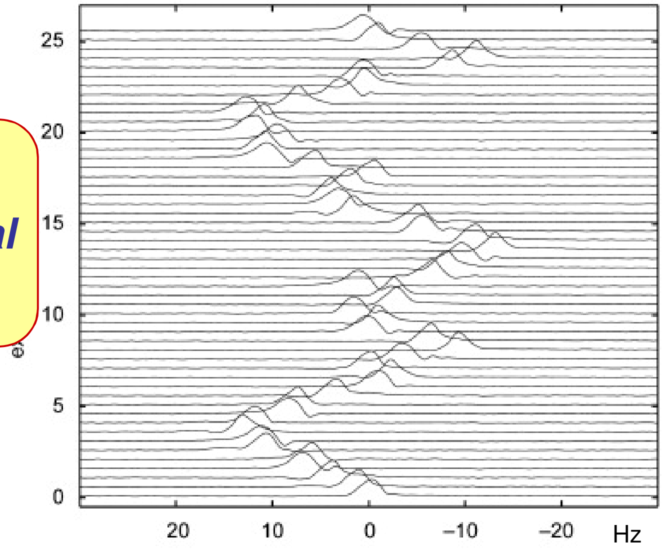


Magnetic field stability and homogeneity

Field-frequency lock

Stability in time

Continuous observation of independent NMR signal - deuterium



Shim

maintain homogeneity