Chapter 8
Introductory Signal Acquisition Methods

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- **Previous sessions:**
  - Spin precession (Chap. 2&3)
  - RF excitation (Chap. 3)
  - Concept of T1, T2 and T2* (Chap.4)
  - Signal detection (Chap.7)
- **Today's content**
  - Free Induction Decay (FID) and T2*
  - Spin Echo (SE) and T2
  - Inversion Recovery (IR) and T1
  - Sequence diagram and Repeated scans signal

FID and T2*

- FID signal (global signal of the sample)

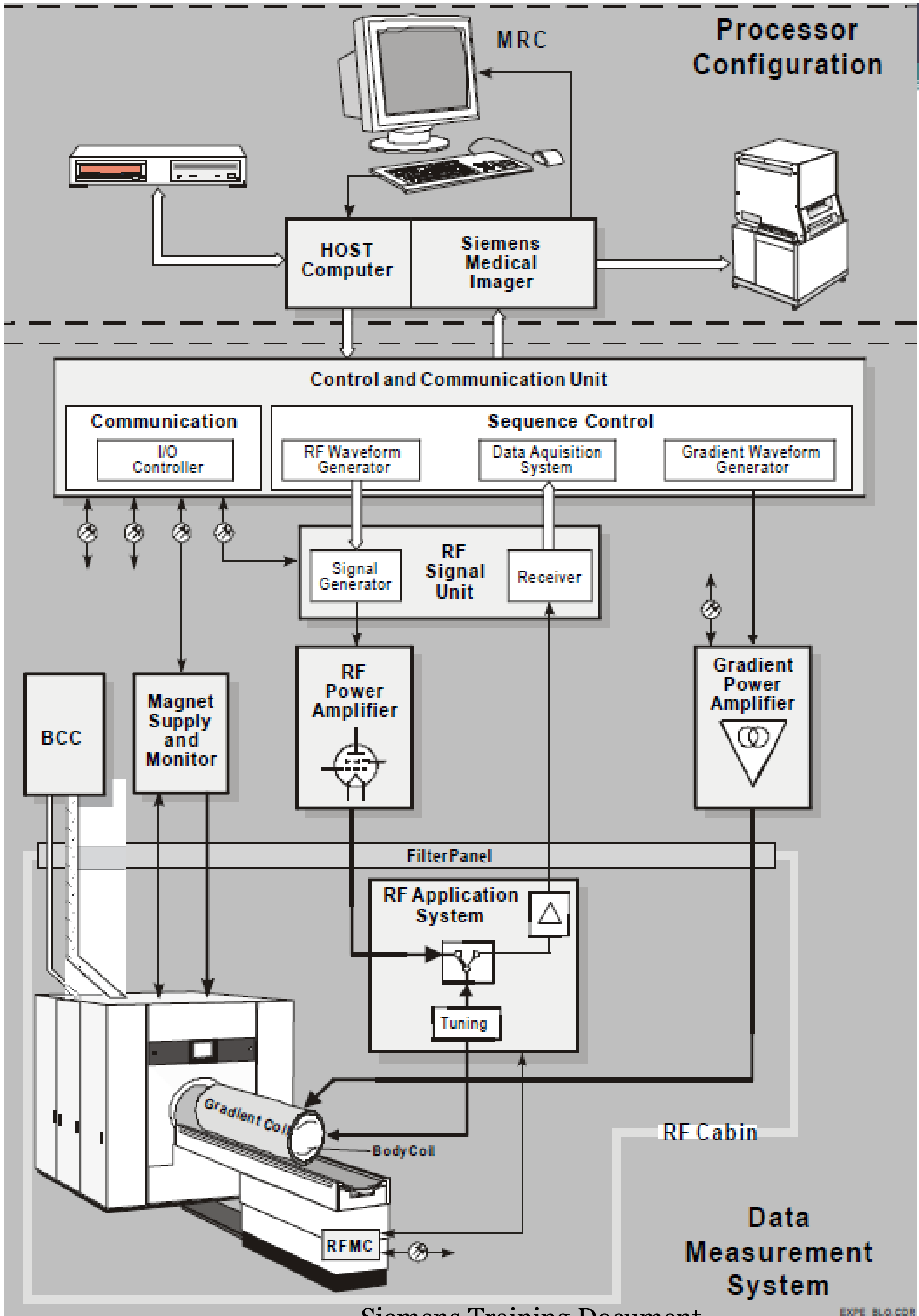
$$S(t) \propto \omega_0 \int d^3r e^{-\frac{t}{T_2(\vec{r})}} \mathcal{B}_\perp(\vec{r}) M_\perp(\vec{r},0) e^{i\left(\left(\Omega-\omega(\vec{r})\right)t+\phi_0(\vec{r})-\theta_{\mathcal{B}}(\vec{r})\right)}$$

- A simpler version

$$S(t) \propto \omega_0 \mathcal{B}_\perp M_\perp e^{-\frac{t}{T_2}} e^{i(\Omega-\omega_0)t} \int d^3r$$

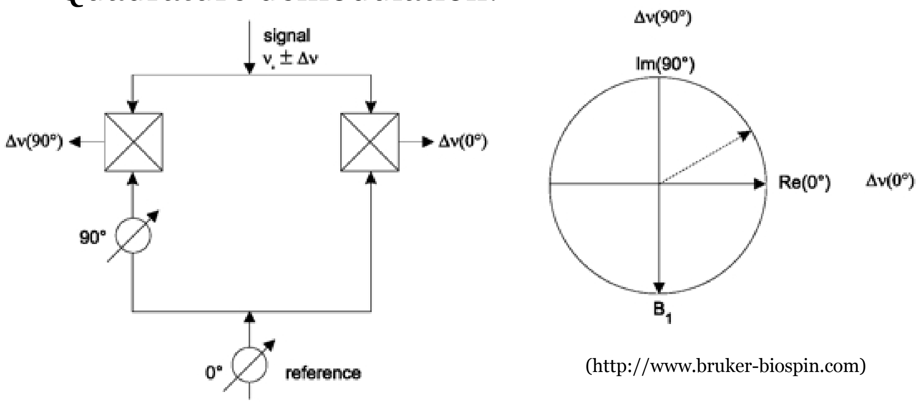
$$= S_0 e^{-\frac{t}{T_2}} e^{i(\Omega-\omega_0)t}$$

- Simplifications:
  - Magnetic field and receive field (e.g. $\omega(\vec{r}) = \omega_0$), baseline phase terms ϕ_0, spin density and T2 are spatially independent



Siemens Training Document

Quadrature demodulation:

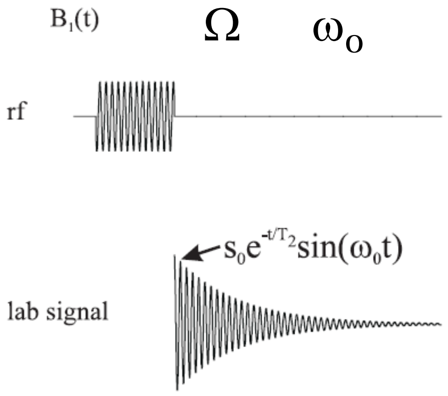


(http://www.bruker-biospin.com)

FID and T2*

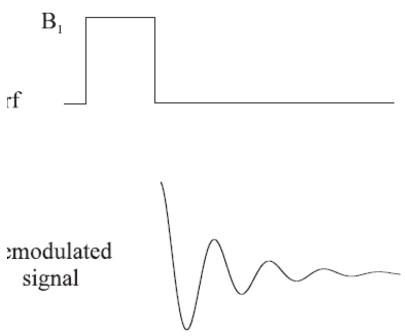
$$S(t) = S_0\ e^{-t/T_2} e^{i(\Omega - \omega_0)t}$$

$\Omega = 0$
or
$\Omega \quad \omega_0$



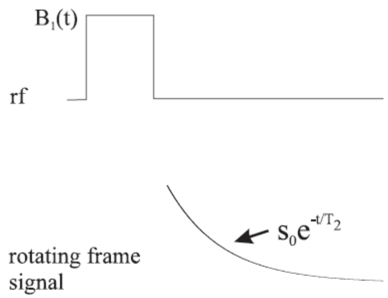
(a)

$\Omega \quad \omega_0$

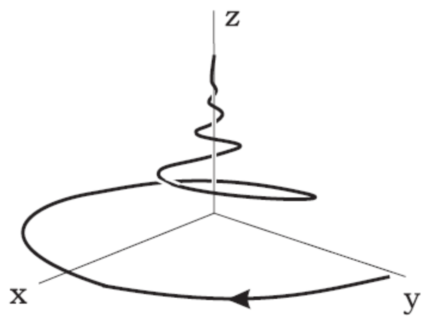


(c)

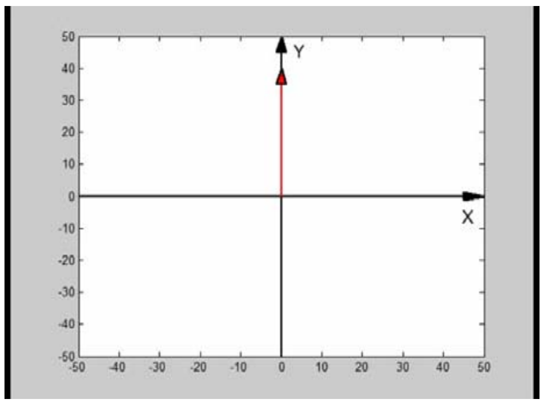
$\Omega = \omega_0$

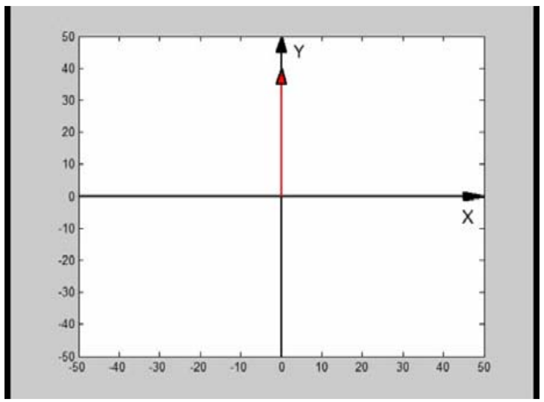


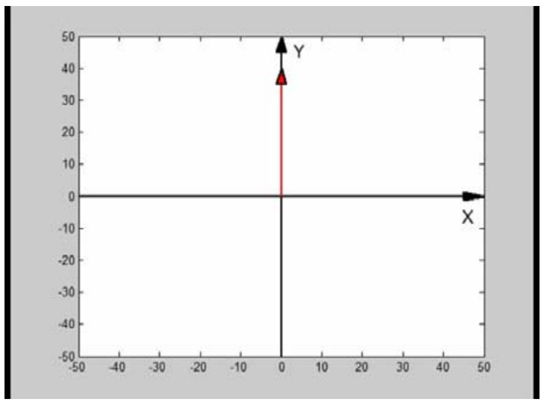
(b) (Fig. 8.1)



(Fig. 4.3)



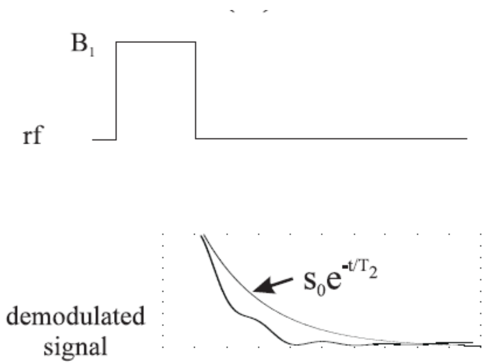




FID and T2*

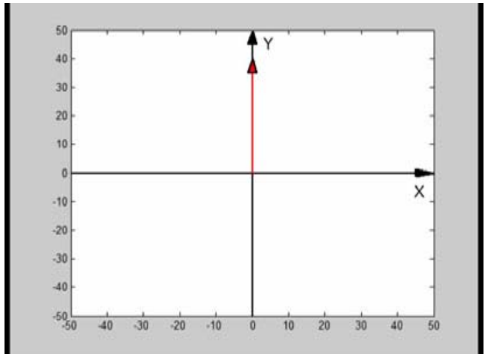
Practical issue: local & global field inhomogeneity exist

$$S(t) = S_0 \int e^{-t/T_2} e^{i(\Omega - \omega(\vec{r}))t}$$

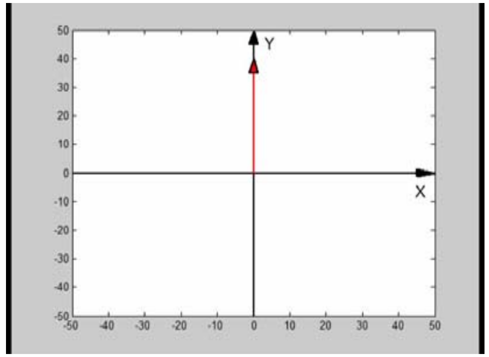


(d)

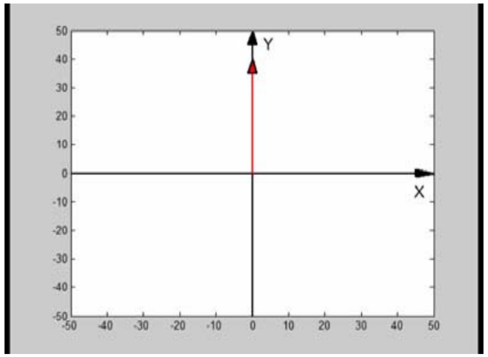
(Fig. 8.1 and Prob. 8.1)



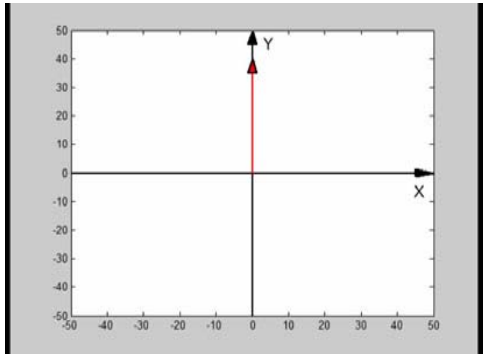
90% $\Omega - \omega(\vec{r})$=0Hz
10% $\Omega - \omega(\vec{r})$=50Hz



90% $\Omega - \omega(\vec{r})$=0Hz
5% $\Omega - \omega(\vec{r})$=±50Hz



75% $\Omega - \omega(\vec{r})$=0Hz
25% $\Omega - \omega(\vec{r})$ ±50Hz
40 spins



75% $\Omega - \omega(\vec{r})$=0Hz
25% $\Omega - \omega(\vec{r})$ ±50Hz
40,000 spins

T2* Decay

$$\frac{1}{T_2*} = \frac{1}{T_2} + \frac{1}{T_2'}$$

- **Definition:**

  Combined external field (inhomogeneity) effects (T2') and thermodynamic effects (T2)

- **T2' origins:**

  External: B_0 field, boundaries (Prob. 8.2), partial volume

  Internal : chemical shift, microscopic motion (diffusion, capillary blood)

  Effective spatial scale: ~voxel size to molecular size

- **Indications:**

$$M_\perp(\vec{r}, t) = M_\perp(\vec{r}, 0)e^{-\frac{t}{T_2*}}$$

Estimate T_2'

$$\phi(\vec{r},t) = -\gamma\left(B_0 + \Delta B(\vec{r})\right)t$$

(global, non-quantitative)

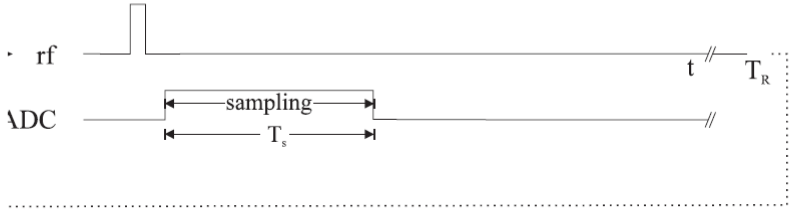
$$\sum_{sample} e^{i\phi(\vec{r},t)} \propto e^{-\frac{t}{T_{2'}}} \to 0$$

Valid only for spectrally symmetric source and when T2<<T2'

- Alternative: using definition

$$\frac{1}{T_2{}'} = \frac{1}{T_2} - \frac{1}{T_2 *}$$

FID sampling and repeated scans



(Fig. 8.2)

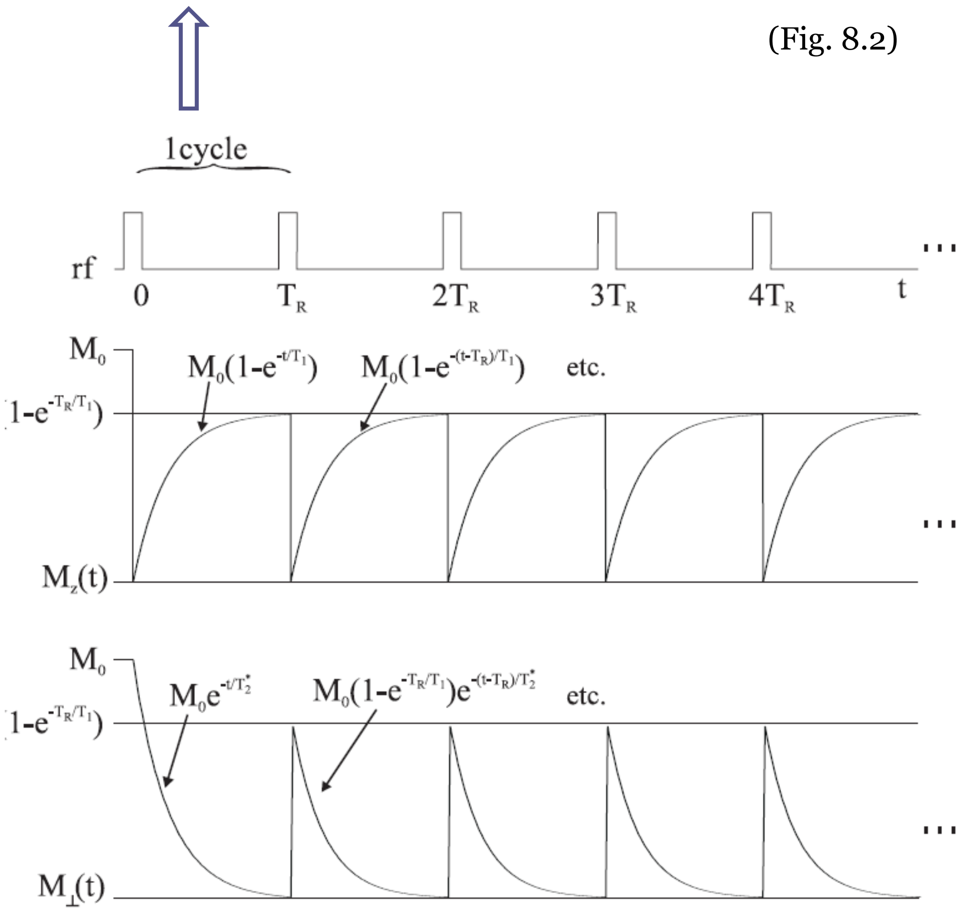
With a 90° excitation:

$$\begin{cases} M_z(0^+) = 0 \\ M_\perp(0^+) = M_0 \end{cases}$$

$$\begin{cases} M_z(TR^-) = M_0(1 - e^{-TR/T1}) \\ M_\perp(TR^-) = M_0 e^{-TR/T_2^*} \end{cases}$$

$$\vdots$$

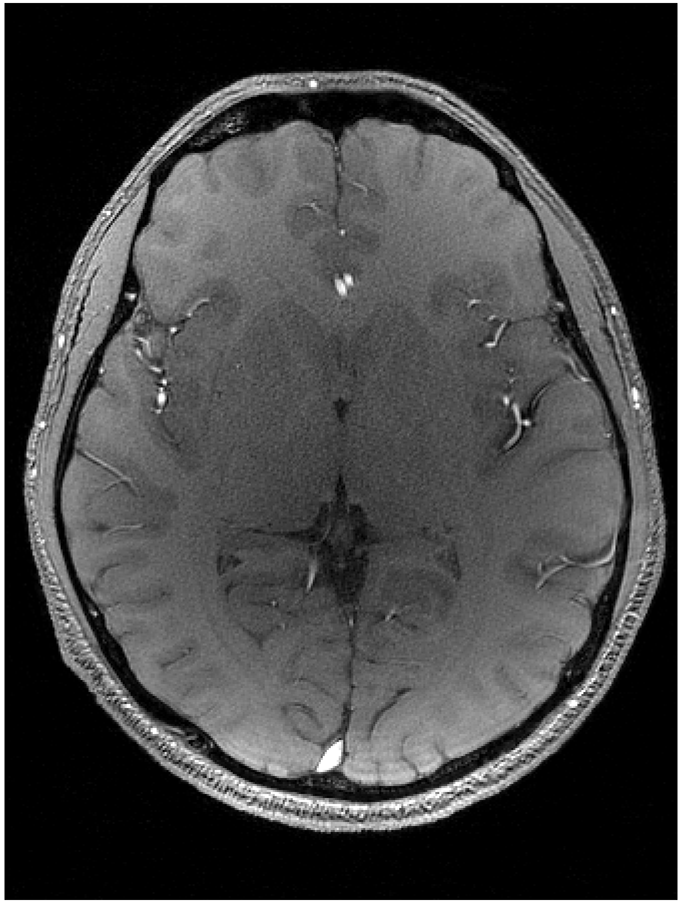
$$\begin{cases} M_z(nTR^-) = M_0(1 - e^{-TR/T1}) \\ M_\perp(nTR^-) = M_0(1 - e^{-TR/T1})e^{-TR/T_2^*} \end{cases}$$



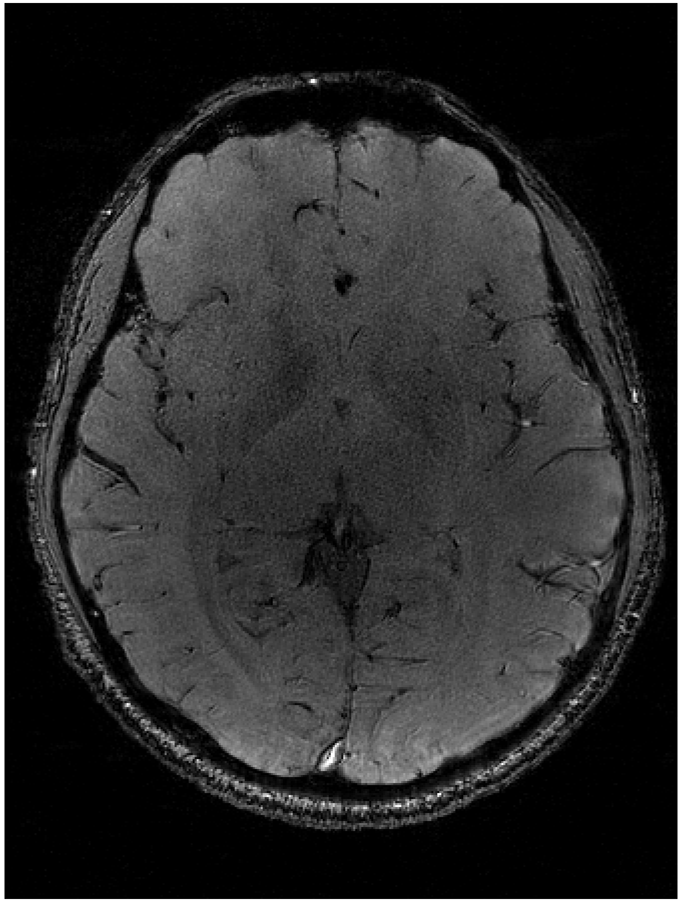
(Fig. 8.6)

FID repeated scan examples (Short TR Gradient echo)

Short TE, T_1W



Long TE, $T_1W+T_2{}^*W$



SE and T_2

- Why do we need SE?
  - Introduce T2 weightings
  - Reduce signal loss due to field inhomogeneity

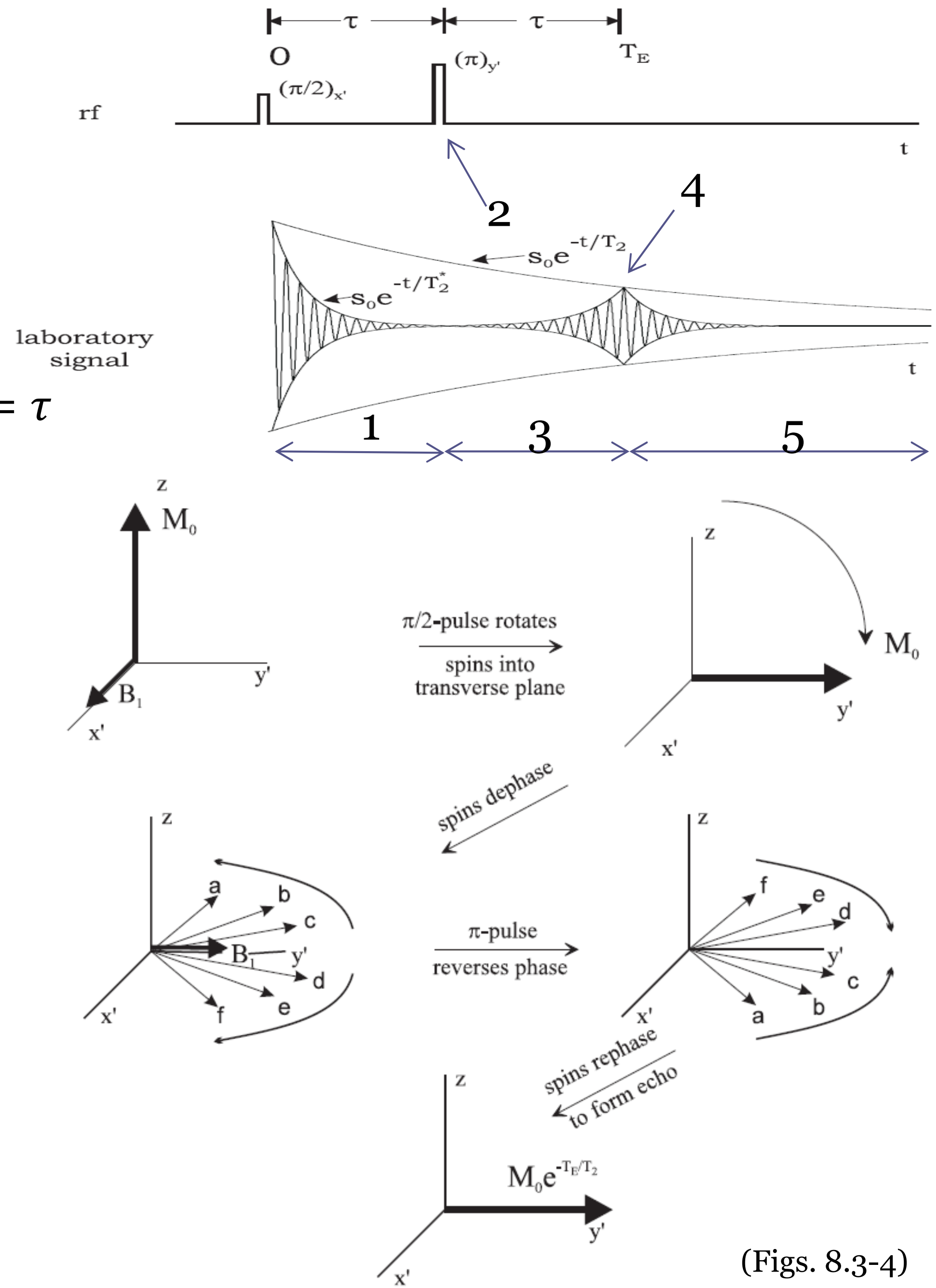
GE, T1W+T2*W

SE, T2W

SE and T_2

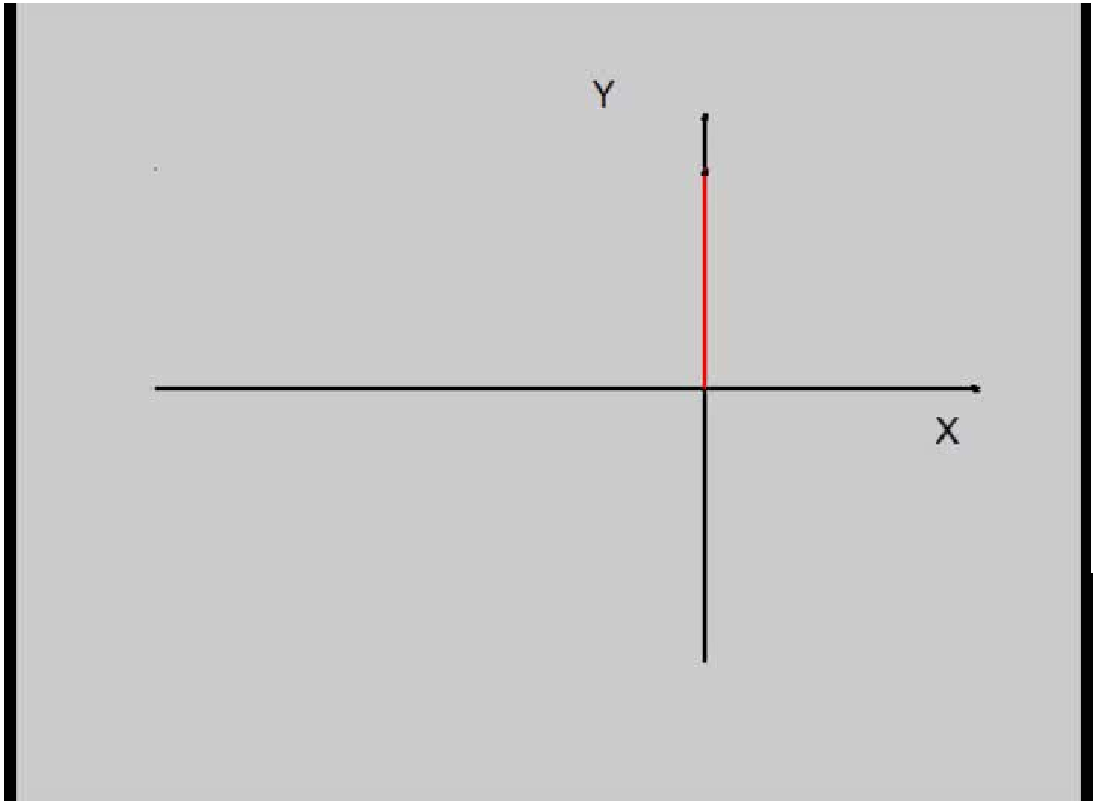
- How SE works
  1. $\phi(\vec{r},t) = -\gamma\Delta B(\vec{r})t, 0 < t < \tau$
  2. $\phi(\vec{r},\tau^{+}) = -\phi(\vec{r},\tau^{-}) = \gamma\Delta B(\vec{r})\tau, t = \tau$
  3. $\phi(\vec{r},t) = \gamma\Delta B(\vec{r})\tau - \gamma\Delta B(\vec{r})(t-\tau),$
     $\tau \; < t < \tau$
  4. $\phi(\vec{r},2\tau) = 0, t = 2\tau \equiv TE$
  5. $\phi(\vec{r},t) = -\gamma\Delta B(\vec{r})(t-2\tau,) \;\; t > 2\tau$

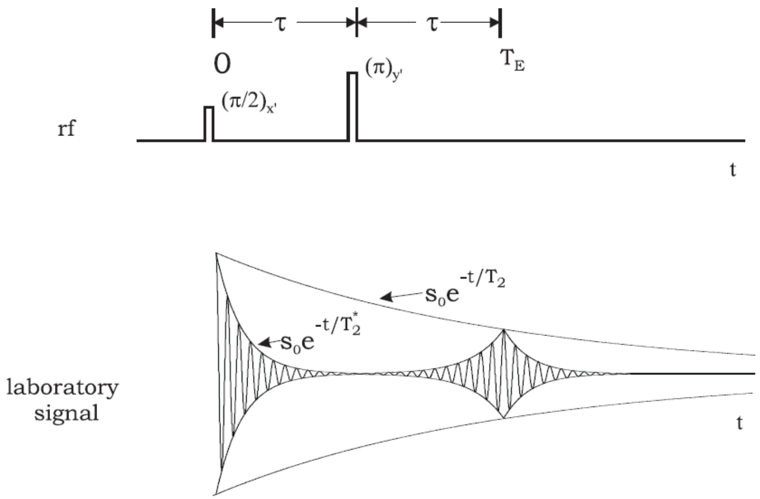
- Quick thoughts:
  - The effect of the phase between B_1 and M ?
  - Refoc flip angle other than 180°?



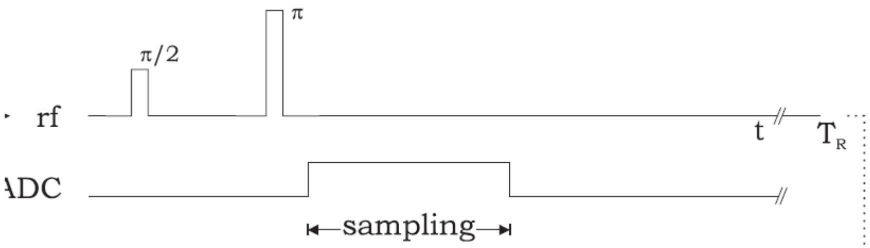
(Figs. 8.3-4)

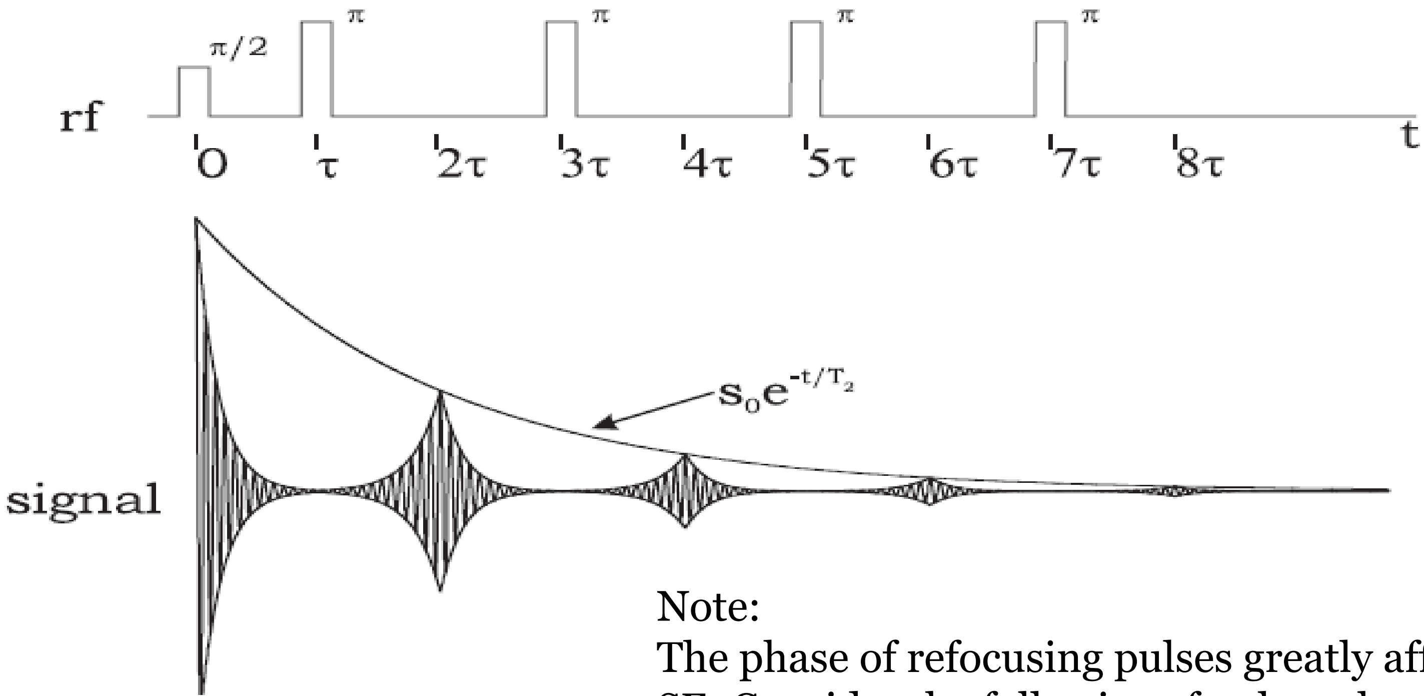
SE signal envelope





SE sampling: single-/multi-echo





Note:
The phase of refocusing pulses greatly affects the signal of ME-SE. Consider the following rf pulse schemes:

1) 90°(x) - 170°(y) - 170°(y) - 170°(y) - 170°(y) …
2) 90°(x) - 170°(y) - 170°(-y) - 170°(y) - 170°(-y) … (CPMG seq)

Limitation of SE

- Maximal signal limited to T2 decay which is not recoverable
- T2' decay on both sides of the echo acts as low pass filter, blurring the image (Chap. 13)
- True T2 is difficult for precise quantification
  - Motion, partial volume effects, RF pulse, data acquisition, etc.
- Extra consideration for multiple spin echo acquisition
  - RF pulse phase
  - RF energy deposition
  - Multiple signal pathways
- Long scan time
- Interesting question:
  - Is the two-spin model in Prob. 8.1 has signal behavior equivalent to a spin echo?

IR and T1

- T1 describes signal recovery rate along B_o, i.e. M_z
- How to introduce T1 weighting into S(t)?
  A: Introduce perturbation to M_z
  (already did with repeated GE scans)

$$M_z(nTR^-) = M_0(1 - e^{-TR/T1})$$

- Instead of $\pi/2$ flip angle, a π pulse can be used to completely Invert M_z to negative, and introduce T1 weighting into signal during Recovery.

Eq. 4.12

$$M_z(t) = M_z(0) + M_0\left(1 - e^{-t/T1}\right) = M_0\left(1 - 2e^{-t/T1}\right)$$

IR and T1

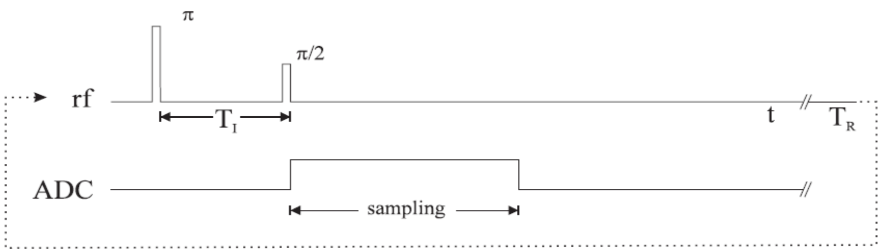
$$M_z(t) = M_0(1 - 2e^{-t/T1})$$

- At t=TI after inversion pulse

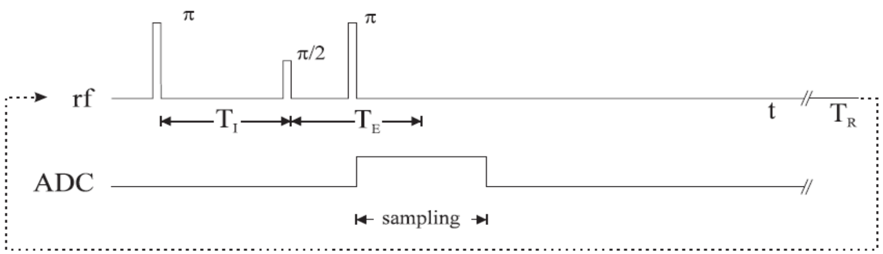
$$M_z(TI) = M_0(1 - 2e^{-TI/T1})$$

- With a π/2 excitation pulse at TI, T1 weighting can be introduced into M of the FID

$$M_\perp(t) = |M_z(TI)|e^{-(t-TI)/T_2^*}, \qquad t > TI$$

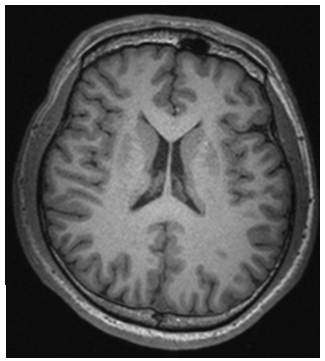


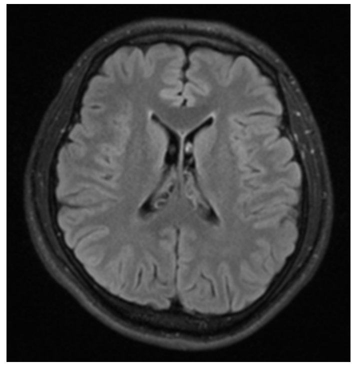
(a)



(b)

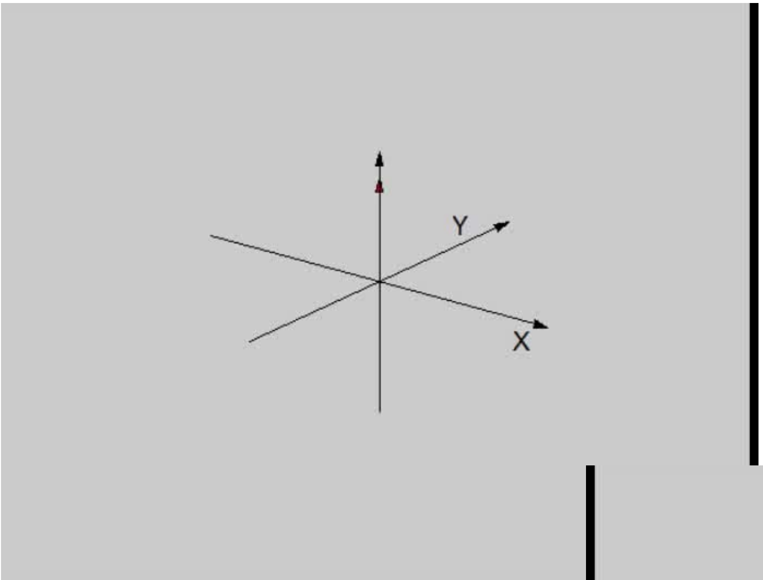
(Fig. 8.10)



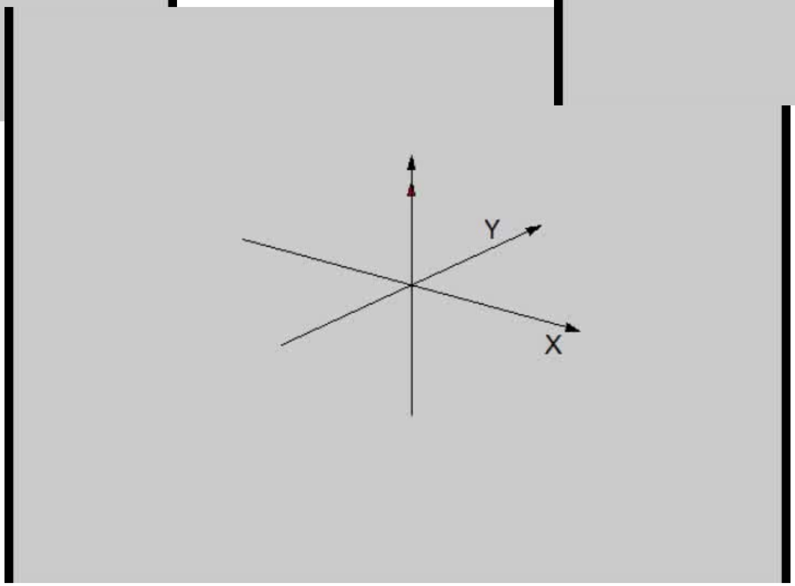


IR and T1

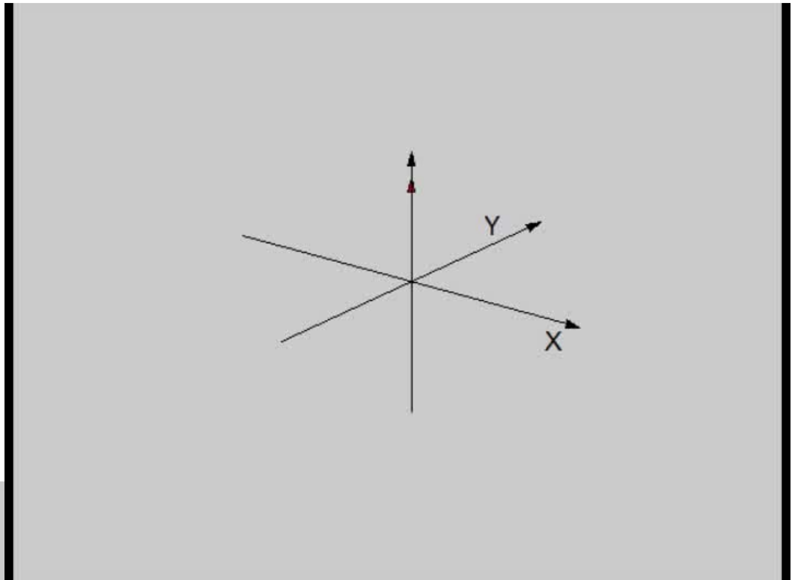
T1=300/1000ms



TI=100ms



TI=208ms



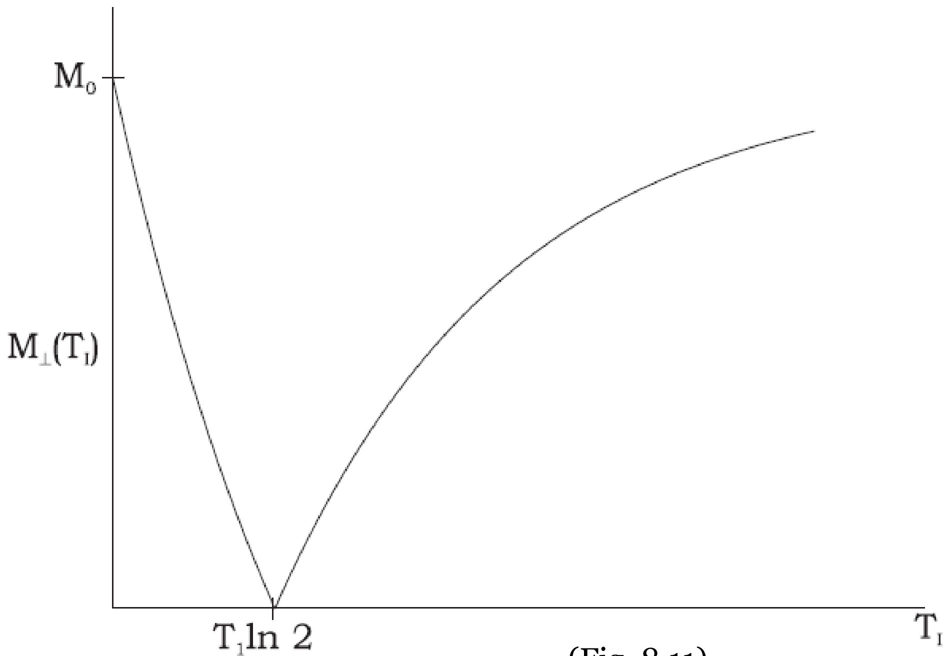
TI=300ms

Q: TI to null the
T1=1000ms spins?

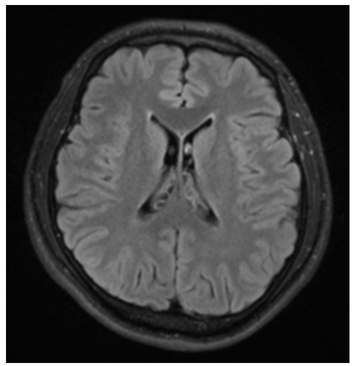
IR and T1

- To determine T1, simply measure the recovery curve and determine the nulling TI

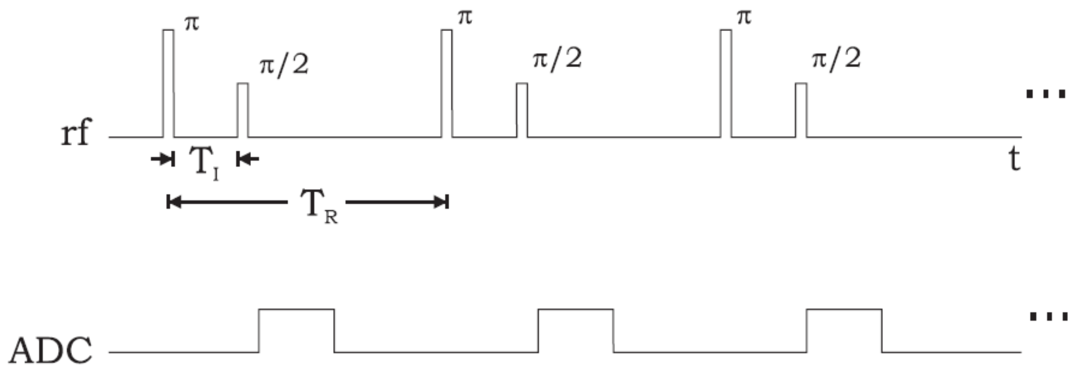
$$M_0\left(1 - 2e^{-TI_{null}/T1}\right) = 0 \quad \rightarrow \quad T_{I,null} = T_1 \ln 2$$



(Fig. 8.11)



Repeated IR scans



(Fig. 8.12)

$$\begin{cases} M_z(0^+) = 0 \\ M_\perp(0^+) = M_0 \end{cases} \qquad \begin{cases} M_z(TI^-) = M_0(1-2e^{-TI/T1}) \\ M_\perp(TI^-) = 0 \end{cases}$$

$$\begin{cases} M_z(TR^-) = M_0(1-e^{-(TR-TI)/T1}) \\ M_\perp(TR^-) = M_0|1-2e^{-TI/T1}|e^{-(TR-TI)/T_2^*} \end{cases}$$

$$\vdots$$

$$\begin{cases} M_z(nTR^-) = M_0(1-e^{-(TR-TI)/T1}) \\ M_\perp(nTR^-) = M_0|1+e^{-TR/T1}-2e^{-TI/T1}|e^{-(TR-TI)/T_2^*} \end{cases}$$

Homework

- Prob. 8.1-8.5

Next Class

Chapter 9.1-9.4