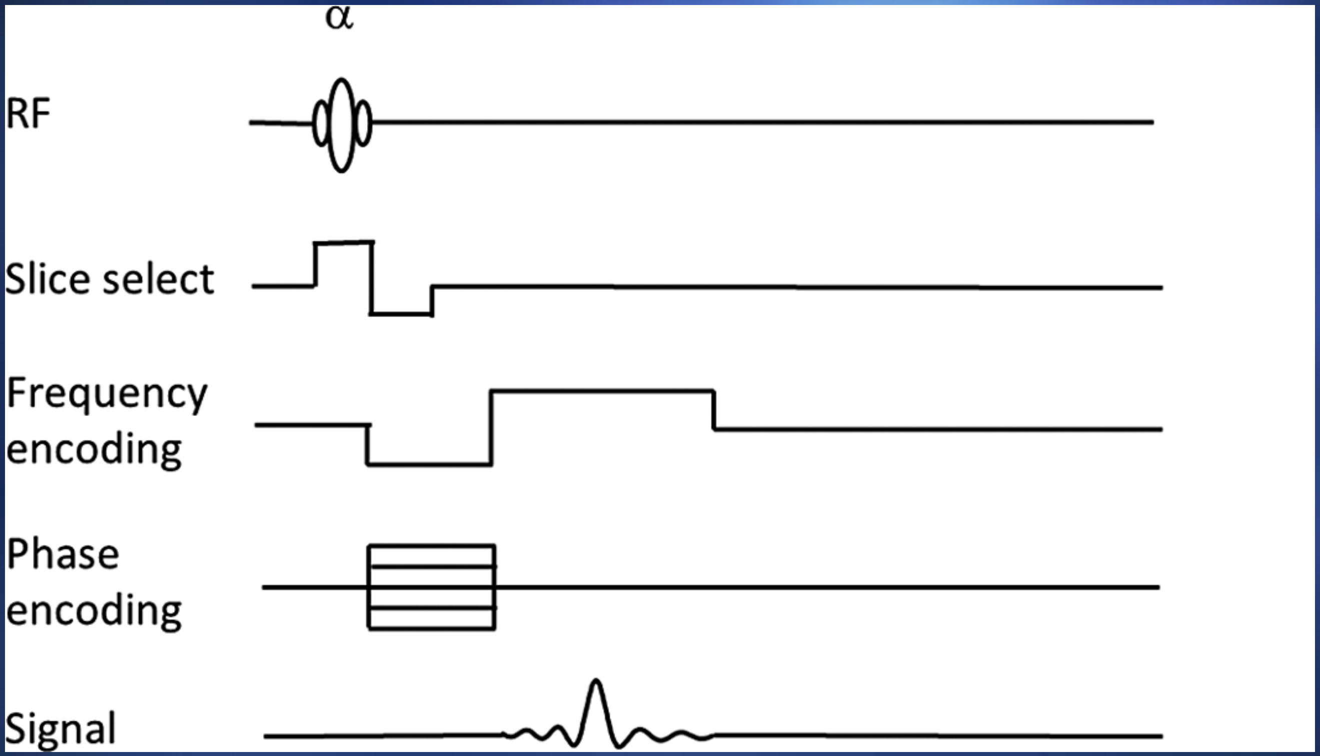
Speeding Things Up: the Gradient-Echo Pulse Sequence

Gradient-Echo Pulse Sequence

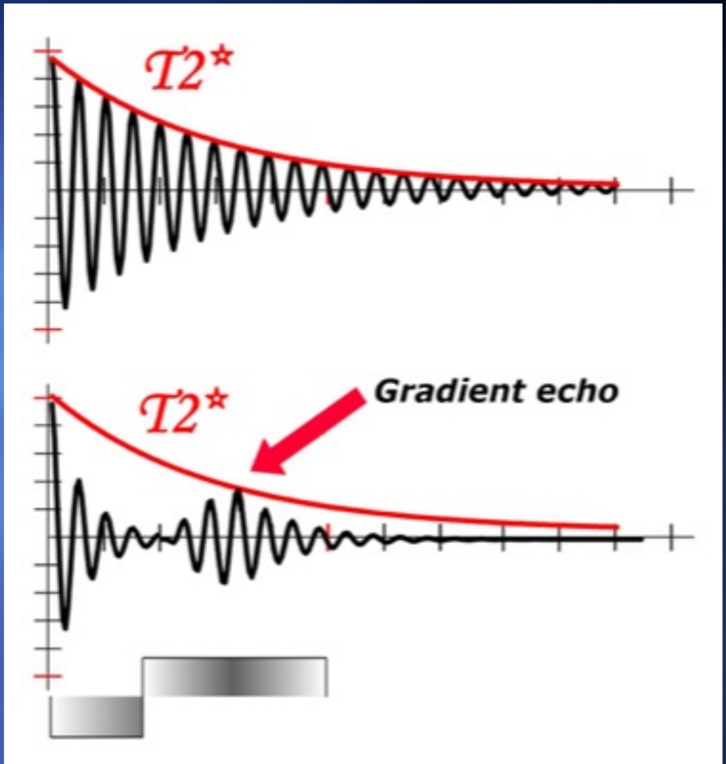


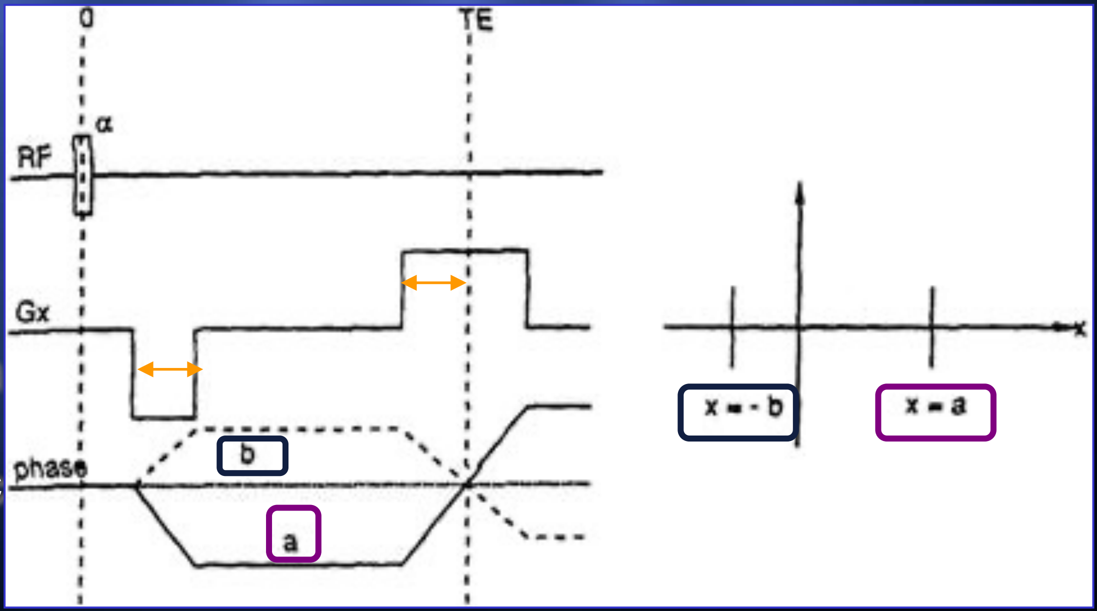
- ✓ the refocusing pulse is omitted the echo is generated only by switching of gradients on the frequency encoding axis
- ✓ flip angle of the excitation pulse is usually less than 90^0

www.imaios.com/en/e-Courses/e-MRI/MRI-Sequences/gradient-echo

Gradient Echo

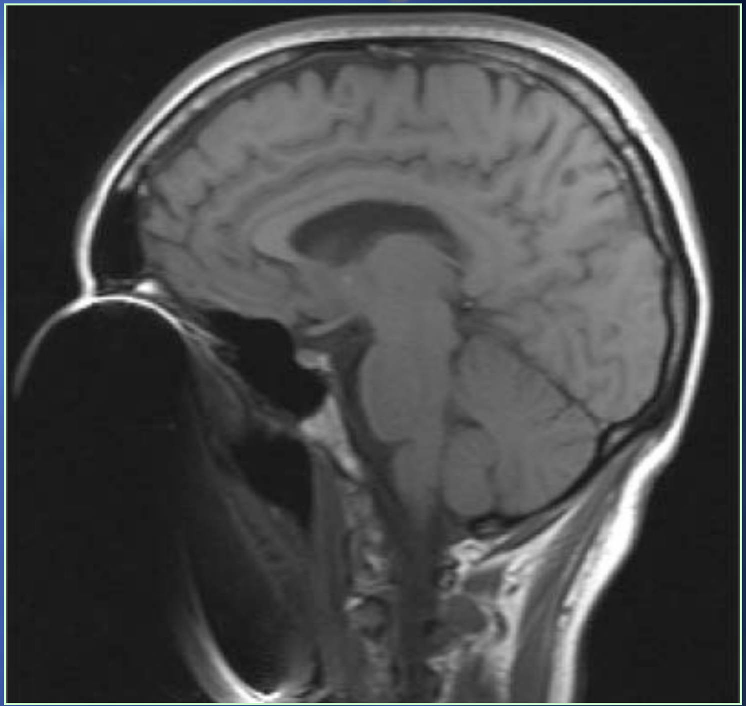
- ✓ No 180^0 pulse
- ✓ T_2* contrast
- ✓ No compensation for static field inhomogeneity
  - Magnetic susceptibility
    - ❖ corresponds to the internal magnetization of a tissue resulting from the interactions with an external magnetic field

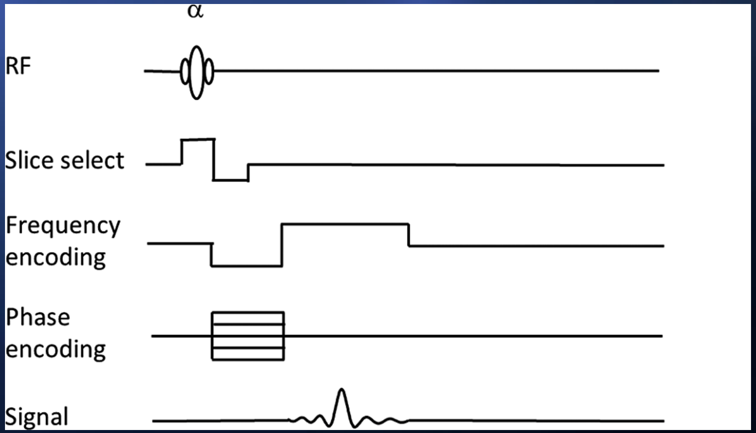




Gradient-Echo Pulse Sequence

- the echo is T2* intensity
  - less signal than in a spin-echo sequence at the same echo time
- particularly sensitive to image distortion due to magnetic field inhomogeneities
  - for example at the interface between different tissues or where there are air-filled sinuses or cavities in the body





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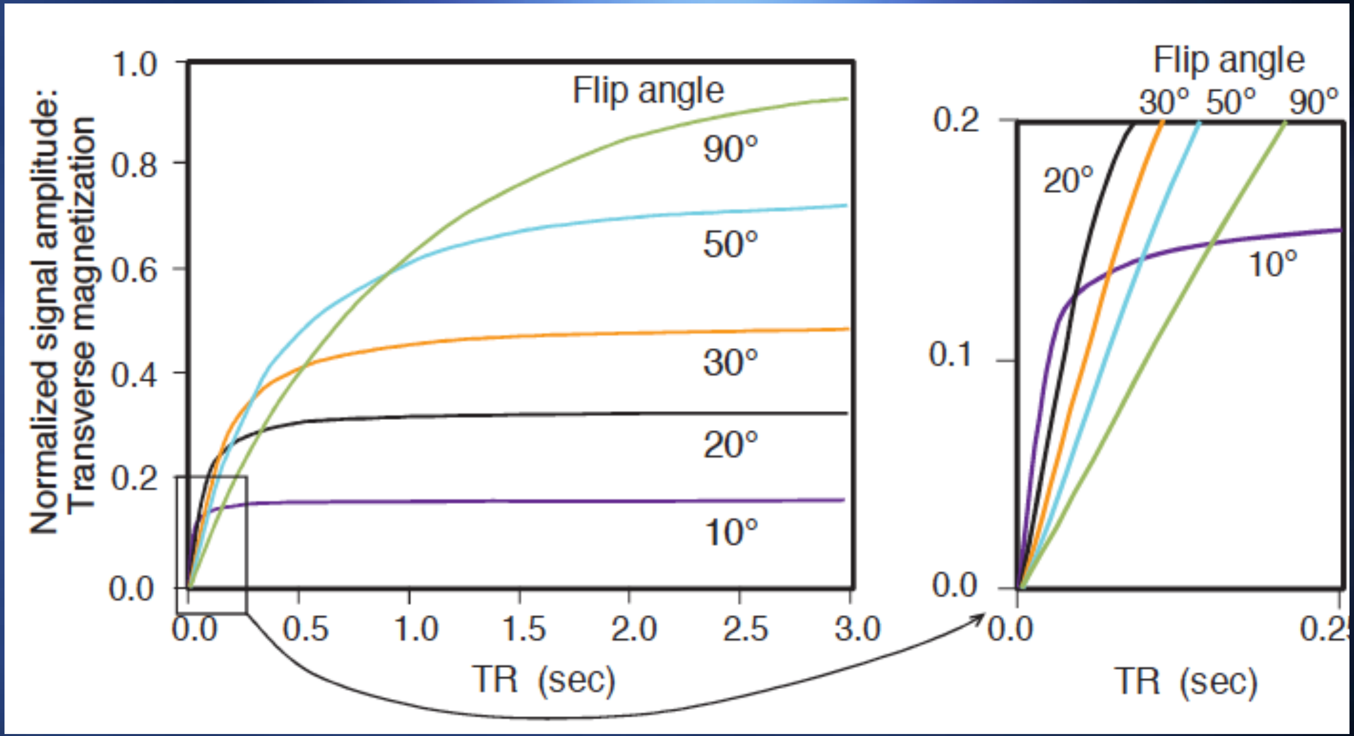
Flip angle and T_R

Given

$T_R << T_1$

the signal is larger if

$\alpha < \pi/2$



T_R defines
the total acquisition time

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Gradient-Echo Pulse Sequence

flip angle $\alpha = 10^o$

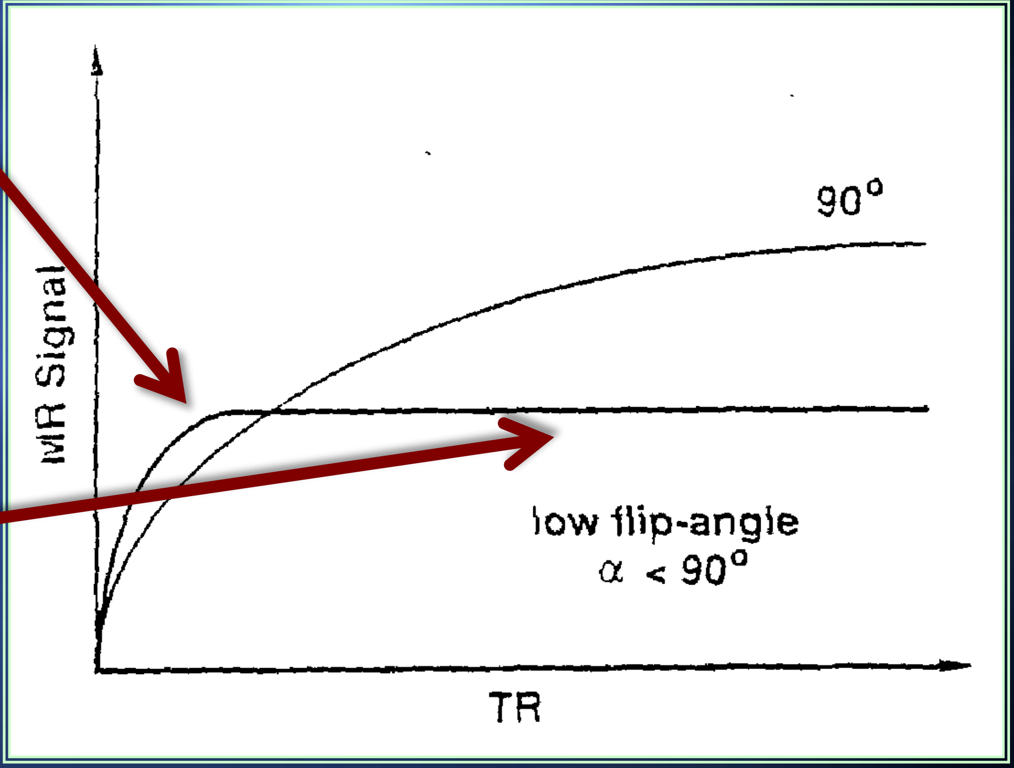
- ✓ **immediately after excitation $M_z = 0.98|M|$**
  - **M_z reduced by 2% only from its initial value**
- ✓ **T_R can be very much shorter**
  - **resulting in much quicker image acquisition**
- ✓ **$M_{xy} = 0.17\ |M|$**
  - **so we have sacrificed most of our signal**

often in MRI, there is a trade-off between image quality and acquisition time

www.imaios.com/en/e-Courses/e-MRI/MRI-Sequences/gradient-echo

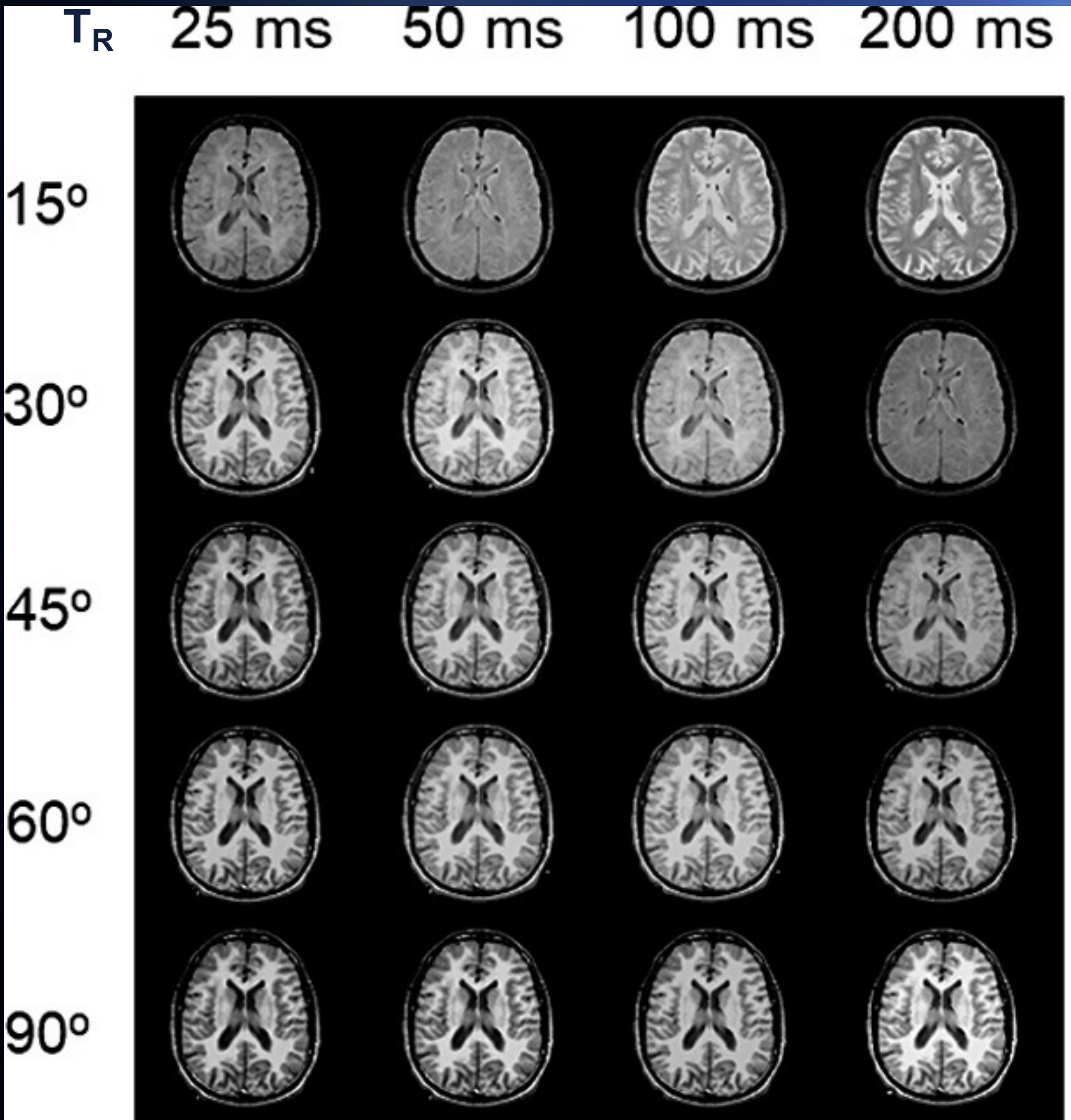
Flip angle and T_R

- ✓ Given a short T_R, the signal is larger if $\alpha < \pi/2$
- ✓ Given small α, the signal recovers faster but it saturates at a lower value



T_R defines
the total acquisition time

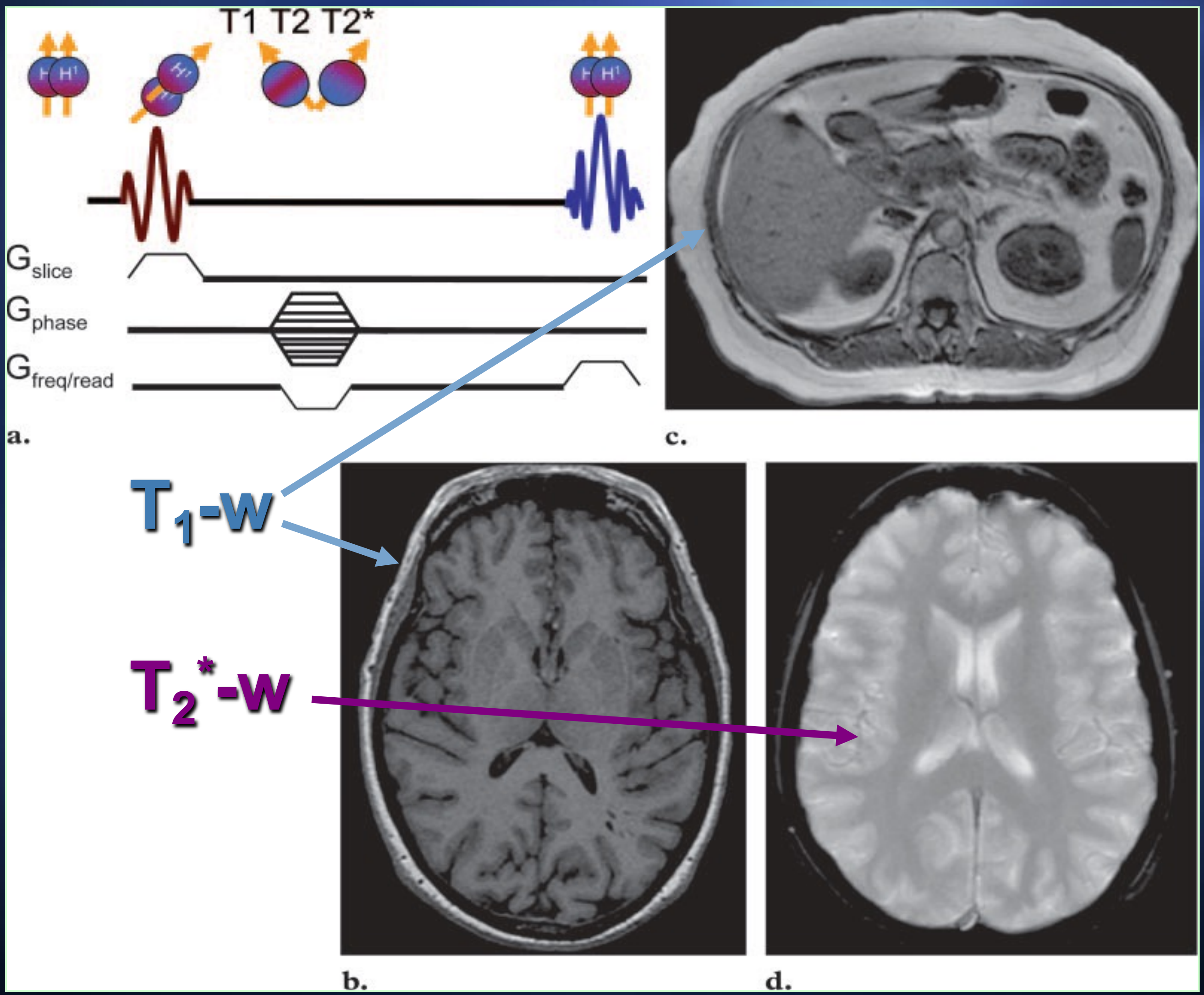
Gradient-Echo Pulse Sequence



$$I \propto \rho(x,y)\frac{\left(1-e^{-\frac{T_R}{T_1}}\right)}{1-\cos\alpha\, e^{-\frac{T_R}{T_1}}}\sin\alpha\, e^{-\frac{T_E}{T_2*}}$$

- ✓ **large α and short T_R: T_1 weighting**
- ✓ **α reduced: weighting switches to proton density and then to T_2***
  - **even with T_R as short as 100 ms**

Gradient echo sequence



http://www.imaios.com/en/e-Courses/e-MRI/Image-quality-and-artifacts/magnetic-susceptibility

K-space

Path through k-space

- $k_x = \gamma G_x t$; $k_y = \gamma G_y T$

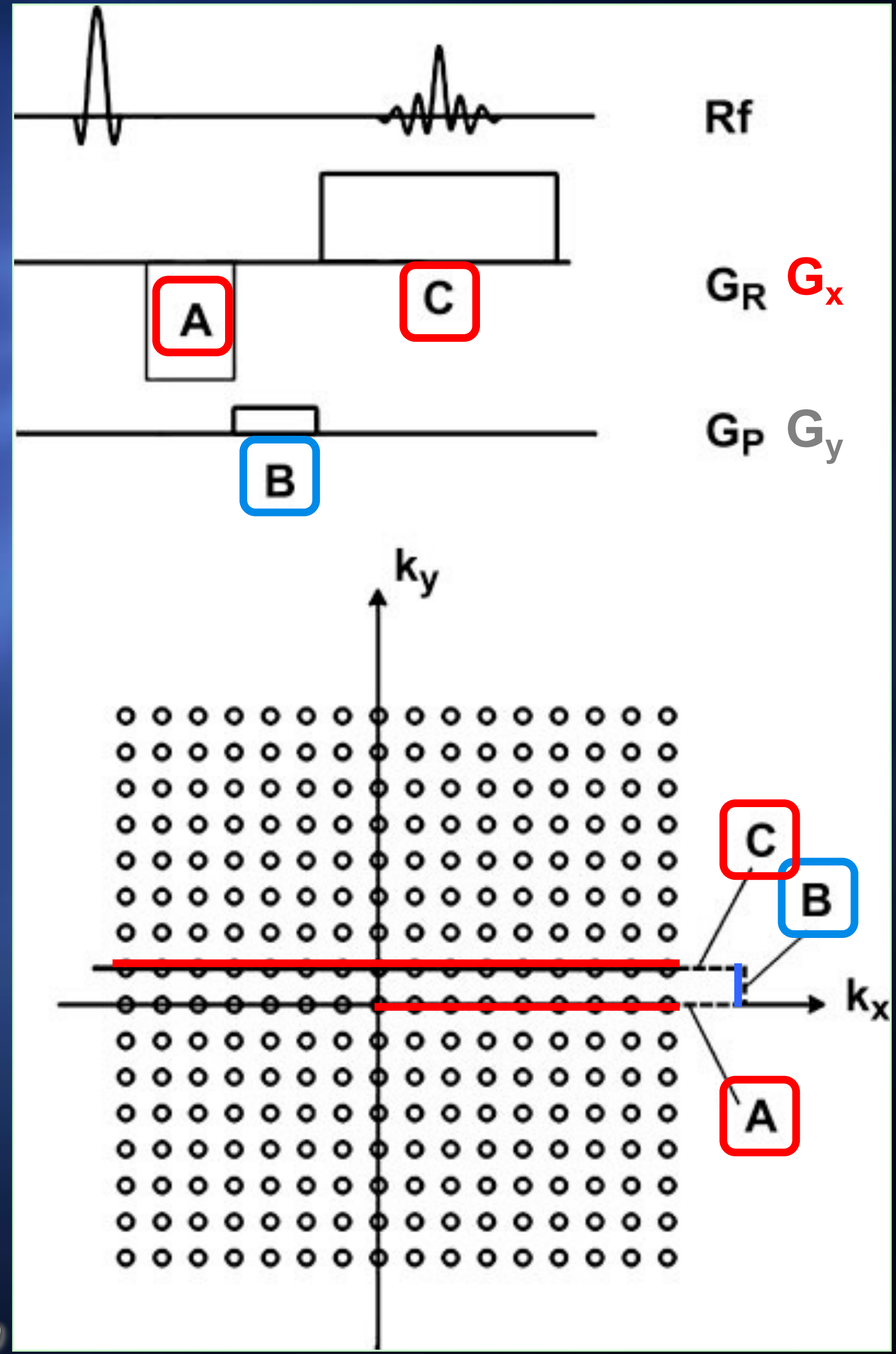
✓ The prewinding gradient A carries the k-space trajectory in the k_x direction out of the sampling area

✓ Phase encoding with B causes an offset of the trajectory in the k_y direction, where signal from one k-line is read out under C

- Data are acquired only during the last part (red line), and signal during A and B is discarded (dashed line)

✓ The experiment is repeated with different B

M.A. Jacobs RadioGraphics 2007; 27:1213–1229



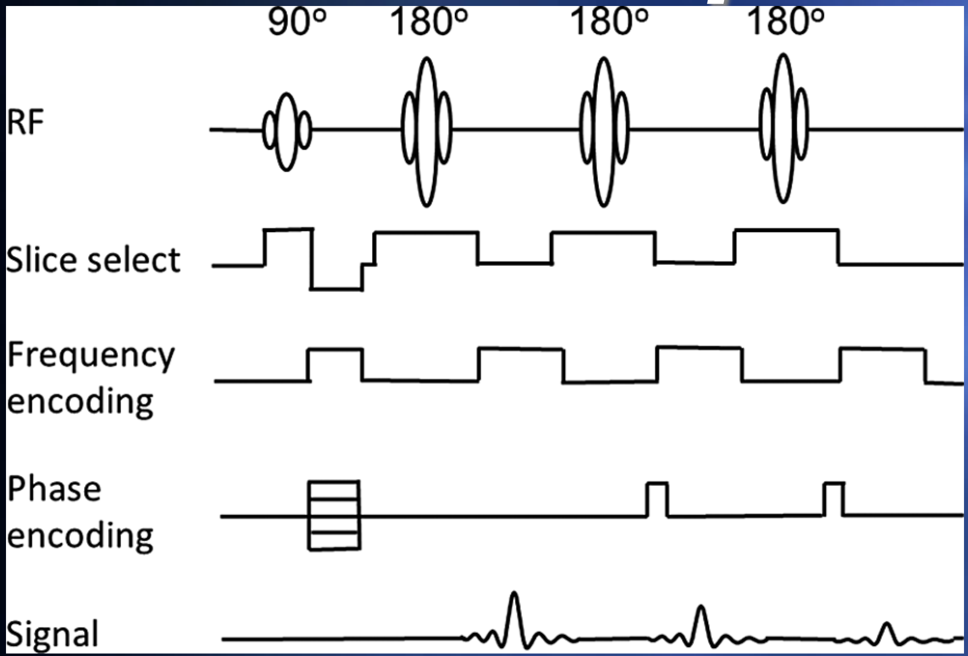
Spoiler gradient

- ✓ If T_R is so short to be comparable to the T_2 values of tissues the effect of subsequent excitation pulses on residual M_{xy} as well as on recovering M_Z must be considered

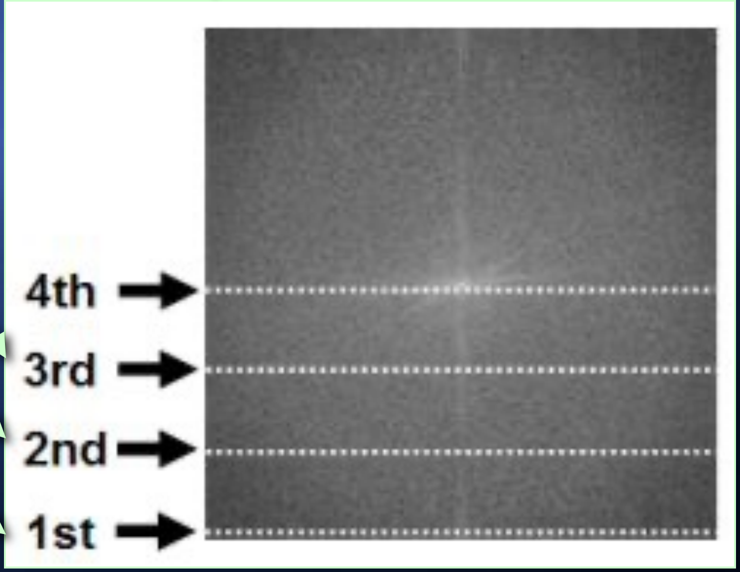
- ✓ the simplest approach is to add a strong gradient pulse after acquisition of each echo signal
  - before the next excitation pulse
- ✓ This so-called ‘spoiler gradient’ completely dephases the residual M_{XY}
  - so that we only have to consider M_Z

https://www.imaios.com/en/e-mri/sequences/spoiled-gradient-echo-sequences

fast spin-echo (FSE) or turbo spin-echo (TSE)

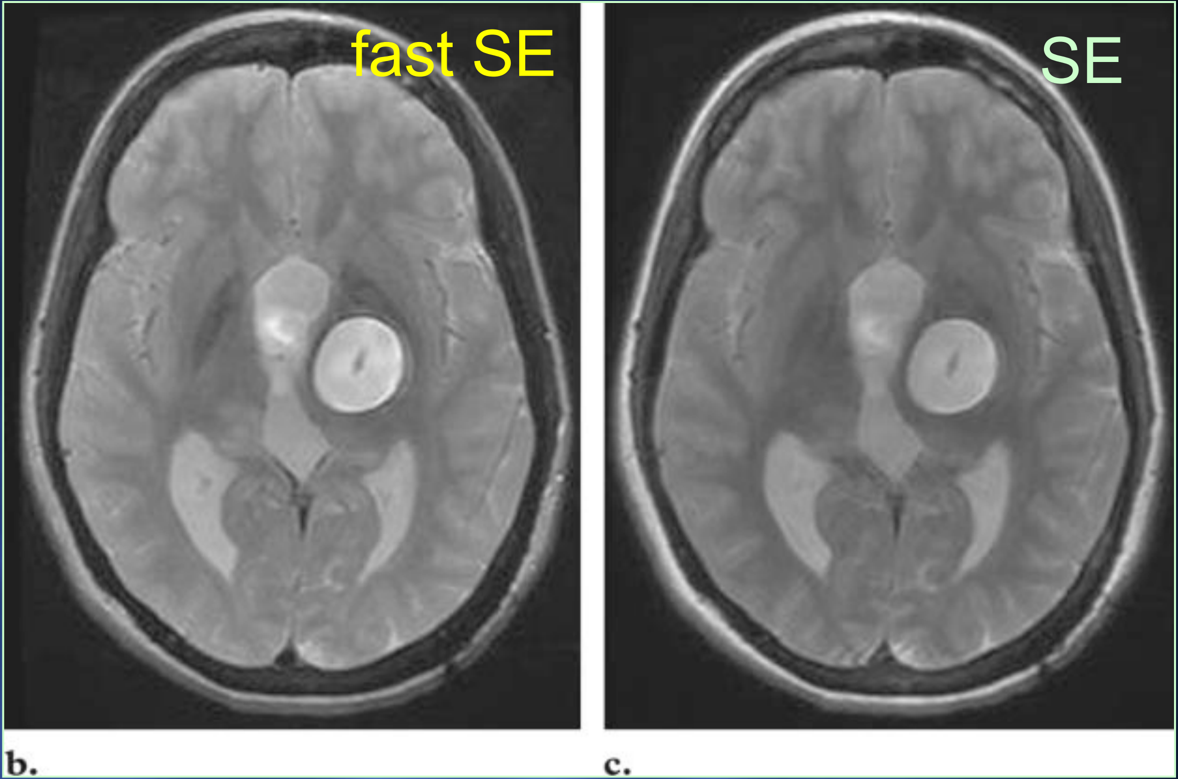


- **before each echo there is an additional phase encoding gradient**
  - **each echo is collected from a different line in k-space**



http://www.imaios.com/en/e-Courses/e-MRI/MRI-Sequences/Ultrafast-spin-echo

fast SE



b) Axial T2-weighted fast SE image
c) conventional SE image
provide comparable depiction of a brain tumor

- ✓ **The acquisition time for conventional SE imaging was 7 minutes 17 seconds, whereas that for fast SE imaging with an echo train length (ETL) of 16 was 34 seconds**

Fast SE

- ✓ echo train length (ETL) or turbo factor (TF) is typically 4–32
- ✓ ETL is limited by the repetition time
- ✓ there is a trade-off with the number of slices imaged
  - interleaved excitation of multiple slices during the T_R
- ✓ limit to the achievable ETL since echoes acquired at very long T_E contain very little signal

Fast SE

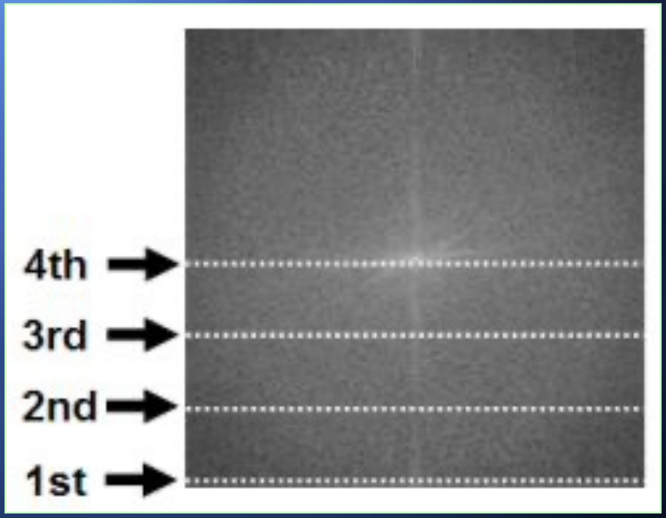
How much weighting is there when different lines in k-space have been acquired at different echo times?

The centre of k-space dominate the contrast properties of the image

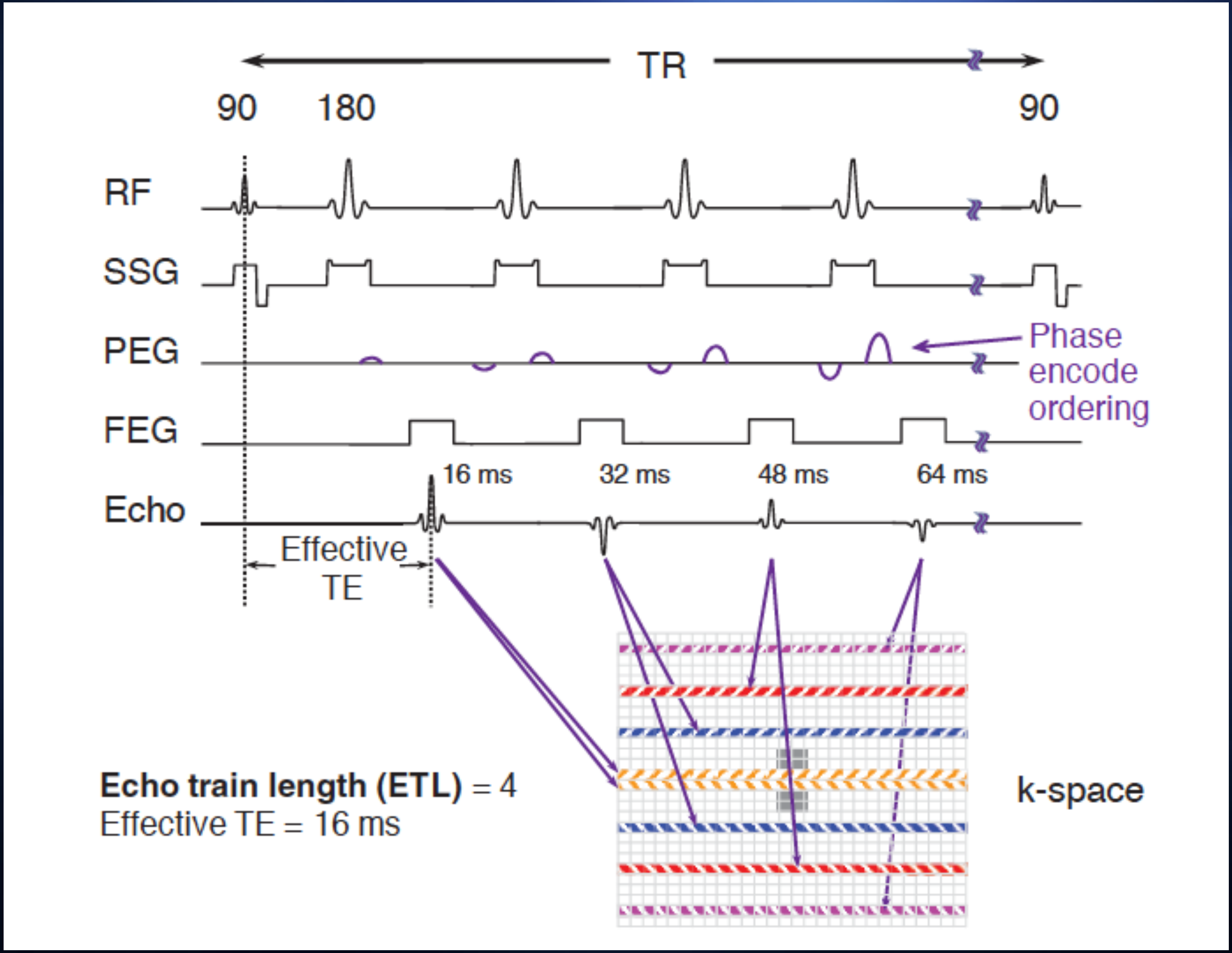
- where magnetisation is in phase throughout the imaged object

✓ The degree of T_2-weighting in a fast SE image is dominated by echoes close to the centre of the k_y-axis

- effective echo time or pseudo echo time



Fast SE



TR
90
180
90
RF
SSG
PEG
FEG
Echo
Phase
encode
ordering
16 ms
32 ms
48 ms
64 ms
Effective
TE
k-space
Echo train length (ETL) = 4
Effective TE = 16 ms

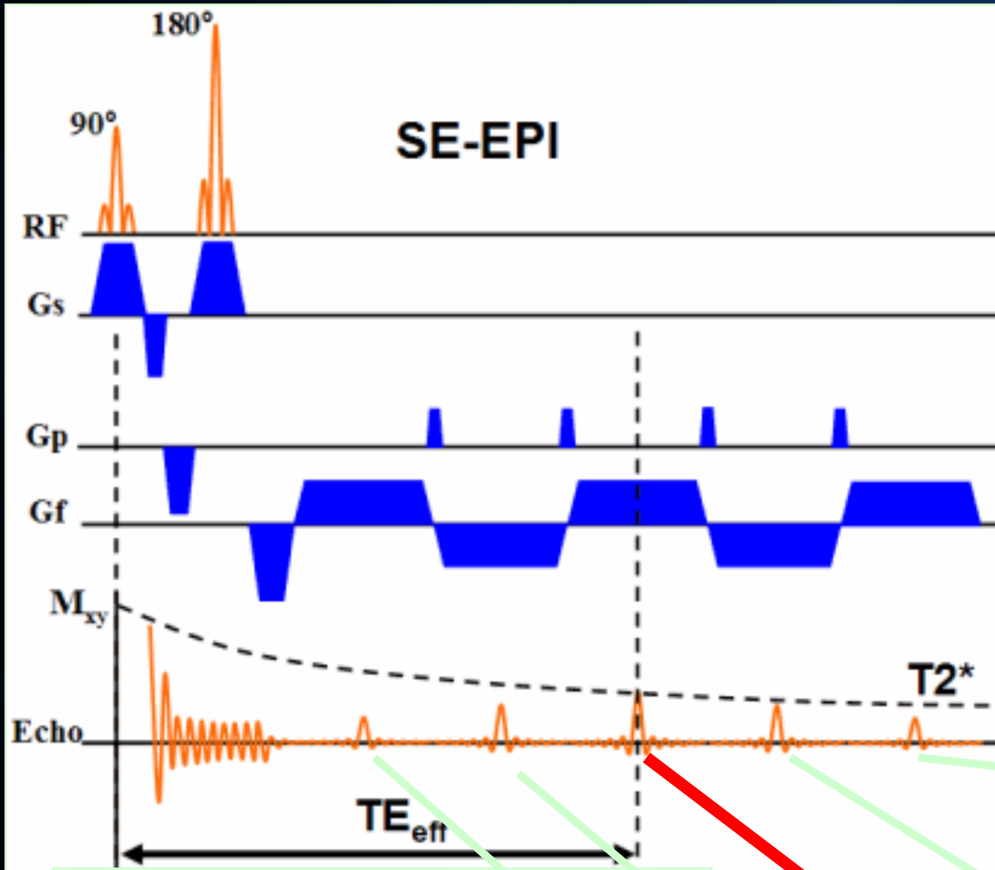
Fast SE

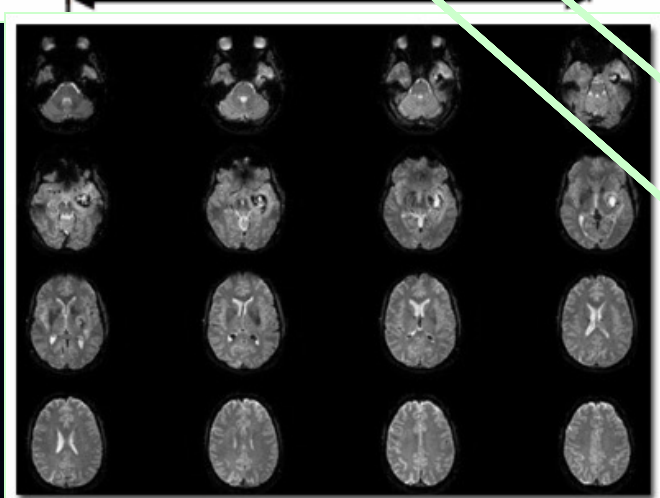
- ✓ echoes acquired at long TE are typically positioned towards the edges of k-space
  - very long T_E contain very little signal
  - at high ETL this can become an issue because of the loss of high spatial resolution data and consequent image blurring

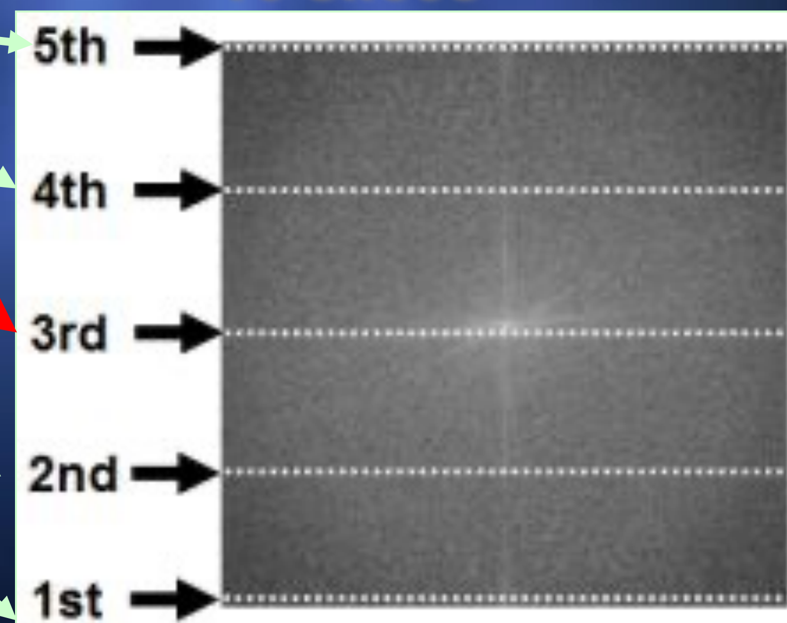
- ✓ The appearance of the image is determined by the k-space trajectory
  - identical sequences with different phase encoding patterns can produce very different images!

Echo planar imaging

- ✓ "Single shot" acquisition
  - A mixture of SE and GRE
- ✓ A brain in 3 s
  - 16 slices



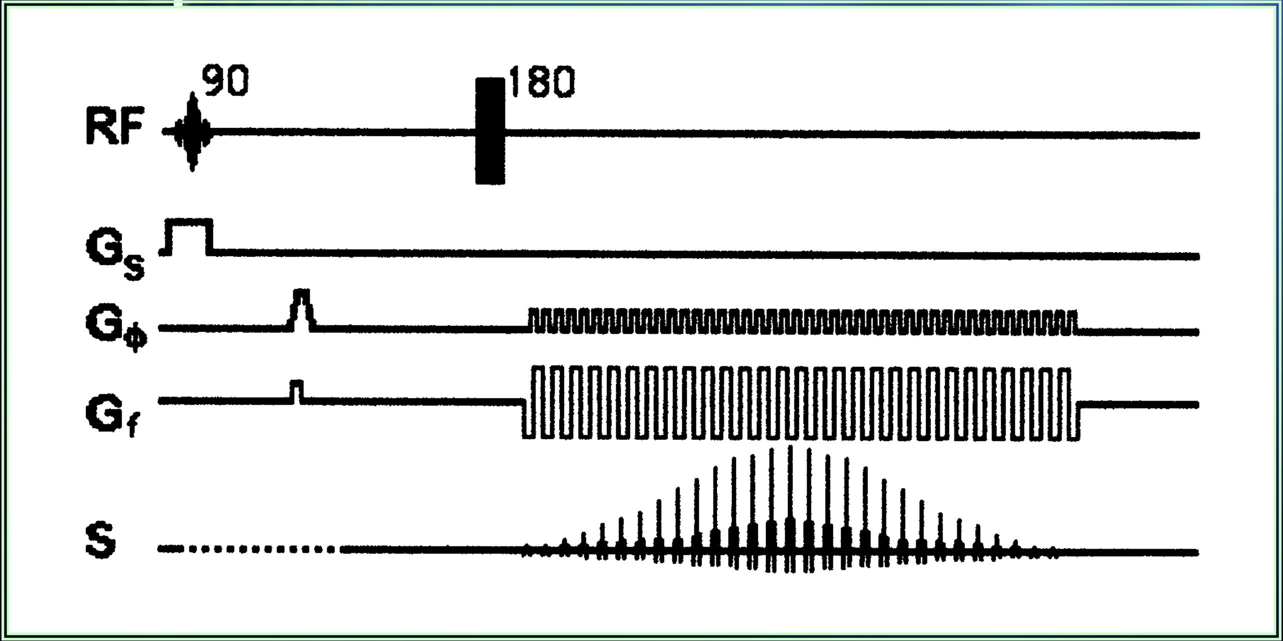




www.imaios.com/en/e-Courses/e-MRI/MRI-Sequences/echo-planar-imaging

Echo Planar Imaging

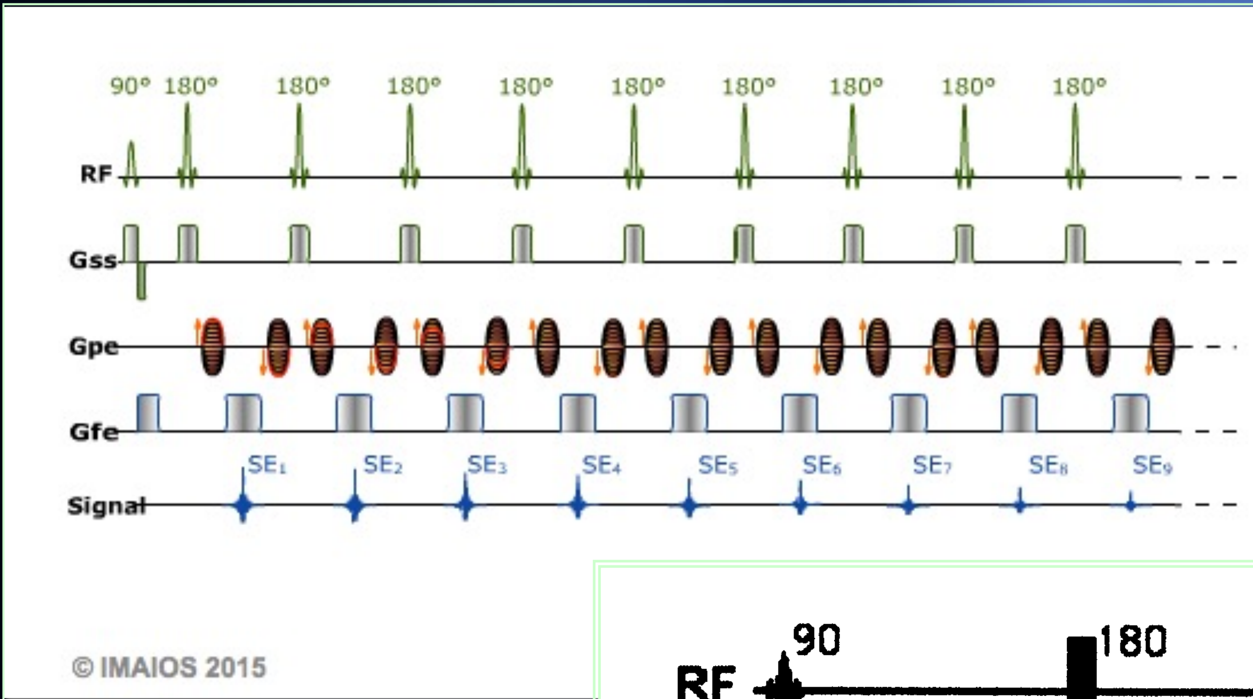
- Oscillating gradients to explore all the k-space
- The phase encoding gradients are summed after each echo acquisition
- Gradient frequencies~ KHz
- ΔTe ~ ms
- Artifacts are visible if the gradients are not perfectly repeated



$$k_x = \gamma \int_0^t ds G_x(s)$$

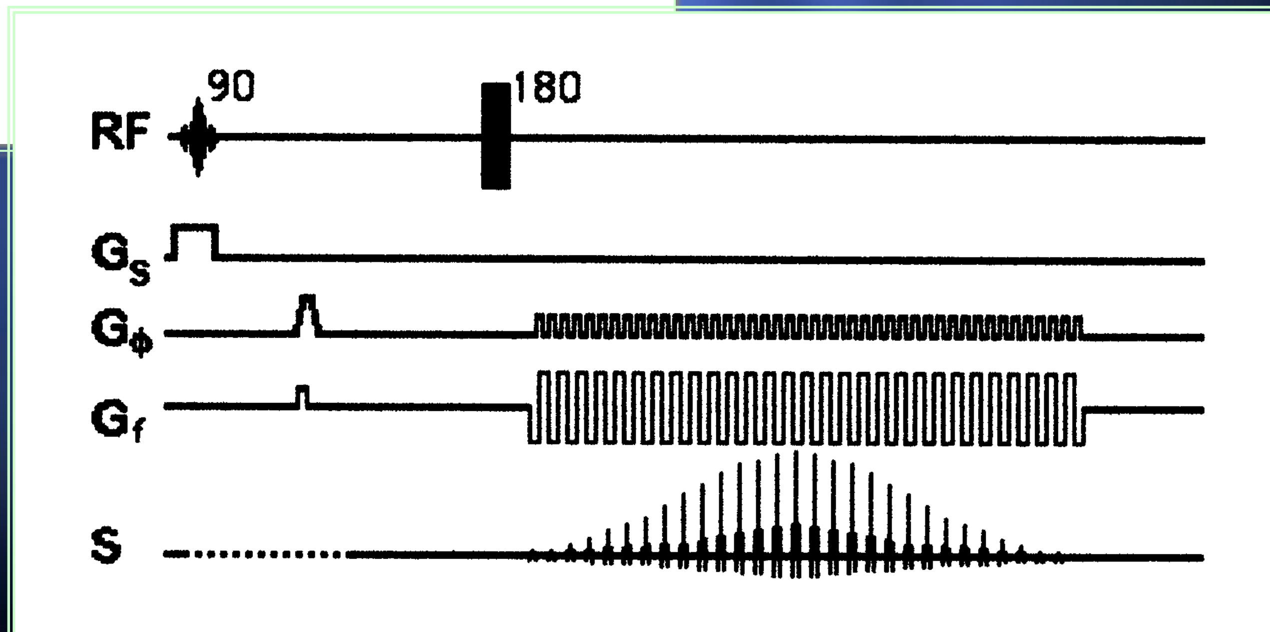
$$k_y = \gamma \int_0^t ds G_y(s)$$

Ultrafast Spin Echo & EPI



Multiple echos in order

to fill the whole k-space



Acquisition time reduction strategies

How to reduce the acquisition time with minimum effects on the image quality !?!?

✓Multislice sequence

✓Gradient echo sequences

- Reduced flip angle and reduced Tr and TE

✓Multiple rows filling from 1 excitation pulse

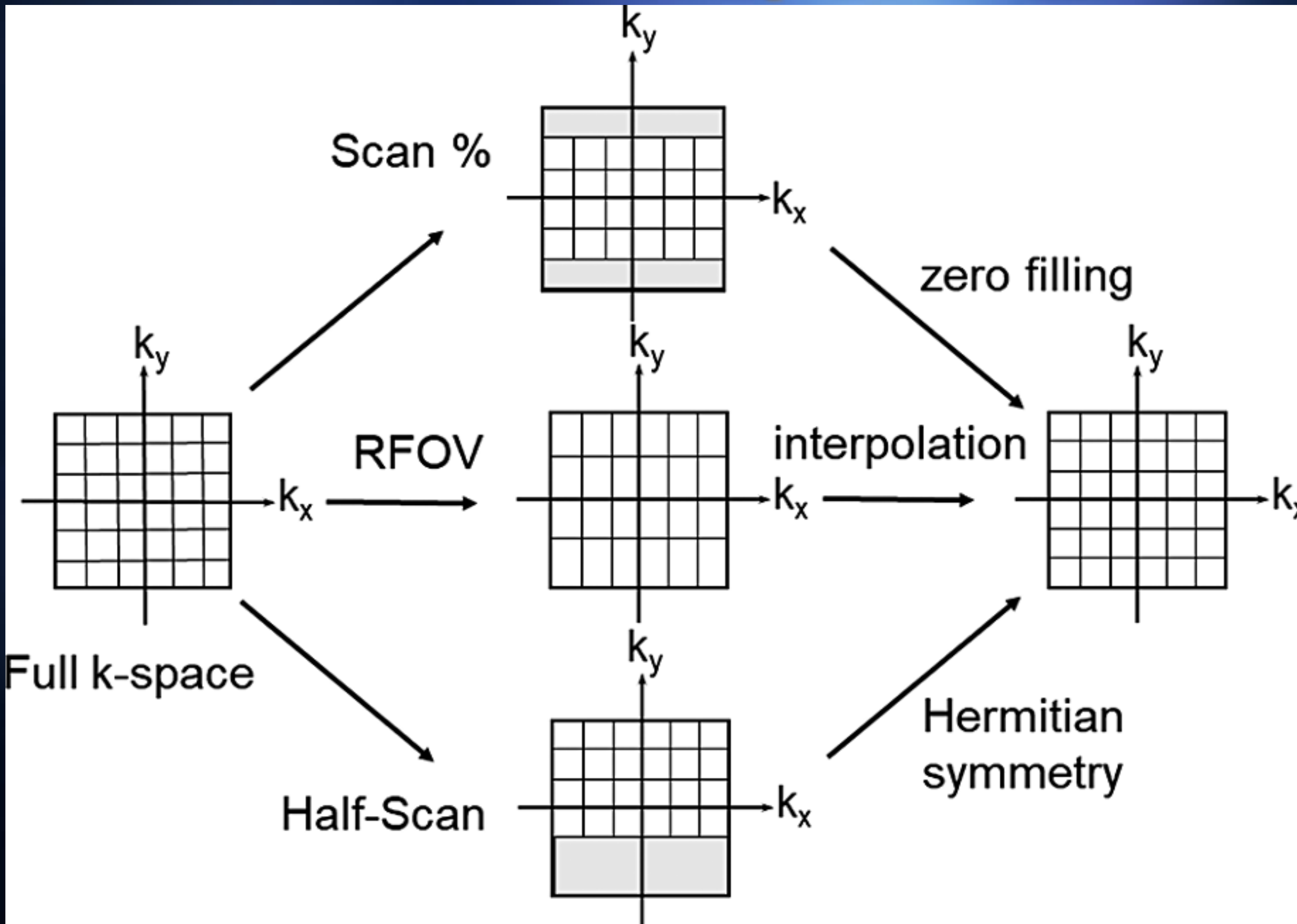
- Fast and EPI imaging

✓Incomplete filling of the k-space

✓Parallel imaging

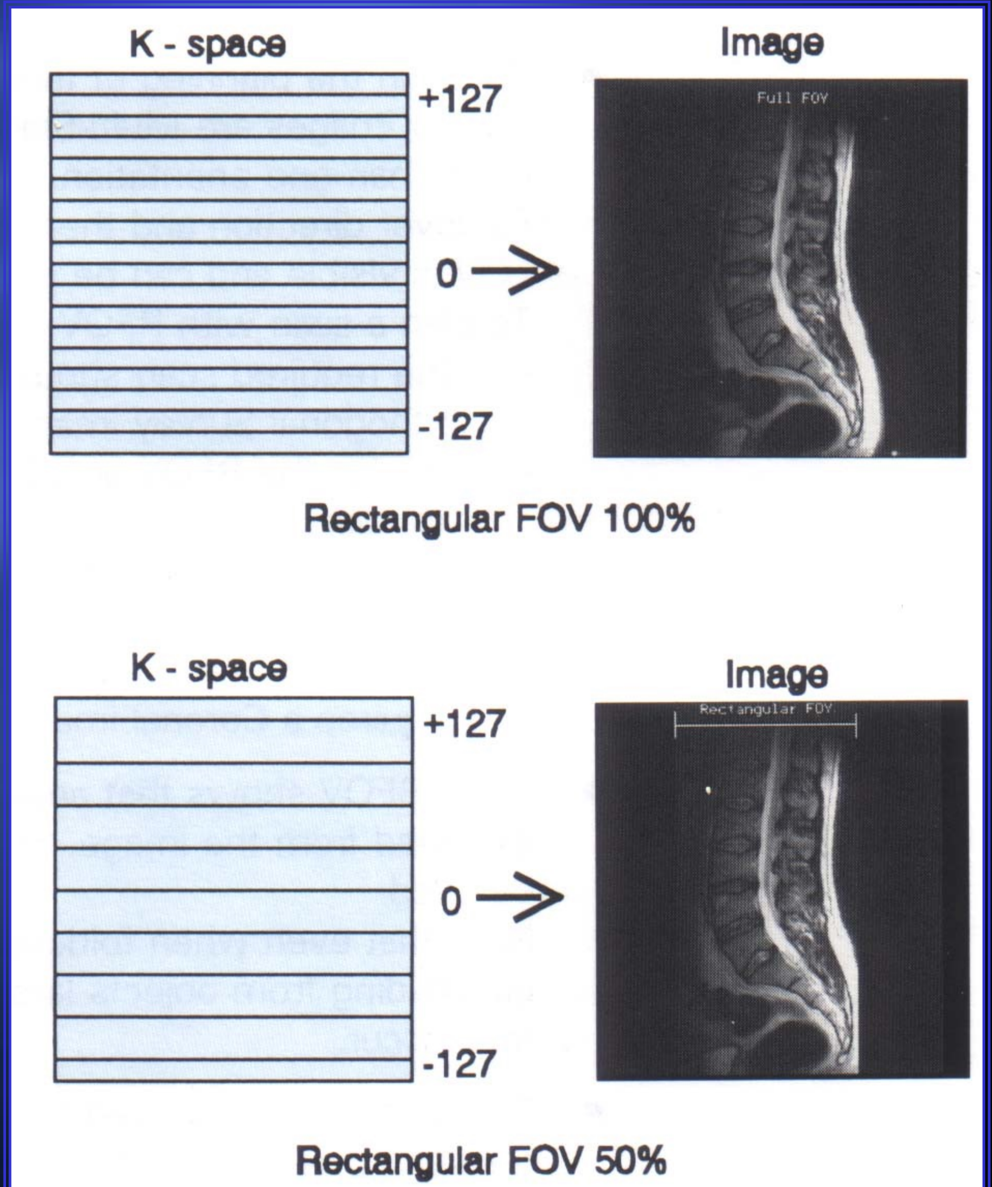
- How an artifacts becomes a resource !

Reduced acquisition of the k-space

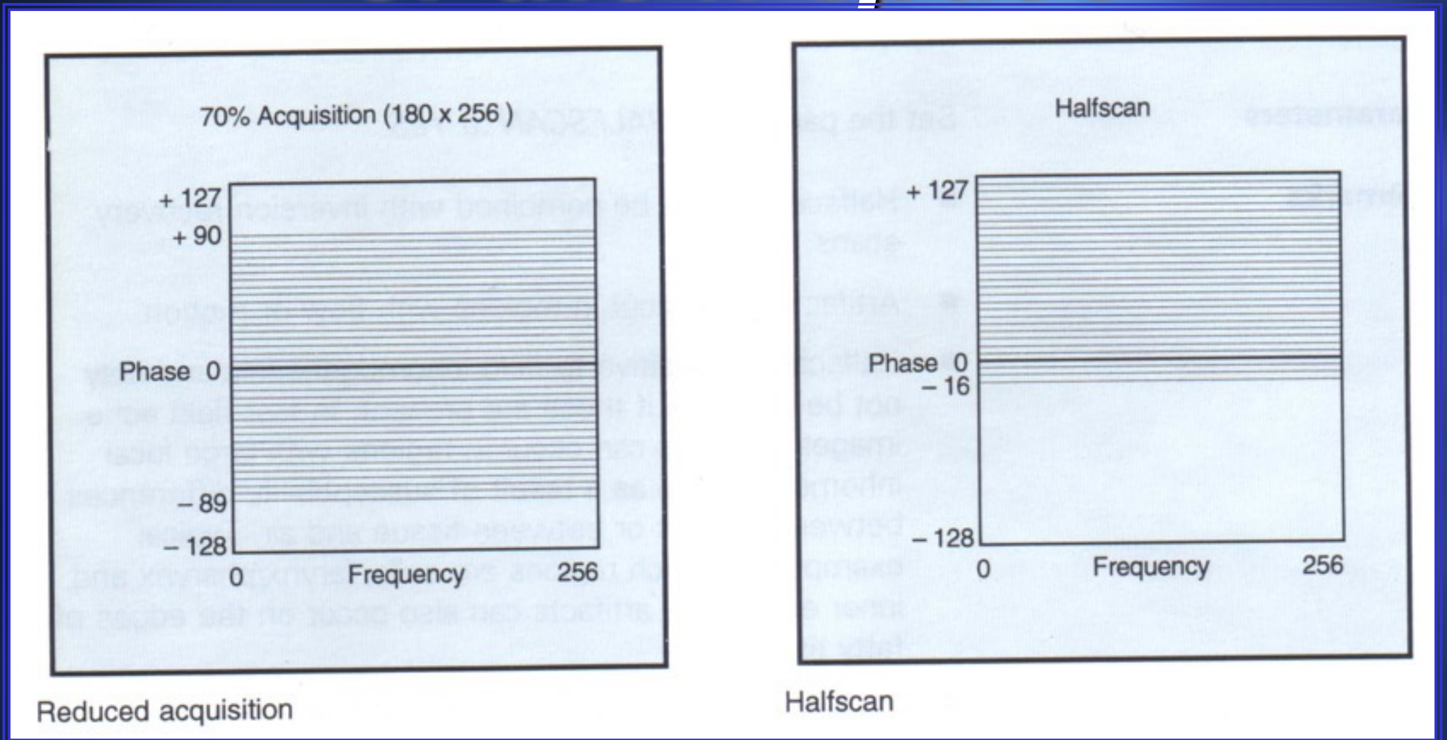


rectangular FOV

- ✓ Δk_x Δk_y may be not equal
  - FOV rectangualar in the image space
  - Δk_x sampling step in the K-space



Reduced acquisition of the k-space



- ✓ **Acquiring the central part of the k-space the spatial resolution is affected**
- ✓ **In halfscan approach the spatial resolution is preserved but the SNR is decreased**

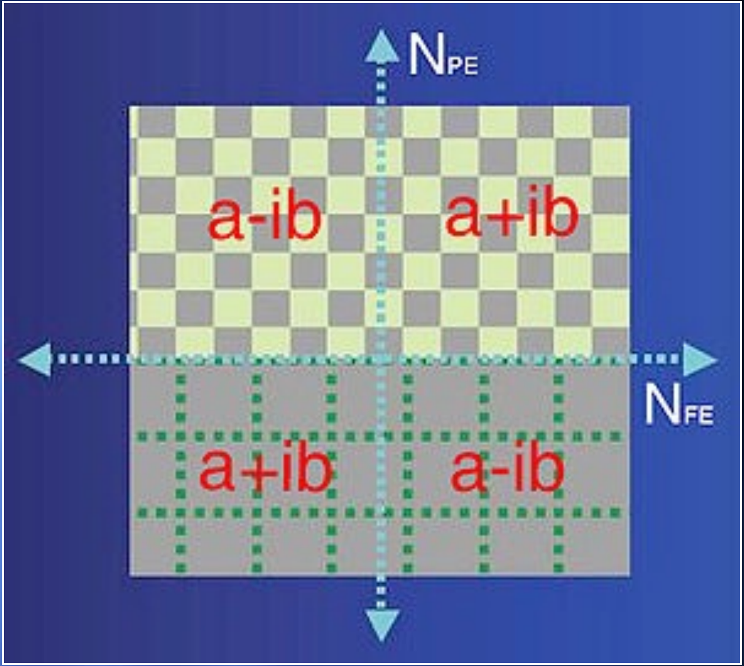
Half scan

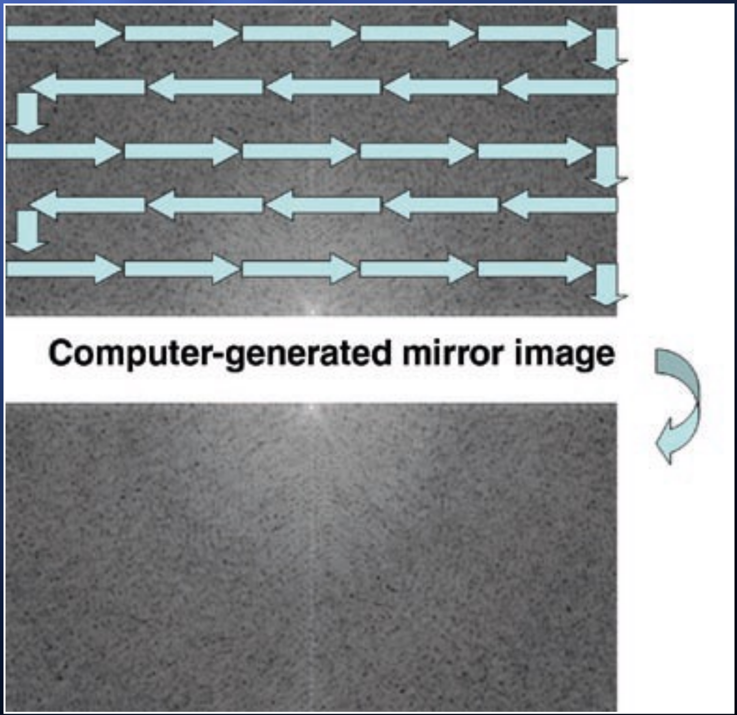
- ✓ K-space: complex conjugate simmetry

$S(-k_{FE},-k_{PE}) = S^*(k_{FE},k_{PE})$

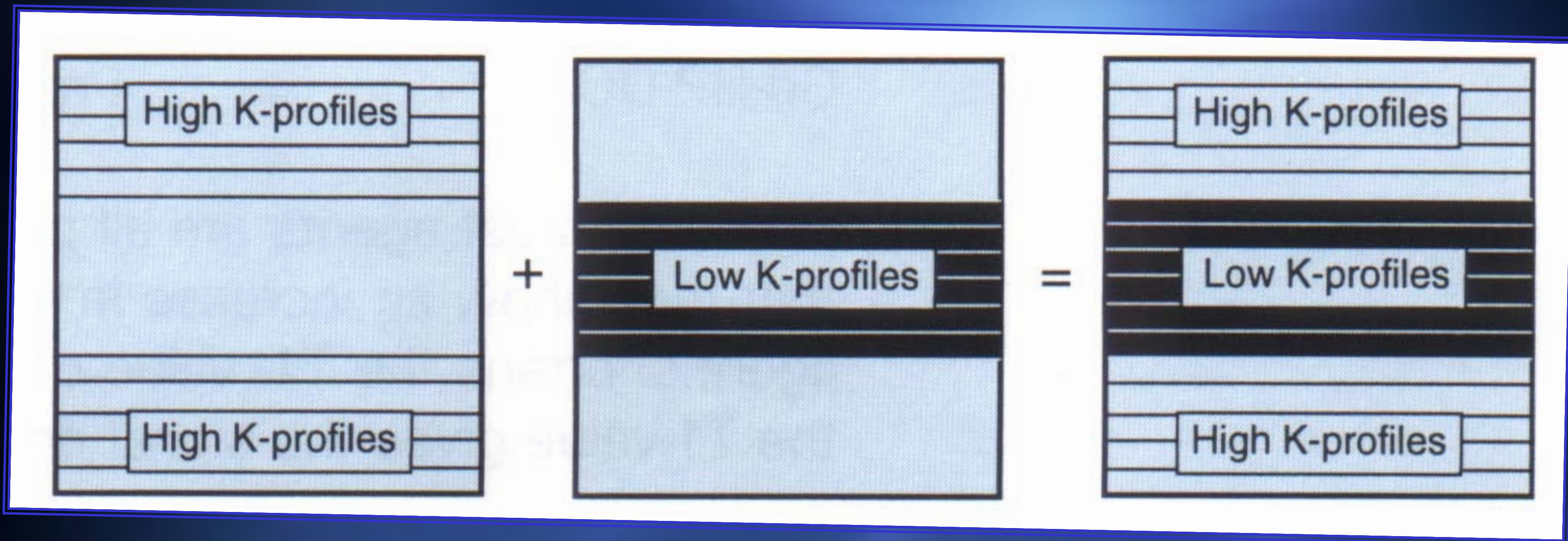
- ✓ Time-saving mechanism at the expense of the SNR
- ✓ In single-shot techniques (EPI) it is a powerful technique
  - Due to the very low signal of the late echos ..

Gallager et al AJR 2008; 190:1396–1405





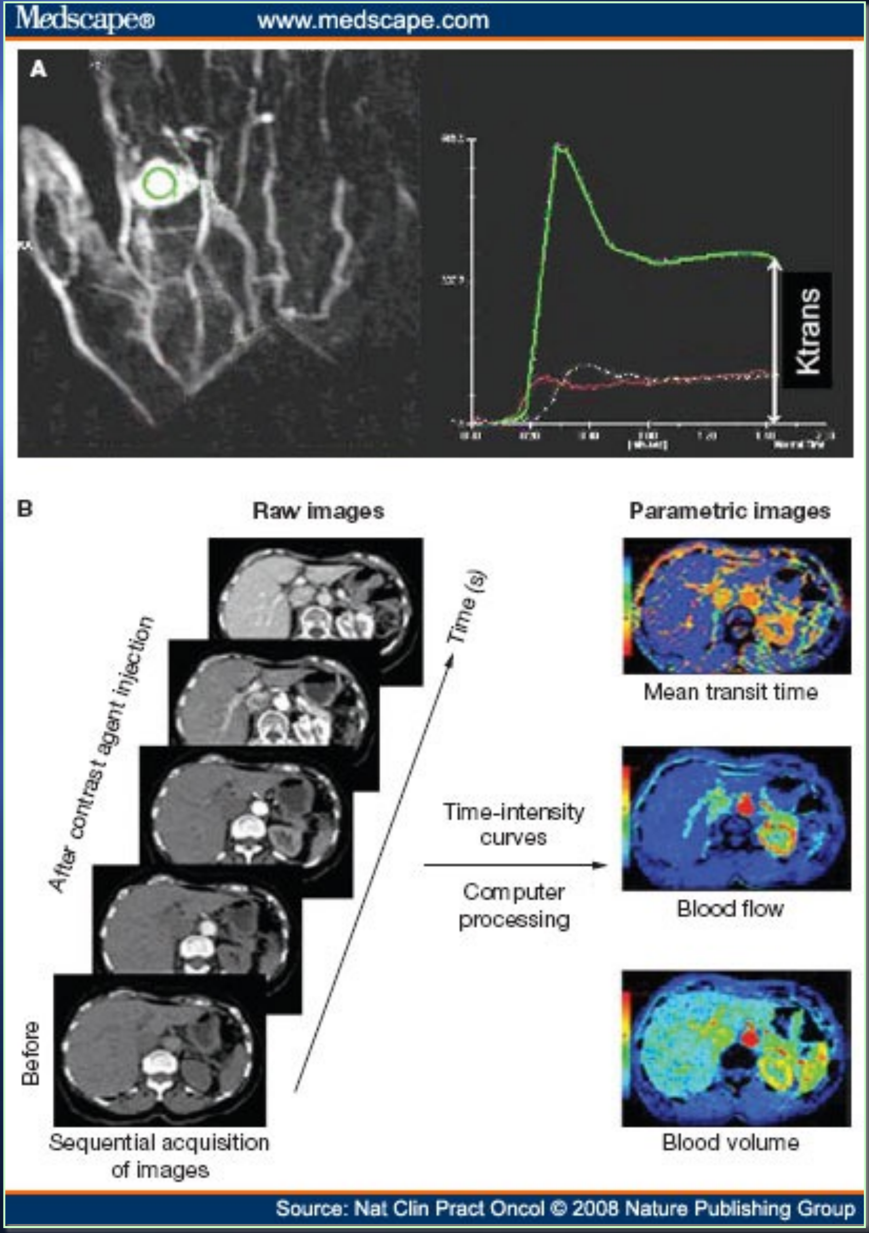
Reduced acquisition of the k-space (II)



- **KeyHole technique:**
  - Fast dynamic acquisition

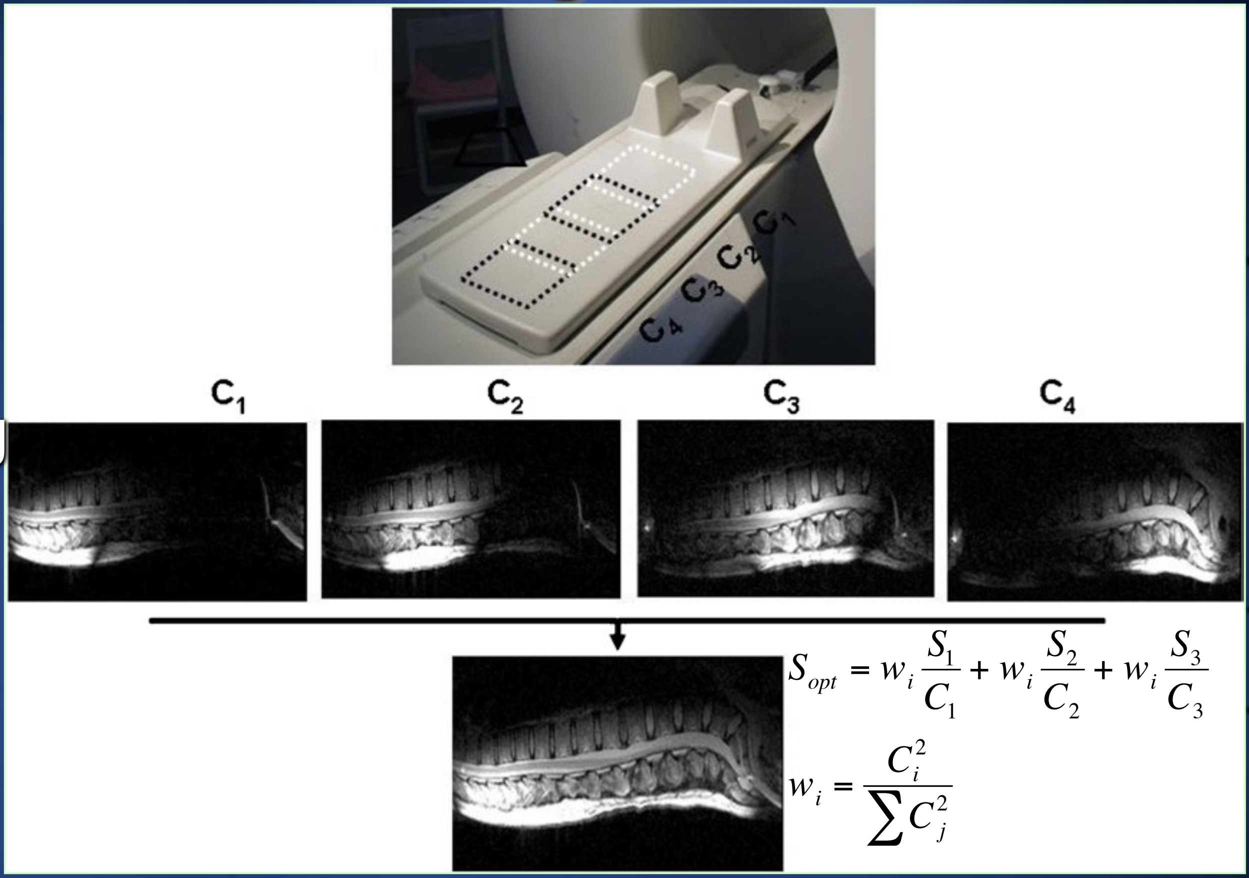
Dynamic contrast-enhanced MRI

- DCE-MRI enables analysis of blood vessels generated by a tumor
- The T1w images are taken after an injection of the contrast agent
- The concentration of the contrast agent is measured, when it passes from the blood vessels to the extra-cellular space of the tissue and whether it goes back to the blood vessels
  - it cannot enter inside the cells



Phased array coils

The use of multiple receiver coils to augment the time-consuming Fourier encoding has reduced acquisition times significantly



DJ Larkman & RG Nunes
Phys. Med. Biol. 52 (2007) R15–R55

- ✓ A typical spine coil which uses an array of four coils arranged linearly which reflects the extended anatomy of the spine
- ✓ Each coil element C, produces a separate image shown as C1–C4, the bottom image is an optimal combination of these images performed on a pixel by pixel basis using equation

http://www.imaios.com/en/e-Courses/e-MRI/Parallel-imaging/phased-array-coils

Artificial Contrast Agents

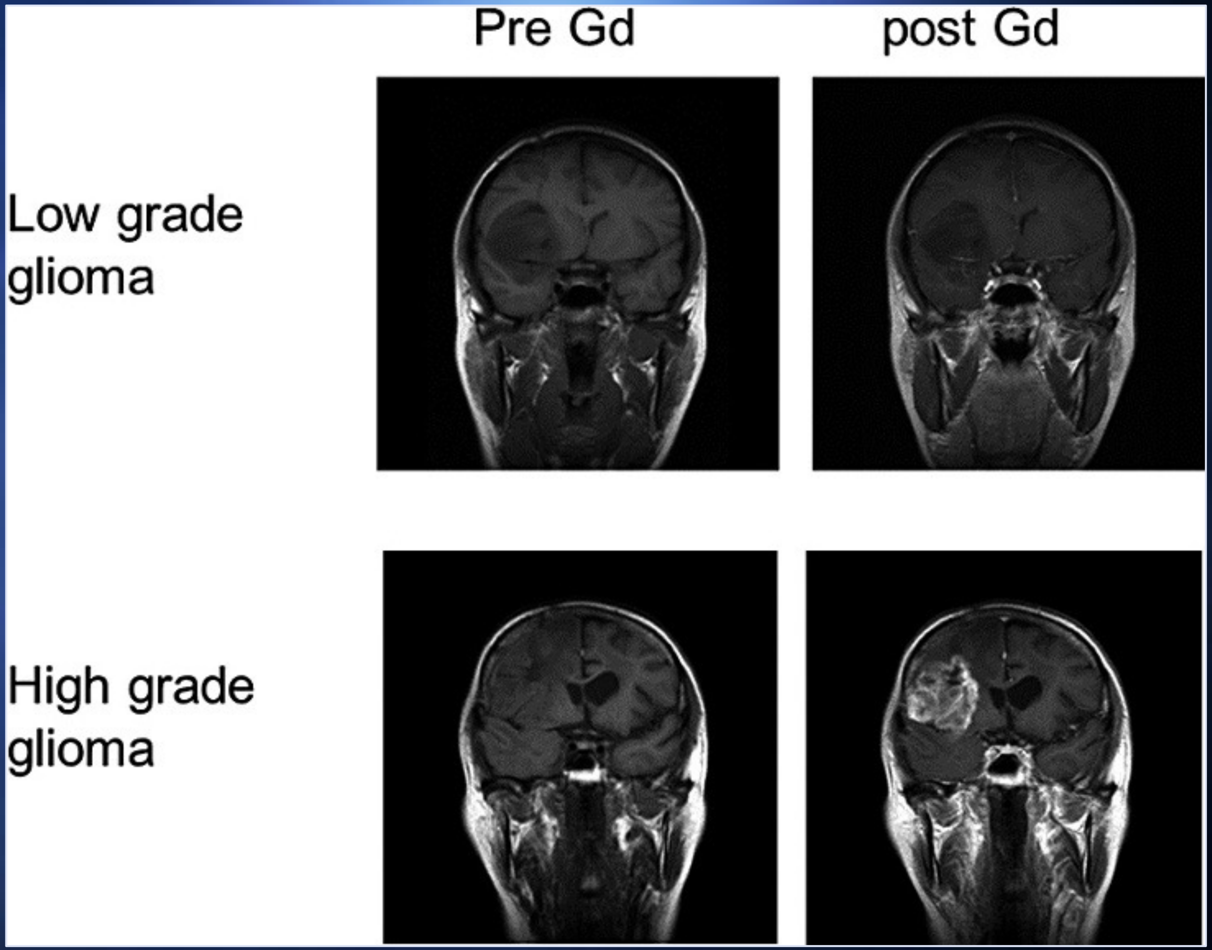
- ✓ it may be advantageous to introduce exogenous agents which affect contrast in a way that reflects some pathological or physiological process
- ✓ MRI agents generally work by reducing the T1 and/or T2 of tissue in which they reside
  - resulting in local changes in signal intensity

Artificial Contrast Agents

- the contrast agents in clinical use are intravascularly injected agents based on the gadolinium ion (Gd)
  - gadolinium-based contrast agents
    - GBCAs
- Gadolinium is a paramagnetic ion, which affects signal primarily by shortening T_1
  - Because it is a toxic heavy metal, it is used in a chelated form, in which each gadolinium ion is embedded in a molecular ‘cage’ to reduce toxicity

Artificial Contrast Agents

- ✓ In a high-grade glioma, where the blood-brain barrier is compromised, GBCA crosses into the tumour and causes signal enhancement
  - due to T_1 shortening
- ✓ Being able to differentiate tumour grade makes a great difference to the patient's



Artificial Contrast Agents

applications categories

- ✓ To change signal from selected tissues or areas of pathology
  - usually on the basis of vascularity
  - usually signal increases
- ✓ To enhance signal from flowing blood
  - contrast-enhanced MR angiography
- ✓ To eliminate signal from organs that might otherwise obscure structures of interest or cause artefacts
  - such as the bowel
- ✓ For dynamic studies of perfusion or function
- ✓ In emerging areas such as molecular imaging

GBCA safety

- ✓ a very favourable safety profile compared to agents used in x-ray imaging

However

- ✓ guidance limiting the use of GBCAs in renal failure patients
- ✓ in 2014 it emerged that there are permanent changes in signal intensity in some parts of the brain following repeated GBCA administration, believed to result from retention of Gd
  - there are no known clinical consequences

one-off administration of GBCA as part of an MRI examination appears to be safe