Turbo/Fast Spin Echo

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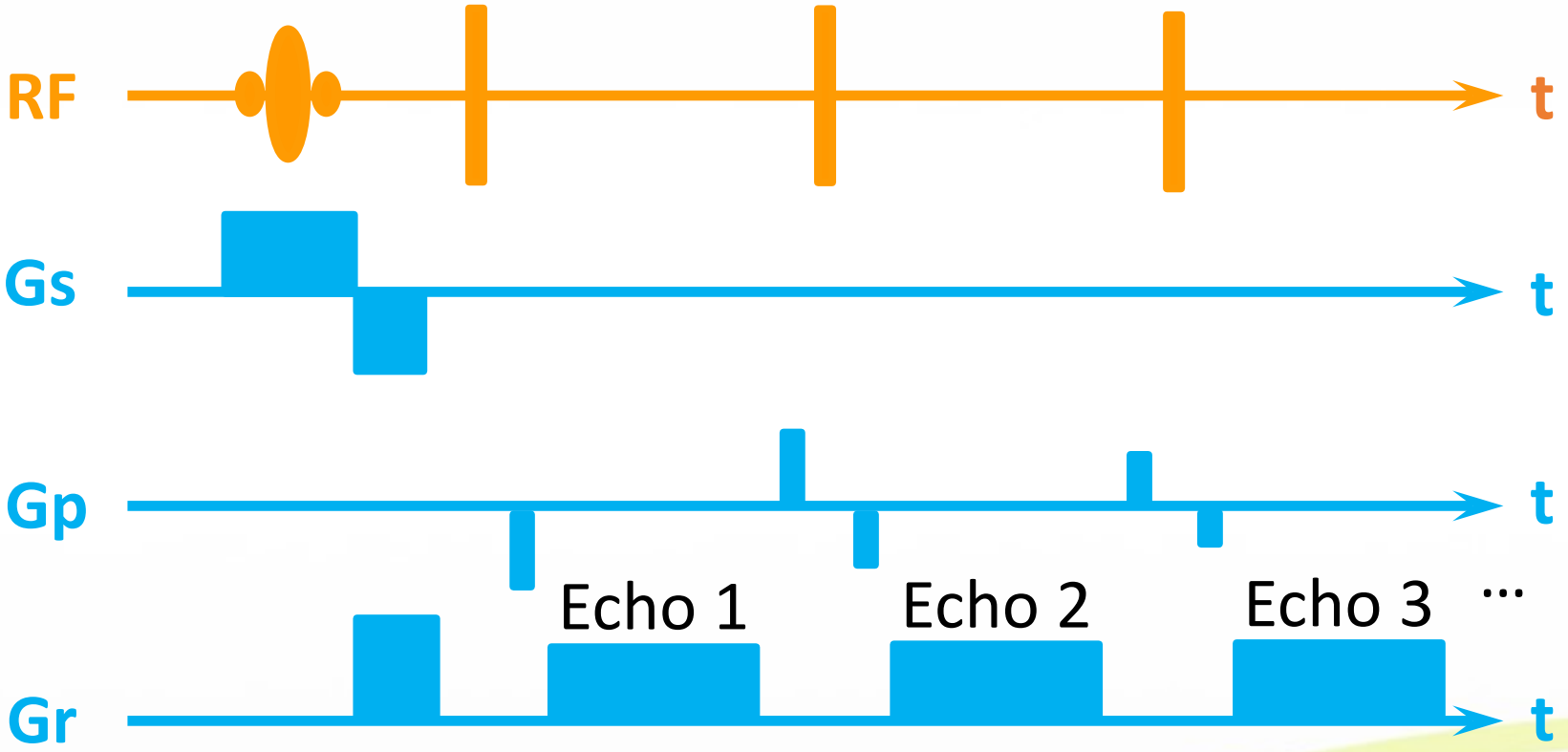
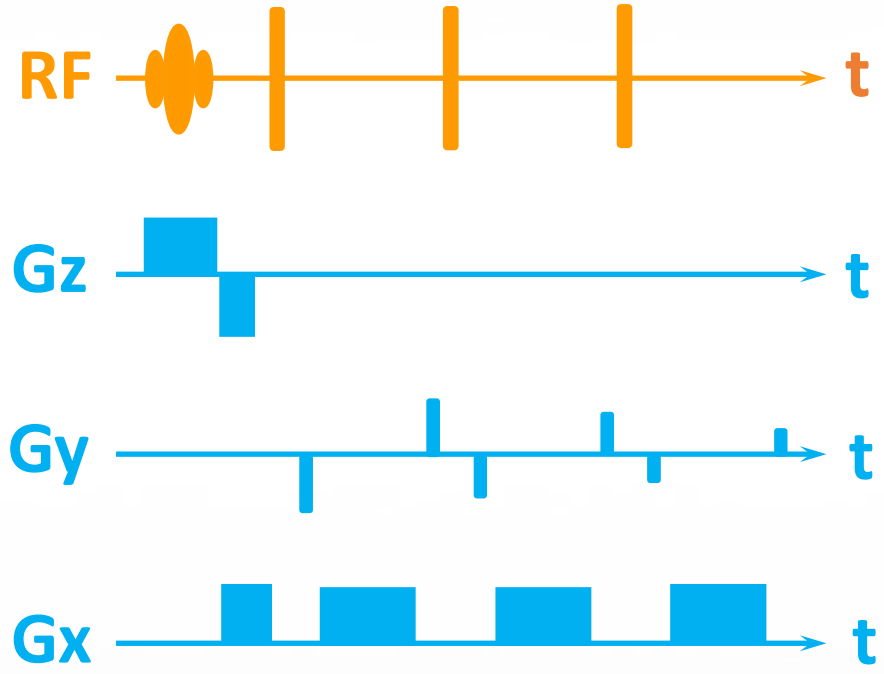
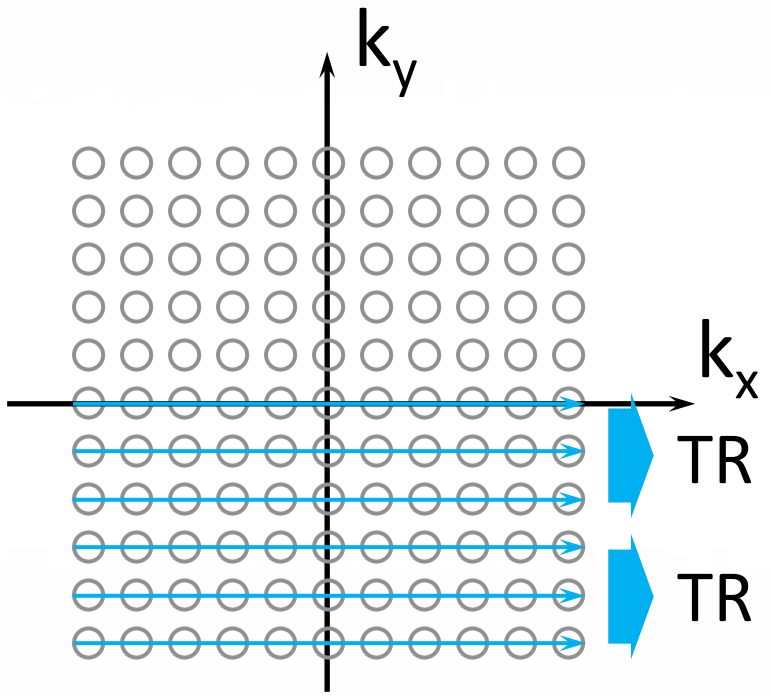
Pulse sequence of FSE/TSE



Each k-line is filled by an echo

TSE/FSE

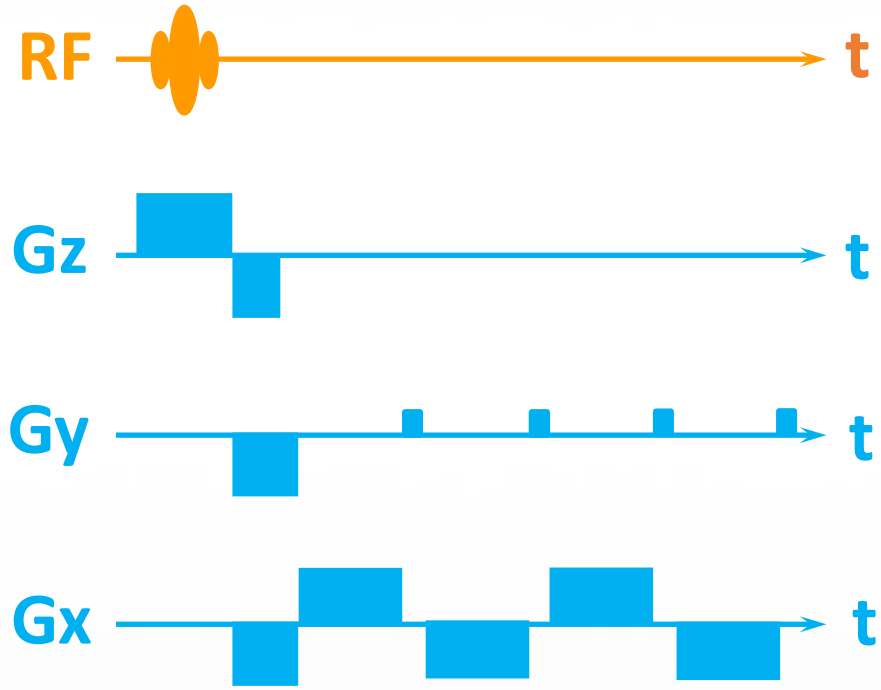


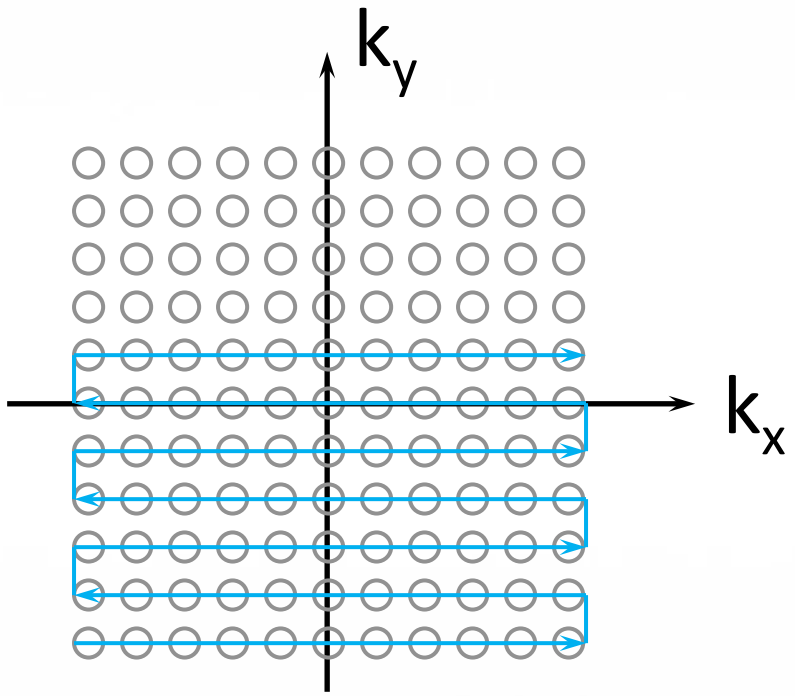


Comparison of EPI and TSE

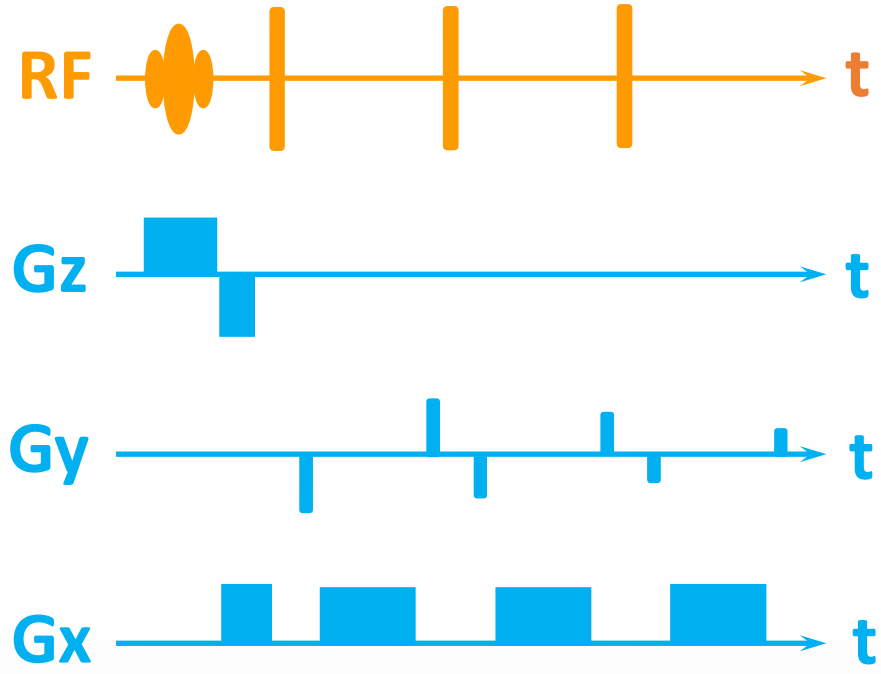
- EPI: collect k-space data by a series of gradient echoes
  - Single-shot/multi-shot
- TSE: collect k-space data by a series of spin echoes
  - Single-shot/multi-shot

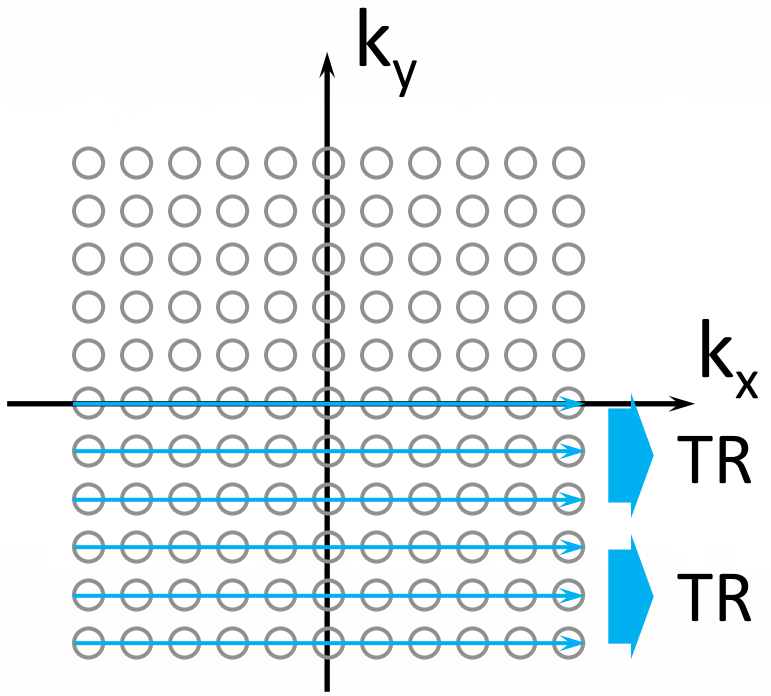
EPI





TSE/FSE





Similar with conventional spin-echo

- But TSE acquires multiple k-lines after every 90° excitation
  - With multiple inversion pulses
  - Echo train length (ETL)
- Fewer excitation pulses → reduced scan time of single-slice image

20-sec orbit MRI

GE 1.5 Tesla
Fast spin-echo

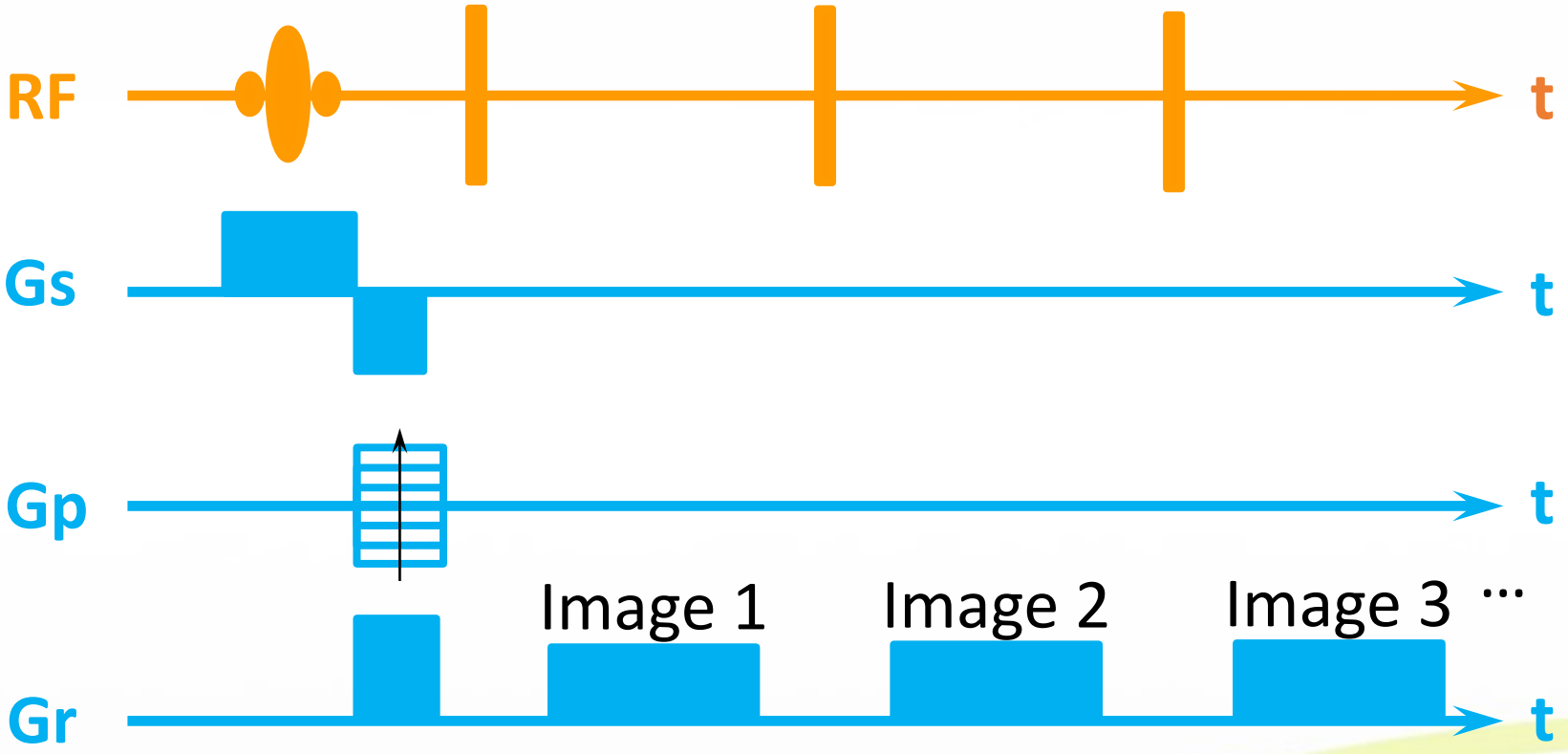
ETL = 12
TR = 2000
Scan time = 20 sec

Free of involuntary motion artifact

Multiple spin-echo

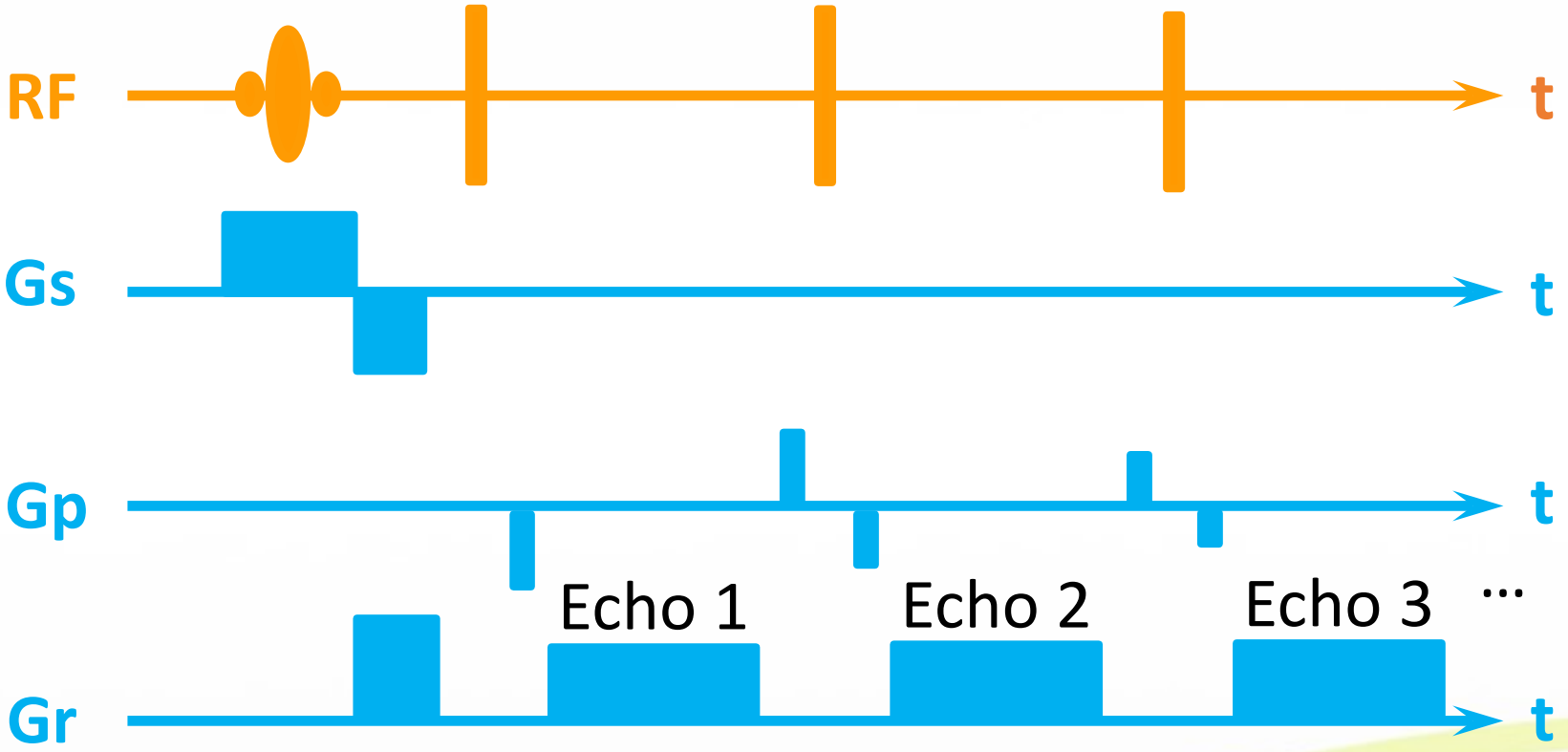
- Not a news to collect multiple spin-echo
  - 90°-180°-echo-180°-echo-…
- **Multi-echo spin-echo**: each echo is used for an image with different TE
- **TSE**: all echoes are used to fill one k-space

Multi-echo spin-echo



Each echo is used in respective image

Pulse sequence of FSE/TSE



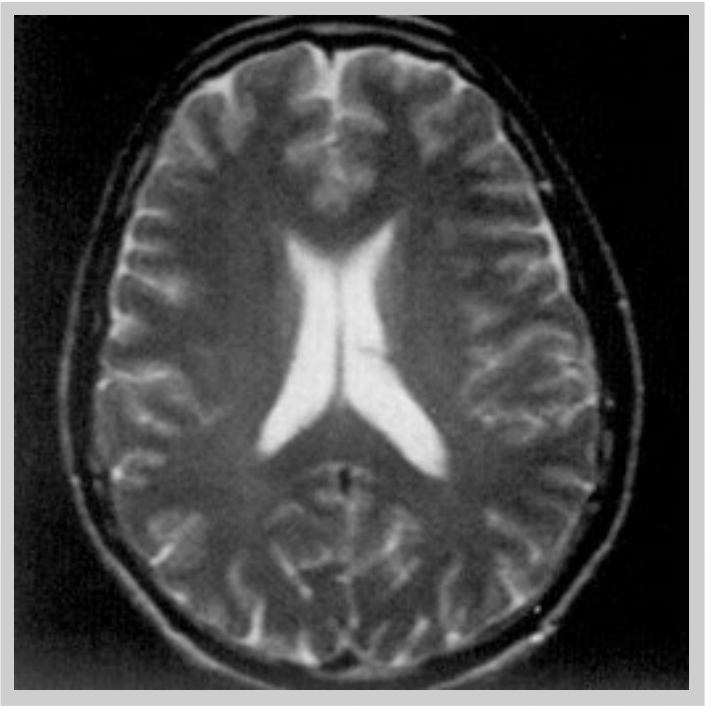
All echoes are filled in the k-space of one image

It is expected that…

- All spin-echo MRI can be modified into the TSE version
- Image behavior of TSE should be quite similar with conventional SE

T2WI of conventional SE and TSE

SE (TE = 100)



TSE (TE = 100)

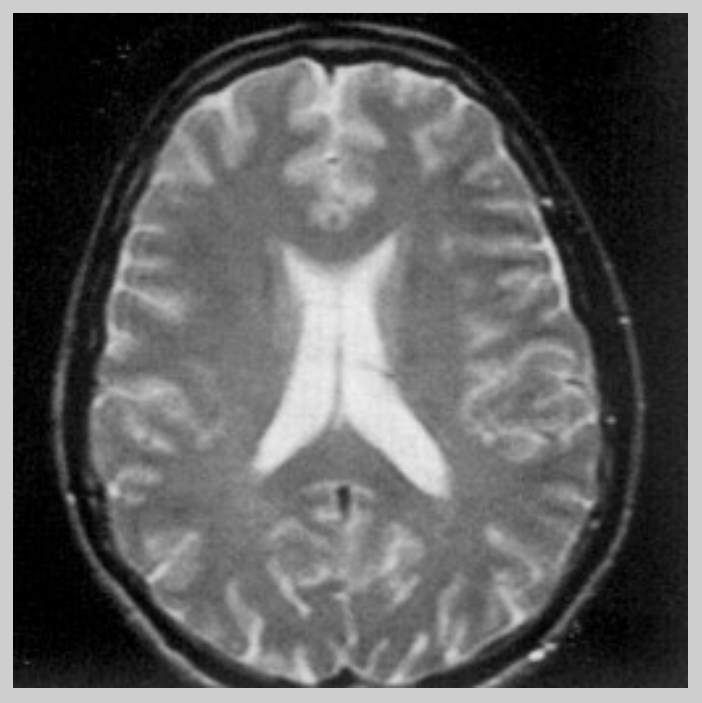
Acronyms

- Turbo Spin-Echo (Siemens)
- Fast Spin-Echo (GE and others)
- RARE (Bruker)
  - Rapid Imaging with Refocused Echoes
  - Juergen Hennig, 1986

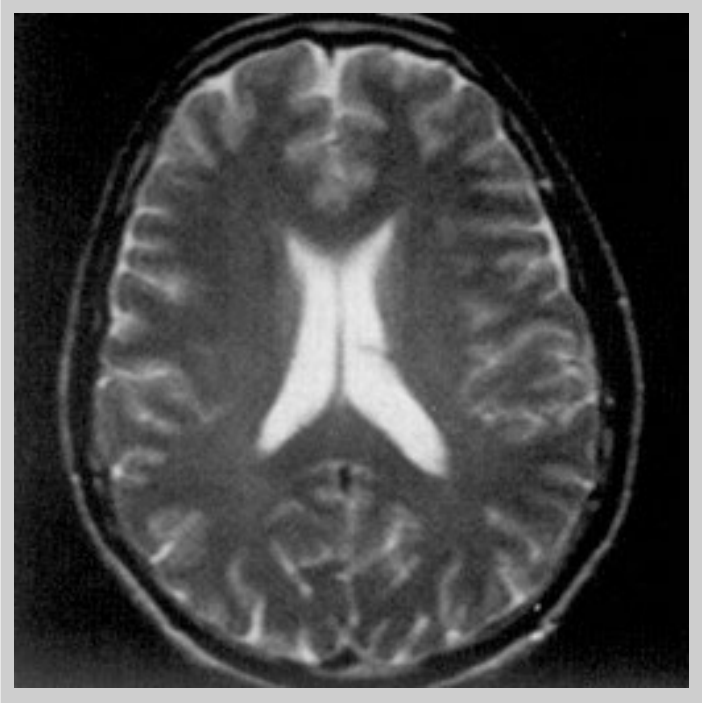
The importance of TSE

- Spin-echo: standard of MRI
- TSE image is very similar with SE
- Scan time is substantially reduced!
  - 256x256, TR = 2 sec: scan time is reduced from 8+ mins (SE) to 1 min (TSE, ETL = 8)

Conventional SE and TSE looks similar



SE (6+ mins)



TSE (48 sec)

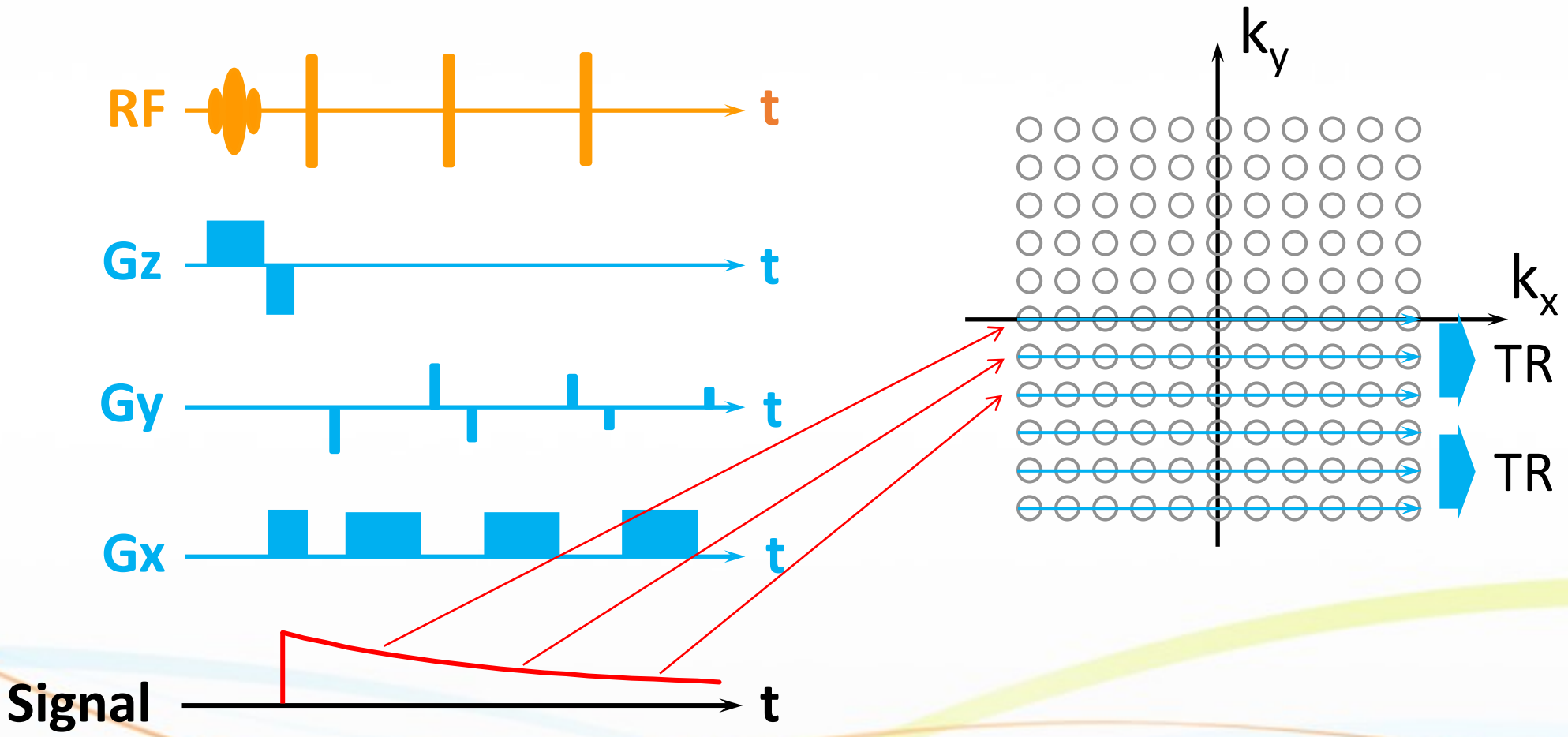
Scan time of TSE

- Scan time = TR x N_{PE} / ETL
- ETL: number of spin-echo collected in one TR
  - Turbo factor (Siemens TSE)
- Higher ETL → faster scan

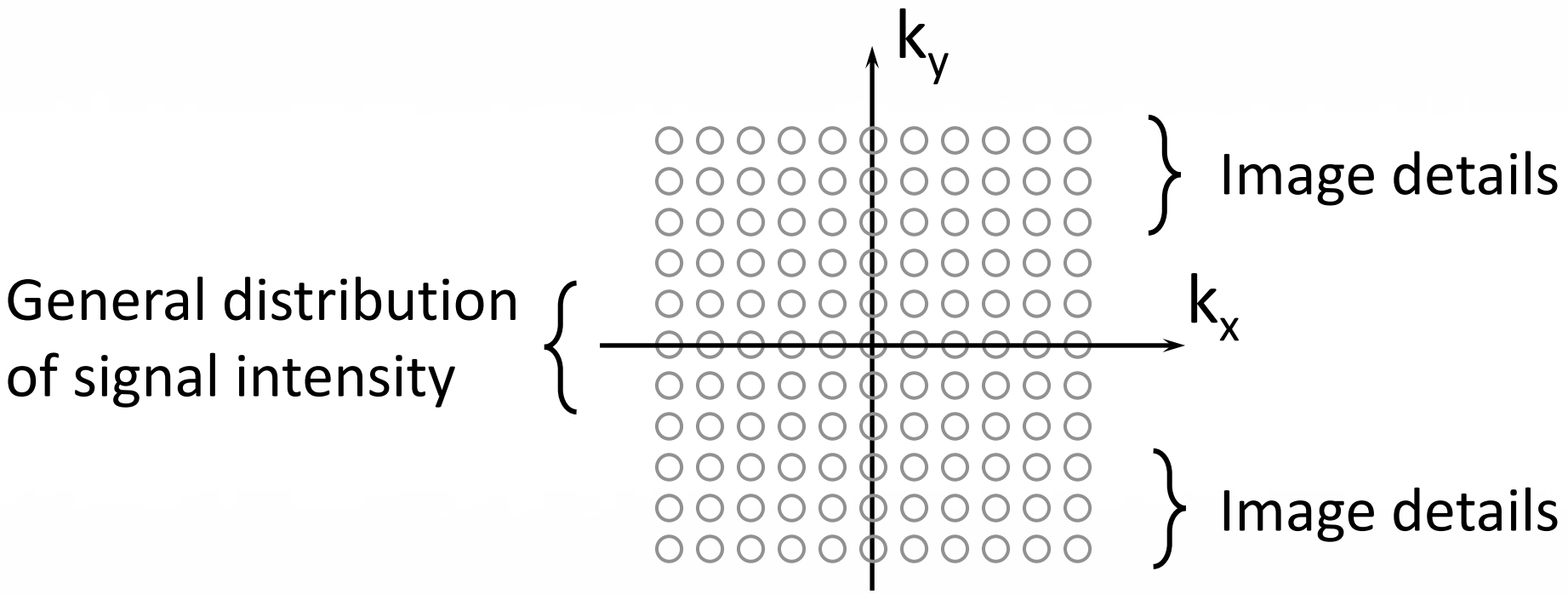
T2-contrast of TSE?

- TE of each echo is different
- Different T2-contrast for each echo
- How to determine T2-contrast of TSE?
- Effective TE

Multi-shot TSE/FSE

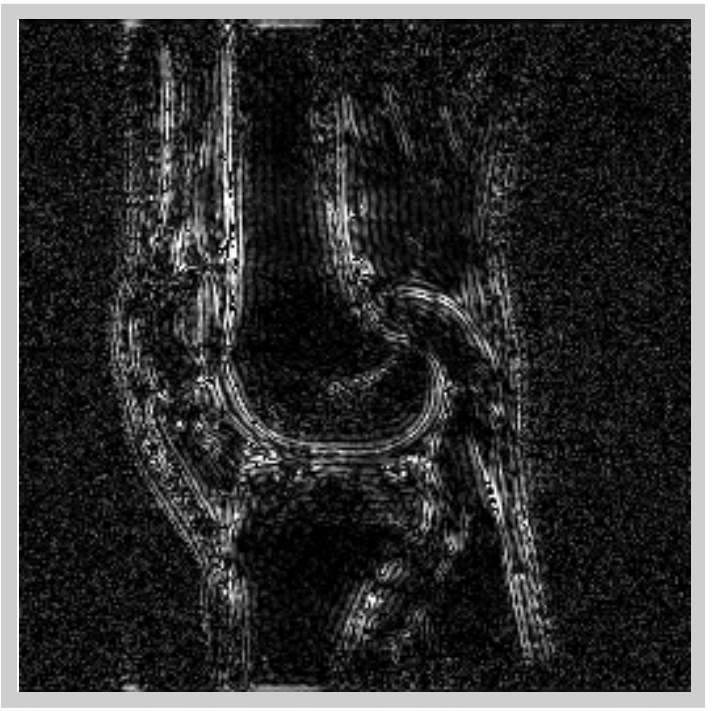


TSE/FSE



Global image contrast is dominated by central k-space data

The central and peripheral k-space



Images reconstructed by the central 64x64 points (left) and the rest in a 256x256 k-space (right)

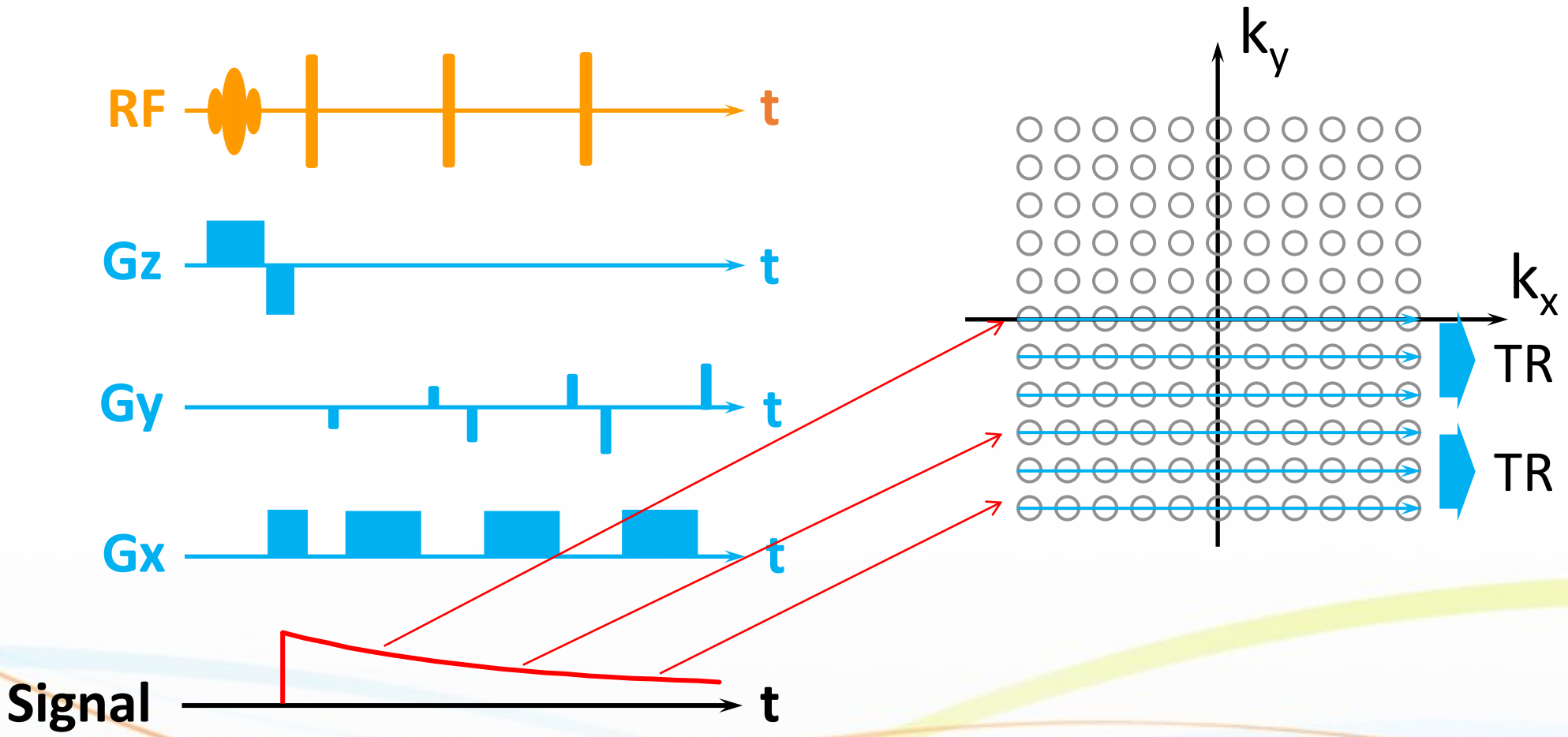
Effective TE

- Central k-space data set image contrast
- Although TE of each echo is different, image contrast is dominated by those echoes at lower phase encoding (k_{PE})
- TE_{eff}: TE of echoes filled at the center k-space

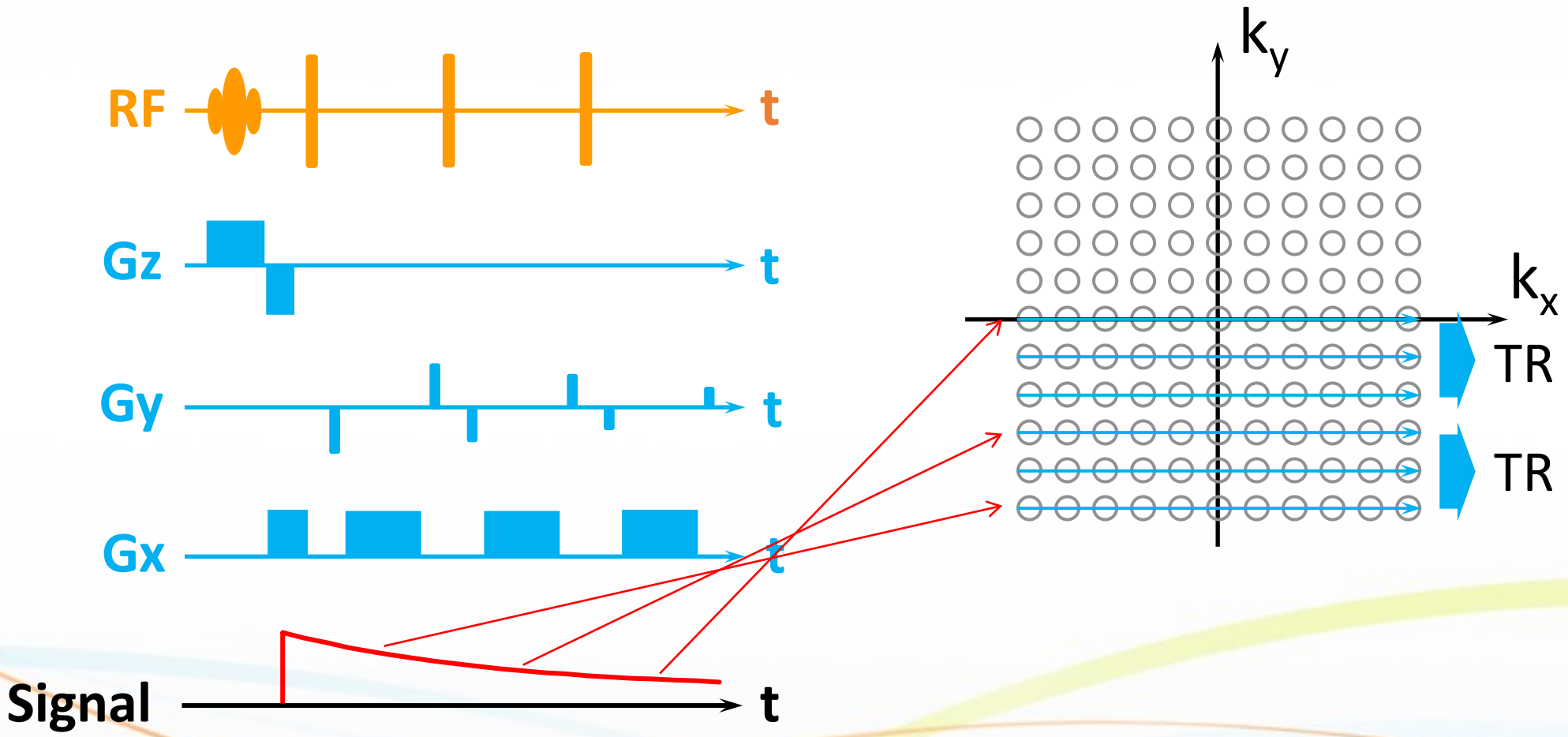
Effective TE and phase encoding order

- The order of phase encoding determines which echo will be filled at the center k-space
- Phase encoding order decides the TE_{eff}

Fill central k-space with early echo: **PDWI**



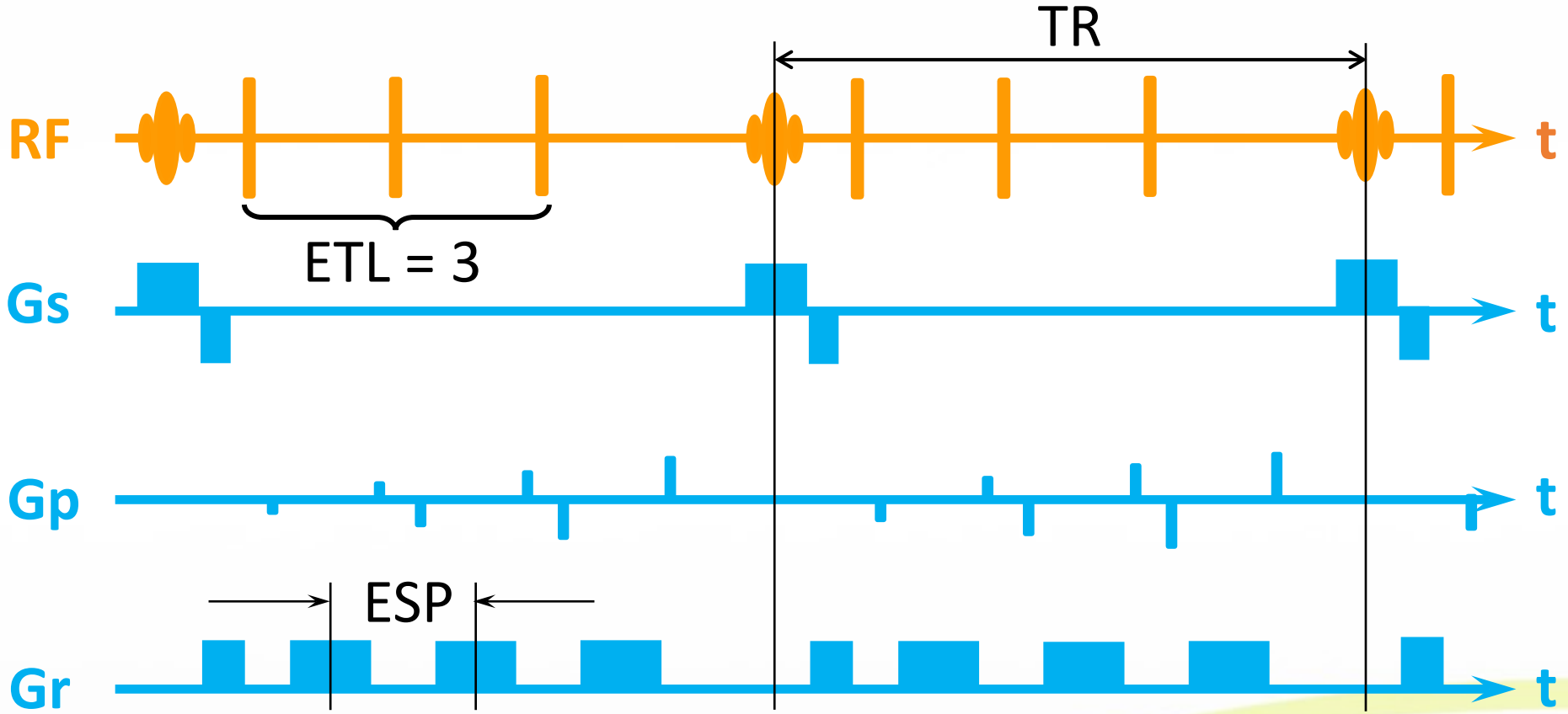
Fill central k-space with late echo: **T2WI**



Further acceleration: single-shot

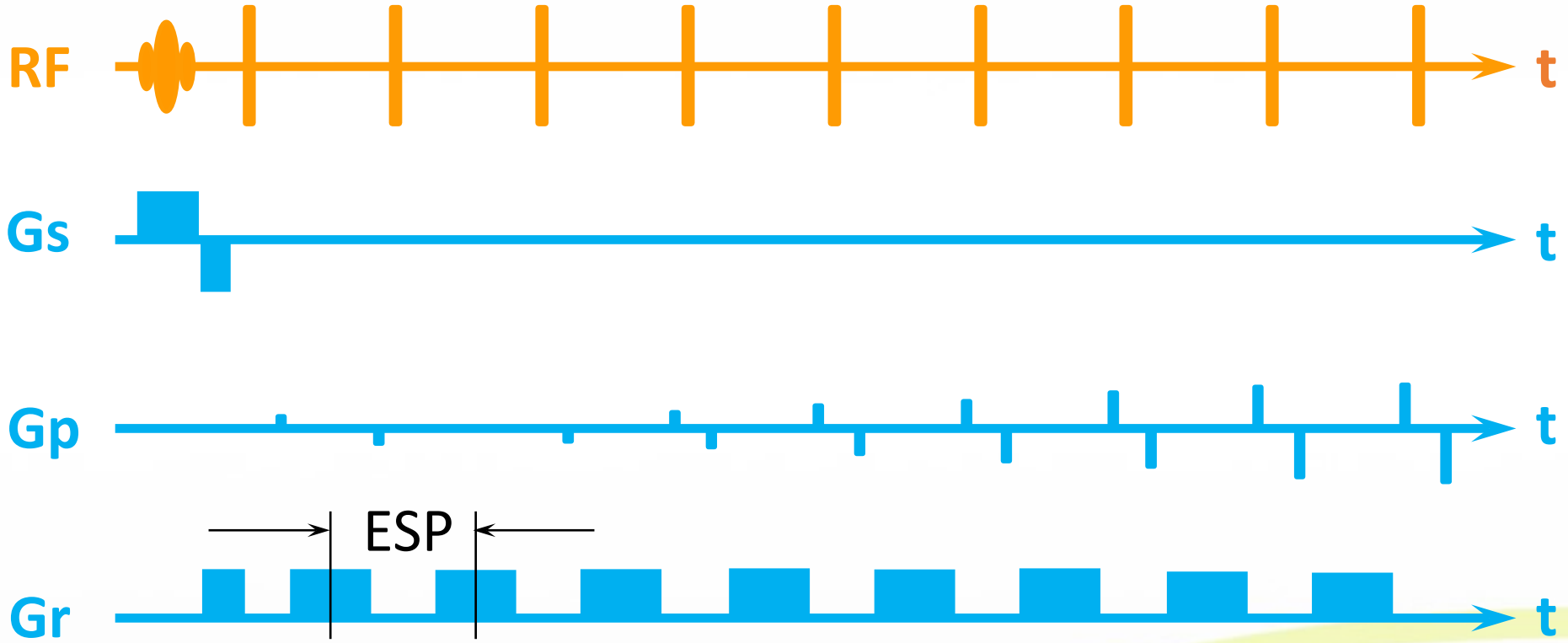
- How about acquire all k-space data with only one echo train?
- Preparation pulse and gradients + all readout time < 1 to 2 T2

Multi-shot FSE/TSE



Scan time = TR x N_{PE} / ETL

Single-shot FSE/TSE

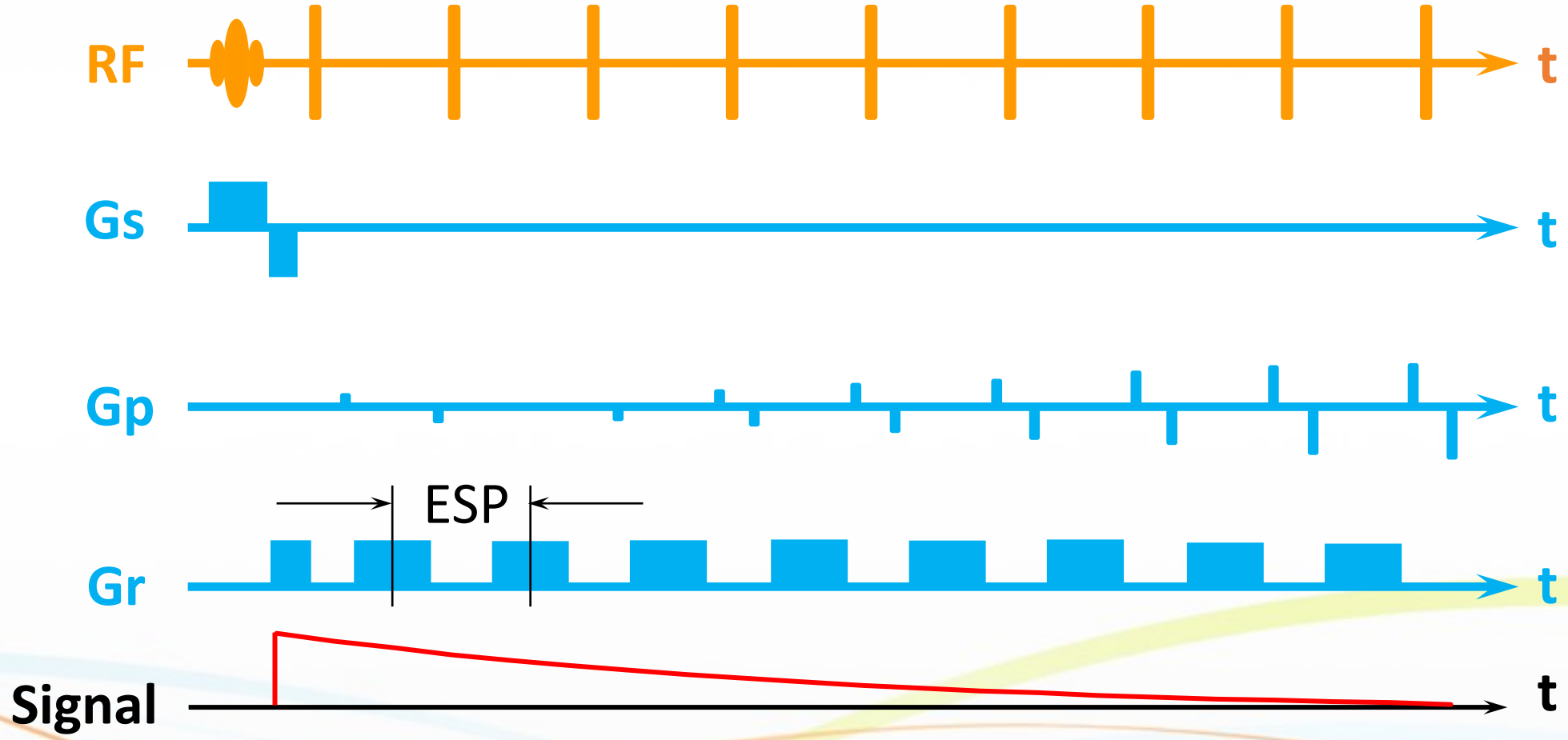


ETL = N_{PE} (TR = ?)

Feasibility of single-shot TSE

- Minimization of ESP
  - No more than 4 ms (usually 5-10 ms for 256 readout)
  - If ETL = 256, scan time = 1 sec
- Signals of most tissues are gone due to T2 decay
  - Except long-T2 tissue
- Using other techniques together to reduce ETL
  - Partial Fourier, parallel imaging, …

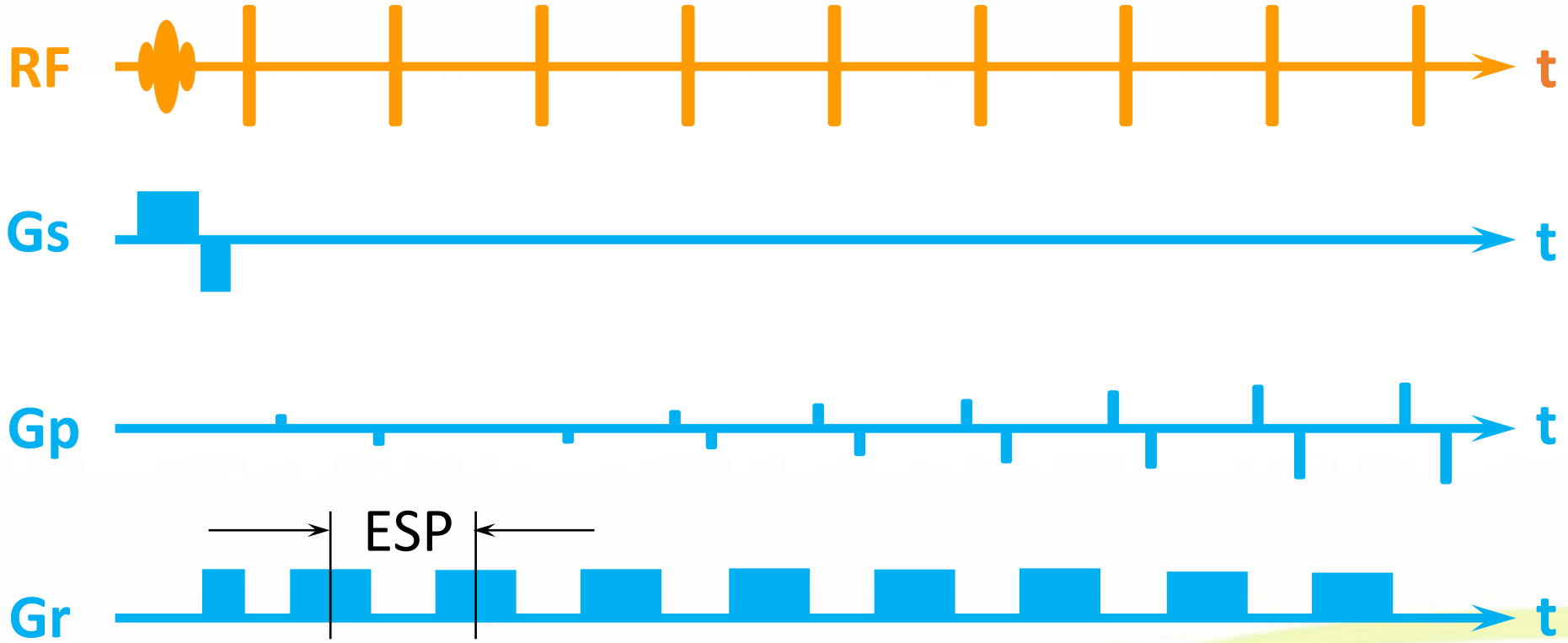
No signal for very late echoes



SAR concern of TSE

- Energy is transferred to human body during RF excitation
- RF energy is proportional to square of flip angle
  - 180° RF (inversion pulse) is 4 times of a 90° pulse and 36 times of a 30° pulse
- Specific Absorption Rate (SAR): the amount of energy deposited in tissues by RF irradiation

SAR concern of single-shot TSE



A lot of inversion pulses….

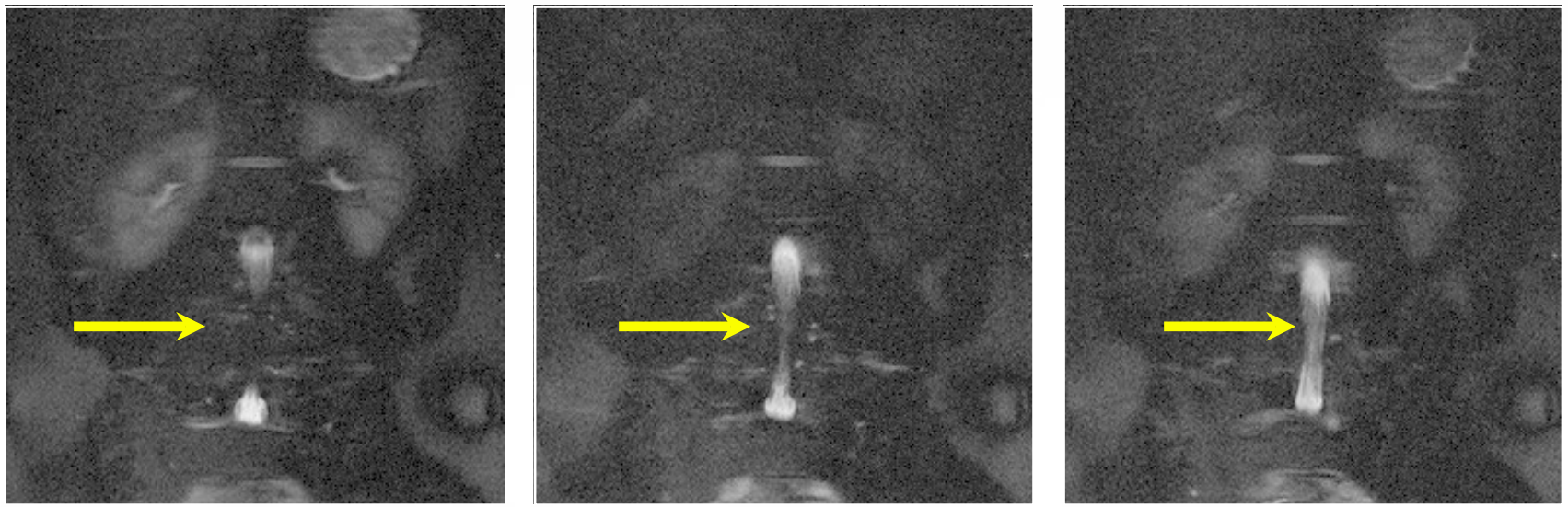
SAR concern of single-shot TSE

- High SAR during a short period of time could lead to heating of tissues.
  - Single-shot TSE is probably the worst scenario.
- Minimization of ESP?
  - ESP can not be too short due to limitation of SAR
- More severe at high fields
  - SAR is proportional to square of Larmor frequency

Applications of single-shot TSE

- Observation of long-T2 tissues
  - Spinal cord, biliary tract, pancreatic duct, …
- High risk of motion artifacts
  - Fetal imaging, gastrointestinal (GI) imaging, …

Observation of long-T2 tissues

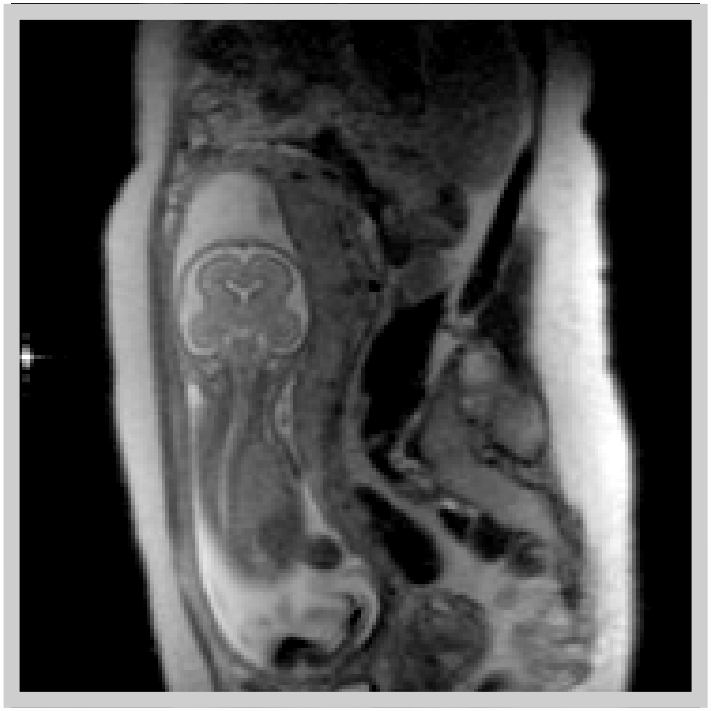


CSF in the spinal cord: long T2 tissue

Imaging of spinal cord

Strong T2W 2D images

1-sec fetal MRI



Siemens 1.5 Tesla
HASTE
ETL = 128
256 x 240
Scan time = 1 sec

22 weeks gestation

Free of fetal motion artifacts

HASTE

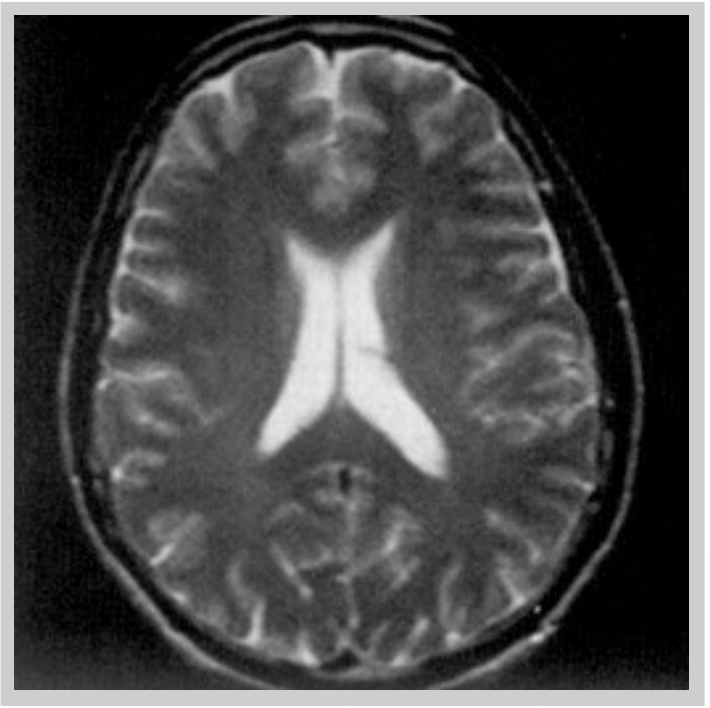
- Half-Fourier acquisition single-shot turbo SE
  - Siemens
- GE: single-shot fast spin-echo
- Half Fourier + SS-TSE = ultra short scan
- High SAR: 180°→130°

Multi-shot TSE

- Standard sequence for T2WI
  - Image behavior similar with conventional SE
  - Avoid susceptibility-induced signal loss in GE
- “Workhorse” in modern MRI
- Largely reduced scan time of single-slice image without significant sacrifice in image quality

T2WI of conventional SE and TSE

SE (TE = 100)

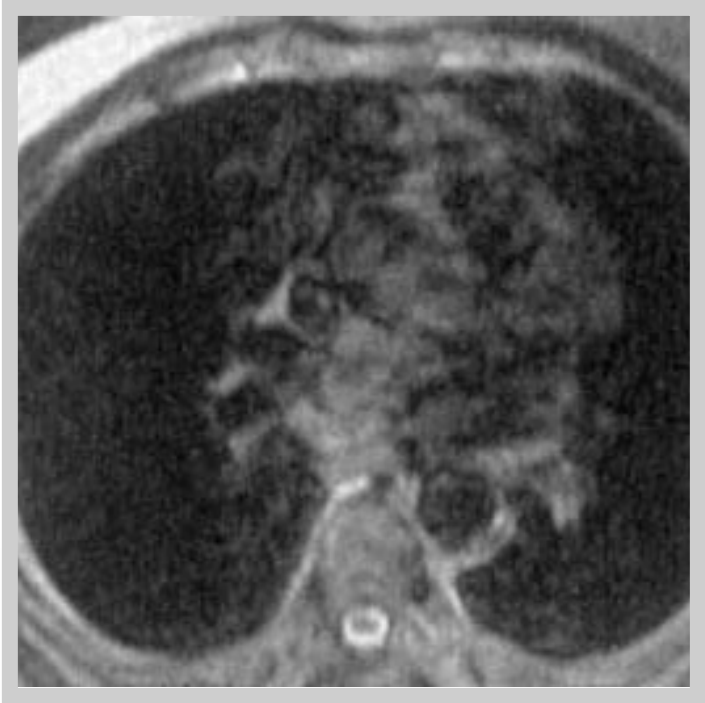


TSE (TE = 100)

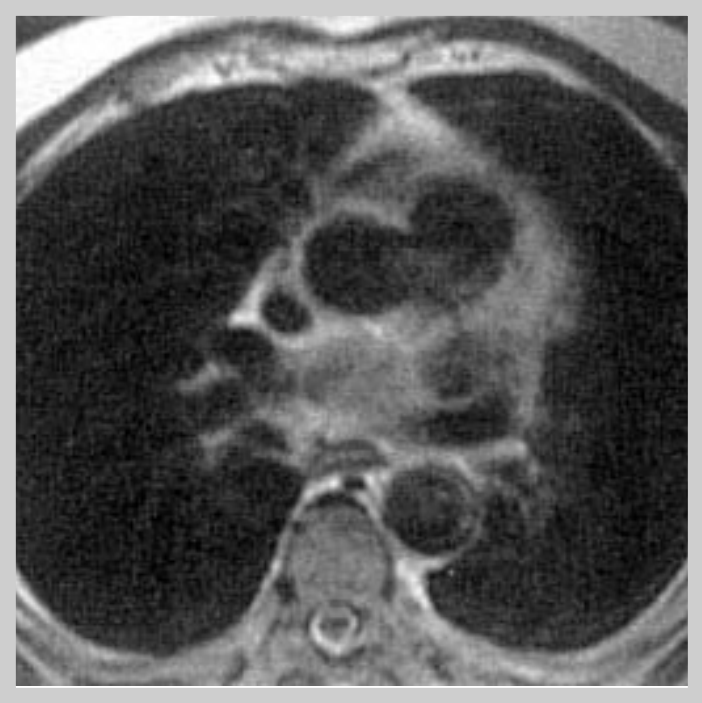
Advantages of rapid scan

- In addition to reduction of motion artifacts, the advantage of short scan time can be traded for…
  - Longer TR for better T1 recovery (SNR)
  - More number of averages (SNR)
  - Larger number of phase encoding (resolution)

Reduction of motion artifacts

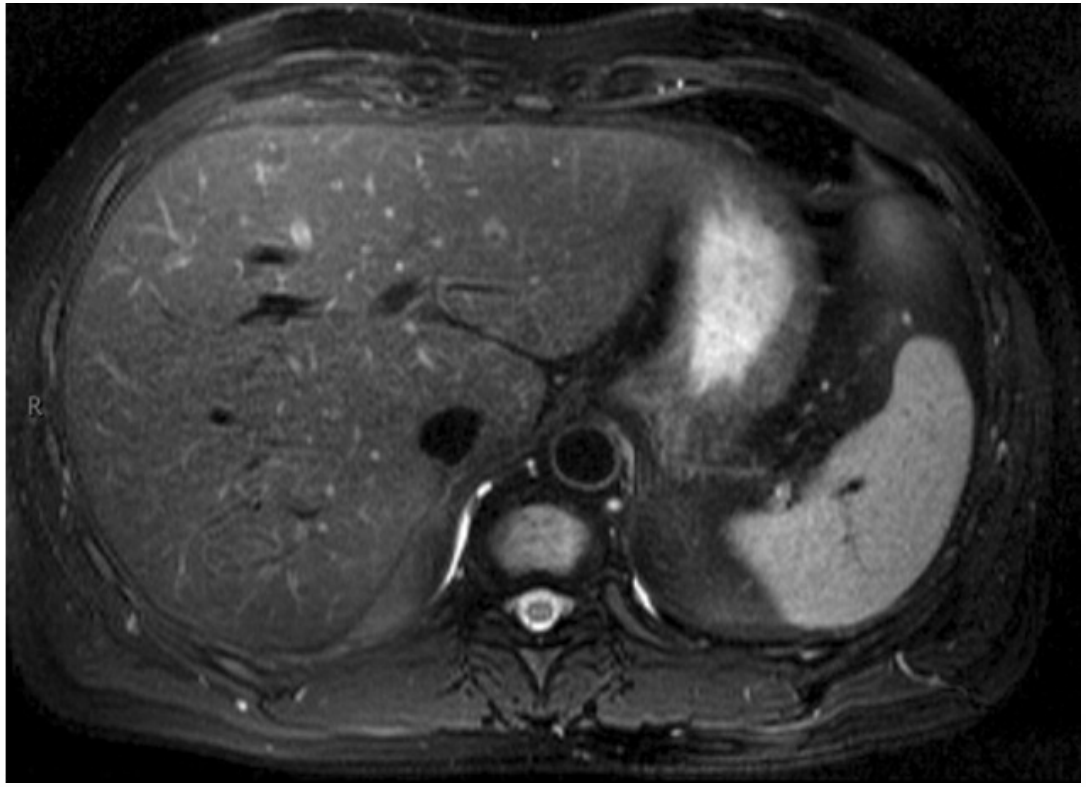


SE (ECG gating)



TSE (no gating)

High resolution in abdomen MRI



Siemens 1.5 Tesla
T2W TSE
TE = 80
ETL = 21
320 x 224
Respiratory gating
Scan time ~ 4 min

High SNR due to long TR

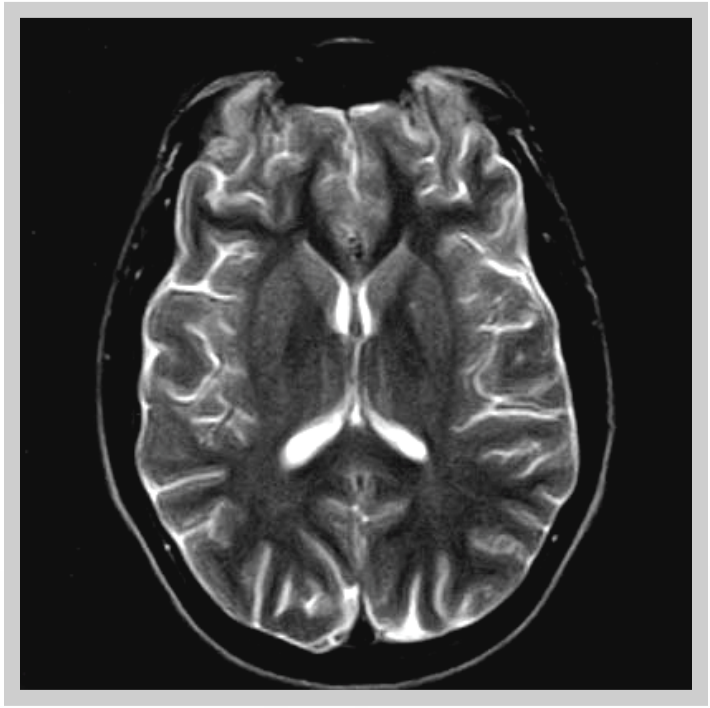
Siemens 1.5 Tesla
Turbo Spin-echo

512 matrix
3 mm slice

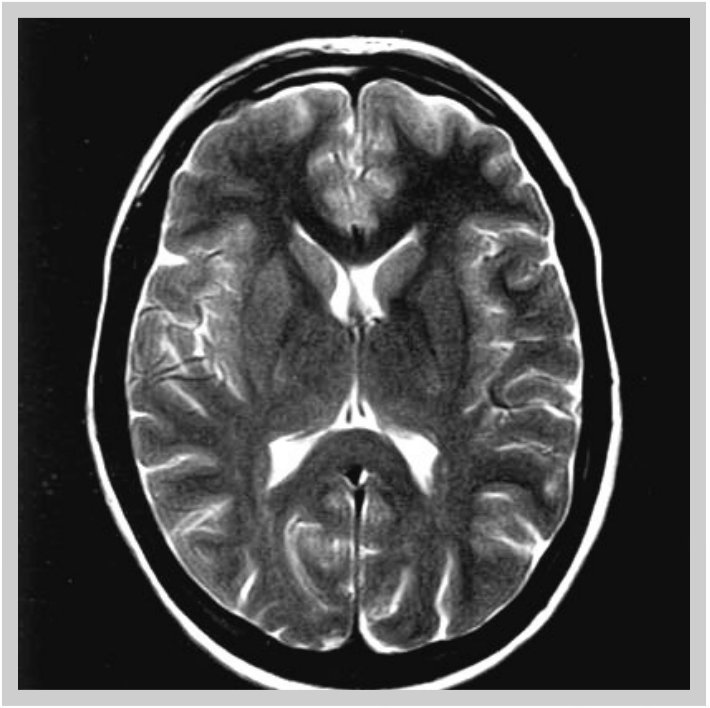
Scan time = 7 min

Bright CSF and high resolution helps enhancement of nerve roots

High resolution in brain MRI



256x256, 57 sec



512x512, 2m45s

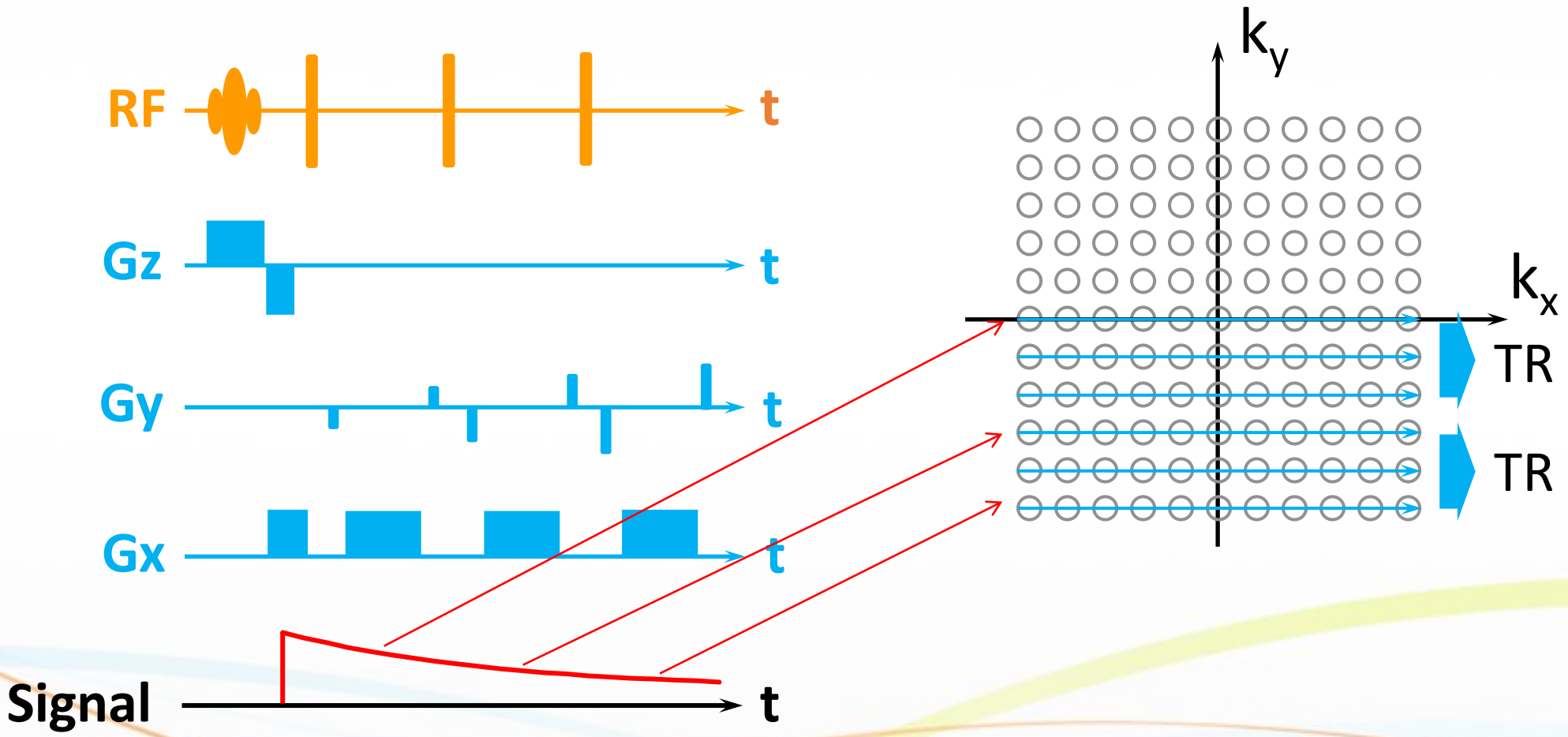
Other properties of TSE

- Compare with SE at the same TE
  - Brighter fat
  - Stronger magnetization transfer effects (MTC)
  - Decreased sensitivity to susceptibility
- No time to explain…

TSE-related artifacts

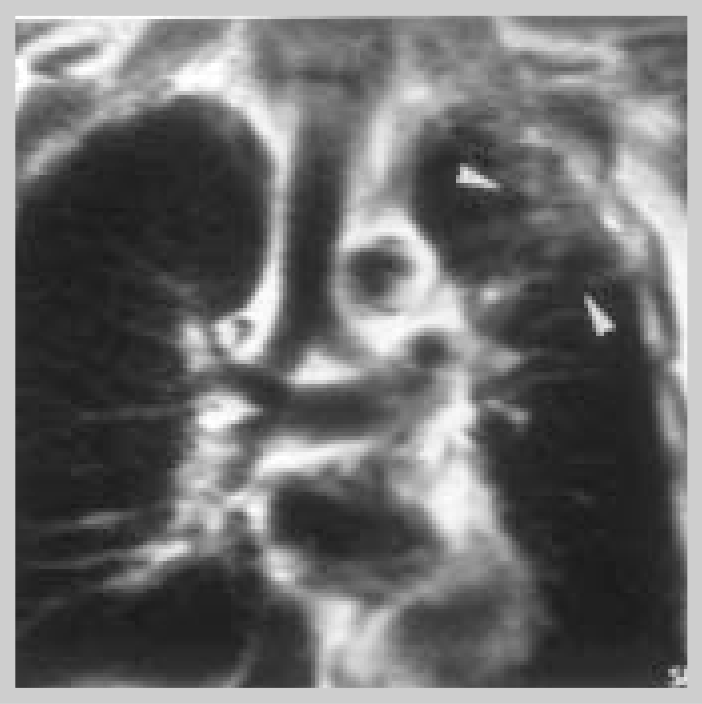
- Image blurring: phase encoding lines modulated by T2 decay
  - Especially when TE_{eff} is short
  - More blurring for long ETL and short-T2 tissues
- Pseudo-edge enhancement

Fill central k-space with early echo



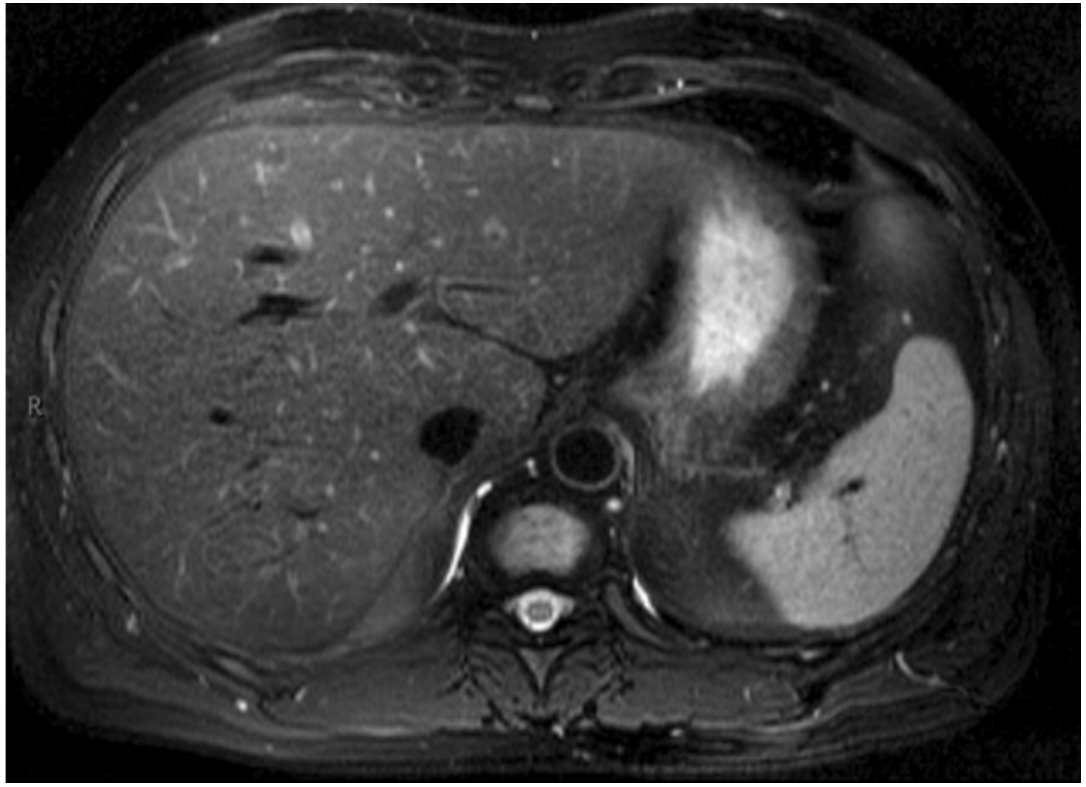
Comparison of blurring at different ETL

ETL 15 (ECG, BH, 14 sec)

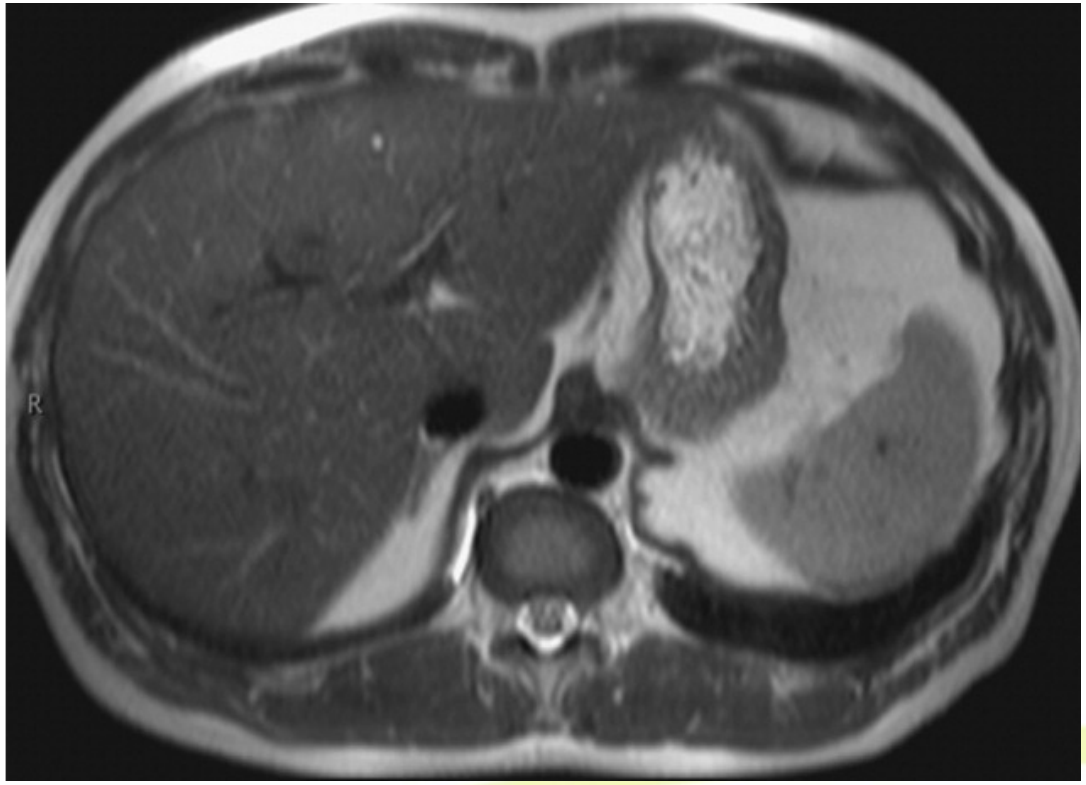


ETL 85 (0.4 sec)

Comparison of blurring at different ETL



Multi-shot TSE (ETL 21, Fat-SAT)



HASTE (ETL 80)

TSE/FSE