Al-Mustaqbal University

Biomedical Engineering Department

Class: 5th

Subject: Biomedical Instrumentation Design II

Lecturer: Mr. Mahir Rahman Al-Hajaj

1st term – Lect. 6: FSE

Email: mahir.rahman@uomus.edu.iq

MRI Design: 13. Conventional Spin Echo

- Pulse sequences: a series of RF pulses, gradient applications and intervening time intervals. All pulse sequences contain these elements. They differ only in the way they are coordinated and timed.
- Conventional spin echo (SE or CSE) pulse sequences are used to produce T1, T2 or proton density-weighted images and are one of the most basic pulse sequences used in MRI.
- In a spin echo pulse sequence, there is a 90° excitation pulse followed by a 180° rephasing pulse followed by an echo.

MRI Design: 13. Conventional Spin Echo

Mechanisms of CSE

- After the application of the 90° RF pulse, the magnetic moments of the spins lose precessional coherence, and this results in a decay of coherent magnetization in the transverse plane and the ability to generate a signal is lost.
- Magnetic moments that experience an increase in precessional frequency gain phase relative to those that experience a decrease in precessional frequency, which lag.
- A 180° RF pulse flips magnetic moments of the dephased spins through 180°. The rephasing of the fast and slow spins takes place.

MRI Design: 13. Conventional Spin Echo

Mechanisms of CSE

- The coherent signal in the receiver coil is regenerated and can be measured. This regenerated signal is called an **echo** and because an RF pulse has been used to generate it, it is specifically called a **spin echo**.
- Rephasing the spins eliminates the effect of the magnetic field inhomogeneities. Whenever a 180° RF rephasing pulse is applied, a spin echo results.
- Rephasing pulses may be applied either once or several times to produce either one or several spin echoes.

MRI Design: 13. Conventional Spin Echo

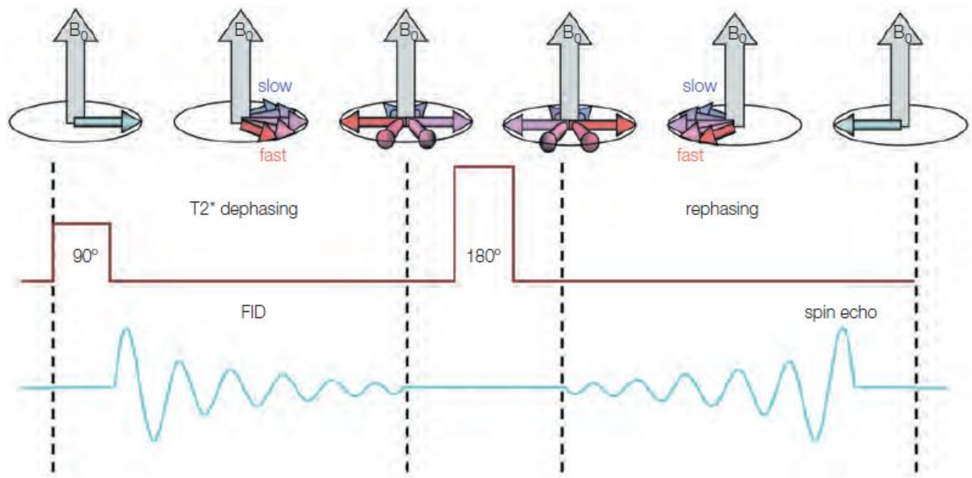


Figure 13.1 180° RF rephasing.

MRI Design: 13. Conventional Spin Echo

Contrast in CSE

CSE is usually used in one of two ways:

- A **single spin echo** pulse consists of a single 180° RF pulse applied after the excitation pulse to produce a single spin echo. This is a typical sequence used to produce a T1 weighted set of images.

- The **TR** is the length of time from one 90° RF pulse to the next 90° RF pulse in a particular slice. For T1 weighted imaging a short TR is used.
- The **TE** is the length of time from the 90° RF pulse to the midpoint or peak of the signal generated after the 180° RF pulse; that is, the spin echo. For T1 weighted imaging a short TE is used.

MRI Design: 13. Conventional Spin Echo

Contrast in CSE

.

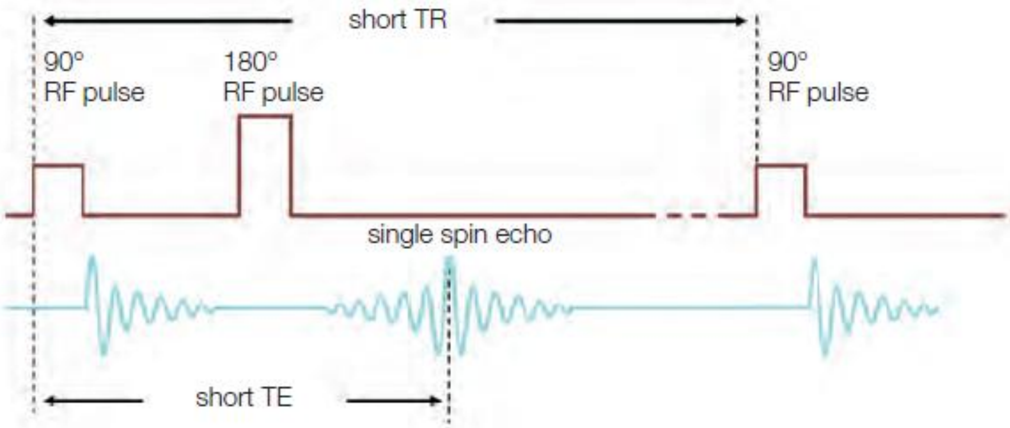


Figure 13.2 Single-echo spin echo sequence.

MRI Design: 13. Conventional Spin Echo

Contrast in CSE

CSE is usually used in one of two ways:

- A **dual-echo sequence** consists of two 180° pulses applied to produce two spin echoes. This is a sequence that provides two images per slice location: one that is proton density-weighted and one that is T2-weighted. The first echo has a short TE and a long TR and results in a set of proton density-weighted images.
- The second echo has a long TE and a long TR and results in a T2-weighted set of images. This echo has less amplitude than the first echo because more T2 decay has occurred by this point.

MRI Design: 13. Conventional Spin Echo

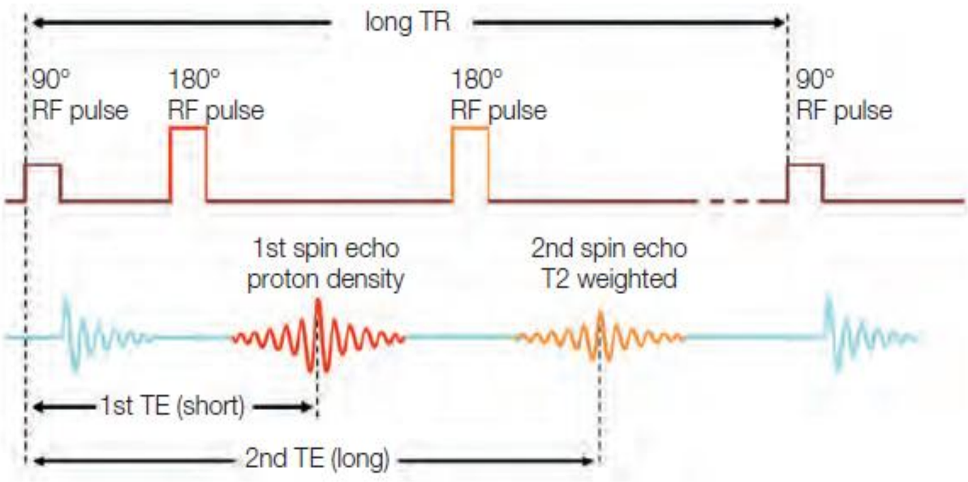


Figure 13.3 Dual-echo spin echo sequence.

MRI Design: 13. Conventional Spin Echo

Typical values

- Single echo (for T1 weighting): • TR: 400–700ms, • TE: 10–30ms
- Dual echo (for PD/T2 weighting): • TR: 2000+ms, • TE1: 20ms, • TE2: 80ms

Table 13.1 Advantages and disadvantage of conventional spin echo.

Advantages	Disadvantage
Good image quality Very versatile True T2 weighting Available on all systems Gold standard for image contrast and weighting	Long scan times

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- Fast or turbo spin echo (FSE or TSE) is a much faster version of CSE, and sometimes called a rapid acquisition with relaxation enhancement ***(RARE)*** sequence.
- In spin echo sequences, one phase encoding only is performed during each TR. The scan time is a function of TR, NSA (***number of excitations (NEX)***, also known on some systems as the ***number of signals averaged (NSA)***, is an important determinant of SNR) and phase matrix.
- To speed up a conventional sequence, TSE performs the same number of phase encodings, thereby maintaining the phase matrix and resolution, but more than one phase encoding is performed per TR, reducing the scan time.

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- TSE employs a train of 180° rephasing pulses, each one producing a spin echo. This train of spin echoes is called an **echo train**. The number of 180° RF pulses and resultant echoes is called the **echo train length (ETL)** or **turbo factor**. The spacing between each echo is called the **echo spacing**.
- After each rephasing, a phase-encoding step is performed and data from the resultant echo is stored in a different line of K space (k-space is an array of numbers representing spatial frequencies in the MR image).

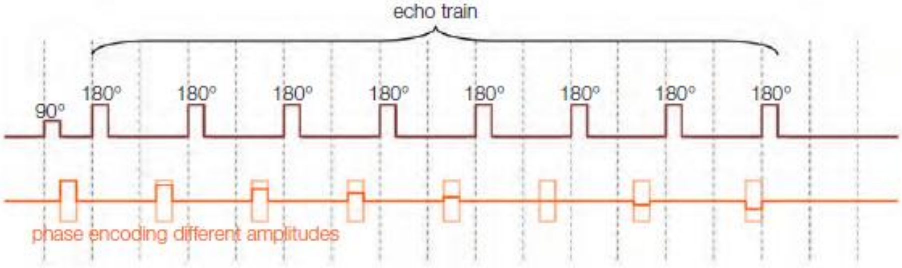


Figure 14.1 The echo train in TSE.

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- Typically, 2 to 30 180° RF pulses are applied during every TR. As several phase encodings are also performed during each TR, several lines of K-space are filled each TR and the scan time is reduced.
- The *higher* the turbo factor the *shorter* the scan time.
- Scan time = TR x number of phase-encoding steps x number of excitations (NSA).

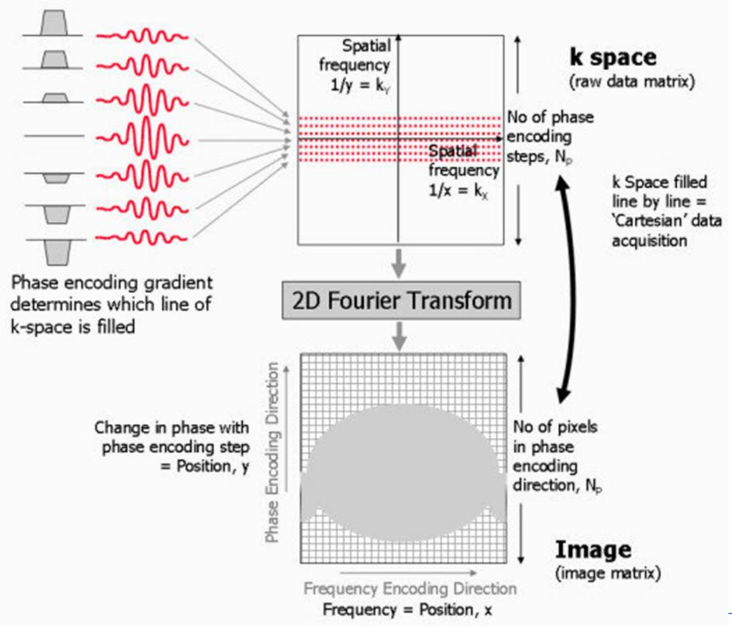
Table 14.1 TSE time-saving illustrations.

Pulse sequence	Scan time
SE, 256 phase encodings, 1NSA	$256 \times 1 \times TR = 256 \times TR$
TSE, 256 phase encodings, 1 NSA, ETL 16	$256 \times 1 \times TR/16 = 16 \times TR$

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- Each echo has a different TE, and data from each echo is used to produce one image.
- This is different from CSE, where several echoes may be generated with a different TE but each echo is used to produce a different image.
- In TSE, multiple echoes with a different TE are used to produce the same image. This would normally result in a mixture of weighting. In TSE, this problem is overcome by using **phase reordering**.
- In any sequence, each phase-encoding step applies a different slope of phase gradient to phase shift each slice by a different amount. This ensures that data is placed in a different line of K space.
- The phase-encoding gradient is reversed prior to each excitation pulse to rephase the spins and shorten the sequence time.

MRI Design: 14. Fast or turbo spin echo FSE or TSE



MRI Design: 14. Fast or turbo spin echo FSE or TSE

- Generating MR an image from the raw data through k-space mapping and Fourier transformation.
- **Phase Encoding and Spatial Frequency:**
- The MRI scanner applies a phase encoding gradient, which determines which line of k-space (a 2D data matrix) is filled during acquisition. This gradient varies in intensity for each step, encoding spatial position information along the y-axis.
- K-space stores data points based on spatial frequency in two directions: 1/y along the phase-encoding direction and 1/x along the frequency-encoding direction. The number of phase encoding steps (N_p) affects the resolution along the phase encoding direction.

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- Generating MR an image from the raw data through k-space mapping and Fourier transformation.
- **Phase Encoding and Spatial Frequency:**
- **Data Collection in K-space:**
- K-space is filled line by line in a Cartesian (rectangular grid) manner during acquisition, where each line corresponds to a different phase encoding level.
- Each line in k-space represents a set of spatial frequency data, which, when combined, contains all the information needed to form an image.

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- Generating MR an image from the raw data through k-space mapping and Fourier transformation.
- **Phase Encoding and Spatial Frequency:**
- **2D Fourier Transform:**
- After collecting all necessary lines in k-space, a 2D Fourier Transform is applied to convert the frequency data into spatial information.
- The Fourier transform translates the frequency and phase information from k-space into pixel intensities in the final image.

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- Generating MR an image from the raw data through k-space mapping and Fourier transformation.
- **Phase Encoding and Spatial Frequency:**
- **Image Formation:**
- The final output is an image matrix, where each pixel represents a specific position in the scanned area.
- The number of pixels in the matrix along both the frequency encoding and phase encoding directions determines the spatial resolution of the image.

The process of creating an MR image involves mapping spatial frequencies into k-space, transforming this frequency data into spatial domain information, and then creating a detailed MRI image.

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- The very *steep* gradient slopes significantly *reduce the amplitude* of the resultant echo/signal, because they reduce the rephasing effect of the 180° rephasing pulse.
- *Shallow* gradients, on the other hand, do not have this effect and the *amplitude of the resultant echo/signal is maximized*.

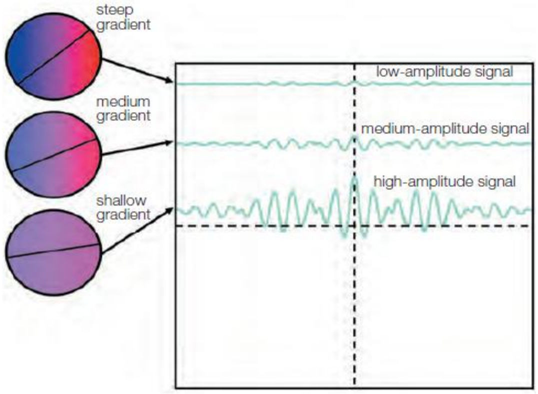


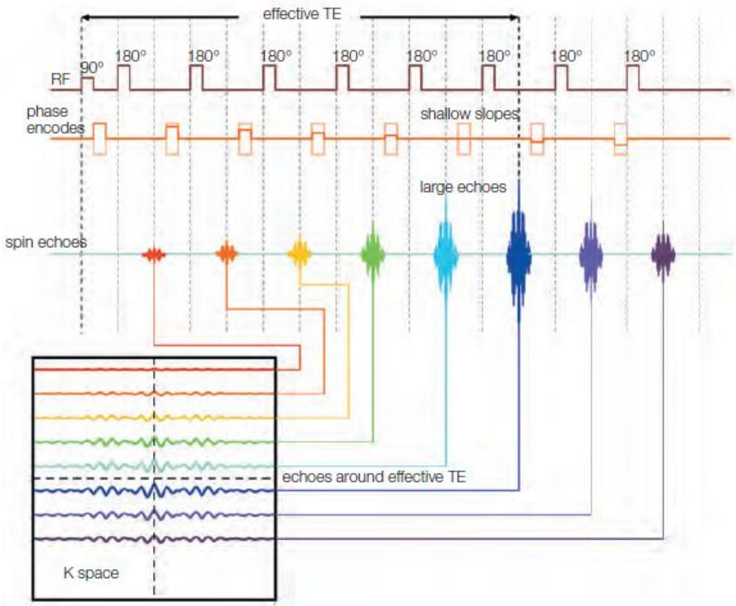
Figure 14.2 Phase encoding versus signal amplitude.

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- When **effective TE** is selected, the resultant image must have a weighting corresponding to that TE; that is, if the TE is set at 102 ms a T2 weighted image is obtained (assuming the TR is long).
- The system orders the phase encodings so that:

  - most signals (the shallowest ones) are used on echoes produced from 180° pulses nearest to the effective TE selected.
  - The steepest gradients (which reduce the signal) are reserved for those echoes that are produced by 180° pulses furthest away from the effective TE.
  - Therefore, the resultant image is mostly made from data acquired at approximately the correct TE, although some other data is present.

MRI Design: 14. Fast or turbo spin echo FSE or TSE



MRI Design: 14. Fast or turbo spin echo FSE or TSE

- **How k-space data is filled over time to create an image?**
- **RF Pulses and Spin Echoes:**
- The sequence begins with a 90° RF pulse, followed by multiple 180° RF refocusing pulses.
- Each 180° pulse generates a spin echo, with echo amplitudes varying depending on the timing and the gradient settings.
- **Phase Encoding and Gradient Slopes:**
- A phase encoding gradient is applied after each RF pulse, with a different slope for each echo. This gradient changes the position in k-space that each echo corresponds to, effectively encoding spatial information.
- Shallow slopes in the gradient produce smaller phase shifts, filling the center of k-space, where large echoes (blue and purple) are located. These center echoes contribute to image contrast.

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- **How k-space data is filled over time to create an image?**
- **Effective Echo Time (TE):**
- The effective TE is the central time point where the strongest signal (largest echo) is obtained, shown by the largest echo in blue. This point is critical in defining the overall contrast of the image.
- **Filling K-Space:**
- The k-space is filled over time. Each echo, from different phase-encoding gradients, fills a separate line of k-space.
- The largest echo around the effective TE contributes the most signal strength to the center of k-space, impacting contrast, while other echoes fill peripheral areas, contributing to resolution.

How varying gradient slopes and refocusing pulses create spin echoes that fill k-space line by line, forming the basis of MRI image data.

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- The contrast of TSE is unique!!!
  - In T2 weighted scans, water and fat are hyperintense (bright). Why?
  - Muscle is often darker than in conventional spin echo T2 weighted images. Why?
- When used with a very long echo train and long TE, TSE can sometimes result in images that are blurred. Why?
- Extending the TR lengthens the scan time, but this is more than compensated for by the use of long echo trains. Discuss !

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- The TSE produces T1, T2 or proton density scans in a fraction of the time of CSE.
- Since the scan times are reduced, phase matrix size can be increased to improve spatial resolution.
- TSE is normally used in the brain, spine, joints, extremities and pelvis.
- As TSE is incompatible with phase-reordered respiratory compensation techniques, it can only be used in the chest and abdomen with respiratory triggering, breath-hold or multiple NSA.

MRI Design: 14. Fast or turbo spin echo FSE or TSE

- Using very long TEs and TRs permits very heavy T2 weighting (watergrams) that is used in, e.g., gallbladder imaging, where only signal from bile in the biliary system is seen.
- Systems that have sufficiently powerful gradients can use TSE in a single-shot mode (SS_TSE) or half Fourier single-shot TSE (HASTE) to permit image acquisition in a single breath-hold. In addition, using very long TEs and TRs permits very heavy T2 weighting (watergrams). An example of this technique is in gallbladder imaging, where only signal from bile in the biliary system is seen. Table 15.2 lists some advantages and disadvantages of TSE.

28

THANK YOU