Pulse Sequence Design Made Easier…

1

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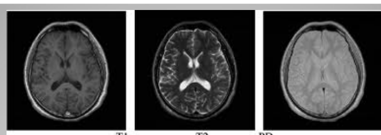
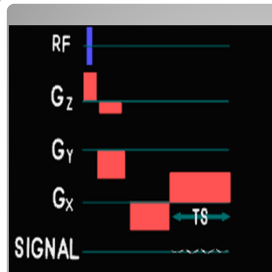
2



- A pulse sequence is a timing diagram designed with a series of RF pulses, gradients switching, and signal readout used in MR image formation.

Pulse Sequence Design Made Easier…

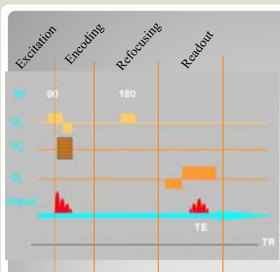
3



- Pulse Sequences generally have the following characteristics:
- An RF line characterizing RF Pulse applications
- Gradients switching to encode the volume for spatial localization
- Signal reception used to create MR image

Pulse sequence components

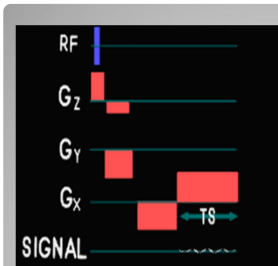
4



- There are four processes in pulse sequence design:
- Excitation
  - RF pulse(s) is/are applied
- Encoding
  - Phase encoding is performed to determine how K-space is filled
- Refocusing
  - Refocusing Net Magnetization back into transverse plane
- Readout
  - Signal is encoded and recorded

Pulse sequence processes

5

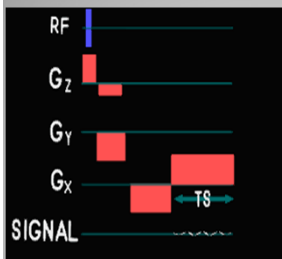


- This is a timing diagram. All lines are read left to right and top to bottom simultaneously.
- Above line is positive direction.
- Below line is negative direction.
- The RF line characterizes RF pulse applications. The height and width of the pulse determines how much (watts) and how long the pulse is applied.
- Gradients are switched on and off to spatially localize the volume or the slice for image reconstruction.
- Gradients are switched on and off for:
  - Slice Selection
  - Phase Encoding
  - Frequency Encoding or Readout

Pulse Sequence Guidelines

6

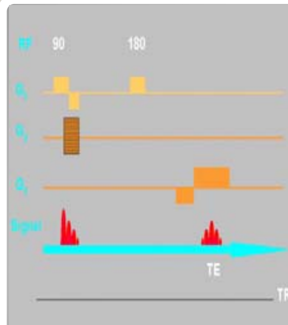
Pulse Sequence Guidelines



- The gradient on while the RF is applied is the Slice Select Gradient.
- The gradient on while the signal is received or recorded is the Frequency Encoding or Readout Gradient.
- The gradient that changes amplitude per TR and on prior to refocusing is the Phase Encoding Gradient.

7

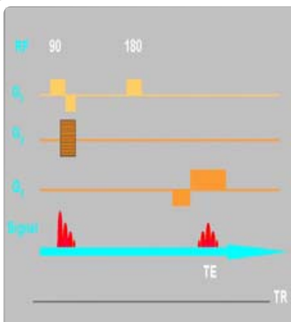
Pulse Sequence Quiz



- Which gradient is the slice select gradient?
  - ?

8

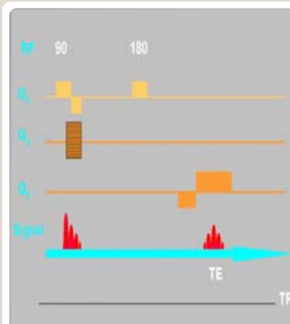
Pulse Sequence Quiz



- Which gradient is the slice select gradient?
  - **Gz**

9

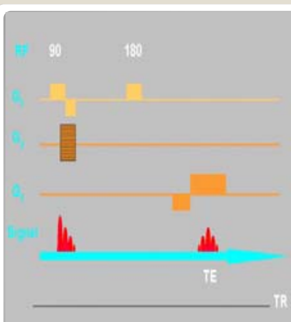
Pulse Sequence Quiz



- Which gradient is the slice select gradient?
  - Gz
- Which gradient is the phase encoding gradient?
  - ?

10

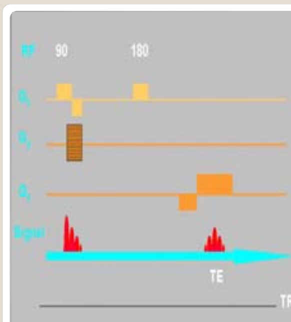
Pulse Sequence Quiz



- Which gradient is the slice select gradient?
  - Gz
- Which gradient is the phase encoding gradient?
  - **Gy**

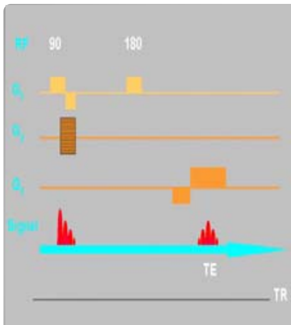
11

Pulse Sequence Quiz



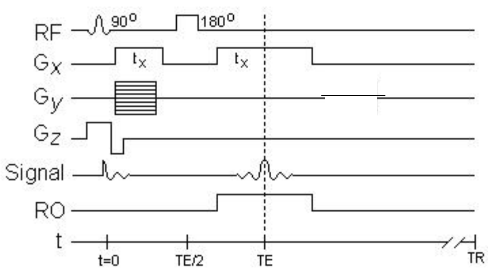
- Which gradient is the slice select gradient?
  - Gz
- Which gradient is the phase encoding gradient?
  - Gy
- Which gradient is the frequency encoding gradient?
  - ?

12

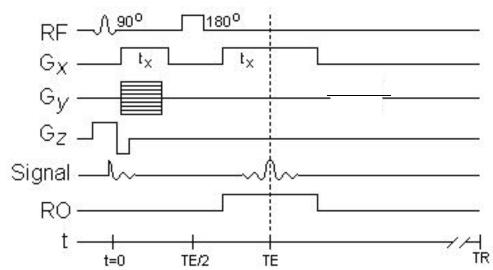


- Which gradient is the slice select gradient?
  - Gz
- Which gradient is the phase encoding gradient?
  - Gy
- Which gradient is the frequency encoding gradient?
  - **Gx**

Pulse Sequence Quiz



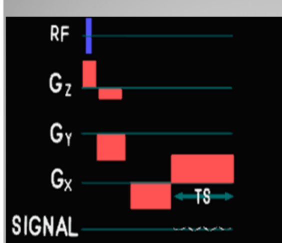
What slice orientation will the images created from this pulse sequence have?



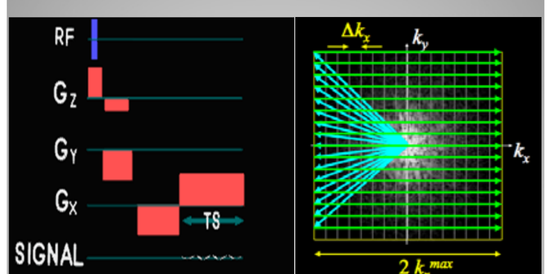
What slice orientation will the images created from this pulse sequence have? **AXIALS**

(Gz - is the slice select gradient)

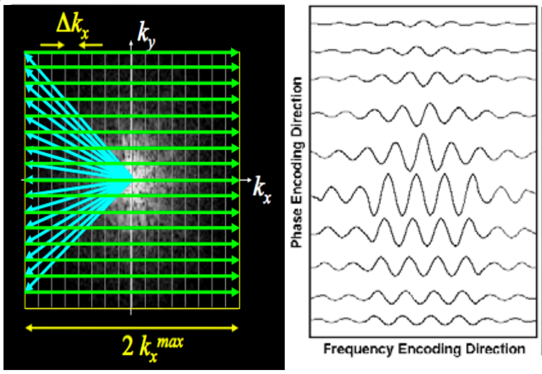
More on Phase Encoding…



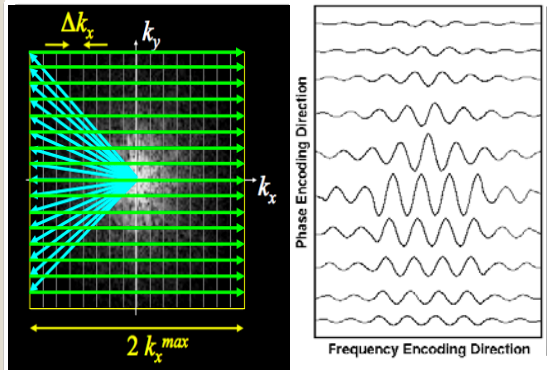
- Phase encoding is performed to provide spatial localization and to guide k-space filling.
- What do you notice about the phase encoding gradient?



Phase amplitude changes every TR

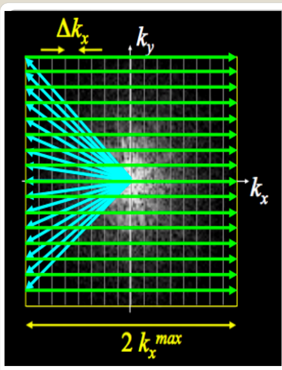


Each amplitude designates another line in k-space



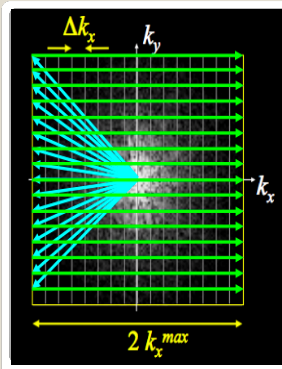
What do you notice about the signal as gradient changes?

20



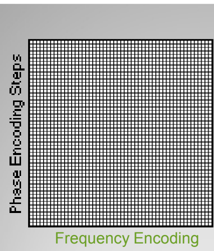
- Signal gets stronger with low amplitude gradients (shallow).
- The signal gets weaker with high amplitude gradients (steeper).

21



- Outer lines of K-space, use high amplitude gradients which yield low signal return.
- Center lines of K-space use low amplitude gradients which yield high signal return.
- Outer lines reconstructed yield spatial resolution.
- Center lines reconstructed yield signal (S/N) and contrast.

22



High Spatial Resolution

High S/N and Contrast

High Spatial Resolution

K-Space Filling

23

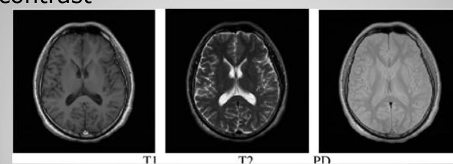
24

Conventional Pulse Sequences

- There are three conventional pulse sequence designs.
  - Spin Echo
  - Gradient Recalled Echo
  - Inversion Recovery

Spin Echo Pulse Sequence (SE)

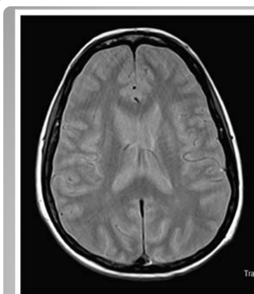
- Spin Echo pulse sequences begin with a 90° RF pulse followed by at least one 180° RF pulse.
- Produces T1-, T2-, and PD-wt. type tissue contrast



SE T1-weighted

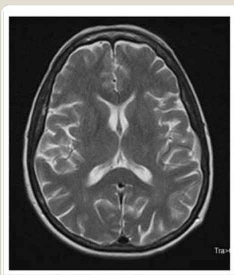
- Image parameters
  Short TR - contrast
  Short TE - signal
- Image Contrast
  Bright Fat - short T1
  Dark CSF - long T1

SE Double Echo Proton Density



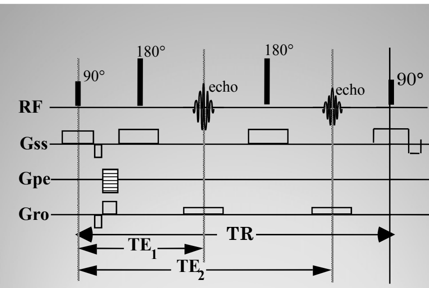
- Image Parameters
  Long TR - signal
  Short TE - signal
- Image Contrast
  Bright or Gray Fat
  Gray CSF
- Contrast based on proton concentration

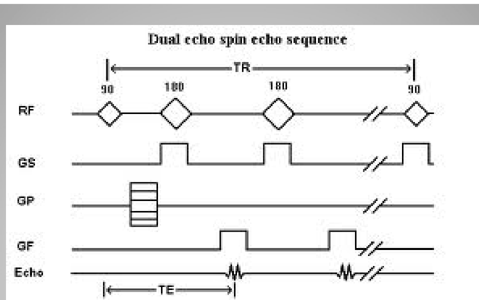
SE Double Echo T2-weighted



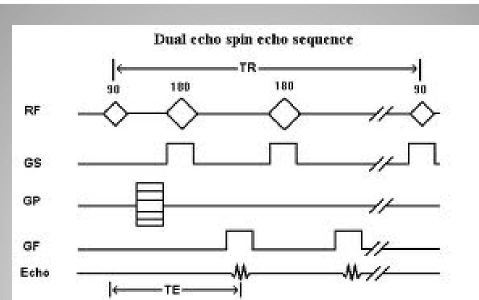
- Image Parameters
  Long TR - signal
  Long TE - contrast
- Image Contrast
  Dark Fat – short T2
  Bright CSF – Long T2

Conventional Spin Echo Diagram

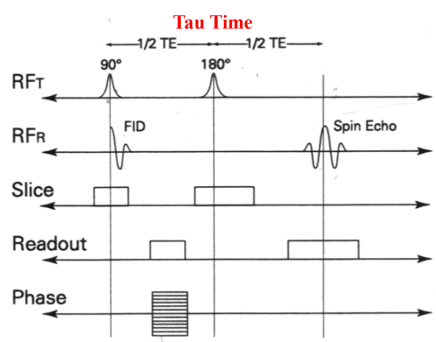




Which two processes are repeated in a Dual SE Sequence?

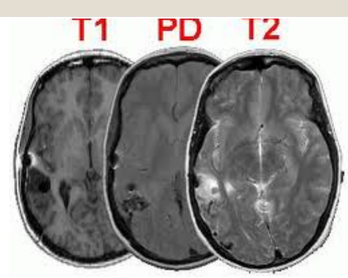


Which two processes are repeated in a Dual SE Sequence? **Refocusing and Readout**



Effects of the 180⁰ Pulse

- eliminates signal loss due to field inhomogeneities
- eliminates signal loss due to susceptibility effects
- eliminates signal loss due to water/fat dephasing
- all signal decay is caused by T2 relaxation only



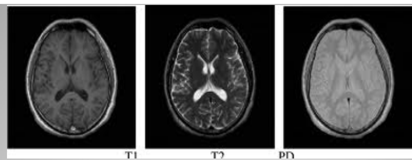
Spin Echo Parameters

T1 is TR Dependent

PD is TR and TE Dependent

T2 is TE Dependent

Spin Echo Parameters that manipulate Tissue Characteristics

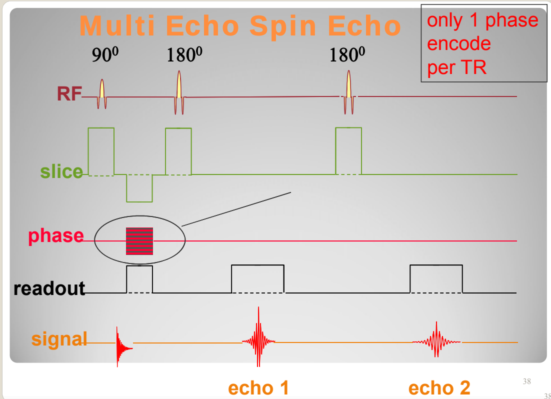


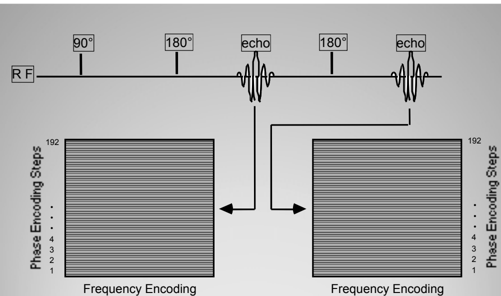
ST = TR(msec) x Npe x NEX /60,000(msec)

ST: Scan time in minutes
Npe: Number of phase steps
NEX: Number of acquisitions, NAQ, NEX, NSA

2DFT Scan Time Formula

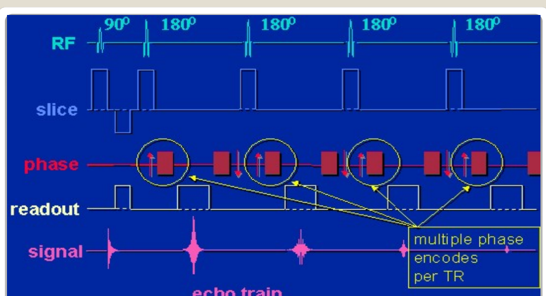
Multi Echo Spin Echo



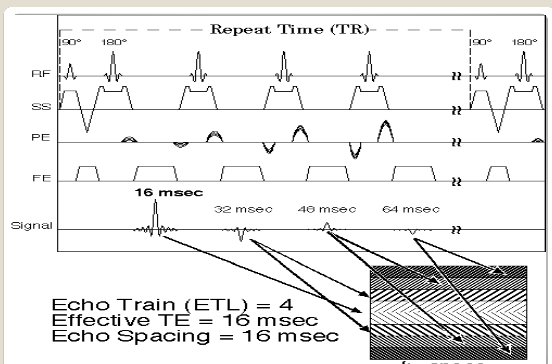


- First developed as the RARE (Rapid Acquisition with Relaxation Enhancement) method.
- A 90° pulse initiates the sequence, followed by multiple 180° pulses to generate multiple echoes.
- However separate phase encodes are used prior to each echo to fill k-space more rapidly.

Fast Spin Echo



Fast Spin Echo Pulse Diagram



Fast Imaging Parameters

Parameter Acronyms
- ETE
- ETL or Turbo Factor
- ETS

Terminology
- Effective TE
  - The TE placed in portion of k-space with greatest impact on signal.
- Echo Train Length
  - Number of Echoes acquired per TR
- Echo Train Spacing
  - Time (msec) between echoes in Echo Train

Fast Imaging Parameters

- ETE
  - Selectable and determines TE in center of k-space.
  - Therefore determines image contrast.
- ETL
  - Selectable and determines number of echoes acquired per TR.
  - Determines how fast sequence is run; higher the ETL the shorter the scan time.
  - Higher ETL reduce time for slices.
- ETS
  - Not selectable; higher spacing leads to blurriness.

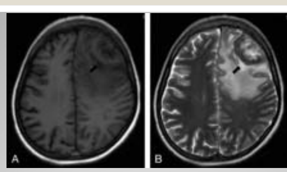
Fast or Turbo SE Guidelines

- Optimal TR is 2000 – 4000msec
  - or longer so magnetization fully recovers.
  - Longer TR's allow more signal and slices.
- Shorter TR (<2000msec) image not T2-weighted even though CSF is bright.
  - Too much T1 contrast added to the image.
- ETE time is long >80msec.
  - Longer ETE's are allowed due to longer TR (signal)

Single Shot FSE concept

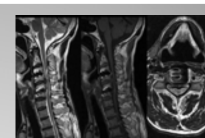
- Single shot FSE or TSE acquires 53% of k-space and reconstructs in Half-Fourier algorithm to achieve final resolution.
- Allows T2-wt studies with reduced motion artifacts and low susceptibility.
- Adaptable for breath hold exams and uncooperative patients.

Fast Imaging Scan Time Formula



$$\text{Scan Time (Minutes)} = \frac{TR(msec) \times Npe \times NEX}{60{,}000(msec) \times ETL}$$

SE & FSE Contrast Parameter Guidelines



TE	TR	WEIGHTING
short	short	T1
long	long	T2
short	long	Proton density

Vendor Terminology

- **Spin Echo**

All vendors use Spin Echo designation

- **Fast Imaging T2**

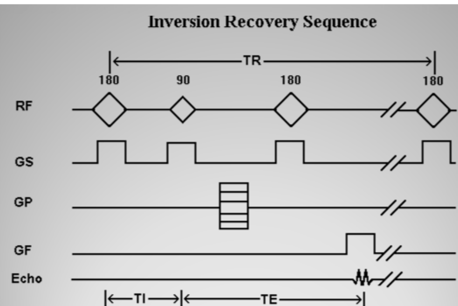
Siemens:	Turbo Spin Echo
GE:	Fast Spin Echo
Hitachi:	Fast Spin Echo
Philips:	Turbo Spin Echo
Picker:	Fast Spin Echo
Toshiba:	Fast Spin Echo

- **Single Shot SE**

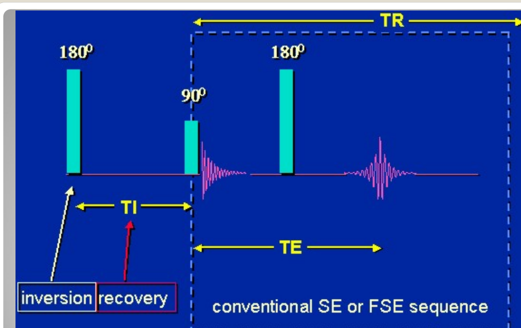
Siemens:	HASTE
GE:	SSFSE
Hitachi:	SSFSE
Philips:	SSTSE
Picker:	EXPRESS
Toshiba:	FASE

- **FSE w / 90°Flip-Back**

Siemens:	RESTORE
GE:	FRFSE
Hitachi:	Driven Equilibrium
Philips:	DRIVE
Toshiba:	FSE T2 puls

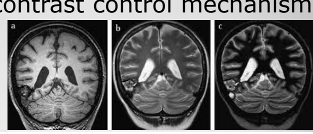


Inversion Recovery Sequence



Inversion Spin Echo Diagram

- Inversion Recovery pulse sequences are highly sensitive to differences in T1 values of tissues.
- Especially useful where T1 values are similar.
- The primary contrast control mechanism is TI.

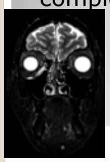


Inversion Recovery

- **TI, Time of Inversion**, is the length of time net magnetization is allowed to recover before starting the 90° RF pulse (Spin Echo).
- **STIR, Short TI or Tau Inversion Recovery**, sequences are created by shortening the TI time to 69% of T1 relaxation of fat for fat suppression.
- **FLAIR, Fluid Attenuated Inversion Recovery**, sequences are created by lengthening the TI time to 69% of T1 relaxation of water for water suppression.

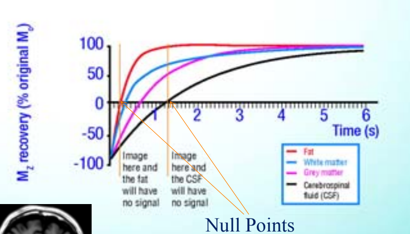
Inversion Recovery

- The effect of inverting the magnetization vector by the 180° RF pulse allows for the tissues dynamic range to be increased.
- The magnitude of magnetization M is a function of time after a 180° pulse.
- Magnetization starts negative (-Z), passes through zero at t = .69 T1 and recovers completely by t = 5T1.



Null Point – Suppression Point

- Suppression occurs at the tissue's NULL POINT.
- Null point is the point at which net magnetization crosses the transverse plane.
- The Null point is approximately 69% of the T1 of the tissue to be suppressed.



IR Parameter Guidelines

Desired Contrast	Inversion Time (TI)
Heavily T1-wt	TI is approx. ¼ TR
STIR (Fat Suppressed)	85 – 250msec
FLAIR (Water Suppressed)	1900 - 2500msec

T2 FSE and T2 STIR

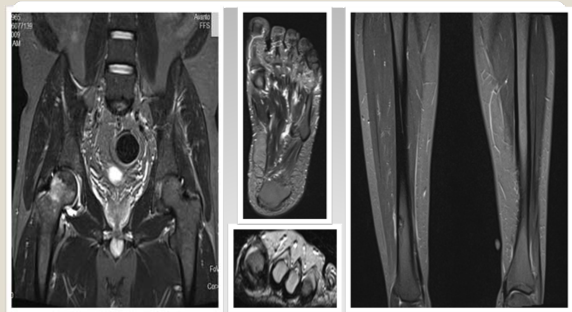
STIR Parameter Guidelines

- TE long 50 - 80msec
- TR long 4000 – 10,000msec
- ETL 16 – 20
- TI null point of fat

STIR Imaging Guidelines

- STIR should not be used with contrast because STIR will suppress both the fat and the contrast.
- Useful in MSK imaging – normal bone is fatty marrow – bone bruises and fractures are clearly seen.

STIR Images - MSK

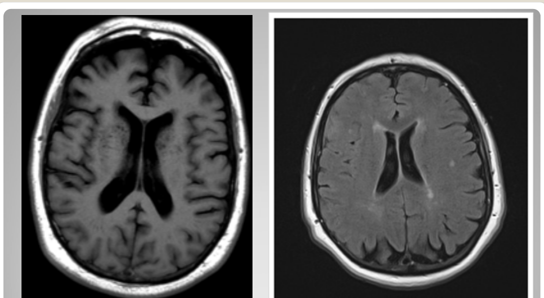


Fluid Attenuated IR

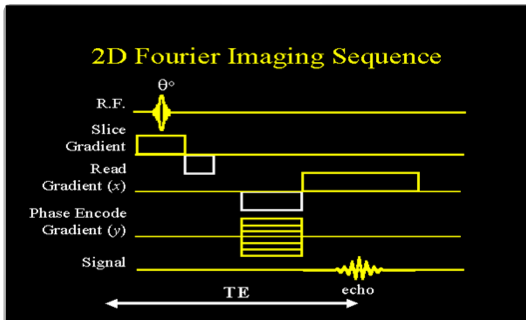
- Helps visualize stroke.
- Helps in determining Multiple Sclerosis
- Achieves suppression of CSF.

Fluid Attenuated IR Parameters

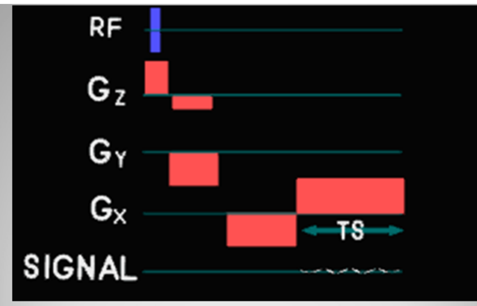
- Long TE, Long TR, Long ETL
- TI/TAU time of 1700 - 3200msec (depending on magnetic field strength)
- Used in brain and cord imaging – see periventricular and cord lesions more clearly



FLAIR Axial Brain



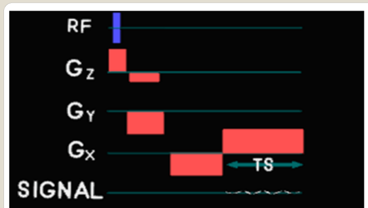
Gradient Recalled Echo Diagram (Static)



Gradient Recalled Echo Diagram (Dynamic)

Gradient Recalled Echo (GRE)

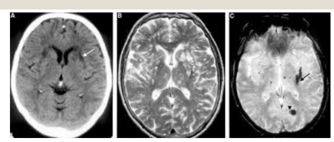
- In Gradient Recalled Echo, a reversed gradient technique refocuses the spin phases.
- Flip angles less than 90° are optimized to enhance T1 or T2 tissue-like contrast (T2*).
- Flip angles less than 90°, flip some component of longitudinal magnetization vector into the transverse plane, while portions remain.



Gradient Echo sequences show a wide range of variations compared to the Spin Echo and Inversion Recovery sequences.

Gradient Reversal

- The major benefit is the use of the gradients to refocus the net magnetization instead of an RF pulse.
- A gradient reversal in the readout direction is used to create the echo.
- Spins will either speed up or slow down pending the gradient influence.
- This is different from the 180° RF pulse which flips the spins for refocusing.

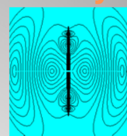


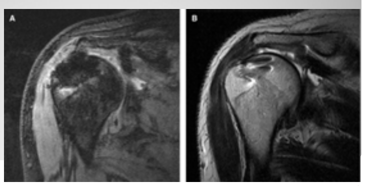
The spins are refocused by reversing the speed of the spins rather than flipping them over to the other side of the x-y plane as occurs with the spin echo sequence.

Magnetic susceptibility artifacts are more pronounced on gradient echo sequences.

Magnetic Susceptibility

- Magnetic susceptibility, caused by protons of one tissue precessing faster than the protons of an adjacent tissue, is exaggerated due to the affect the spins have on each other while under the influence of the reversed gradient.





- The MR signal returned is due primarily to T1 longitudinal magnetization.
- The MR signal returned is also due to faster T2 relaxation rates due to field inhomogeneities.
- The information is therefore T2* information, which is T2 relaxation due to magnetic field inhomogeneities as well as tissue characteristics.

Gradient Recalled Echo (GRE)

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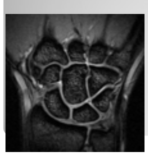
short FA	T2*-weighted
medium FA	PD-weighted
long FA	T1-weighted

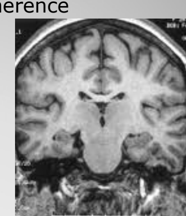


Flip Angles

Flip Angle	Degree Range	Contrast
Short	1 - 35°	T2*
Medium	36 - 59°	PD
Long	60 - 90°	T1

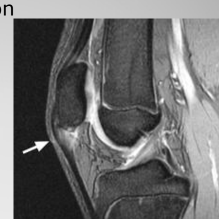
Flip Angles control GRE Contrast

- Spoiled GRE Incoherent
  - aka SPGR, FLASH, T1-FFE
  - Uses gradients or RF to spoil or destroy accumulated transverse coherence
  - maximizes T1 contrast



Gradient Recalled Echo

- Refocused GRE Coherent
  - Aka FISP, GRASS, FFE, Rephased SARGE
  - Uses RF or gradients to refocus accumulated transverse magnetization
  - Maximizes T2 Contrast



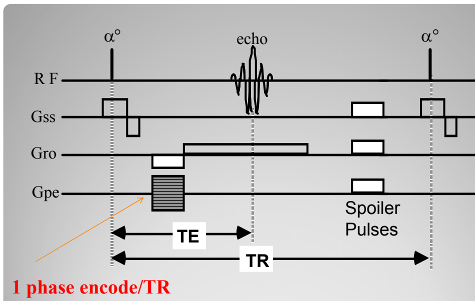
Gradient Recalled Echo

Fast Gradient Echo

- A Fast GRE sequence generates gradient echoes very rapidly using similar fast imaging techniques to fill k-space.
- Image contrast cannot be controlled with the flip angle, TR, and TE.
- **Rather, a preparation pulse (TI) creates the desired contrast.**
- The sequence is initiated with the 180° preparation pulse followed by a waiting period (the inversion time).
- Inversion times of 200 to 1000msec are used.

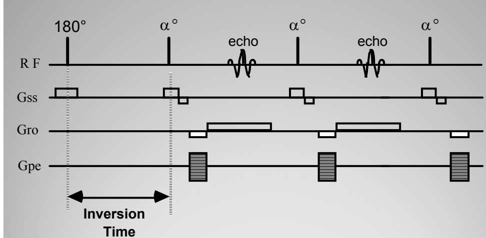
79

Conventional GRE w/ Spoilers



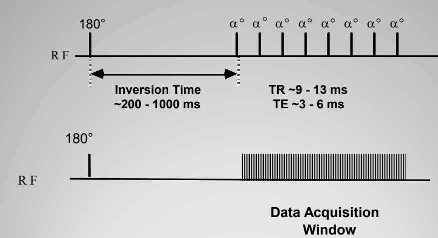
80

Fast GRE Pulse Diagram



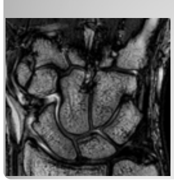
81

Fast GRE Pulse Diagram



82

More on GRE..



- MR signal is a composite of fat and water in the imaging voxel.
- Water and fat resonate at slightly different frequencies.
- TE time will determine whether fat and water will appear in-phase or out-of-phase.

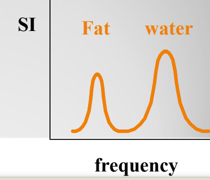
83

Field Strength (T)	0.5	1	1.5
W-F Offset (Hz)	75	150	225
in	0.00	0.00	0.00
out	6.71	3.36	2.24
in	13.42	6.71	4.47
out	20.13	10.07	6.71
in	26.84	13.42	8.95
out	33.55	16.78	11.18
in	40.26	20.13	13.42
out	46.97	23.49	15.67
in	53.68	26.94	17.89
out	60.39	30.33	20.13
in	67.10	33.74	22.37
out	73.81	37.14	24.60
in	80.52	40.55	26.84

84

Field Strength (T)	0.5	1	1.5
W-F Offset (Hz)	75	150	225
in	0.00	0.00	0.00
out	6.71	3.36	2.24
in	13.42	6.71	4.47
out	20.13	10.07	6.71
in	26.84	13.42	8.95
out	33.55	16.78	11.18
in	40.26	20.13	13.42
out	46.97	23.49	15.67
in	53.68	26.94	17.89
out	60.39	30.33	20.13
in	67.10	33.74	22.37
out	73.81	37.14	24.60
in	80.52	40.55	26.84

- Frequency difference in ppm
  - Fat frequency minus water frequency divided by the water frequency equals the frequency difference.
  - This difference is about 3.3 - 3.5ppm.
- Frequency difference in hertz
  - Multiply 3.5ppm by the imaging system's operating frequency.



Quiz

- Determine the frequency difference between fat and water at 3.0T?

- Hints:
  - To find the operating frequency you must use the Larmor equation ώ = γ x β
  - Multiply 3.5ppm by the imaging system's operating frequency to find the frequency difference.

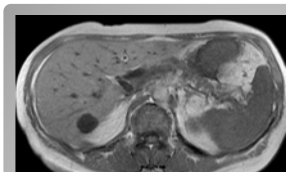
Fat / Water difference in hertz

Answer:

1st: Larmor Equation: ώ = γ x β
ώ = 42.58mHz x 3.0T
ώ = 127.74 mHz

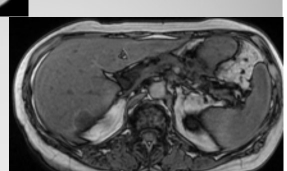
2nd: 3.5ppm x operating frequency
3.5ppm x 127.74mHz = 447 Hz @3.0T

0.35T 14.90 mHz x 3.5ppm = 52.1 Hz
1.5T 63.86 mHz x 3.5ppm = 223 Hz



Out of Phase

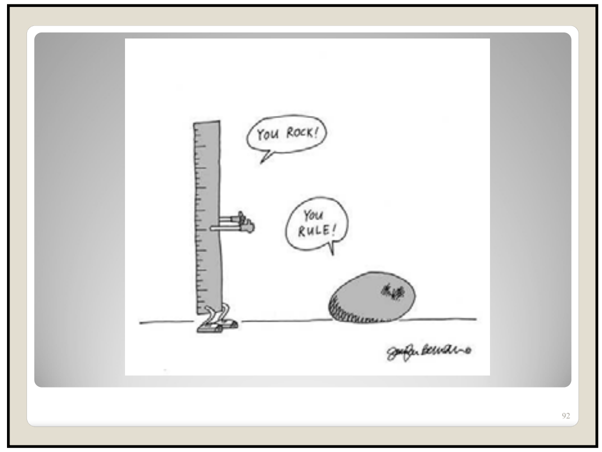
In-phase



Gradient Echo Vendor Acronyms

Sequence	Siemens	GE	Philips	Hitachi	Toshiba	Picker
Spoiled GE	FLASH	SPGR	T1-FFE	RSSG	FE	T1 Fast
Coherent GE	FISP	GRASS	FFE	Re-SARGE	FE	
SSFP	TrueFISP	FIESTA	T2-FFE	SARGE	True SSFP	CE Fast
UltraFast	TurboFLASH	FastSPGR	TFE	RGE	Fast GE	RF Fast
UltraFast	3D MPRAGE	3D FastSPGR	3DTFE	MPRAGE		


Snapshots at jasonlove.com
Professor Herman stopped when he heard that unmistakable thud – another brain had imploded.
Thanks for sharing your time with me!
91


YOU ROCK!
YOU RULE!
92