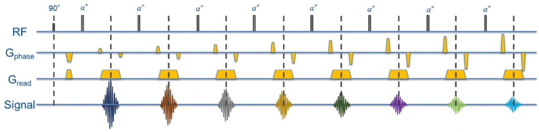
BME599 | F23 | | HW2 | Robert Jones | 10/24/2023 |

1.

PROBLEM 1: Extended phase graphs. Shown below is a sequence diagram of a fast spin echo (FSE) with its first 8 refocusing pulses within one repetition time (TR). Each RF pulse is designated as a delta function, so you do not need worry about the slice profile. Refocusing pulses are spaced 5*ms* apart (echo spacing).



a. Please write a function using EPG to simulate spin echo train echo amplitudes for a sequence with $90°_x$ excitation, followed by refocusing pulses of $[\alpha+(90-\alpha/2)]_y$, α_y, α_y ,… for 64 echoes for T1 = [200:100:1500] ms, and T2 = [50:30:300] ms

i. Simulate echo amplitudes with α = 180°, and plot amplitudes with five different T1 and T2 combinations

ii. Simulate echo amplitudes with α = 120°, and plot amplitudes with five different T1 and T2 combinations

iii. Simulate echo amplitudes with α = 60°, and plot amplitudes with five different T1 and T2 combinations

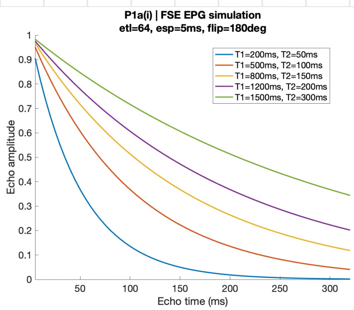
b. Plot 4 contour plots signals vs T1 and T2 for the 6th, 16th, 32nd, and 48th echoes using various α

c. Discuss the contrast you get with different flip angles.

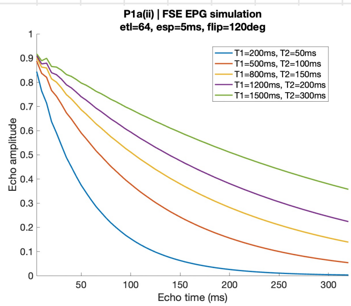
a.) 5 different T1, T2 combinations were tested:

[T1, T2] = [200, 50] ms, [500, 100] ms, [800, 150] ms, [1200, 200] ms, [1500, 300] ms

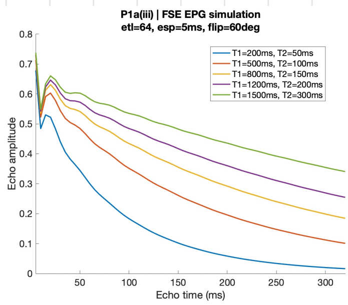
(i.) $\alpha = 180°$



(ii.) $\alpha = 120°$



(iii.) $\alpha = 60°$



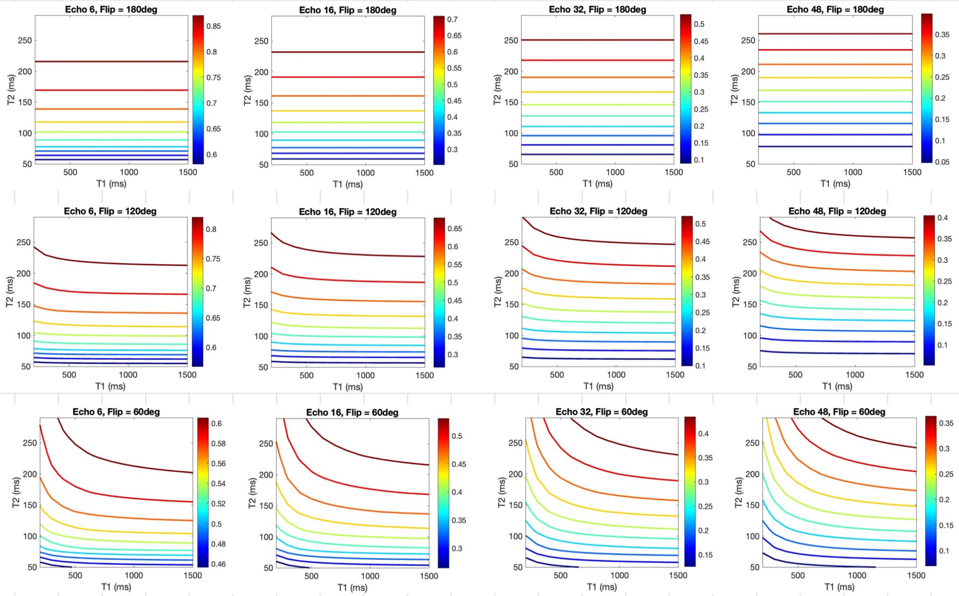
(1.) b.)

Echo 6 Echo 16 Echo 32 Echo 64

$\alpha = 180^\circ$

$\alpha = 120^\circ$

$\alpha = 60^\circ$

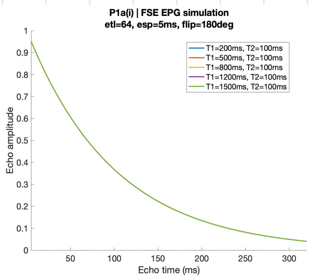


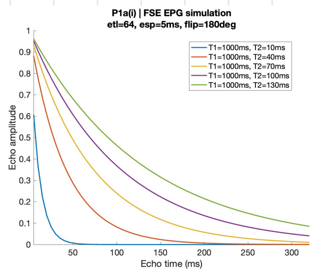
In the contour plots above,

- x-axes = T1 (ms), y-axes = T2 (ms),
- Colorbars depict echo (transverse magn. $|M_{xy}|$) signal $\in [0, 1]$ corresponding to colors of contours.

1. c.) Using a flip angle of $\alpha = 180°$, the echo signals are constant for fixed $T1$ values, regardless of the T_2 value.
This suggests that large (inversion) flip angles of $\alpha = 180°$ would be used to generate $T2w$ contrast:

Differences in signal intensity arise solely due to differences in $T2$; tissues with identical $T2$ will have identical signal, regardless of their T_1 time.





This can also be seen by generating plots similar to those in part 1(a.), (shown above) but holding either $T2$ (left) or T_1 (right) constant. This shows when $\alpha = 180°$, contrast is generated by differences in $T2$ times, and not by T_1 times.

When flip angle decreases, ($\alpha = 120°$, $\alpha = 60°$), the contour plots show more signal variation with respect to both varying T_1 and T_2 times. This suggests smaller flip angles ($< 180°$) could be used to generate more $T_1 w$ or mixed (T_1/T_2-w) contrasts (than using $\alpha = 180°$).

(2) (a.) For the T_1W contrast, we want a Short TE and Short TR;

a short TE decreases T_2-weighting and a short TR increases T_1-weighting

Thus, we chose TR/TE values of:

$$\boxed{TR/TE = 500/15 \text{ ms for } T_1W \text{ contrast}}$$

For T_2W contrast, we want to choose a long TE and long TR;

a long TE increases T_2W contrast and a long TR decreases T_1W contrast.

$$\boxed{TR/TE = 6000/100 \text{ ms for } T_2W \text{ contrast}}$$

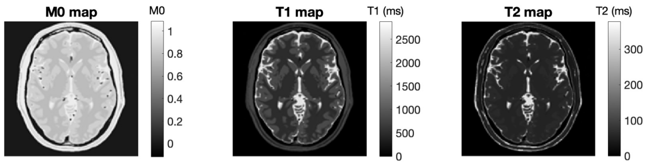
For PD weighted contrast, we want to choose a short TE and long TR;

a short TE decreases T_2W contrast and a long TR decreases T_1W contrast,

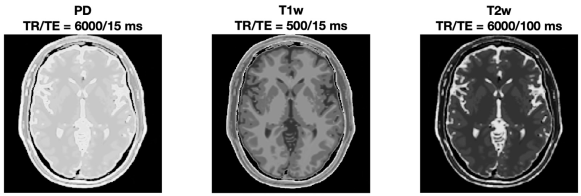
giving us a PD weighted contrast that is neither T_1 or T_2 weighted.

$$\boxed{TR/TE = 6000/15 \text{ ms for PD weighted contrast}}$$

Given Brain Parameter Maps:

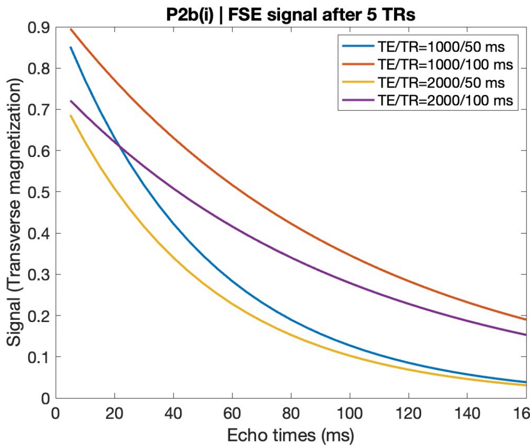


Simulated SE Contrasts:



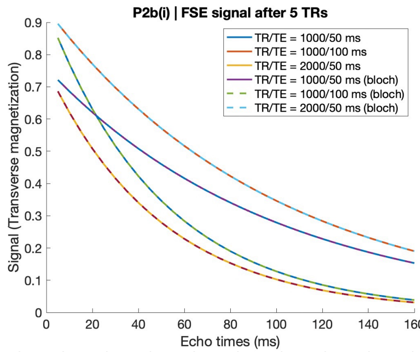
② b.) (i.) FSE: TR = 3 s, ESP = 5 ms, ETL = 32, $\alpha_{exc.} = 90°$, $\alpha_{refocus} = 180°$

With a TR of 3s, we can assume the residual magnetization has decayed/relaxed completely to equilibrium before the start of the next TR; thus the steady state signal can be used.



(line colors depict different (T_1, T_2) values; see legend)

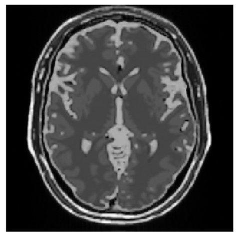
Comparing the EPG multi-TR simulation to the steady state FSE Bloch simulation, we see the 2 methods yield identical signal profiles after the 5th (final) TR.



(2)

(ii.) We chose the k-space filling order so that the center PE line in k-space would be filled by the echo at time TE = 80ms. With ESP = 5ms, this was echo #16.

FSE sim | TE_{eff} = 80 ms

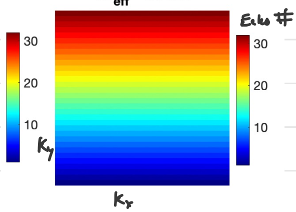


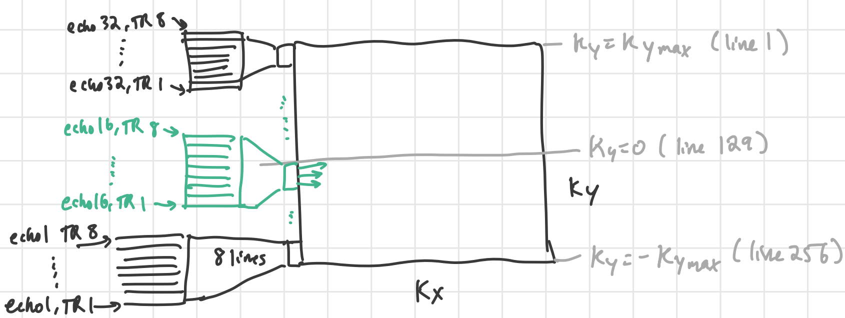
The simulated image is shown on the right. We filled k-space from bottom to top, with TE_{eff} = 80ms, which created a T_2W contrast.

For ETL = 32, ESP = 5 ms, we filled k-space as shown on the right:

- Each color shows the lines filled by each echo from the 32-echo train.
- Each echo filled 8 different lines, which correspond to 8 different TRs.
- The first echo filled the bottom 8 lines of kspace.
  - ↳ Echo 1, TR 1 = line 256 (bottom line)
  - Echo 1, TR 2 = line 255 (second from bottom)
  - ⋮
  - Echo 1, TR 8 = line 249 (8^{th} from bottom)
- The center kspace line (line 129) was filled by echo 16, with its echo time being 80ms in order to make TE_{eff} = 80ms.

FSE simulation - kspace filling order
TE_{eff} = 80 ms





(2)

(ii.) We chose the k-space filling order so that the center PE line in k-space would be filled by the echo at time $TE = 80ms$.
With $ESP = 5ms$, this was echo #16.

With an $ETL = 32$, we can fill 32 lines of k-space in each TR.
Thus, to fill 256 (PE) lines, we need $256/32 = 8$ TR's.

The total acquisition time would be:

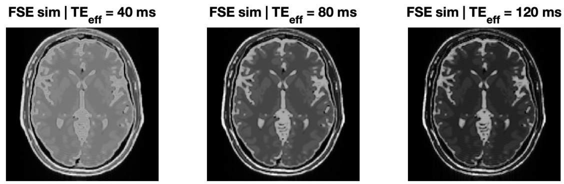
$$T_{acq} = \frac{TR \cdot N_y}{ETL} = \frac{3s \cdot 256}{32} = \boxed{24\,s = T_{acq,FSE,ETL=32}}$$

For a single SE scan with equivalent contrast, we would fill one line of k-space (PE line) per TR; or our ETL would be 1. Thus:

$$T_{acq} = TR \cdot N_y = (3s)(256) = \boxed{768\,sec = T_{acq,SE,ETL=1}}$$

The FSE sequence results in a reduction in total acquisition time directly proportional to ETL.

(2.) (iii.) We used a similar approach as (ii.) to simulate $TE_{eff} = 40\,ms$ and $TE_{eff} = 120\,ms$ images, shown below.



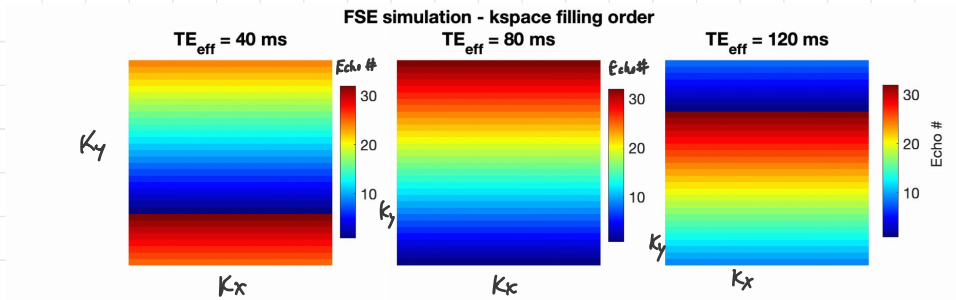
To fill k-space, we ensured the echo filling the central line ($K_y = 0$) of k-space came from the echo occurring at the desired TE_{eff}.

- k-center-echo # = TE_{eff} / ESP
- For $TE_{eff} = 40\,ms$, we used the 8^{th} to fill the kspace center ($40\,ms / 5\,ms/echo = 8^{th}$ echo)
- For $TE_{eff} = 120\,ms$, we used the 24^{th} echo ($120\,ms / 5\,ms/echo = 24^{th}$ echo)

For simplicity, we used a similar "bottom-to-top" approach to fill k-space, but simply shifted the starting line to be filled by the first echo to ensure the center line was filled to make TE_{eff} the desired time.

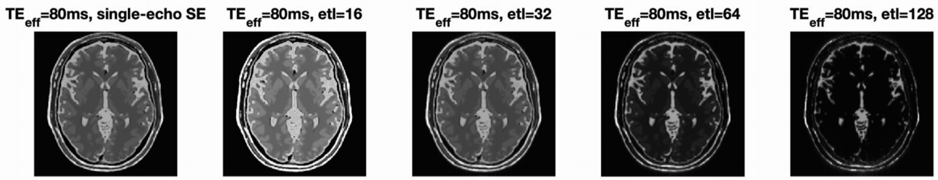
For $TE_{eff} = 40\,ms$, we started filling k-space with echo 1 at line 192 (64^{th} line from bottom), and for $TE_{eff} = 120\,ms$, we started filling kspace at line 64 (192^{nd} from bottom); when the top of kspace was reached, we wrapped around to the bottom line and continued.

(color = echo # used to fill line of kspace; Note each color/echo contains 8 different echoes from different TRs (i.e., 8 lines/echo))



② b.) (iii.)

(iv.) As the ETL becomes longer, the image quality degrades. This is due to the later echoes in long echo trains having less overall signal, as they are occurring a long time after the initial excitation. This causes the k-space to contain some lines with very small/low signals, resulting in a loss of SNR and CNR in the reconstructed images.

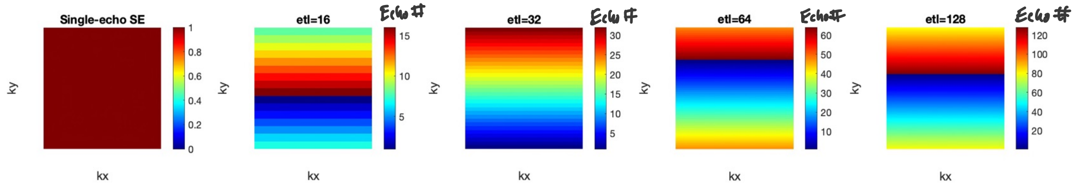


Increasing ETL

(Fixed TE_{eff}, Fixed ESP)

Corresponding k-space filling order plots are below.

(color = echo # used to fill that k_y line)



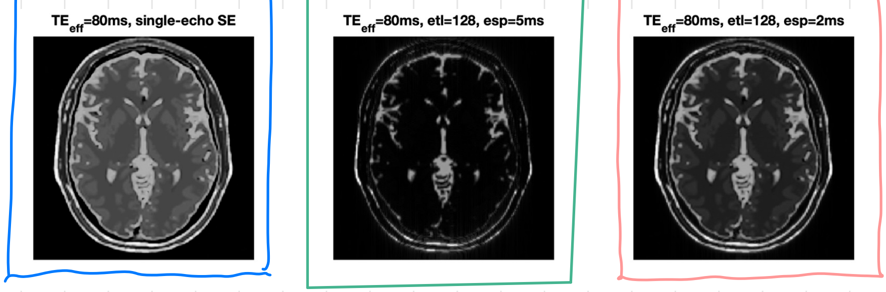
(2.) c.) One way to improve image quality for very long echo trains could be to decrease the echo spacing. This would leave more signal left at later echoes which could help improve image quality, SNR and CNR.

I tested using an FSE sequence with exactly the same parameters, but using an echo spacing of 2ms instead of 5ms. This appeared to improve the image quality.

Single SE, TE=80ms

FSE: ESP=5ms (ETL=128, TE_{eff}=80ms)

FSE: ESP=2ms (ETL=128, TE_{eff}=80ms)



The k-space filling orders are shown below. Again, the color of each K_y line indicates the echo used to fill that k-space line.

Echo 16 $\equiv K_y=0$

Echo 40 $\equiv K_y=0$