BME 599 HW 2

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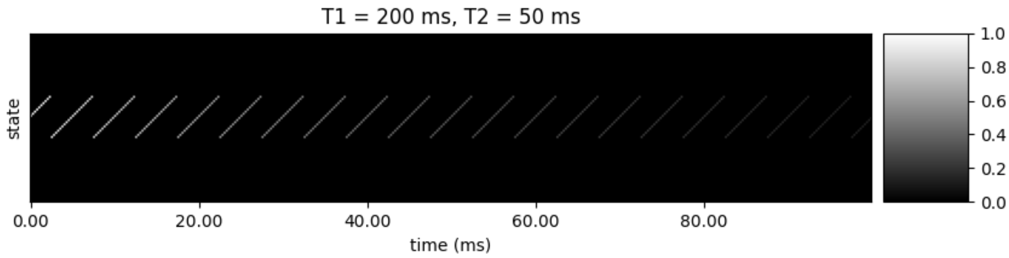
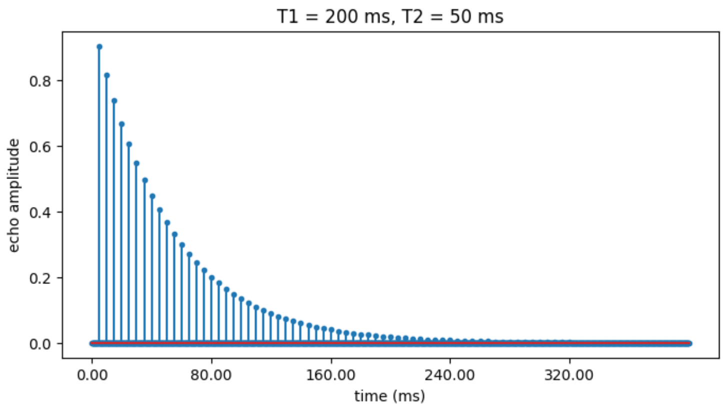
Problem 1: Extended phase graphs

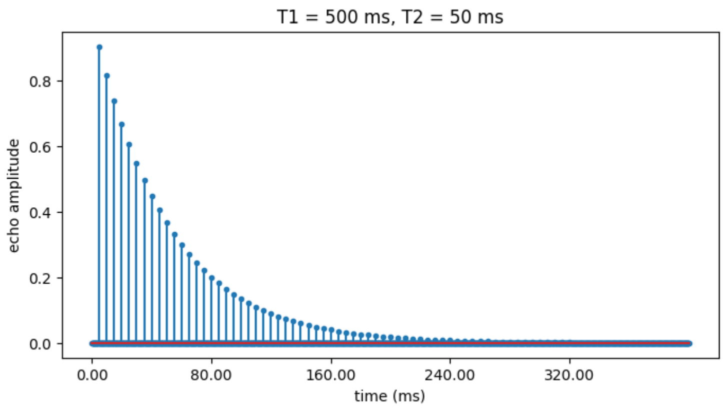
a. EPG simulation of spin-echo train

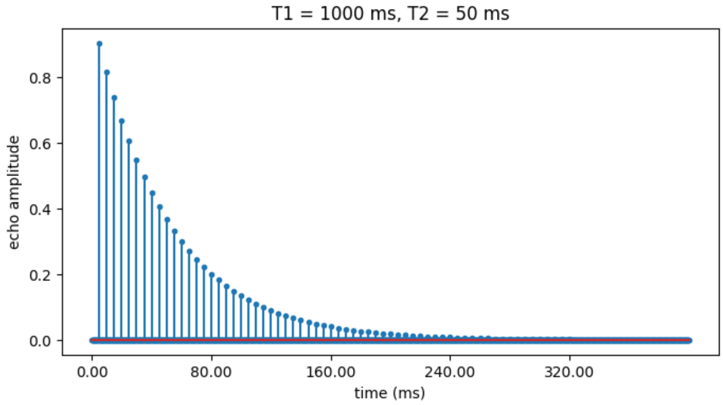
i. echo with $\alpha = 180°$,
the EPG of the flip angle 180 is

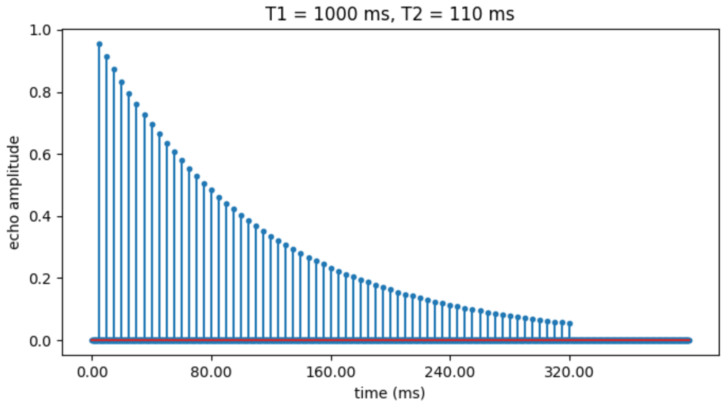


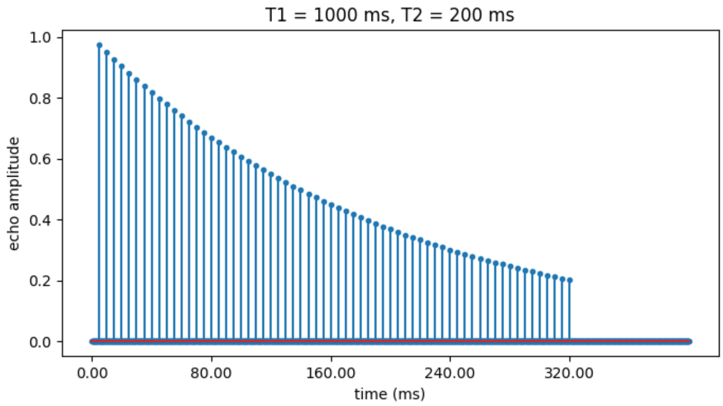
for different combination of T1 and T2:



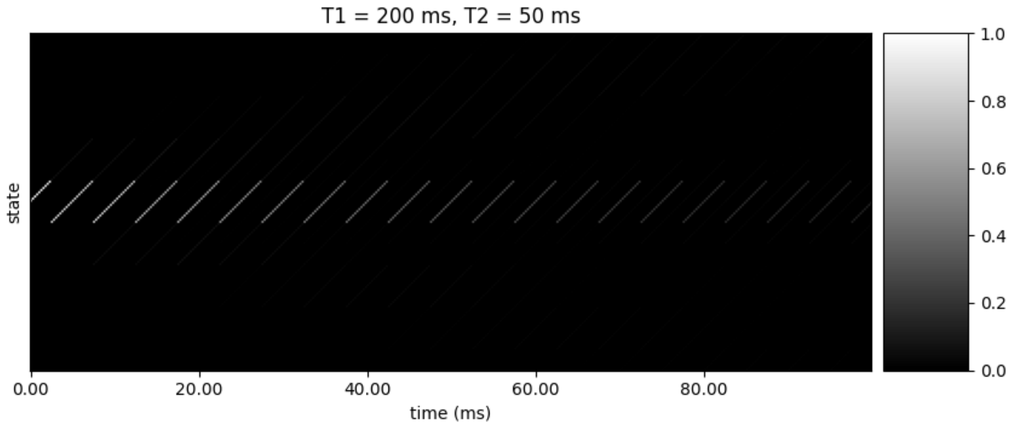



T1 = 1000 ms, T2 = 50 ms
echo amplitude
0.0
0.2
0.4
0.6
0.8
0.00
80.00
160.00
240.00
320.00
time (ms)

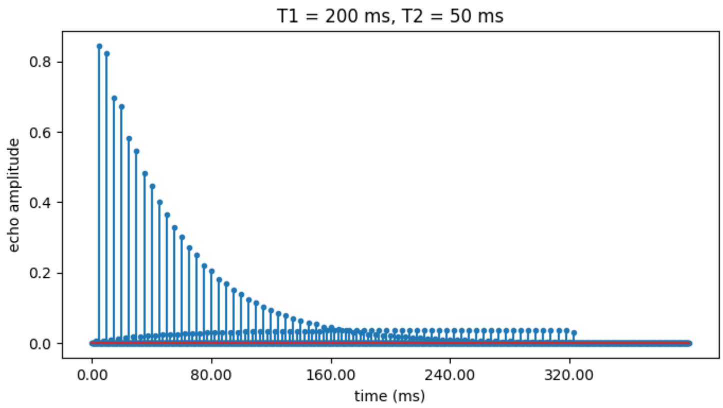

T1 = 1000 ms, T2 = 110 ms
echo amplitude
0.0
0.2
0.4
0.6
0.8
1.0
0.00
80.00
160.00
240.00
320.00
time (ms)

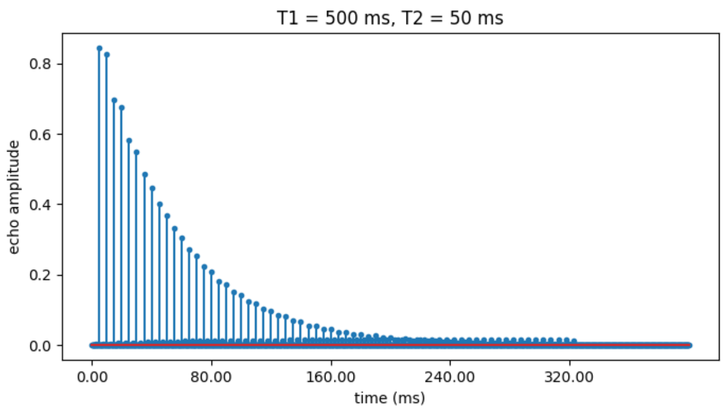

T1 = 1000 ms, T2 = 200 ms
echo amplitude
0.0
0.2
0.4
0.6
0.8
1.0
0.00
80.00
160.00
240.00
320.00
time (ms)

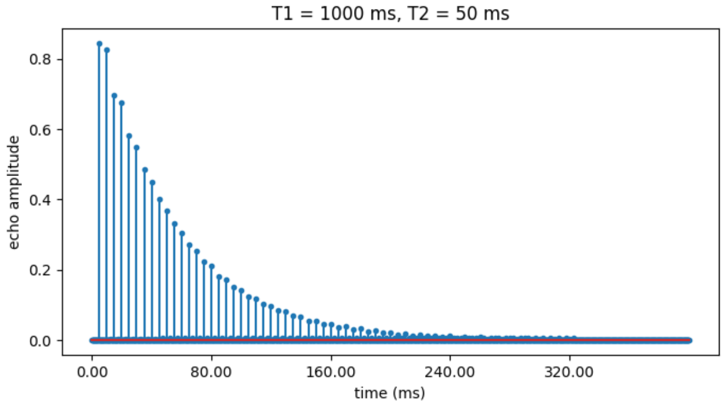
ii. echo with $\alpha = 120°$,
the EPG of the flip angle of 120 deg is

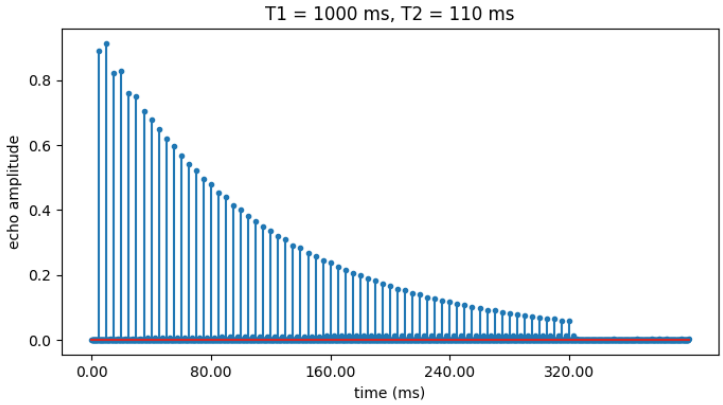


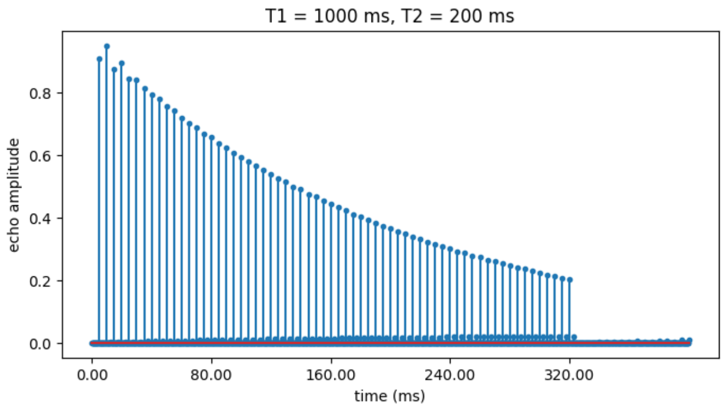
for different combination of T1 and T2:



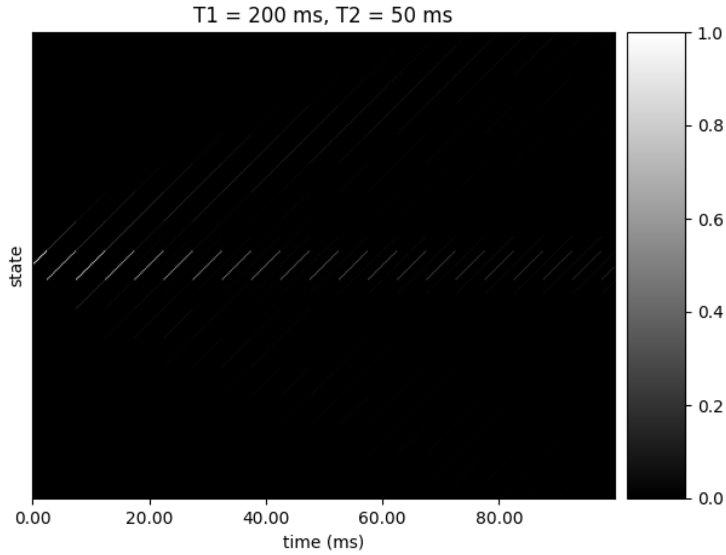



T1 = 1000 ms, T2 = 50 ms
echo amplitude
time (ms)
0.0
0.2
0.4
0.6
0.8
0.00
80.00
160.00
240.00
320.00

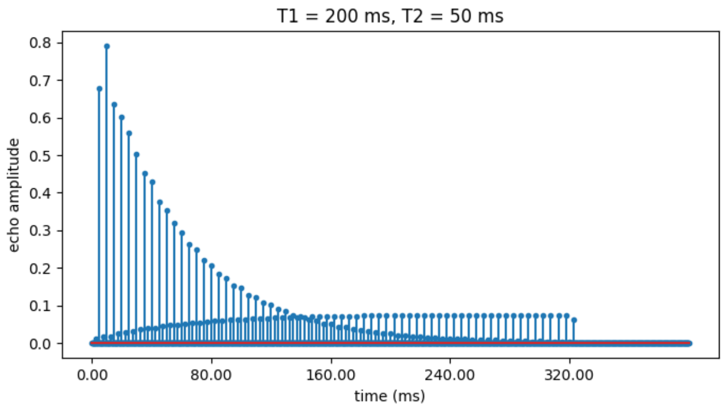

T1 = 1000 ms, T2 = 110 ms
echo amplitude
time (ms)
0.0
0.2
0.4
0.6
0.8
0.00
80.00
160.00
240.00
320.00

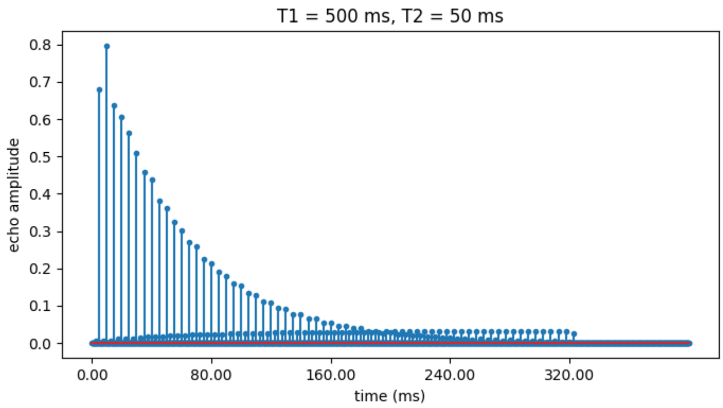

T1 = 1000 ms, T2 = 200 ms
echo amplitude
time (ms)
0.0
0.2
0.4
0.6
0.8
0.00
80.00
160.00
240.00
320.00

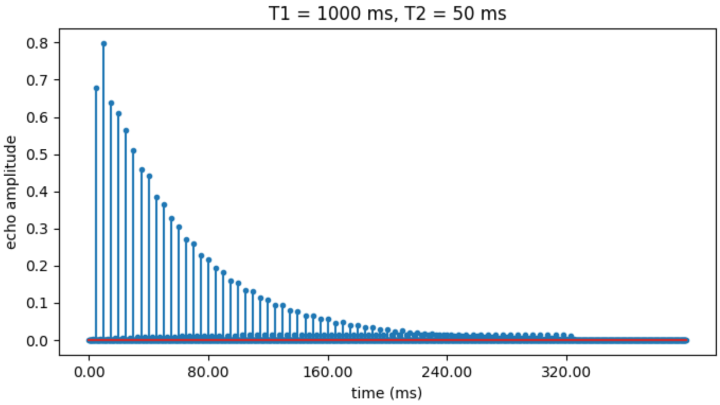
iii. echo with $\alpha = 60°$,
the RPG of the flip angle of 60 deg is

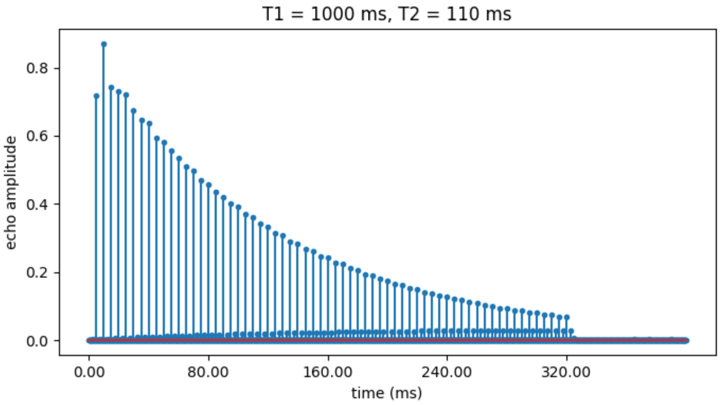


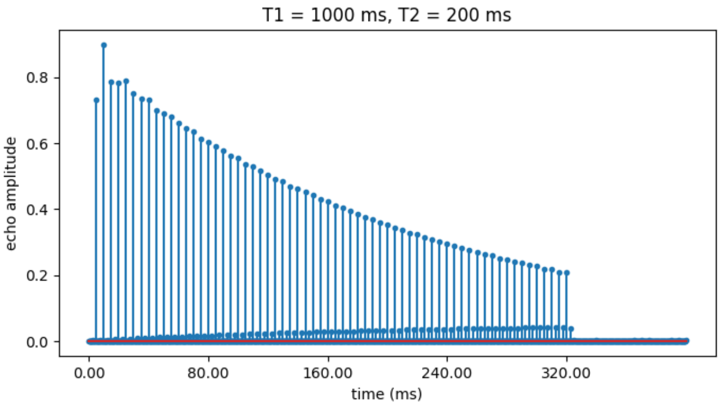
for different combination of T1 and T2:





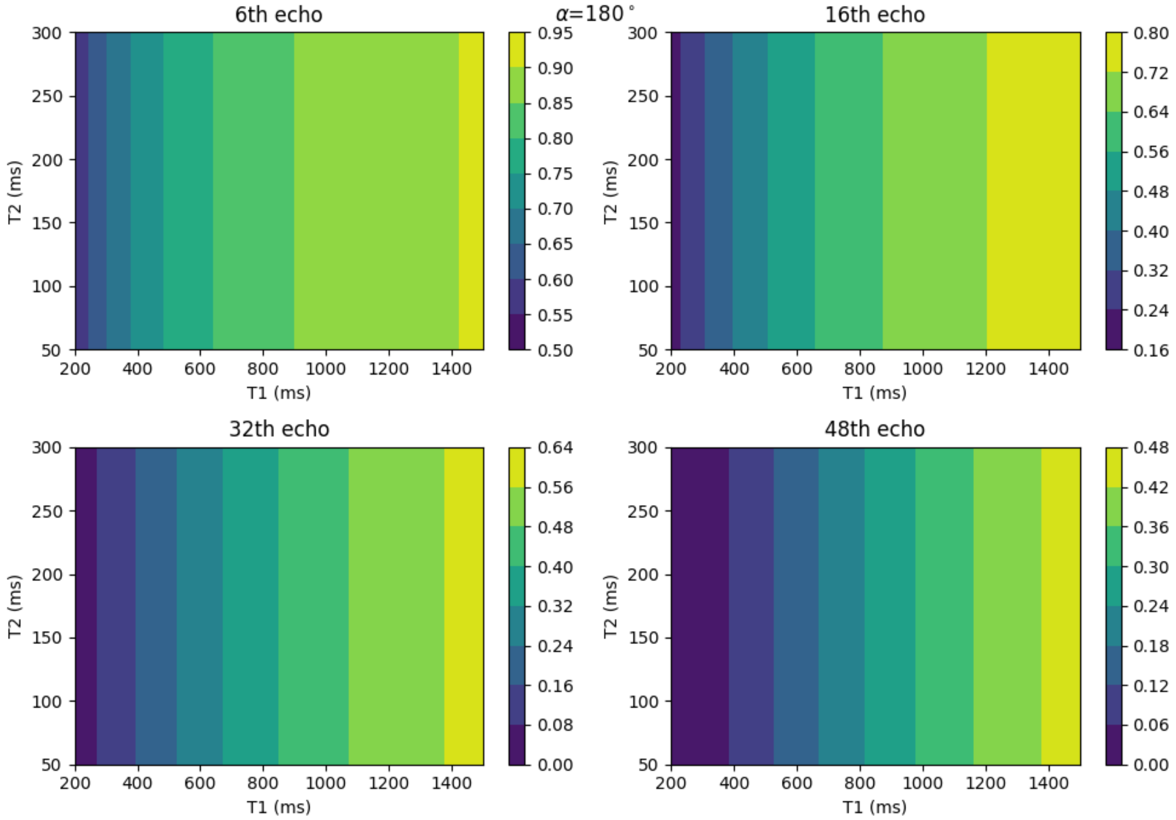

T1 = 1000 ms, T2 = 50 ms
echo amplitude
time (ms)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.00
80.00
160.00
240.00
320.00


T1 = 1000 ms, T2 = 110 ms
echo amplitude
time (ms)
0.0
0.2
0.4
0.6
0.8
0.00
80.00
160.00
240.00
320.00

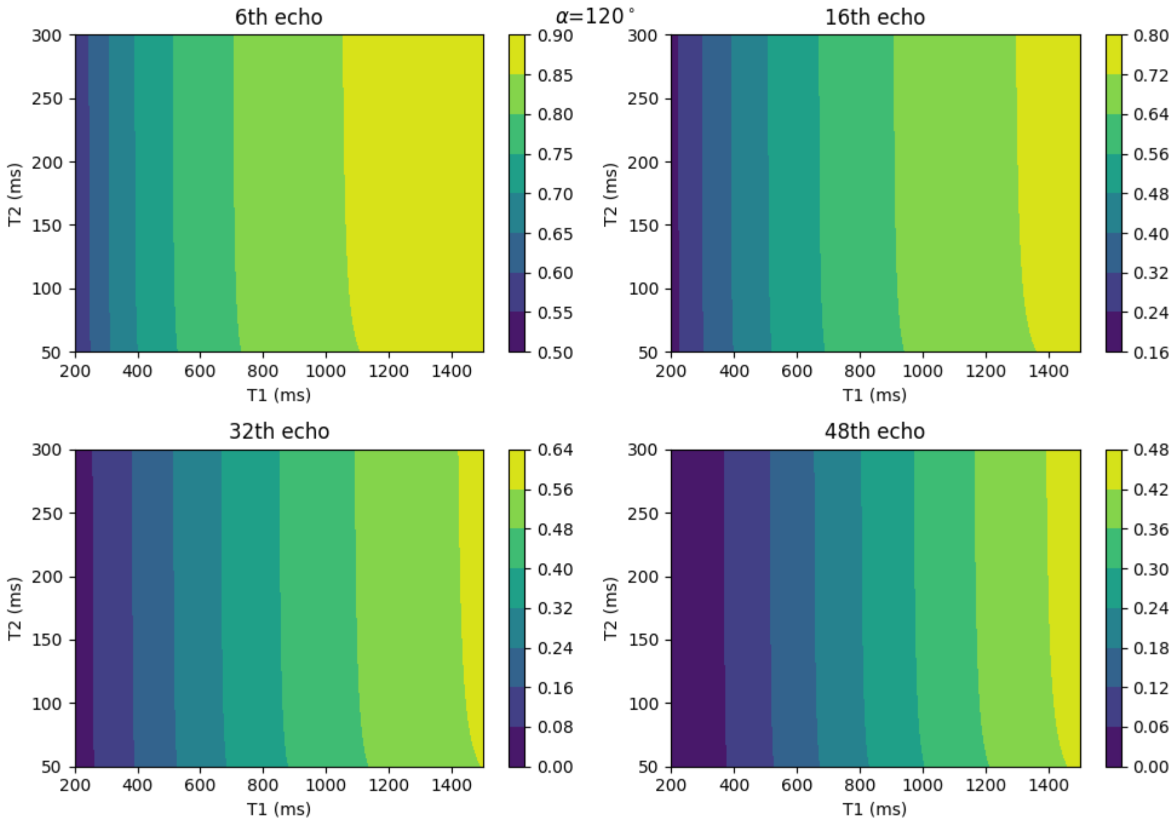

T1 = 1000 ms, T2 = 200 ms
echo amplitude
time (ms)
0.0
0.2
0.4
0.6
0.8
0.00
80.00
160.00
240.00
320.00

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

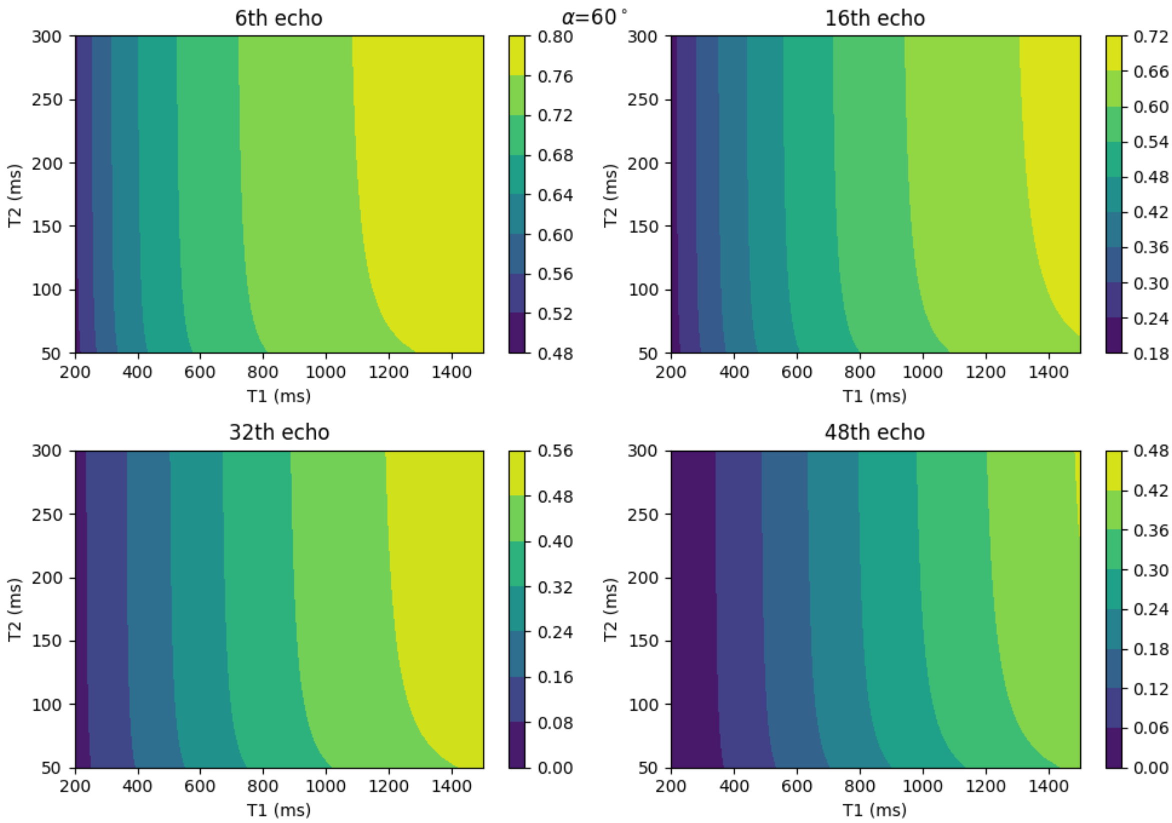
for $\alpha = 180°$:



for $\alpha = 120°$:



for $\alpha = 60°$:



c. Discuss the contrast you get with different flip angles

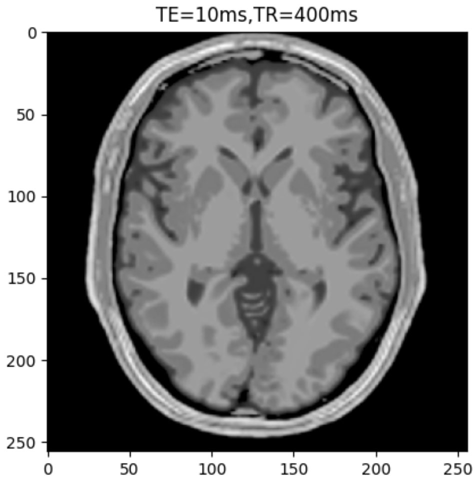
The echoes produced by rf pulse 180° are more T2-weighted image.
The smaller flip angles like 120° and 60°, produces echoes with more T1-weighted combined images, and the effect will be stronger with the increase of the number of echoes. Because, each echo will have signals from the longitudinal direction where the magnetization experiences the T1 decay.

Problem 2: single and multiple spin echo sequences

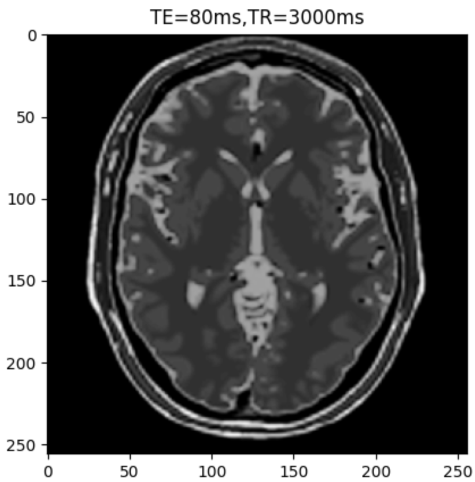
a. Single-echo spin echo

(images are obtained after the 4th echo)

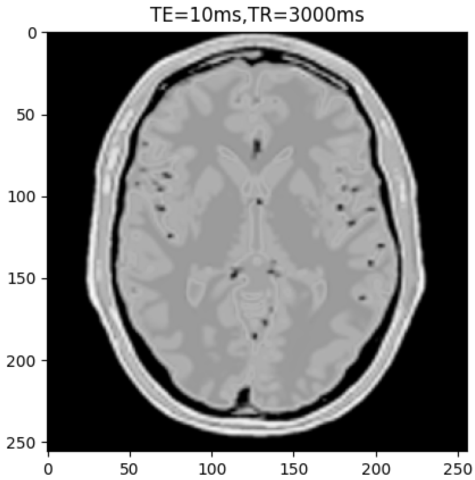
T1-weighted: (short TR gives the magnetization cannot be fully recovered in T1 recovery, thus leads to T1-weighted contrast in the images, and short TE makes the T2-relaxation less different)



T2-weighted: (long TR makes sure the magnetization almost get full T1 recovery, thus there's less T1 effects in each echo, and long TE makes short T2 signal decay fast, thus lead to more T2-weighted contrast)

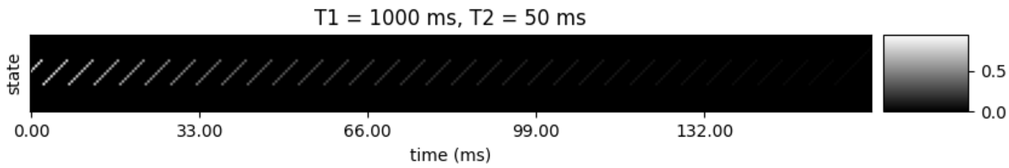


proton density weighted: (long TR reduces the T1-decay between echoes, thus at the beginning of each echo, the magnetization is almost fully recover, and short TE makes that all T2-decay are small, then less difference in T2-weights. Thus the main effects left on the image is proton density)

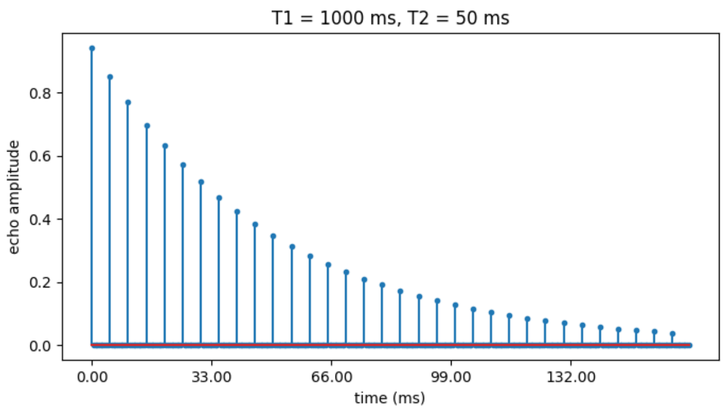


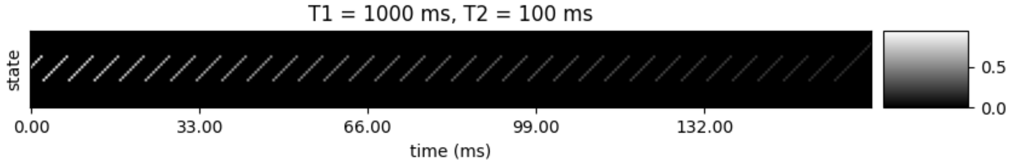
b. Fast spin echo

i. different T1,T2 combination:

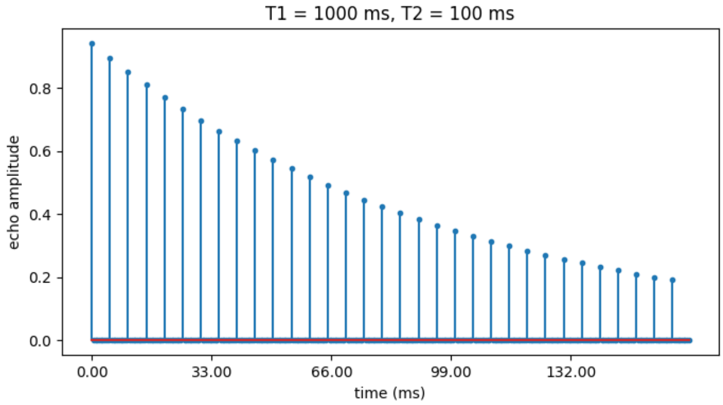


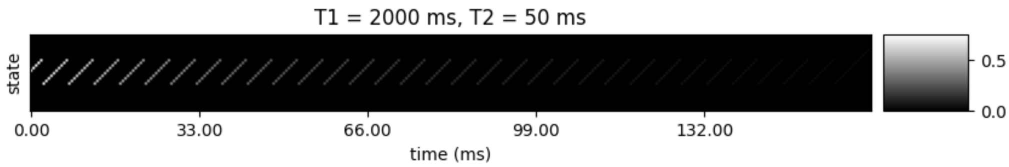
transverse magnetization magnitude in the 5th TR



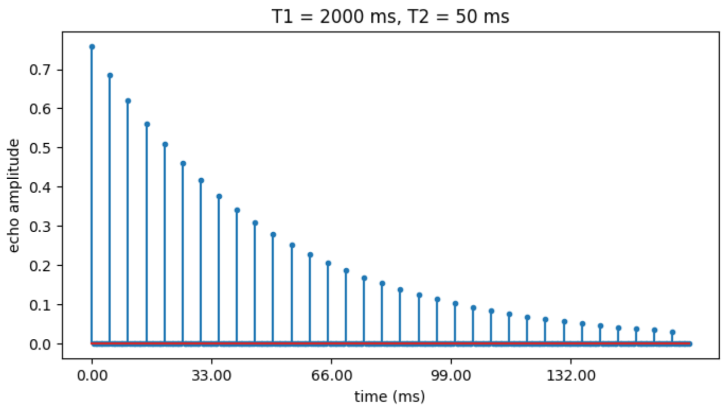


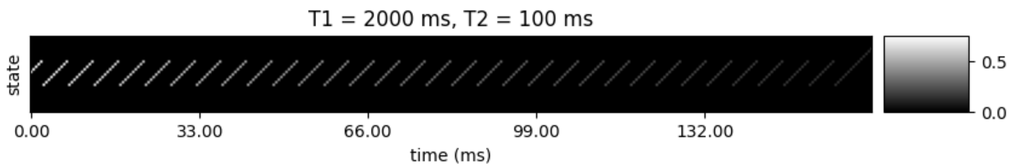
transverse magnetization magnitude in the 5th TR



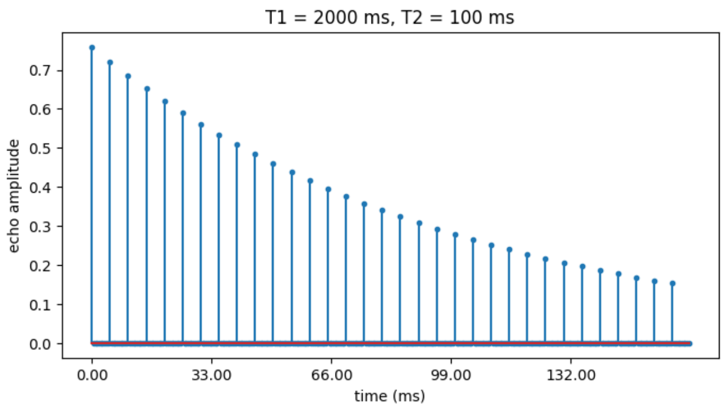


transverse magnetization magnitude in the 5th TR





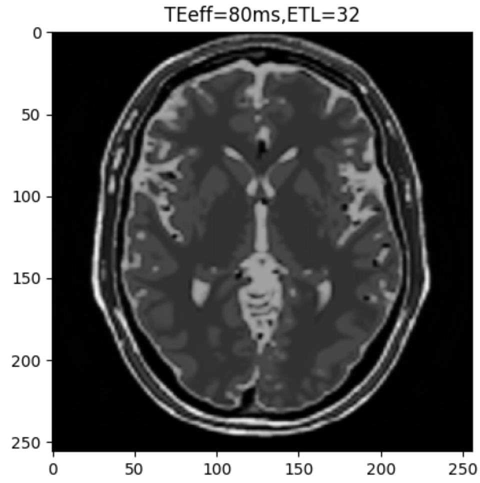
transverse magnetization magnitude in the 5th TR



ii. choose k-space filling order,
(here i choose to acquire the image with 256×256, thus need 256 echoes)

ETL = 32, then will need 256/32=8 TRs. And since $TE_{eff} = 80$ms, thus it corresponds to the 16th echo in one TR. The acquisition I choose is (the line conut from 0, and the center k-space line is #128)

the acquired image is

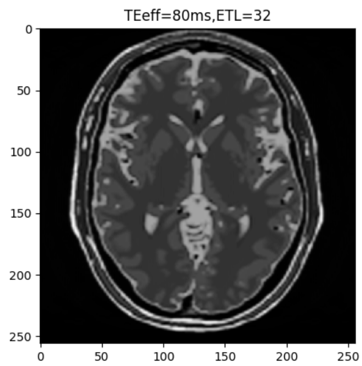


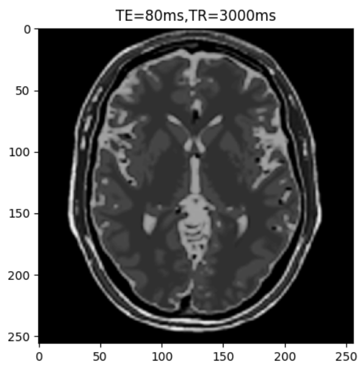
$$
\begin{array}{r|l}
TR\ \#1 & 8, 16, 24, 32, 40, 48, 56, 64, 72, 80, 88, 96, 104, 112, 120, \boxed{128}, 136, 144, 152, 160, 168, 176, 184, 192, 200, 208, 216, 224, 232, 240, 248, 0 \\
TR\ \#2 & 9, 17, 25, 33, 41, 49, 57, 65, 73, 81, 89, 97, 105, 113, 121, 129, 137, 145, 153, 161, 169, 177, 185, 193, 201, 209, 217, 225, 233, 241, 249, 1 \\
TR\ \#3 & 10, 18, 26, 34, 42, 50, 58, 66, 74, 82, 90, 98, 106, 114, 122, 130, 138, 146, 154, 162, 170, 178, 186, 194, 202, 210, 218, 226, 234, 242, 250, 2 \\
TR\ \#4 & 11, 19, 27, 35, 43, 51, 59, 67, 75, 83, 91, 99, 107, 115, 123, 131, 139, 147, 155, 163, 171, 179, 187, 195, 203, 211, 219, 227, 235, 243, 251, 3 \\
TR\ \#5 & 12, 20, 28, 36, 44, 52, 60, 68, 76, 84, 92, 100, 108, 116, 124, 132, 140, 148, 156, 164, 172, 180, 188, 196, 204, 212, 220, 228, 236, 244, 252, 4 \\
TR\ \#6 & 13, 21, 29, 37, 45, 53, 61, 69, 77, 85, 93, 101, 109, 117, 125, 133, 141, 149, 157, 165, 173, 181, 189, 197, 205, 213, 221, 229, 237, 245, 253, 5 \\
TR\ \#7 & 14, 22, 30, 38, 46, 54, 62, 70, 78, 86, 94, 102, 110, 118, 126, 134, 142, 150, 158, 166, 174, 182, 190, 198, 206, 214, 222, 230, 238, 246, 254, 6 \\
TR\ \#8 & 15, 23, 31, 39, 47, 55, 63, 71, 79, 87, 95, 103, 111, 119, 127, 135, 143, 151, 159, 167, 175, 183, 191, 199, 207, 215, 223, 231, 239, 247, 255, 7
\end{array}
$$

the total acquisition time is

$$8 \times TR = 8 \times 3 = 24 seconds$$

compare the image with single-echo spin echo scan with equivalent image contrast:

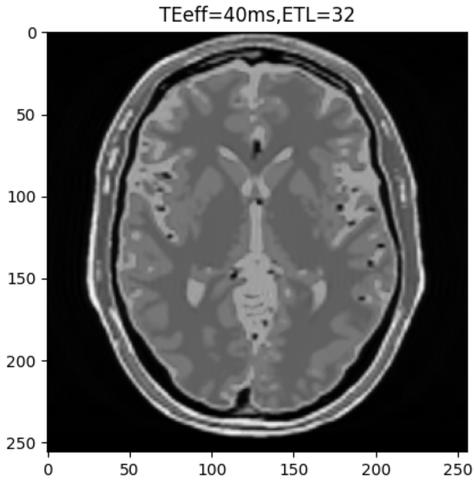




left: FSE　　　　right: SE

images looks similar.

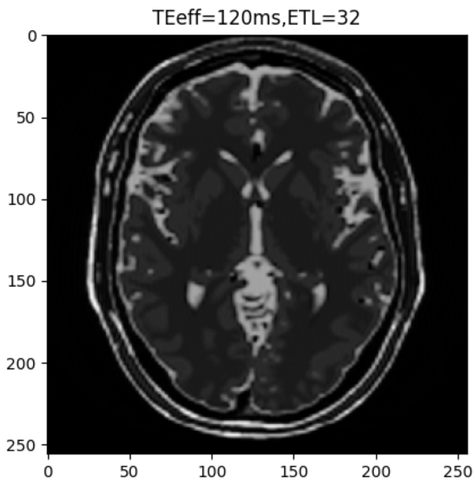
iii. FSE image with effective echo times of 40ms:



the acquisition order is

TR #1	72, 80, 88, 96, 104, 112, 120, $\boxed{128}$, 136, 144, 152, 160, 168, 176, 184, 192, 200, 208, 216, 224, 232, 240, 248, 0, 8, 16, 24, 32, 40, 48, 56, 64
TR #2	73, 81, 89, 97, 105, 113, 121, 129, 137, 145, 153, 161, 169, 177, 185, 193, 201, 209, 217, 225, 233, 241, 249, 1, 9, 17, 25, 33, 41, 49, 57, 65
TR #3	74, 82, 90, 98, 106, 114, 122, 130, 138, 146, 154, 162, 170, 178, 186, 194, 202, 210, 218, 226, 234, 242, 250, 2, 10, 18, 26, 34, 42, 50, 58, 66
TR #4	75, 83, 91, 99, 107, 115, 123, 131, 139, 147, 155, 163, 171, 179, 187, 195, 203, 211, 219, 227, 235, 243, 251, 3, 11, 19, 27, 35, 43, 51, 59, 67
TR #5	76, 84, 92, 100, 108, 116, 124, 132, 140, 148, 156, 164, 172, 180, 188, 196, 204, 212, 220, 228, 236, 244, 252, 4, 12, 20, 28, 36, 44, 52, 60, 68
TR #6	77, 85, 93, 101, 109, 117, 125, 133, 141, 149, 157, 165, 173, 181, 189, 197, 205, 213, 221, 229, 237, 245, 253, 5, 13, 21, 29, 37, 45, 53, 61, 69
TR #7	78, 86, 94, 102, 110, 118, 126, 134, 142, 150, 158, 166, 174, 182, 190, 198, 206, 214, 222, 230, 238, 246, 254, 6, 14, 22, 30, 38, 46, 54, 62, 70
TR #8	79, 87, 95, 103, 111, 119, 127, 135, 143, 151, 159, 167, 175, 183, 191, 199, 207, 215, 223, 231, 239, 247, 255, 7, 15, 23, 31, 39, 47, 55, 63, 71

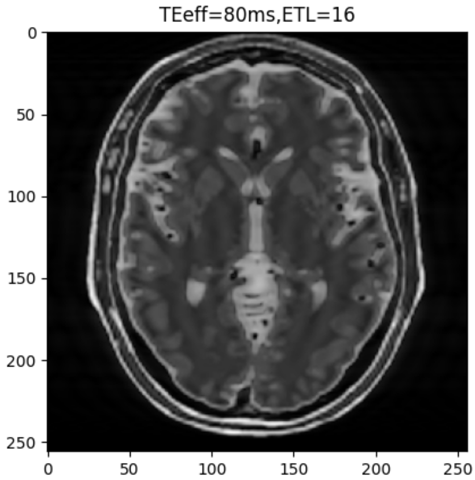
FSE image with effective echo time of 120 ms:



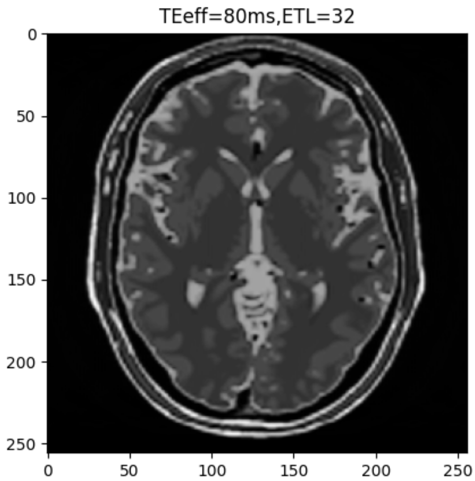
the acquisition order is

TR #1	200, 208, 216, 224, 232, 240, 248, 0, 8, 16, 24, 32, 40, 48, 56, 64, 72, 80, 88, 96, 104, 112, 120, $\boxed{128}$, 136, 144, 152, 160, 168, 176, 184, 192
TR #2	201, 209, 217, 225, 233, 241, 249, 1, 9, 17, 25, 33, 41, 49, 57, 65, 73, 81, 89, 97, 105, 113, 121, 129, 137, 145, 153, 161, 169, 177, 185, 193
TR #3	202, 210, 218, 226, 234, 242, 250, 2, 10, 18, 26, 34, 42, 50, 58, 66, 74, 82, 90, 98, 106, 114, 122, 130, 138, 146, 154, 162, 170, 178, 186, 194
TR #4	203, 211, 219, 227, 235, 243, 251, 3, 11, 19, 27, 35, 43, 51, 59, 67, 75, 83, 91, 99, 107, 115, 123, 131, 139, 147, 155, 163, 171, 179, 187, 195
TR #5	204, 212, 220, 228, 236, 244, 252, 4, 12, 20, 28, 36, 44, 52, 60, 68, 76, 84, 92, 100, 108, 116, 124, 132, 140, 148, 156, 164, 172, 180, 188, 196
TR #6	205, 213, 221, 229, 237, 245, 253, 5, 13, 21, 29, 37, 45, 53, 61, 69, 77, 85, 93, 101, 109, 117, 125, 133, 141, 149, 157, 165, 173, 181, 189, 197
TR #7	206, 214, 222, 230, 238, 246, 254, 6, 14, 22, 30, 38, 46, 54, 62, 70, 78, 86, 94, 102, 110, 118, 126, 134, 142, 150, 158, 166, 174, 182, 190, 198
TR #8	207, 215, 223, 231, 239, 247, 255, 7, 15, 23, 31, 39, 47, 55, 63, 71, 79, 87, 95, 103, 111, 119, 127, 135, 143, 151, 159, 167, 175, 183, 191, 199

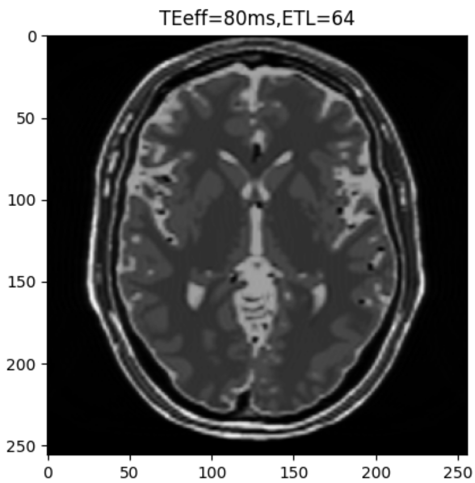
iv. TEeff=80ms, and ETL of 16:



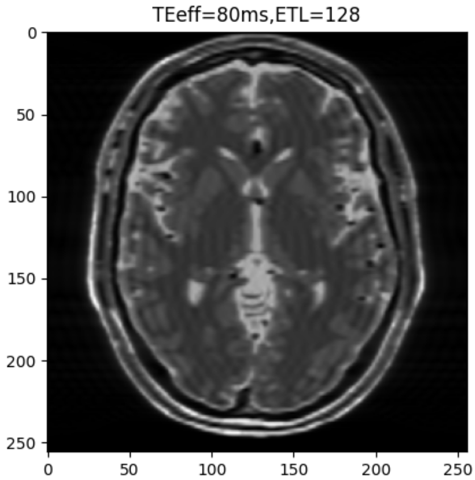
TEeff=80ms, and ETL of 32:



TEeff=80ms, and ETL of 64:



TEeff=80ms, and ETL of 128:



c. **BONUS**

maybe use smaller flip angle instead of 180 refocusing pulse, and use the stimulated echoes to do imaging