HL2011: Exercise Set 2
The Signal, Slice selection

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1 Preparations

If you haven't done it already, download the package `seemri.zip` from Bilda and unzip it to a suitable directory. Start Matlab and add the path to seemri using the matlab command `addpath` <*path to seemri*>. In matlab, type `help seemri` and make sure you get the help page. You are now ready to start.

Define some useful constants:

```
gammabar = 42.58e6;
gamma = 2*pi*gammabar;
```

2 The Signal

The free induction decay (FID) is the most basic of signals. It is acquired by applying an RF pulse and measuring the signal as it decays due to the relaxation processes. In this exercise you will measure the FID signals from three different RF pulses and investigate how they are related.

First set B_0, pulse duration t_p and create an imaging volume with $T_1 = 0.5$ s and $T_2 = 0.02$ s.

```
B0 = 2;
tp = 10e-6;
iv = ImagingVolume(0, 0, 0.5, 0.02);
```

Create rectangular RF pulse objects, `rf1`, `rf2` and `rf3` for the following three pulses: $90^\circ_{x'}$, $90^\circ_{-y'}$ and $45^\circ_{x'}$. The subscript indicates the direction of B_1 in the rotating frame of reference. *Note*: this is not the same as the resulting direction of $\vec{M}$. Use your results from Exercise 1 to determine the B1 amplitude and the initial phase corresponding to the B_1 direction.

In the simulator the `ADC` object determines at what times the signal will be sampled, see `help ADC`. The following lines measures the first 0.2 s of the signal with a sampling interval of 0.2/100 s.

```
[S1, ts] = seemri(iv, B0, rf1, [], [], ADC(0.2, 0.2/100));
iv.toEquilibrium();
[S2, ts] = seemri(iv, B0, rf2, [], [], ADC(0.2, 0.2/100));
iv.toEquilibrium();
[S3, ts] = seemri(iv, B0, rf3, [], [], ADC(0.2, 0.2/100));
iv.toEquilibrium();
```

Plot the three signals magnitude and phase using the commands:

```
figure
subplot(2,1,1)
plot(ts, abs(S1), ts, abs(S2), '--', ts, abs(S3), '-.')
xlabel('Time (s)')
ylabel('Signal magnitude')
subplot(2,1,2)
plot(ts, angle(S1), ts, angle(S2), '--', ts, angle(S3), '-.')
xlabel('Time (s)')
ylabel('Signal phase (radians)');
```

Q1: How are the three signals related (in phase and amplitude)? Verify the direction of $\vec{M}$ after the pulses, and describe the phase of the signal in relationship to the direction of $\vec{M}$.

3 The Spin Echo

Create an imaging volume with 9x9 magnetization vectors, with $T_1 = 0.5$ and $T_2 = 0.02$ and with a B_0-inhomogeneity (with a Cauchy-Lorentz distribution with parameter $1 \cdot 10^{-6}$ T) using the command:

```
iv = ImagingVolume(-4:1:4, -4:1:4, 0.5, 0.02, 1, 'dB0Gamma', 1e-6);
```

Create a spin echo pulse sequence by designing two pulses with flip angle 90° and 180° degrees, applied at times 0 and 5 ms.

Let

```
B0 = 2;
tp = 10e-6;
phi_rf = [0 pi/2];
```

and compute

```
B1_90 =
B1_180 =
f_rf =
```

Create the object representing the two pulses using:

```
rf = RectPulse([B1_90 B1_180], f_rf, phi_rf, tp, [0 5e-3]);
```

and apply the pulse sequence to the imaging volume by

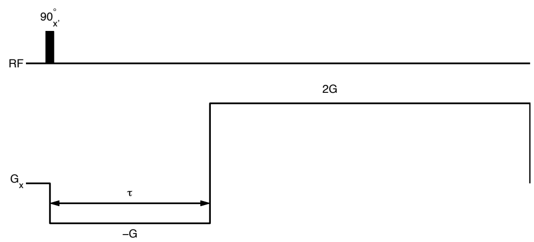
```
[S, ts] = seemri(iv, B0, rf, [], [], ADC(0.02, 0.02/100));
```

Note the dotted line which indicates T_2-decay from the highest peak.

Q2: At what time does the echo occur? Why?

4 Gradient Echo

The pulse sequence below is applied to a spin system in a magnetic field $\vec{B}_0 = B_0\hat{z}$. The initial magnetization is $\vec{M}(\vec{r}, 0) = M_z^0(\vec{r})\hat{z}'$ at position $\vec{r}$.



Q3: Derive the mathematical expression for the signal during the time interval $t > \tau$. You can assume a homogeneous reception field. At what time does the echo occur? See exercise 4.7 from the book, as solved during Lecture 3.

Now, define and try the gradient echo pulse sequence in the simulator. First let

```
B0 = 2;
G = 1.2e-6;
tau = 5e-3;
iv = ImagingVolume(-4:1:4, -4:1:4, 0.5, 0.02, 1, ...
                   'dB0Gamma', 0.1e-6);
```

A rectangular gradient is defined by supplying times at which the gradient changes and the amplitude of the gradient after each time. Define the gradient in the figure above using the command

```
Gx = Gradient([tp tp+tau tp+3*tau], [-G 2*G 0]);
```

Note that the gradient is turned on after the RF pulse not to interfere with the excitation.

You can reuse the RF pulse from the first part of this exercise. Apply the pulse and gradient by

```
[S, ts] = seemri(iv, B0, rf1, Gx, [], ADC(0.02, 0.02/100));
```

Q4: How well did the theory predict the time of the echo?

5 Slice Selection

In this part you will study how the RF pulse and the gradient affect slice selection.

In this exercise, let $B_0 = 3$ T and define an imaging volume containing an array of magnetization vectors, with the following command:

```
B0 = 3;
iv1 = ImagingVolume(-1:0.25:5, -1:0.25:1, 0.8, 0.07, 1, 'PlotScale', 2);
```

The option `'PlotScale'` scales the M-vectors in the plot.

Create a selective RF pulse using the commands:

```
tp = 2e-3;
B1 = 2.9e-6;
rf1 = SincPulse(B1, gammabar*B0, 0, tp);
```

Create a slice selective gradient, with rephasing, using

```
g1 = Gradient([0 tp 1.5*tp], [70e-6 -70e-6 0]);
```

See `help Gradient` for details on how the gradient object is defined.

Apply the sequence to the imaging volume by

```
[S, ts] = seemri(iv1, B0, rf1, g1, [], ADC(1.5*tp, tp/100));
```

and observe what happens.

5.1 The RF pulse frequency's effect on the slice selection

Now we are going to study the effect of the RF pulse frequency on the slice selection. Create two more pulses, `rf2` and `rf3` with 4 and 8 kHz higher frequency than `rf1`.

```
rf2 = SincPulse(B1, gammabar*B0+4e3, 0, tp);
rf3 = SincPulse(B1, gammabar*B0+8e3, 0, tp);
```

and apply them to two new imaging volumes, with the same gradient as before.

```
iv2 = ImagingVolume(-1:0.25:5, -1:0.25:1, 0.8, 0.07, 1, 'PlotScale', 2);
iv3 = ImagingVolume(-1:0.25:5, -1:0.25:1, 0.8, 0.07, 1, 'PlotScale', 2);
[S, ts] = seemri(iv2, B0, rf2, g1, [], ADC(1.5*tp, tp/100));
[S, ts] = seemri(iv3, B0, rf3, g1, [], ADC(1.5*tp, tp/100));
```

Plot the three excited imaging volumes next to each other using the commands:

```
subplot(3,1,1);
plot(iv1)
subplot(3,1,2);
plot(iv2)
subplot(3,1,3);
plot(iv3)
```

Q5: How does the frequency of the RF pulse affect the slice selection? What happens when you increase the frequency of the RF pulse?

5.2 The gradient's effect on slice selection

Now define two more gradients by:

```
g2 = Gradient([0 tp 1.5*tp], [110e-6 -110e-6 0]);
g3 = Gradient([0 tp 1.5*tp], [150e-6 -150e-6 0]);
```

and apply them to each of the imaging volumes using the pulse `rf3`. Don't forget to put the magnetization back to thermal equilibrium, i.e.:

```
iv1.toEquilibrium();
iv2.toEquilibrium();
iv3.toEquilibrium();
[S, ts] = seemri(iv1, B0, rf3, g1, [], ADC(1.5*tp, tp/100));
[S, ts] = seemri(iv2, B0, rf3, g2, [], ADC(1.5*tp, tp/100));
[S, ts] = seemri(iv3, B0, rf3, g3, [], ADC(1.5*tp, tp/100));
```

Again, plot the excited volumes next to each other by

```
subplot(3,1,1);
plot(iv1)
subplot(3,1,2);
plot(iv2)
subplot(3,1,3);
plot(iv3)
```

Q6: How does the amplitude of the gradient affect the position and thickness of the selected slice? What happens when you increase the gradient amplitude?

5.3 Designing a Slice Selection Sequence

Now, your task is to design an RF pulse and gradient that will excite a slice with its normal in the x-direction, that is 2 mm thick and has its center at $x = 1$ mm.

You will use the selective sinc pulse for this purpose. Let the RF pulse duration be $t_p = 2$ ms. This will in term set the bandwidth of the RF pulse. The way the `SincPulse` object is defined, namely the sinc envelope function is truncated to have six zero-crossings on each side of the peak, the bandwidth of the pulse is equal to $\Delta f = 12/t_p$.

```
tp = 2e-3;
Delta_f = 12/tp;
```

Now, design the slice selective gradient. **Q7: What should the amplitude G_{ss} of the gradient be?** The unit of the gradient amplitude is T/mm.

```
Gss =
g = Gradient([0 tp 1.5*tp], [Gss -Gss 0]);
```

Design the RF pulse. **Q8: What should the frequency f_{rf} of the pulse be?**

```
f_rf =
rf = SincPulse(B1, f_rf, 0, tp);
```

Apply the pulse sequence to `iv1`:

```
iv1.toEquilibrium();
[S, ts] = seemri(iv1, B0, rf, g, [], ADC(1.5*tp, tp/100));
```

Did it excite the correct slice? If not try again.

Finally, apply a similar sequence, with the gradient in both the $x-$ and $y-$directions simultaneously.

```
iv1.toEquilibrium();
[S, ts] = seemri(iv1, B0, rf, g, g, ADC(1.5*tp, tp/100));
```

Q9: What is the slice thickness, direction and distance from the origin now? Be careful to use thickness and distance in the direction orthogonal to the slice.

6 Report

Submit an individual report and source code (as separate PDF and .m files) on Canvas by April 9 23:59, or before 10:15 to count as attendance for the session. Provide relevant plots as figures and make sure your report is self-contained.