Contents


```
% BME/EECS516
% MRI Project Template
clc
clear all
% Other m-files required: ift2, ift, ft2, ft, blochsim_516
% Subfunctions: none
% MAT-files required: object18.mat

%Programme: YUZHOU CHEN
%DATA:November 23, 2023
%Oct 2022;
%Last revision: Oct-30-2022
```

Select whether to load complex 2D object or create simple point object

```
complexobj = 0;
if complexobj
   % 2D Object for reconstruction
  load object23;
else
  % Single point object at (x,y,z) = (2,2,0) cm;
  % Point object has T1 of 1000 ms, T2 of 100 ms
  obj_x = 4;
  obj_y = 4;
  obj_z = 0;
  obj_T1 = 1000;
  obj_T2 = 100;
end

FOVx = 16;
FOVy = 12;
Nx = 80;
Ny = 60;
T_read = 8;
T_y = 2;
obj_n = length(obj_x); % Determine number of objects
```

Define simulation constants

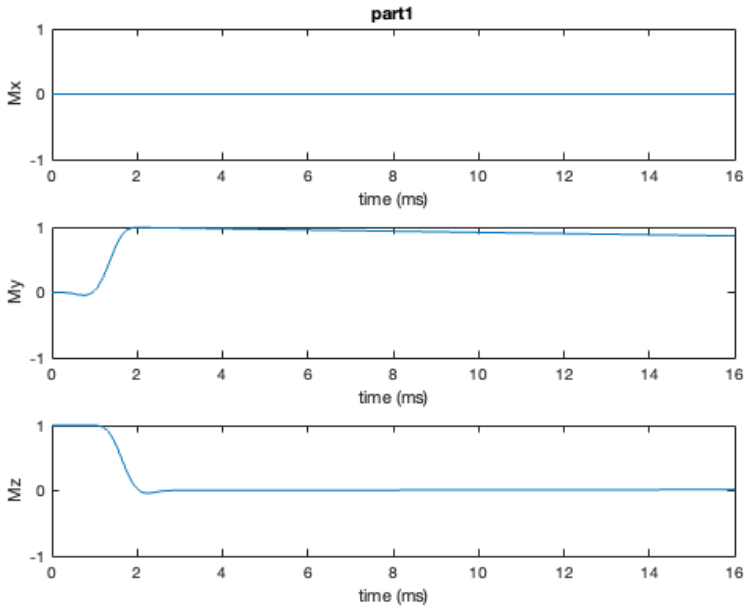
Physical constants

```
gambar = 42570;               % Gamma/2pi in kHz/T
gam = gambar*2*pi;            % Gamma in kiloradians/T

% Simulation values
dt = 0.05;                    % Time step for simulation, ms (50 us step size)
te = 10.0;                    % Echo time, ms
endtime = 16;                 % Total runtime of simulation, ms
time = [0:dt:endtime]';       % Vector containing each time step, ms (size #timepoints x 1)
totalTimepoints = length(time);          % Number of time points for simulation
```

```
% Initialize B vectors, the effective (x,y,z) applied magnetic field
% Vectors define applied magnetic field at time tp_n for object obj_n

bx = zeros([totalTimepoints obj_n]);
by = zeros([totalTimepoints obj_n]);
bz = zeros([totalTimepoints obj_n]);

% Define a 90 RF pulse
rf90pw = 3;                  % Pulse width in ms
sincper = rf90pw/4;          % in ms (this is the sinc stretch parameter)
                             % e.g. sinc(time/sincper) as shown below
rf_timepoints = rf90pw/dt;   % Number of simulation steps for RF
rf_time = [-(rf_timepoints-1) / 2 : (rf_timepoints-1) / 2]'.*dt; % Time vector for creating sinc, centered at 0
rf_shape = hanning(rf_timepoints) .* sinc(rf_time./sincper); % Sinc waveform shape with hanning window, with amplitude 1
rf_amplitude90 = (pi / 2)/(gam * dt * sum(rf_shape));        % REPLACE 0 with amplitude of the RF pulse here, in T
% Scale rf_shape by a_rf90 (amplitude), then fill the remainder of the time with zeros
b1_90 = rf_amplitude90.*[rf_shape; zeros([totalTimepoints-rf_timepoints 1])];
m0 = [0; 0; 1];
gz = 0;
omega_shift = gam * gz * 0;
```

part 1

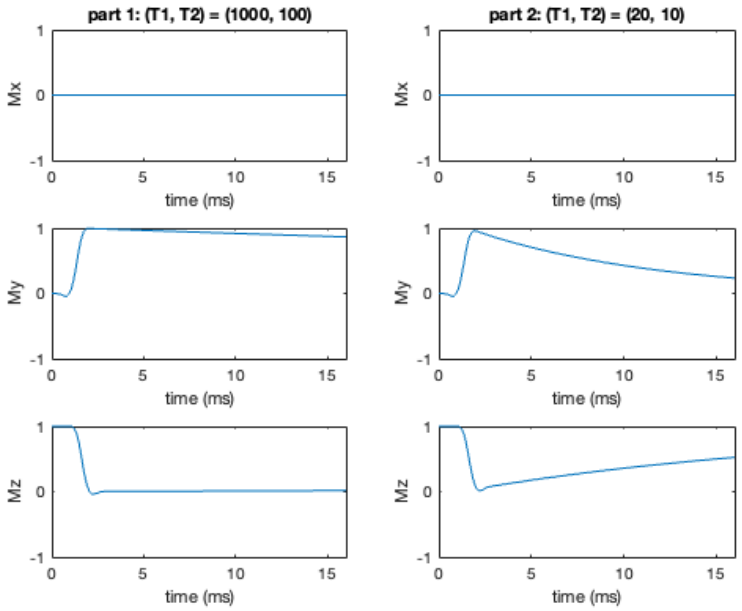
```
bx = b1_90;
[mx,my,mz] = blochsim_516(m0,bx,by,bz,obj_T1,obj_T2,dt);
figure (1)
subplot(3,1,1)
plot(time,mx);xlabel('time (ms)');ylabel('Mx');axis([0 endtime -1 1]);title('part1');
subplot(3,1,2)
plot(time,my);xlabel('time (ms)');ylabel('My');axis([0 endtime -1 1]);
subplot(3,1,3)
plot(time,mz);xlabel('time (ms)');ylabel('Mz');axis([0 endtime -1 1]);
```



part 2

```
obj_T1_1 = 20;
obj_T2_2 = 10;
[mx_2,my_2,mz_2] = blochsim_516(m0,bx,by,bz,obj_T1_1,obj_T2_2,dt);

figure (2)
subplot(3,2,1)
plot(time,mx);xlabel('time (ms)');ylabel('Mx');axis([0 endtime -1 1]);title('part 1: (T1, T2) = (1000, 100)');
subplot(3,2,3)
plot(time,my);xlabel('time (ms)');ylabel('My');axis([0 endtime -1 1]);
subplot(3,2,5)
plot(time,mz);xlabel('time (ms)');ylabel('Mz');axis([0 endtime -1 1]);
```

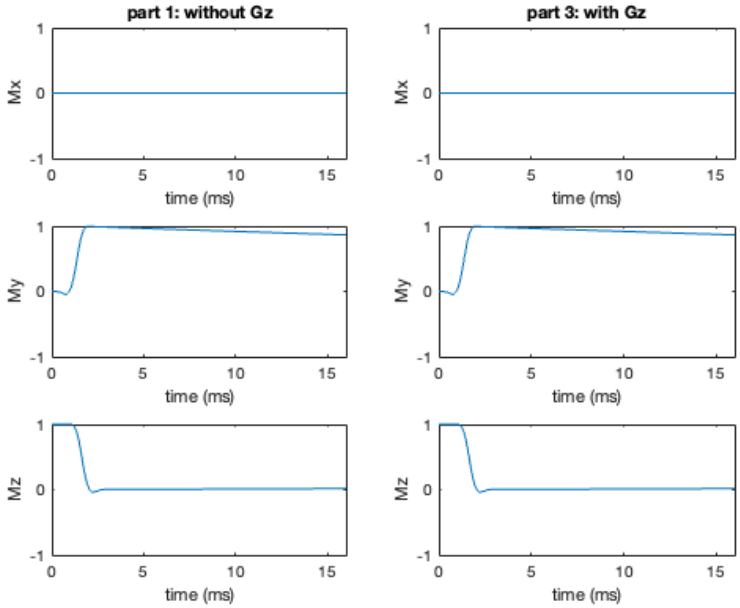
```
subplot(3,2,2)
plot(time,mx_2);xlabel('time (ms)');ylabel('Mx');axis([0 endtime -1 1]);title('part 2: (T1, T2) = (20, 10)');
subplot(3,2,4)
plot(time,my_2);xlabel('time (ms)');ylabel('My');axis([0 endtime -1 1]);
subplot(3,2,6)
plot(time,mz_2);xlabel('time (ms)');ylabel('Mz');axis([0 endtime -1 1]);
```



part 3

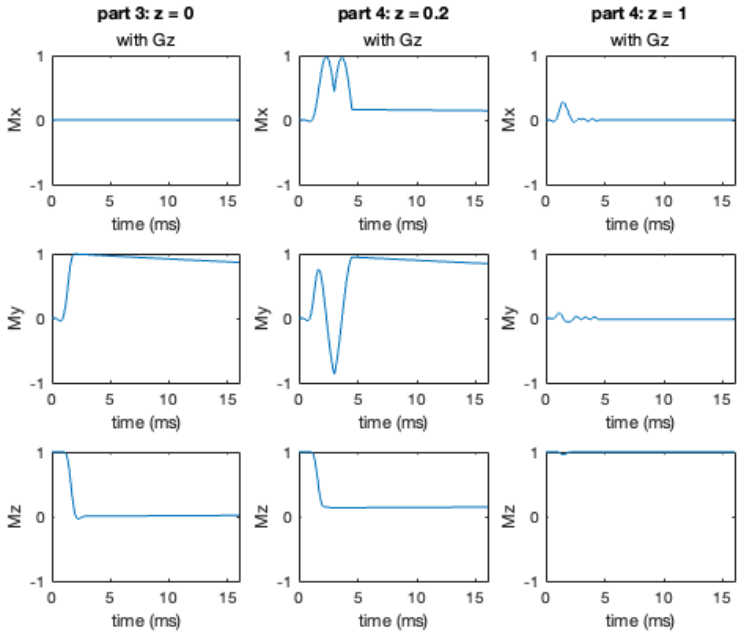
Create gradients Create gz

```
rf90bw = 1 / sincper;    %bandwith of RF
slThick = 1;             % Slick thickness in cm
gz1_a = 2*pi*rf90bw/gam/slThick;                % REPLACE 0 with amplitude of gz1 in T/cm
gz1_pw = rf90pw;           % Match the width of gz1 to the RF pulse
gz2_a = -gz1_a;             % REPLACE 0 with amplitude of gz2 in T/cm
gz2_pw = rf90pw/2;
% Create gz with positve area gz1_a*gz1_pw, followed by negative area gz2_a*gz2pw
% gz step size is dt, with amplitude values in T/cm
gz =  (time < gz1_pw) .* gz1_a ...
       + (time >= gz1_pw).*(time < (gz1_pw+gz2_pw)) .* gz2_a;
bz_3 = gz * obj_z;
[mx_3,my_3,mz_3] = blochsim_516(m0,bx,by,bz_3,obj_T1,obj_T2,dt);

figure (3)
subplot(3,2,1)
plot(time,mx);xlabel('time (ms)');ylabel('Mx');axis([0 endtime -1 1]);title('part 1: without Gz');
subplot(3,2,3)
plot(time,my);xlabel('time (ms)');ylabel('My');axis([0 endtime -1 1]);
subplot(3,2,5)
plot(time,mz);xlabel('time (ms)');ylabel('Mz');axis([0 endtime -1 1]);
subplot(3,2,2)
plot(time,mx_3);xlabel('time (ms)');ylabel('Mx');axis([0 endtime -1 1]);title('part 3: with Gz');
subplot(3,2,4)
plot(time,my_3);xlabel('time (ms)');ylabel('My');axis([0 endtime -1 1]);
subplot(3,2,6)
plot(time,mz_3);xlabel('time (ms)');ylabel('Mz');axis([0 endtime -1 1]);
```



part 4

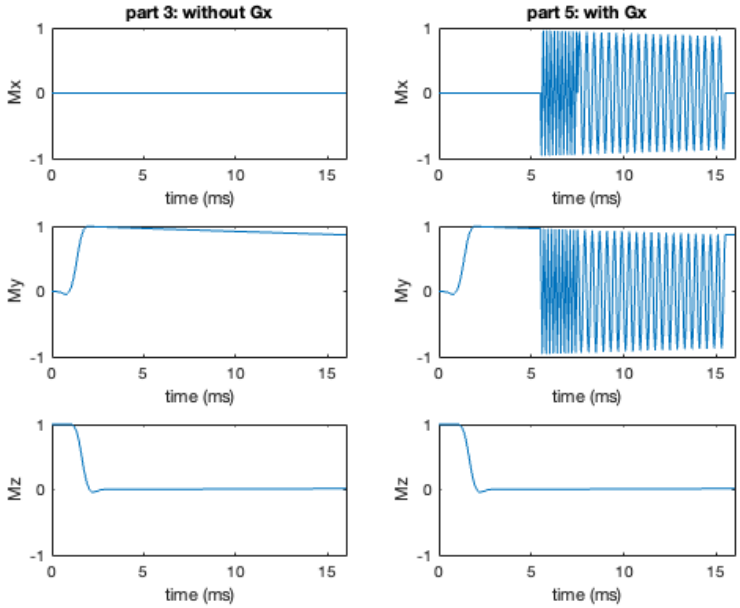
```
obj_z_41 = 0.2;
obj_z_42 = 1;
bz_41 = gz * obj_z_41;
bz_42 = gz * obj_z_42;

[mx_41,my_41,mz_41] = blochsim_516(m0,bx,by,bz_41,obj_T1,obj_T2,dt);
[mx_42,my_42,mz_42] = blochsim_516(m0,bx,by,bz_42,obj_T1,obj_T2,dt);
figure (4)
subplot(3,3,1)
plot(time,mx_3);xlabel('time (ms)');ylabel('Mx');axis([0 endtime -1 1]);title('part 3: z = 0');subtitle('with Gz');
subplot(3,3,4)
plot(time,my_3);xlabel('time (ms)');ylabel('My');axis([0 endtime -1 1]);
subplot(3,3,7)
plot(time,mz_3);xlabel('time (ms)');ylabel('Mz');axis([0 endtime -1 1]);
subplot(3,3,2)
plot(time,mx_41);xlabel('time (ms)');ylabel('Mx');axis([0 endtime -1 1]);title('part 4: z = 0.2');subtitle('with Gz');
subplot(3,3,5)
plot(time,my_41);xlabel('time (ms)');ylabel('My');axis([0 endtime -1 1]);
subplot(3,3,8)
plot(time,mz_41);xlabel('time (ms)');ylabel('Mz');axis([0 endtime -1 1]);
subplot(3,3,3)
plot(time,mx_42);xlabel('time (ms)');ylabel('Mx');axis([0 endtime -1 1]);title('part 4: z = 1');subtitle('with Gz');
subplot(3,3,6)
plot(time,my_42);xlabel('time (ms)');ylabel('My');axis([0 endtime -1 1]);
subplot(3,3,9)
plot(time,mz_42);xlabel('time (ms)');ylabel('Mz');axis([0 endtime -1 1]);
```



part 5

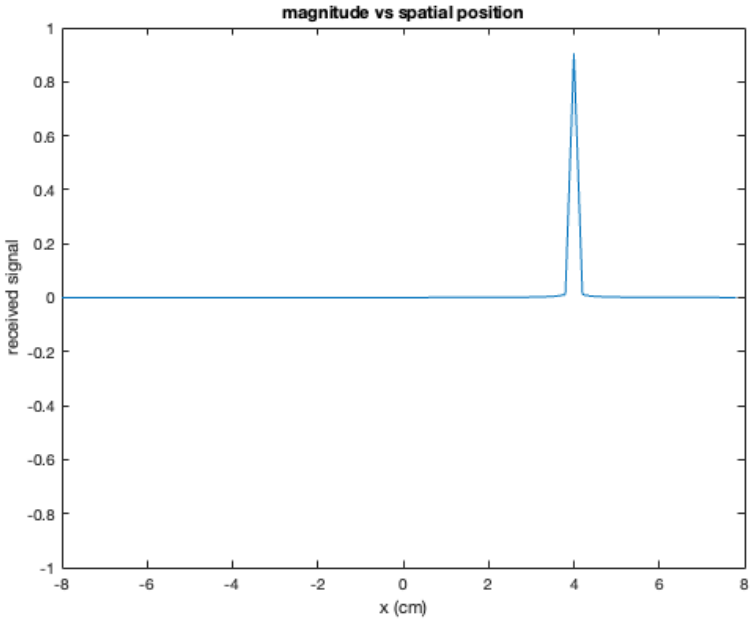
Create gx

```
k_x = 1/FOVx;
gx_5b = Nx* k_x / T_read / gambar;
gx_5a = -2 * gx_5b;

t_gx_1 = 5.5;
t_gx_2 = 7.5;
t_gx_3 = 15.5;

gx_5 =  (time >= t_gx_1).*(time < t_gx_2) .* gx_5a ...
       + (time >= t_gx_2).*(time < t_gx_3) .* gx_5b;

bx_5 = b1_90;
by_5 = zeros([totalTimepoints obj_n]);
bz_5 = gx_5 * obj_x;

[mx_5,my_5,mz_5] = blochsim_516(m0,bx_5,by_5,bz_5,obj_T1,obj_T2,dt);
figure (5)
subplot(3,2,1)
plot(time,mx_3);xlabel('time (ms)');ylabel('Mx');axis([0 endtime -1 1]);title('part 3: without Gx');
subplot(3,2,3)
plot(time,my_3);xlabel('time (ms)');ylabel('My');axis([0 endtime -1 1]);
subplot(3,2,5)
plot(time,mz_3);xlabel('time (ms)');ylabel('Mz');axis([0 endtime -1 1]);
subplot(3,2,2)
plot(time,mx_5);xlabel('time (ms)');ylabel('Mx');axis([0 endtime -1 1]);title('part 5: with Gx');
subplot(3,2,4)
plot(time,my_5);xlabel('time (ms)');ylabel('My');axis([0 endtime -1 1]);
subplot(3,2,6)
plot(time,mz_5);xlabel('time (ms)');ylabel('Mz');axis([0 endtime -1 1]);
```



part 6

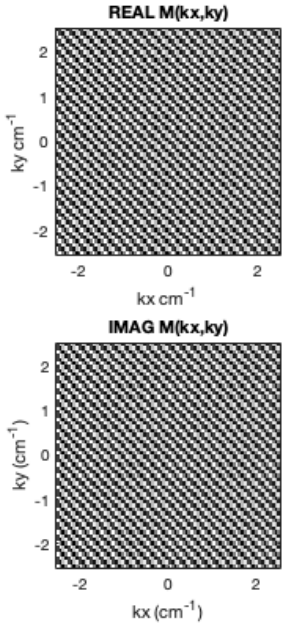
```
nread = 80;
npe = 60;
by_6 = zeros([totalTimepoints obj_n]);
sig_6 = zeros([nread 1]);
gy_6 = zeros([totalTimepoints 1]);
bz_6 = gx_5 * obj_x;
[mx_6,my_6,mz_6] = blochsim_516(m0,bx_5,by_6,bz_6,obj_T1,obj_T2,dt);
M_6 = mx_6 + 1i * my_6;
index_1 = 1;
for index = 1 : totalTimepoints
    if (index >= 151 && index <= 310) && mod(index,2) == 1
    sig_6(index_1,1) = M_6(index,1);
    index_1 = index_1 + 1;
    end
end
xpos = [-nread/2:nread/2-1]/nread.*FOVx;
ypos = [-npe/2:npe/2-1]/npe*FOVy;
figure(6)
plot(xpos,abs(ift(sig_6)));xlabel('x (cm)');ylabel('received signal');axis([-8 8 -1 1]);title('magnitude vs spatial position');
```



part 7

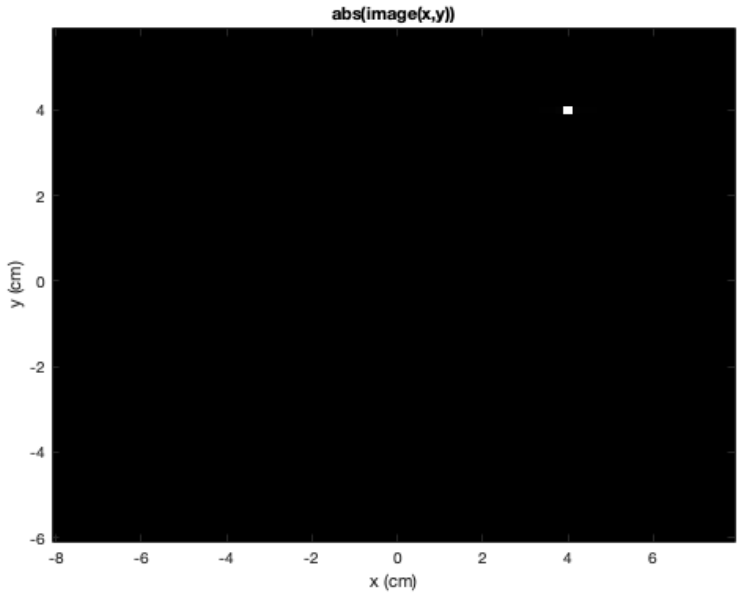
Create gy

```
k_y = 1/FOVy;
gy_max = Ny * k_y / gambar / T_y / 2;
delta_gy = 2 * pi / (gam * 2 *FOVy);
by_7 = zeros([totalTimepoints obj_n]);
sig_7 = zeros([nread npe]);
M_7 = zeros([totalTimepoints npe]);
for pe = 1:npe
    gy_7 = (time >= t_gx_1).*(time < t_gx_2) .* (delta_gy * (pe - 1) - gy_max);
    bz_7 = gx_5 * obj_x + gy_7 * obj_y + gz * obj_z;
    [mx_7,my_7,mz_7] = blochsim_516(m0,bx_5,by_7,bz_7,obj_T1,obj_T2,dt);
    M_7(:,pe)= mx_7 + 1i * my_7;
    index_1 = 1;
    for index = 1 : totalTimepoints
        if (index >= 151 && index <= 310) && mod(index,2) == 1
        sig_7(index_1,pe) = M_7(index,pe);
        index_1 = index_1 + 1;
        end
    end
end

% show images for parts 7-10
W_kx = k_x * Nx;
W_ky = k_y * Ny;
kxpos = linspace(-W_kx/2, W_kx/2, Nx);  % vector of kx locations
kypos = linspace(-W_ky/2, W_ky/2, Ny);  % vector of ky locations

figure(7)
subplot(2,1,1)
imagesc(kxpos,kypos,real(sig_7)'); colormap gray; axis('image'); axis('xy')
xlabel('kx cm^{-1}');
ylabel('ky cm^{-1}');
title('REAL M(kx,ky)')

% disp 'Press any key to continue...'; pause

subplot(2,1,2)
imagesc(kxpos,kypos,imag(sig_7)'); colormap gray; axis('image'); axis('xy')
xlabel('kx (cm^{-1})');
ylabel('ky (cm^{-1})');
title('IMAG M(kx,ky)')
%disp 'Press any key to continue...'; pause
```



part 8

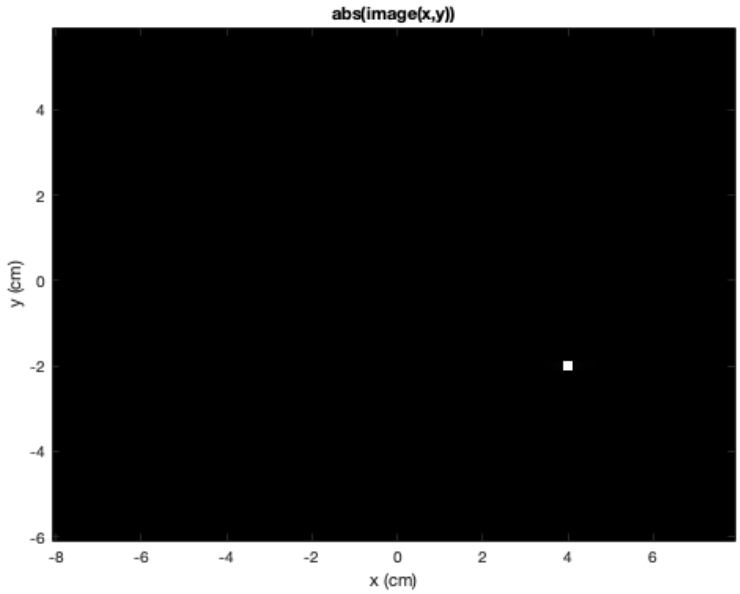
```
figure(8)
imagesc(xpos,ypos,abs(ift2(sig_7))'); colormap gray; axis('image'); axis('xy')
xlabel('x (cm)');
ylabel('y (cm)');
title('abs(image(x,y))')

%disp 'Press any key to continue...'; pause
```



part 9

```
by_9 = zeros([totalTimepoints obj_n]);
sig_9 = zeros([nread npe]);
index_1 = 1;
M_9 = zeros([totalTimepoints npe]);
for pe = 1:npe
    gy_9 = (time >= t_gx_1).*(time < t_gx_2) .* (delta_gy * (pe - 1) - gy_max);
    bz_9 = gx_5 * obj_x + gy_9 * 10 + gz * obj_z;
```

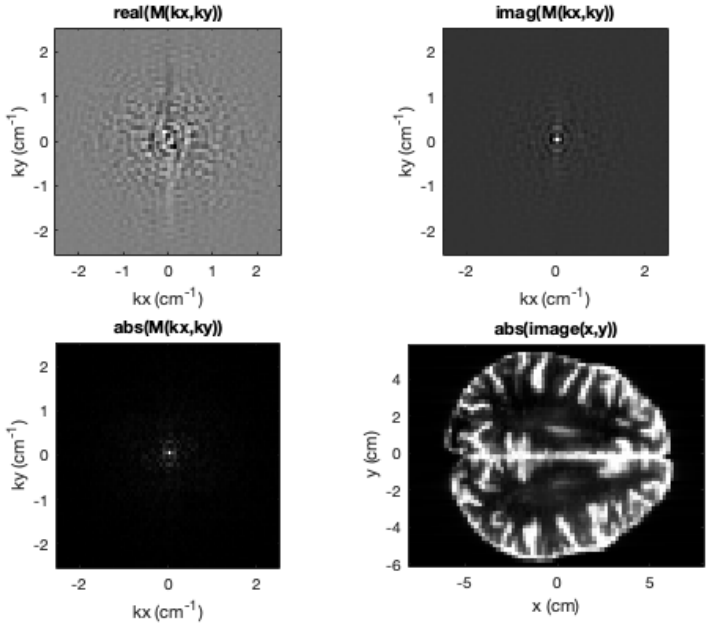
```
    [mx_9,my_9,mz_9] = blochsim_516(m0,bx_5,by_7,bz_9,obj_T1,obj_T2,dt);
    M_9(:,pe)= mx_9 + 1i * my_9;
    index_1 = 1;
    for index = 1 : totalTimepoints
        if (index >= 151 && index <= 310) && mod(index,2) == 1
        sig_9(index_1,pe) = M_9(index,pe);
        index_1 = index_1 + 1;
        end
    end
end

figure(9)
imagesc(xpos,ypos,abs(ift2(sig_9))'); colormap gray; axis('image'); axis('xy')
xlabel('x (cm)');
ylabel('y (cm)');
title('abs(image(x,y))')

%disp 'Press any key to continue...'; pause
```

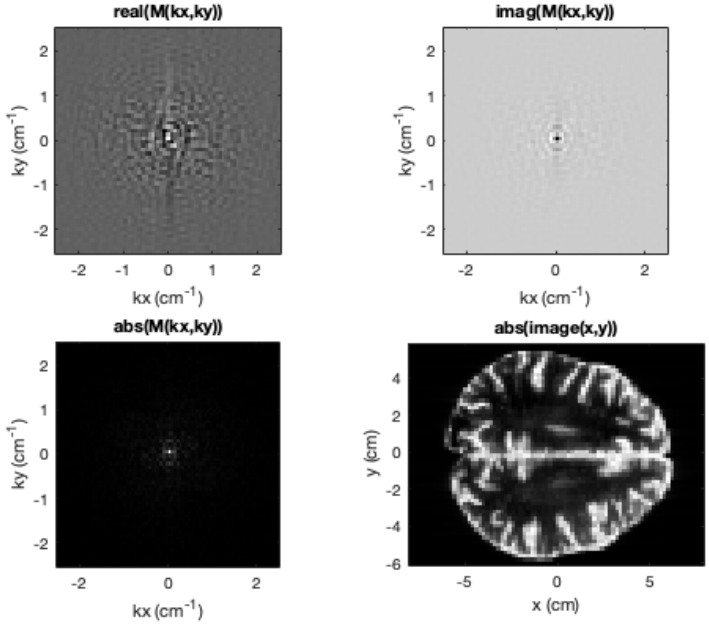


part 10 11

```
load object23.mat
b1_90_x = zeros([totalTimepoints 1]);
b1_90_y = zeros([totalTimepoints 1]);
obj_n = 2850;
m0_10 = [zeros([2 obj_n]);
         ones([1 obj_n])];
M_10 = zeros([totalTimepoints npe]);
sig_10 = zeros([nread npe]);
for slice = 1:2  % slice loop
    if slice == 1
        z_slice = 0;
    else
        z_slice = 1;
    end

    omega_shift = gam * gz1_a * z_slice;
    for tt = 1 : totalTimepoints
        b1_90_x(tt,:) = b1_90(tt,:) * cos(omega_shift * tt * dt);
        b1_90_y(tt,:) = b1_90(tt,:) * sin(omega_shift * tt * dt);
    end
        bx_10 = b1_90_x * ones([1 obj_n]);
        by_10 = b1_90_y * ones([1 obj_n]);
        gx_10 = gx_5;
        gz_10 = gz;
        %figure (10)
    for pe = 1:npe
```

```
        gy_10 = (time >= t_gx_1).*(time < t_gx_2) .* (delta_gy * (pe - 1) - gy_max);
        bz_10 = gx_10 * obj_x + gy_10 * obj_y + gz * obj_z;
        [mx_10,my_10,mz_10] = blochsim_516(m0_10,bx_10,by_10,bz_10,obj_T1,obj_T2,dt);
%         subplot(3,1,1)
%         plot(time,sum(mx_10,2)/obj_n);xlabel('time (ms)');ylabel('Mx');axis([0 endtime -1 1]);title('part 10');
%         subplot(3,1,2)
%         plot(time,sum(my_10,2)/obj_n);xlabel('time (ms)');ylabel('My');axis([0 endtime -1 1]);
%         subplot(3,1,3)
%         plot(time,sum(mz_10,2)/obj_n);xlabel('time (ms)');ylabel('Mz');axis([0 endtime -1 1]);
%         pause(0.01);
        M_10(:,pe) = sum(mx_10,2)+ 1i.*sum(my_10,2);
        index_1 = 1;
        for index = 1 : totalTimepoints
            if (index >= 151 && index <= 310) && mod(index,2) == 1
                sig_10(index_1,pe) = M_10(index,pe);
                index_1 = index_1 + 1;
            end
        end
    end

    %close(figure(10))

    if slice == 1
        figure(11)
    else
        figure(12)
    end

    subplot(2,2,1)
    imagesc(kxpos,kypos,real(sig_10)'); colormap gray; axis('image'); axis('xy')
    xlabel('kx (cm^{-1})');
    ylabel('ky (cm^{-1})');
    title('real(M(kx,ky))')


    subplot(2,2,2)
    imagesc(kxpos,kypos,imag(sig_10)'); colormap gray; axis('image'); axis('xy')
    xlabel('kx (cm^{-1})');
    ylabel('ky (cm^{-1})');
    title('imag(M(kx,ky))')

        subplot(2,2,3)
    imagesc(kxpos,kypos,abs(sig_10)'); colormap gray; axis('image'); axis('xy')
    xlabel('kx (cm^{-1})');
    ylabel('ky (cm^{-1})');
    title('abs(M(kx,ky))')

    subplot(2,2,4)
    imagesc(xpos,ypos,abs(ift2(sig_10))'); colormap gray; axis('image'); axis('xy')
    xlabel('x (cm)');
    ylabel('y (cm)');
    title('abs(image(x,y))')
end
```





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