wInstructions:

Write a report describing your process creating your gradient. What is a gradient? What tools did you use? Why did you select the parameters you selected?

What is a gradient?

An MRI gradient contains a series of coils that when an electrical current is passed through, generates a controlled magnetic field. This magnetic field slightly distorts the pre-existing magnetic field created by the magnet which changes the orientation of various protons. The differing alignments of the different protons causes them to emit different radio frequencies which can be used to identify their location. In MRI, gradients are essential for spatial encoding. Without them, it would be impossible to locate where signals in the body come from. Gradients are magnetic fields that vary linearly with position, allowing the MRI system to encode spatial information along different axes. This slight distortion along the x, y, and z axes allows for spatial encoding, which translates data to a 3D image that can be analyzed to locate targets within the phantom or patient. Gradients aim for a low coil inductance, resulting in a high slew rate, or the measure of how fast a gradient can turn on or off the coils. This leads to a quicker restabilization of the targeted protons and can help quality and speed of imaging. This is especially important when producing clear images of patients in pain who cannot bear to hold still for long periods of time or moving organisms that might not be able to remain still long enough for a clear image. MRI uses a strong static magnetic field (B_0) to align the protons in the body. When a radiofrequency (RF) pulse is applied, these protons get excited and emit signals. However, to know where these signals are coming from in the body, we need to apply gradients.

Types of Gradients:

There are three primary gradient fields in MRI:

- Gx (X-gradient): Encodes spatial information along the left-right (x) axis.

- Gy (Y-gradient): Encodes spatial information along the front-back (y) axis.
- Gz (Z-gradient): Encodes spatial information along the head-foot (z) axis.

These gradients allow us to take "slices" of the body and create detailed images.

Gradient Design

Our group was tasked with designing and building the gradient of an MRI. To do so, we ran code designed for gradient coils for Halbach array based MRI systems based on the Target Field Method initially proposed by Turner. This code is on github. The MRI design program allowed us to adjust different parameters to confine to our required constraints. Because the gradient sits between the magnet and the RF coils within the MRI, the dimensions of our gradient had to be between 4.5 and 6.5 inches. To achieve this, we set the coil radius to 69.85 mm. We also set the gradient coil length to 160 mm in order to cover the entire length of the phantom being scanned. Another constraint we had was to maintain an adequate gradient efficiency. A concern we had was that the gradient coils could get too hot, so we reduced the wires per quadrant to 4 to ensure that the inductance wasn't too high. We were also constrained on a limited amount of time and were forced to drop the set of coils which would create a magnetic field in the Z direction. In the end we were only able to create a gradient design with X and Y fields.

Construction

Once we had the parameters of our gradient set, we transferred the design generated by the code to Inventor Pro (a CAD program) which allowed us to 3D print the design. The print was supposed to result in two hollow cylinders, one with a slightly smaller radius (Y gradient) and one with a slightly larger (X gradient), with 4 quadrants of indents to place the wires. The smaller radius cylinder was supposed to fit inside the other. When fully assembled with the wires, each cylinder would correspond to the generation of one of the dimensions (x or y) of the magnetic field. However, due to 3D printer limitations, the end results of the print were 6 different pieces. The two gradients were made from different materials. The two pieces for the x field of the gradient came out as two cylinders cut into pieces. In order to fit our intended design, we epoxied the two pieces together. As for the 4 pieces, they were split as if the original cylinder was cut in half along the both x and y directions. Like the x field cylinders, we epoxied the pieces together. After we had out two cylinders set, we worked on setting the wires into the grooves. We ended up using 22 gauge wire because that had the closest radius to what we set in the design parameters. Unfortunately, we did not have wire that was the exact same size. To set the wire, we used tape to hold the wire down as we took one long strand of wire and placed it in the grooves. Based on the generated design, each opposite quadrant of the cylinder had to have the wires wired in the opposite orientation (clockwise or counterclockwise). After the strand of wire was taped down, we used epoxy to set the wire firmly in place. Finally we placed the smaller radius cylinder inside the larger one slightly rotated so that the coil quadrants were 90 degrees of each other.

Design Parameters:

Gradient Direction: X & Y

Target Linear Region: 140 mm

Coil Radius: 69.85 mm

- So as to fit outside the RF coil and inside the magnet

Coil Length: 160 mm

- So as to cover the length of the phantom/area being scanned

Wires per quadrant 4

- So that the inductance wasn’t too high (low slew rate) and it didn’t get too overheated

Wire diameter: 1.15 mm

Number of high order terms: 1

Linearity Order: 4

Apodization term: 0.05

- "Multiplication of acquired MR data by a function smoothly tapering off at higher spatial frequencies so as to reduce "ringing" artifacts near edges in the corresponding image or spectrum due to truncation and Gibbs phenomenon. It is a form of filtering."

Simulation DSV: 85 mm

- DSV= Diameter of spherical volume

Simulation Resolution: 5 mm

- Resolution of image

Simulation Output:

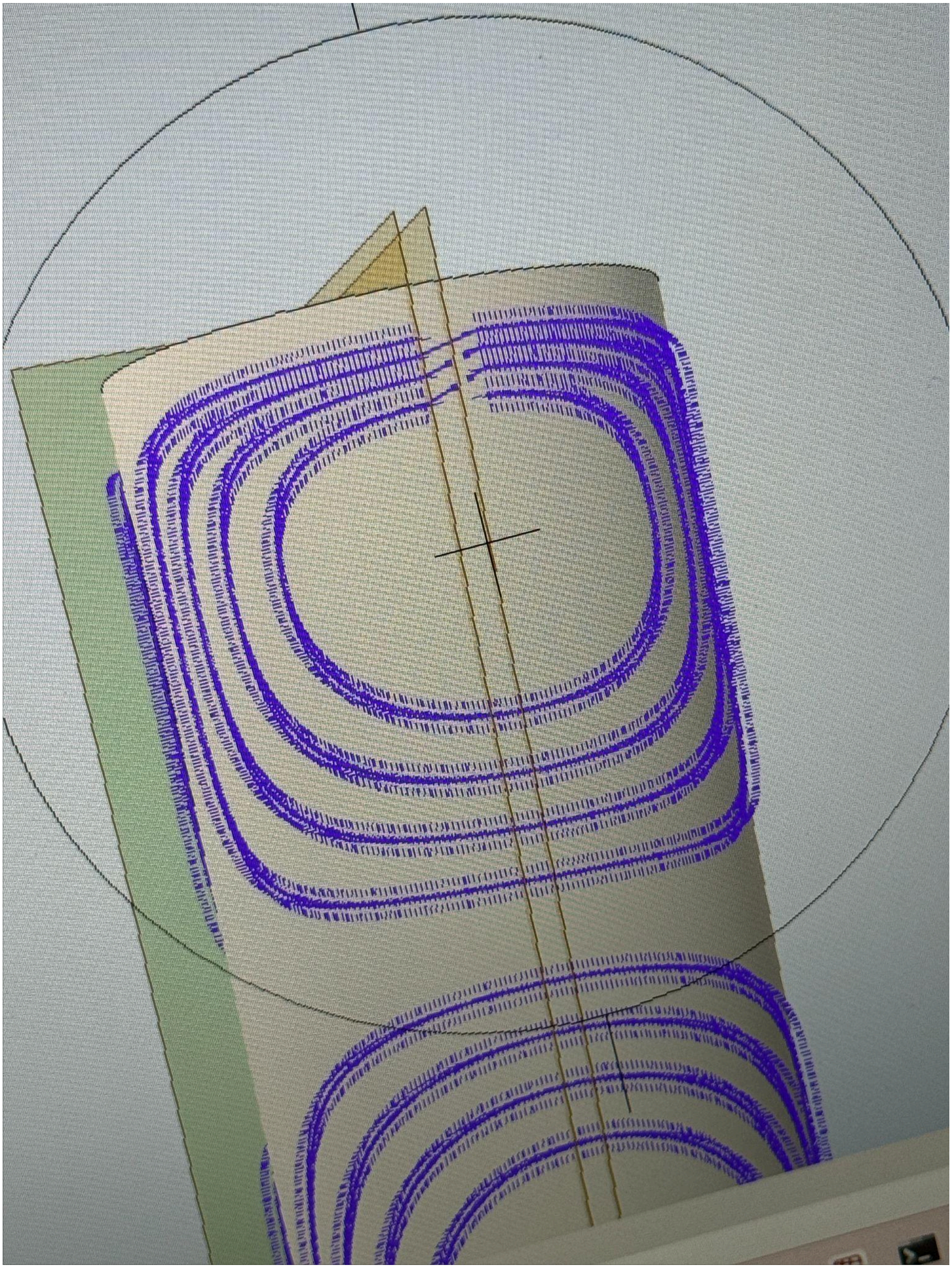
Gradient Efficiency: 0.4218 mT/m/A

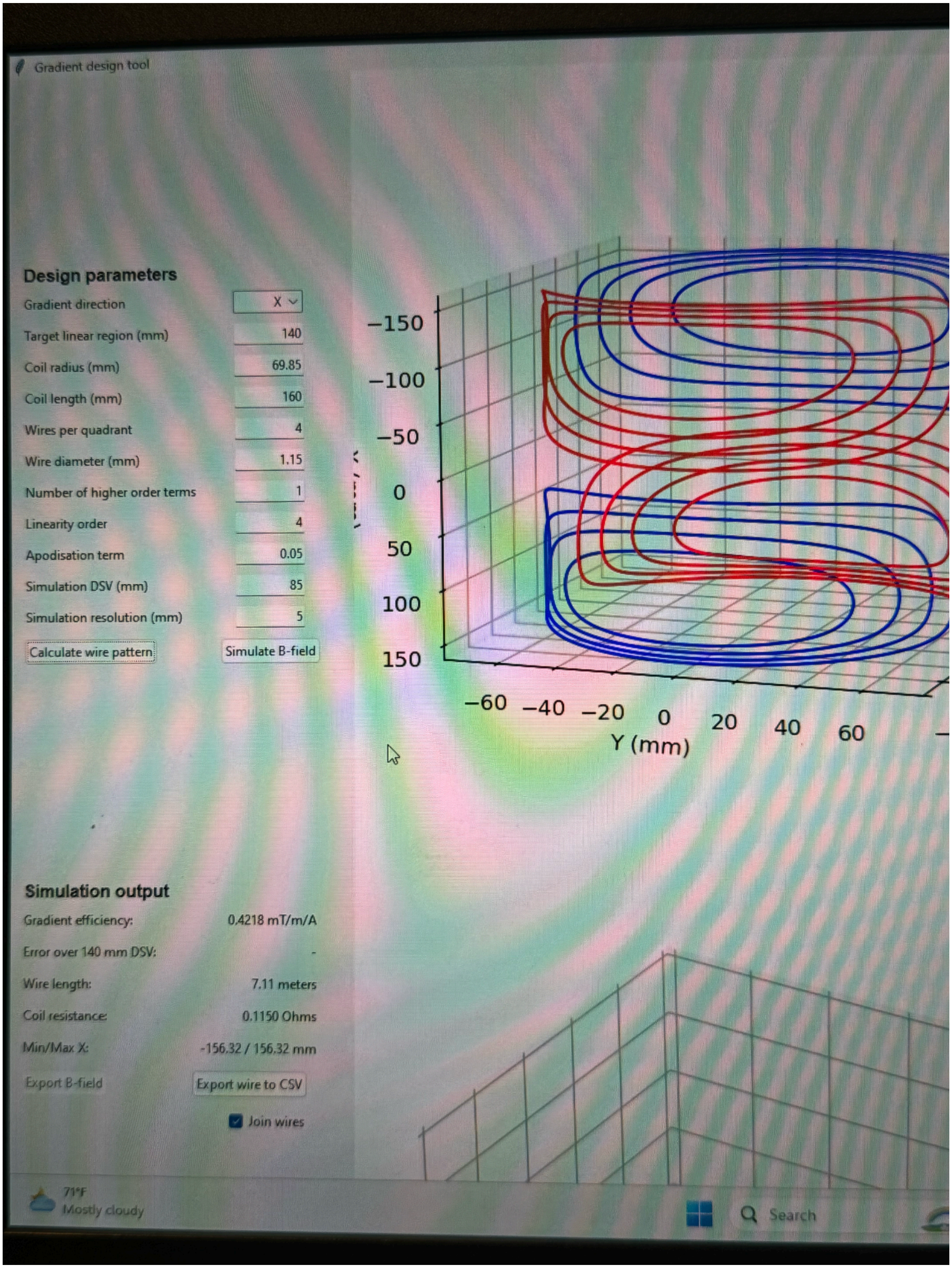
Wire Length: 7.11 m

Coil Resistance: 0.1150 Ohms

- This is low enough

Min/Max X: -156.32/156.32




Gradient design tool
Design parameters
Gradient direction
X
Target linear region (mm)
140
Coil radius (mm)
69.85
Coil length (mm)
160
Wires per quadrant
4
Wire diameter (mm)
1.15
Number of higher order terms
1
Linearity order
4
Apodisation term
0.05
Simulation DSV (mm)
85
Simulation resolution (mm)
5
Calculate wire pattern
Simulate B-field
Simulation output
Gradient efficiency:
0.4218 mT/m/A
Error over 140 mm DSV:
-
Wire length:
7.11 meters
Coil resistance:
0.1150 Ohms
Min/Max X:
-156.32 / 156.32 mm
Export B-field
Export wire to CSV
Join wires
−150
−100
−50
0
50
100
150
−60
−40
−20
0
20
40
60
Y (mm)
71°F
Mostly cloudy
Search

References

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