ES 1401-03 Intro to Engineering-[03]
Group Report

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Group Project: RF Coil

Introduction to RF Coils

A Radiofrequency Coil (RF Coil) is an antenna which impacts the signal to noise ratio of an MRI image. RF coils impact the sensitivity and spatial resolution within an MRI machine, as it serves as a Transmission and Receiver signal (also known as a T_X/R_X).

Transmit coils

We researched how the T_x coil is used to produce magnetic field pulses (B_1+) in order to rotate the net magnetization (M) of the tissue away from alignment with B_0. This is done by exciting protons with a frequency that corresponds to the Larmor frequency. The corresponding frequency depends on the type of nucleus and the strength of the magnetic field. Additionally, to get B_1 perpendicular to B_0 the strength and duration of the R_f pulse can be calculated from knowing the angle of the new axes that the protons will be precessed around. The R_f pulse is created through a resonant circuit that has an inductor and a capacitor. To adjust the frequency capacitance needs to be adjusted.

Receiver coils

R_x coils receive NMR signals When B_1 is removed, protons are able to return to equilibrium and their axes of precession, releasing the previously absorbed energy in the process. The released energy is known as field induction delay (FID), which is considered to be the NMR signal. The magnetic flux in R_x (B-) changes its current with the changing precession of M. The voltage of the receive coil can then be read.

Coil Shapes

A loop coil consists of one or multiple loops of wire. It is a very straightforward design that can be easily produced, making it an ideal choice for our small scanner. Some of the properties of a loop coil that we believed to be advantageous was that it worked well as both a transmit and receive coil for small scale imaging. However the coil did seem to have some problems with its design. These setbacks included inconsistent magnetic fields which would lead to poorer imaging, having weaker SNR if what is being scanned is more deep tissue, and inconsistencies with alignment(the direction of the magnetic field) could lead to coupling issues.

The solenoid coil, which is the shape we decided to be our shape for the final design, is a cylindrical, spiral shape coil. The wire is wound around in a helix structure. It is very similar to a spring shape. A solenoid shape provides a consistent magnetic field, throughout the entire coil, which is “helpful” to prevent variability in the scanner. At least for scanning a wrist which is somewhat small, a consistent magnetic field would provide better imaging. The solenoid shape is also widely used and our optimal shape because of the magnitude of the magnetic field it creates. The solenoid has a condensed magnetic field that helps high SNR proximal to the RF coil. In terms of creating a solenoid coil, similar to the loop, it is very easy to construct as it simply requires the coil to be wound up.

Method

Parts of the RF Coil

Our Methods for the RF Coil consisted of understanding the fundamental parts of building the RF Coil. The main parts of the MRI coil that we needed to build was the coil former and the shield

Shield:

RF shielding was an important component of our design. We intended to block external electromagnetic radiation that would interfere with the NMR signal. We printed out a 3D CAD of a hollow cylinder with a diameter of 4.2 in. We then wrapped copper tape around the entire surface area of the cylinder. Since the tape is not conductive, the gaps between the strips of copper could allow external electromagnetic radiation to penetrate the Rf shield and excite opposing magnetic fields which would disrupt the magnetic flux in the receive coil. Therefore it was necessary to solder the gaps between the strips of copper tape preventing disturbance with higher wavelength resolutions.

Materials:

The RF coil provides multiple different functions in an MRI scanner, primarily working as the T_X/R_X. The materials necessary to build an RF coil consists of two main components – a conductor and an insulator. The conductor material will be used for the coil winding. The optimal material for conducting the coil that our team decided was copper. Copper works as an exceptional conductor as it is cost effective and common in conductive material. Another common conductor in consideration was aluminum, however, it is less conductive which could lead to variability later in the process and ultimately affect image resolution.

Building the radiofrequency coil required an array of materials. After acquiring our models on CAD, a 3D printer was used to print the models made on CAD. Polylactic acid (PLA plastic) was used to print these models due to its inexpensiveness and ability to be altered post-processing with methods of sanding, drilling, and gluing. After acquiring these formers, we began by wrapping copper foil tape around the shield former utilizing its adhesiveness. Then we used sauder of 1.27 mm (0.050 in) diameter along with a soldering iron to sauder the edges of copper foil and decrease disturbances when imaging. (It is important to periodically check that the former is not melting due to the heat of the soldering iron as it is made of PLA plastic.) Though we are not working with low wavelengths in this low-field MRI process, it is vital to ensure that all overlapping copper edges are soldered to ensure that higher frequencies don't disturb images by getting through small edges of copper that may not see. It is also a great method to ensure that all of the copper foil sheets are in unison. Then, we worked on the coil former by wrapping 22 gauge copper wire twenty four times as our solenoid coil. This wire was attached to the coil former down with hot glue. Sauder and a soldering iron were then used again to attach the printed circuit board (PCB) to the coil. More sauder was then used to attach the capacitors to the PCB. After we had our capacitors attached, an LCR meter was used to measure the capacitance and inductance of the circuit. Several tools were used throughout the process such as a scalpel to cut down on glue residue and sandpaper used to sand down melting plastic that disturbed the shape of the formers.

CAD:

To begin constructing our first model of the RF coil, we started on the

Computer-Aided Designing program MatLab. In order to make an RF model, the coil shape, and design had to be decided. For the first model on CAD, the shape of the coil was a single loop, with an optimal size that would fit an average wrist. However, many flaws arised with this design, like creating the loop to only fit the wrist and not accounting for the hand that had to be able to go through the loop. Therefore, we had to change the design element solely to fit the hand, meaning an ergonomic design was beginning to be prioritized at this stage. A new design was called for again when we realized that inductance had not been taken into account when making the coil.

Due to beginner level skills in MATLAB as well as needed changes in the design, other resources were utilized in order to make the RF coil even close to functioning.

The design for the 3D printed RF coil former and the shell former were made within Inventor Pro CAD autodesk. The design was a simple cylindrical shape with a diameter of four inches to hold a coil around with a four inch diameter that the solenoid RF coil design requires. Other dimensions of the coil were a 10-inch long body and an outer diameter of 4.2 inches. The shield former had inner diameter of 4.4 inches and outer diameter of 4.5 inches and was seven inches long in length. The four inches are also large enough to hold the design of the phantom and the outer dimensions of a diameter of 4.5 inches was small enough to fit within the gradient coils.

The original CAD design had the outside of the coil former as having indents in a circular coil around it, these unfortunately did not print properly in the 3D printer messing with the other designs. A reason that the coil former might not have printed the indents properly is due to a possible conversion error between the different files. The coils of the wire there for were not able to be tucked within the walls of the coil holder and instead held against the outside of the inner body with hot glue and tape. This had the effect of making the outer shell that holds the copper covering not being able to wrap around as the inner diameter of it was supposed to be flush against it.

To fix this issue the inner diameter of the copper shell former was changed from 4.2 to 4.4 inches and reprinted with a new length of 7.5 inches to save in printing times. The original designs were ten inches long in order to hold the entirety of a human wrist, even if they had a long wrist but the actual wiring coils only covered 7 inches of the coil former meaning the largest possible space would be 7 inches and the copper shell former only needs to hold that.

Resonance:

A big part of our final design depended heavily on the capacitance(measured in picoFarads) and inductance(measured in microHenries) values, which were calculated using a resonance calculator, where the only parameters was a 2MHz for the resonance frequency (this was in order to be compatible with the rest of the groups) and realistic inductance and capacitance. The values we landed on for the inductance and capacitance was a capacitance of 154.23 pF and around 49.0593 μH.

Solenoid Inductance:

Additionally, with the calculations of the inductance and capacitance, resonant frequencies were used as the constraint to find the parameters for the solenoid shape. This included the diameter of the wire, number of turns and the length of the coil. This was needed to be calculated to see how many turns are necessary with a certain gauge wire to obtain a proper inductance. The inductance values for both of these calculations had to be consistent, which we found to be somewhat of a limitation when making the measurements of the coil.

Result

Using the https://electronbunker.ca/eb/InductanceCalc.html calculator and putting the max number of frequency which is 2000 KHZ and a conductor of size 22 AWG then since we started with 4 for the number of turns until we got 24 turns and that was too small so we took a multiple of 4 until we got a good number for corrected inductance which is 41.0593 and then using another calculator and then using another calulator

ttps://www.omnicalculator.com/physics/resonant-frequency-lcwe put in our frequency (2MHZ) and our inductance (L)(41.0593) and we got capacitance (C) (154.23) (pF)

Conclusion

Overall there were a lot of modifications made throughout our designing process, which significantly improved the performance of the coil in the end. Although this does mean that the coil was effective because of our adjustments, further enhancements could have been made during the design process if we had a comprehensive simulation from the start that would provide us with the coil's performance before we started building and modifying our design. This approach would allow us to identify potential issues more earlier on and just have a more refined design in the end or at least before physically putting together our RF coil. For future iterations of this fabrication, leveraging the MATLAB simulation would enable a much more diverse range of design options, leading to a deepening understanding in RF coils in scanners, as well as a special coil shape that is optimal for a specific scanner (for us the solenoid shape was seen as the best for scanning a wrist).

References:

[The sources we used and what they told us about RF coils]

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