**STASIS – RF Array**

By Stephan Orzada

German Cancer Research Center (DKFZ)



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# Introduction

This document is a complete description of the RF exposition system for the STASIS project.

The plans for all parts of the system, as well as the software can be found in the respective sub-folders with their names resembling the titles in this document.

The array is developed for an RF frequency of 128 MHz, but the matching can be changed down to 123 MHz using trimmer capacitors, which can be operated from the outside.

To connect the antennas of the array to the amplifiers, N-connectors are used.

The maximum allowed input power is 1000 Wpeak per channel, 30 WRMS per channel to a total of 100 WRMS.

# RF Array

## Introduction

The RF Array is intended to resemble an 8 channel transmit Array of a size and type that could be used inside a 3 Tesla MRI System. It is important to note that the array as it is designed for this system is not directly compatible with an MRI system as it is neither non-magnetic nor is it designed with eddy currents or mechanical necessities of the MR environment in mind.

The array’s design is closely related to the design proposed by Vernickel et al. (1) in 2007. It consists of 8 micro strip antenna elements which are each electrically connected to their respective neighbors. A picture of the RF array on its trolley is shown in Figure 1.



Figure 1: Photo of the 8 channel RF array.

## Mechanical Design

The coil housing is made of PMMA (Plexiglas). A schematic can be viewed in Figure 2. The overall length of the housing is 820 m, with the cylinder walls being 800 mm and the end rings (Figure 3) adding another 10 mm at each end. The inner diameter of the array’s housing is 594mm, which is very nearly the inner diameter of a Siemens 60 cm bore (actually 59.5 cm). The inner cylinder of the housing has a wall thickness of 8 mm, while the outer cylinder’s wall thickness is 6 mm. The outer diameter of the housing is 700 mm, leaving a gap of 39 mm between the two cylinders. Within, the antenna elements are placed. The inner wall of the outer cylinders is clad in adhesive copper foil, which is the ground plane for the micro strip antennas. Since the array is not intended for use in an MR environment, there is no need for eddy current prevention and the copper cladding is continuous. The ground plane consists of 4 large pieces of copper foils, connected by gluing bands of copper with electrically conductive adhesive across the abutting edges.

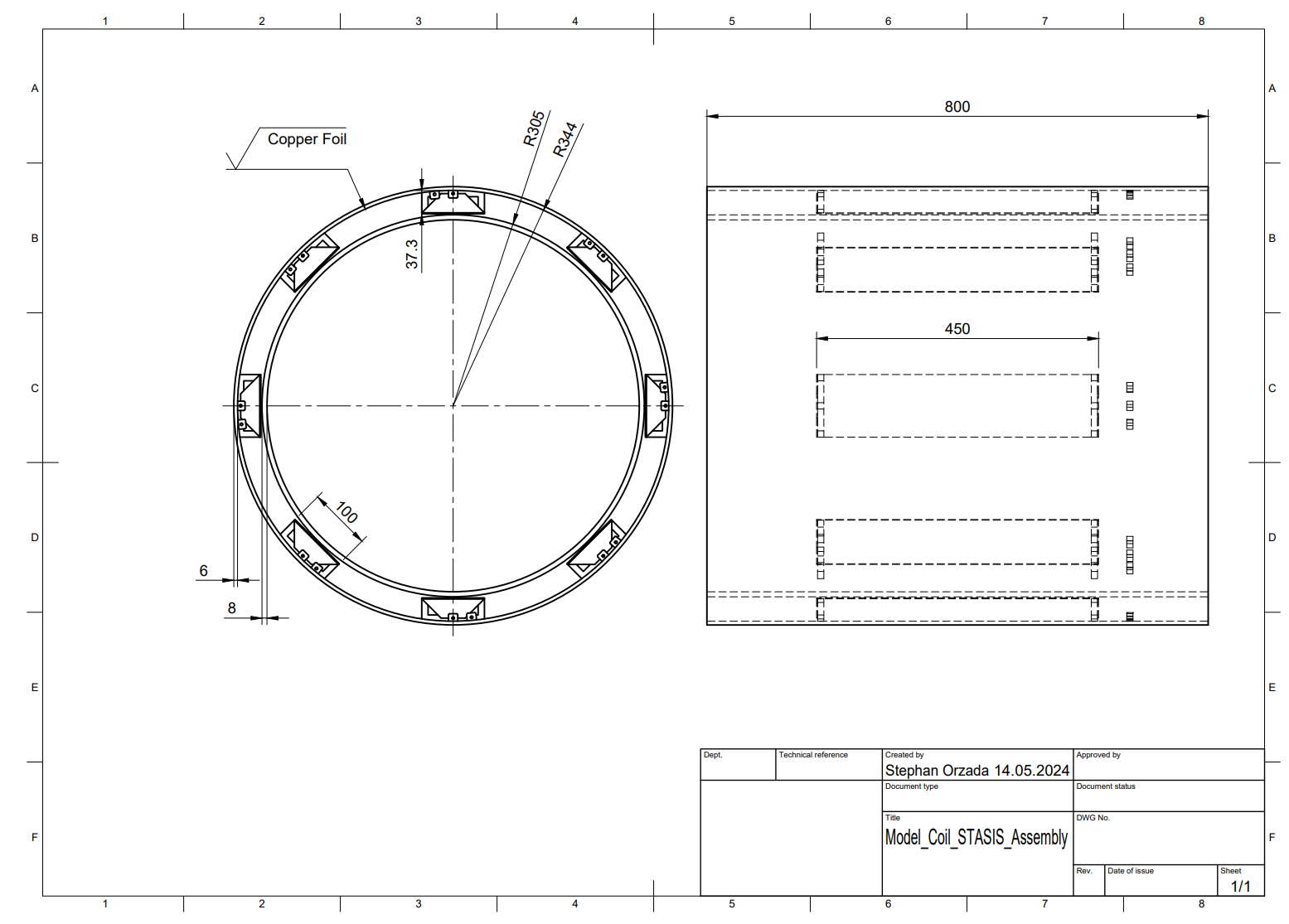


Figure 2: Sketch of the array including the housing. The inner side of the outer cylinder is clad with copper foil. Note that the small holders for the trimmer rods are placed directly in line with the center of the microstrip lines. For more information, refer to the CAD model in the Data.

The width of the antenna elements is 100 mm, while their length is 450 mm. The distance between the center of the microstrip and the ground plane is 37.3 mm. This distance is provided by 3D printed mechanical holders made from PLA. The copper of the microstrips is on the side of the board facing the ground plane. This also means that the capacitors are on this side, which allows the microstrips to be placed closer to the inner cylinder of the housing.

For more information on the exact sizes, please refer to the CAD model.

As can be viewed in Figure 1, the cylinders are screwed to the lids with stainless steel screws.

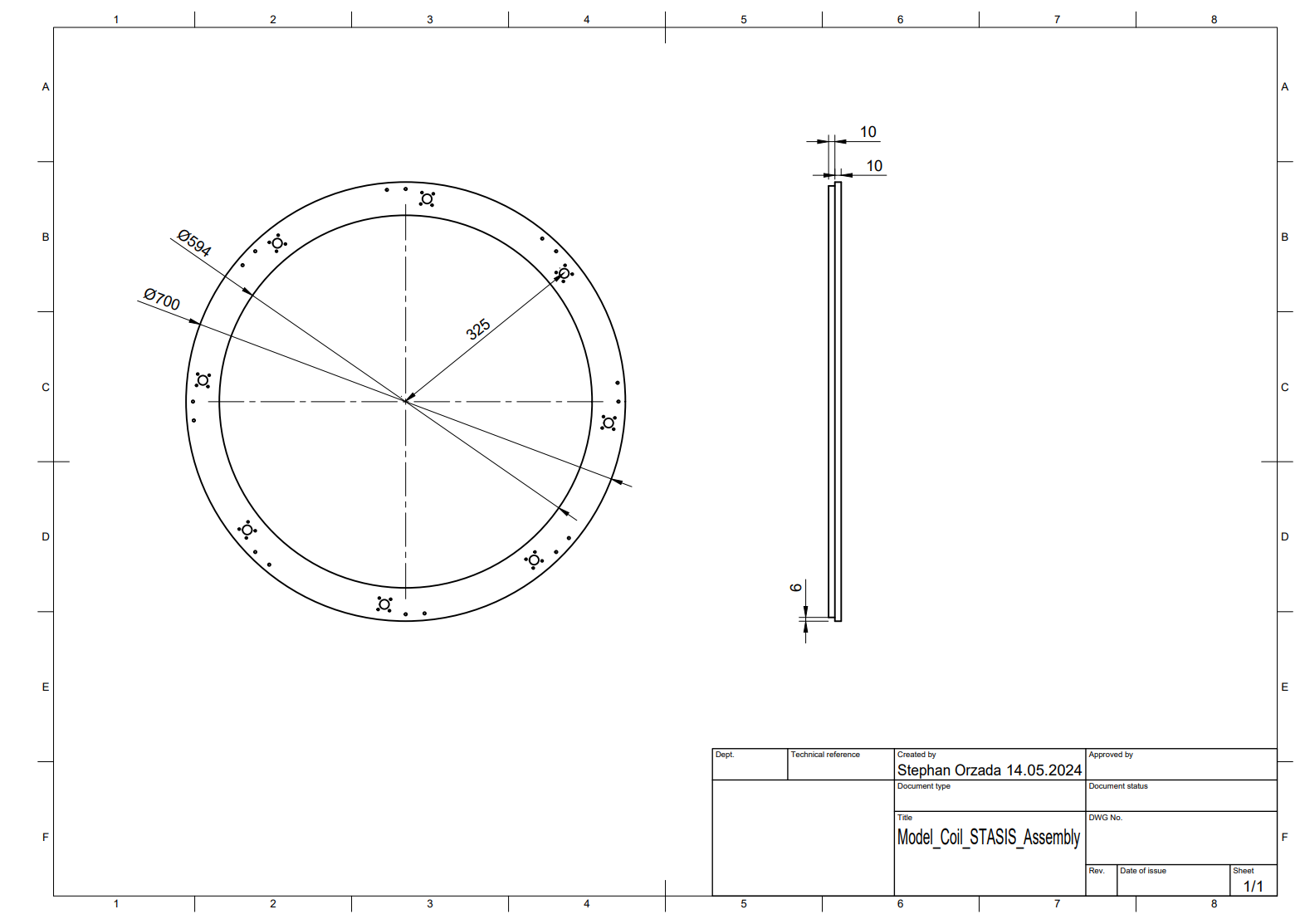


Figure 3: Sketch of one lid of the housing. Positions of the holes for trimmer rods as well as flange mount N connectors are indicated. For more information, refer to the CAD model provided in the data.

## Electrical Design

### Overview

The electrical design of the array is very close to the design proposed by Vernickel et al. (1). The electrical schematics of a single antenna element including the connection to the neighbors can be seen in Figure 4. The values provided in the schematic represent the total capacitances including the parasitic capacitances from the PCBs.

To achieve a homogenous current on the microstrip, it is divided into five sections which are interconnected with pairs of 33 pF capacitors. The end capacitor is 22 pF. To reduce the coupling between neighboring elements, a decoupling network is used, which consists of a 560 pf capacitor connected to two 130 mm long coaxial lines for each direct neighbor. These lines are connected to 7.6 pF capacitors, which are in turn connected to the coaxial lines coming from the neighboring elements. Simulations showed that there can be very high peak voltages across these connecting capacitors. In the actual design, it is therefore necessary to split these into several capacitors in series.

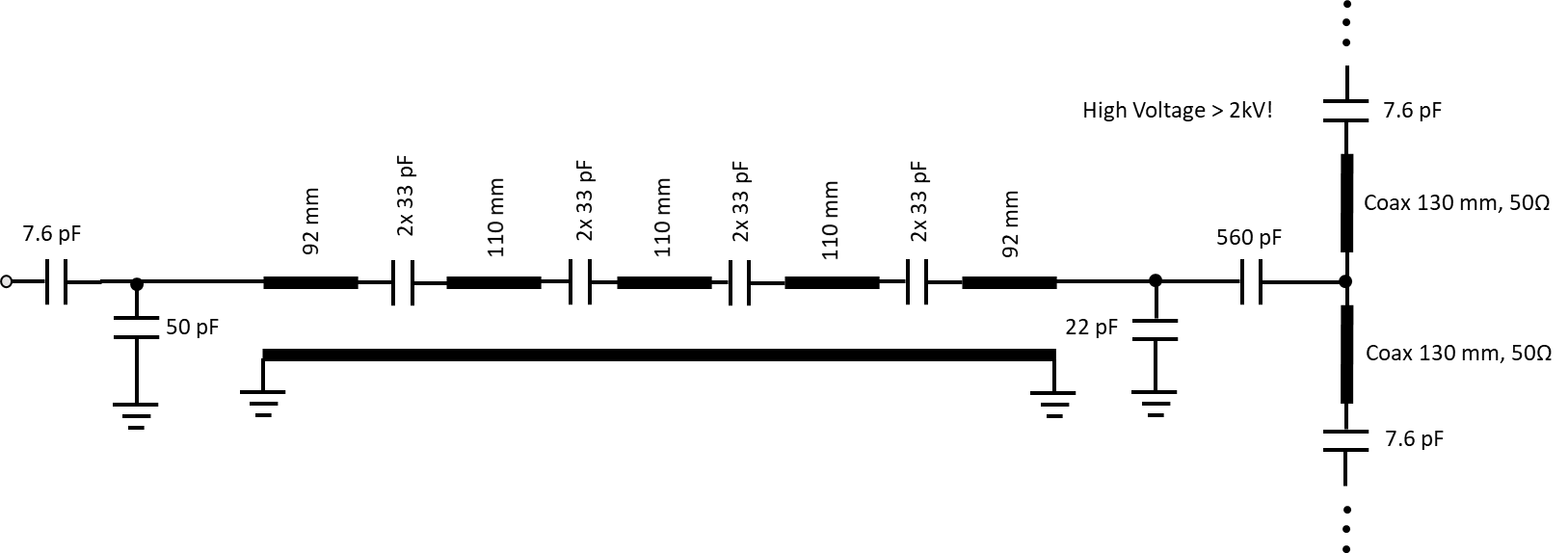


Figure 4: Schematic showing one microstrip element with the connection to the neighboring antennas. The capacitor values given in this schematic are total capacitances. Some of the lumped elements on the actual coil have different values due to parasitic capacitances of the PCBs.

### PCBs

The array has 5 different PCBs:

1. Matching Network Board
2. Strip\_Con Board
3. Stripline Board
4. Endcap Board
5. Decoupling Board

The plans for these can be found in the corresponding folders.

Matching Network Board

Figure 5A shows a picture of the Matching Network Board. The PCB has a thickness of 0.5 mm making it flexible enough to follow the curvature of the ground plane. It is soldered onto the ground plane by its corners, which are not covered by solder stop as can be seen in Figure 5B. This can be achieved by applying solder to the back of the corners, pressing the board onto the array’s ground plane and applying the solder iron to each edge in turn until the board is securely soldered to the ground plane. Due to the large copper area and the low thickness of the board, it exhibits a high parasitic capacitance. Therefore C2 and C3 of Figure 5B are not placed. Instead, an inductor of 0.6 mm silver plated copper wire is wound on a 1.2 mm air core with 7 turns. Note that the landing pad for the connection to the microstrip and the trim capacitor are aligned with the center of the microstrip. In this way, the rods for the trimmer are also aligned with the capacitors, facilitating adjustments of the capacitors from outside the housing (See also Figure 1 and Figure 2). By turning the black knob the parallel capacitor can be adjusted to set the resonant frequency and by turning the red nob, the series capacitor can be adjusted to set the matching.

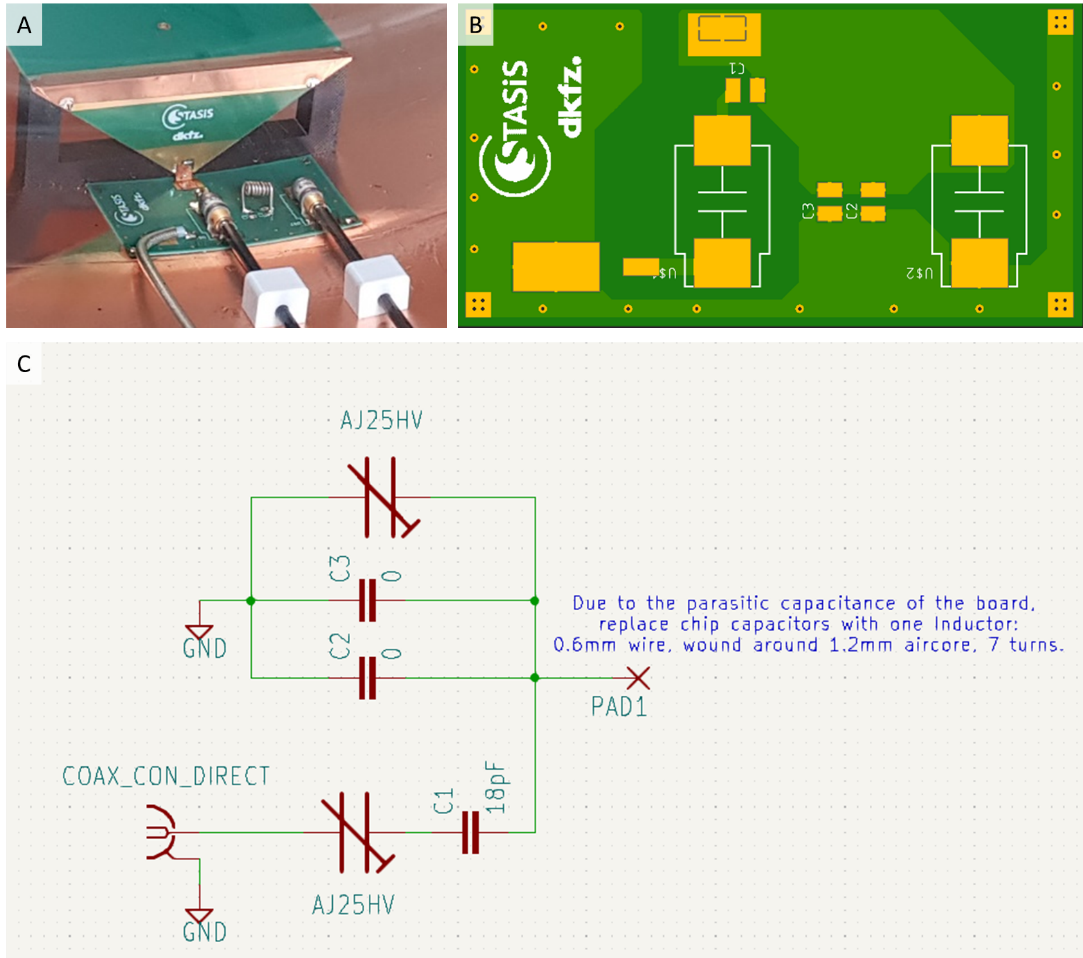


Figure 5: A) Photo of the matching network. B) Top view of the matching network PCB. C) Schematic of the matching network. Note that C2 and C3 are not placed. Instead, a 0.6 mm wire wound 7 turns around a 1.2 mm air core is placed.

Strip\_Con Board

The Strip\_Con Board connects the matching network with the Stripline Board. This is done by soldering copper tape to the adjacent boards. Note that it is sufficient to place a dot of solder at the edges, as the current almost exclusively flows there. The Strip\_Con board is glued to the black 3D printed holder visible in Figure 5A.

Stripline Board

The Stripline Board is glued to the 3D printed holders with the copper pointing towards the ground plane. The capacitors are soldered over the gaps in the metal at the edges of the board. Each gap is bridged with two 33 pF capacitors.

Endcap Board

A picture of two Endcap boards can be seen in Figure 6A. The board has a thickness of 0.5 mm so that it is flexible enough to adapt to the curvature of the ground plane. It is soldered on to the ground plane at the corners. This can be done by applying solder to the back of the corners, pressing the board onto the array’s ground plane and applying the solder iron to each edge in turn until the board is securely soldered to the ground plane. The schematic in Figure 6B shows that the end capacitor is only 10 pF and another 12 pF are provided by the boards large copper area which can also be viewed in Figure 6C.

Decoupling Board

The decoupling board is made of 0.5 mm FR4. It contains three capacitors in series (18 pF, 47 pF, 18 pF). Simulations show that high voltages can occur at these capacitors, therefore the used components have a maximum permissible voltage of at least 1500 V each.

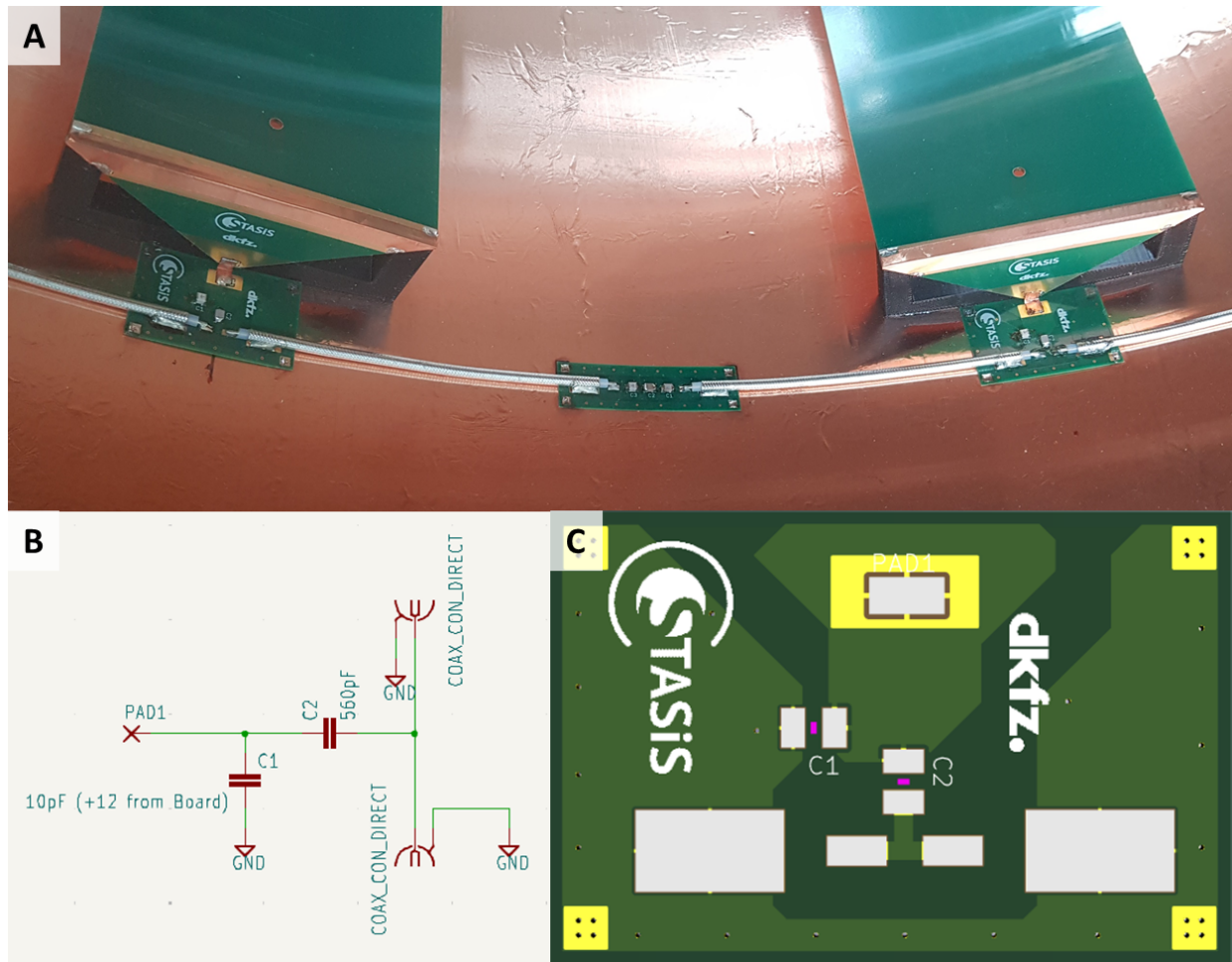


Figure 6: A) Image of the ends of two microstrip lines, showing two Endcap boards, a decoupling board and the coaxial lines for connection. B) Schematic of the Endcap board. Note that due to the large copper area, only a 10 pF capacitor is necessary. The rest of the capacitance is provided by the board. C) Computer generated image of the Endcap PCB.

## Simulation Results

All simulations of the RF array were performed in CST Microwave Studio (Dassault Système, France).

For the simulations the array was loaded with a homogenous phantom with electrical properties that correspond to the mean of the human body at 128 MHz (=52; =0.47 S/m). The dimensions of the phantom can be found in the drawing in Figure 7.

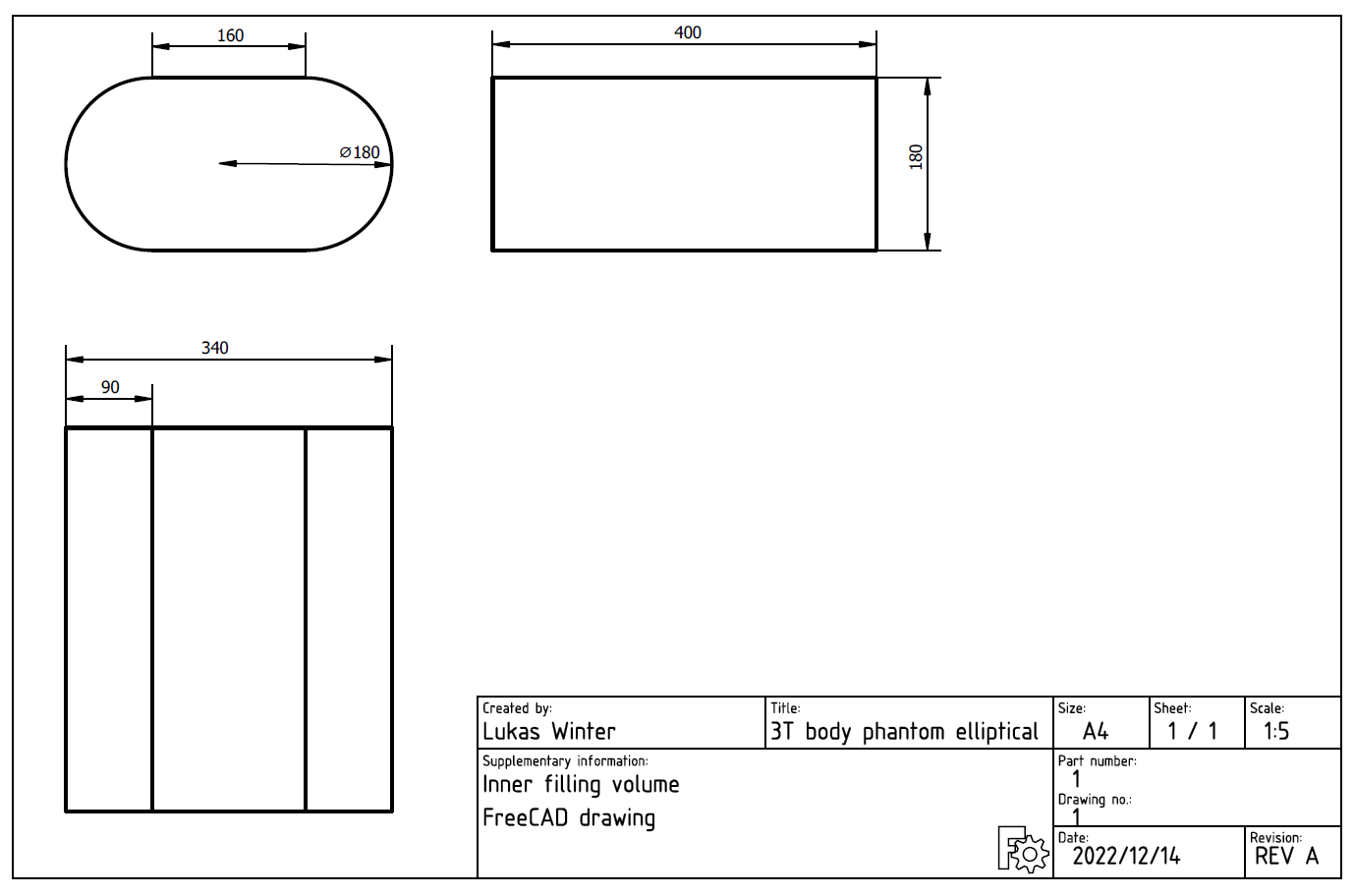


Figure 7: Mechanical drawing of the phantom used for simulations of the RF array.

### S-Parameters

S-parameter curves for the simulated array are shown in Figure 8. For simplicity, the reflection factors for element 1 and 2 are shown, with element 1 being parallel to the mesh and element 2 being 45° oblique to the mesh. Coupling to nearest neighbors is roughly 9 dB, coupling to the other elements is better than -17 dB. A keystone file with the calculated S-parameters is provided within the “Array/Simulation\_Results” folder.

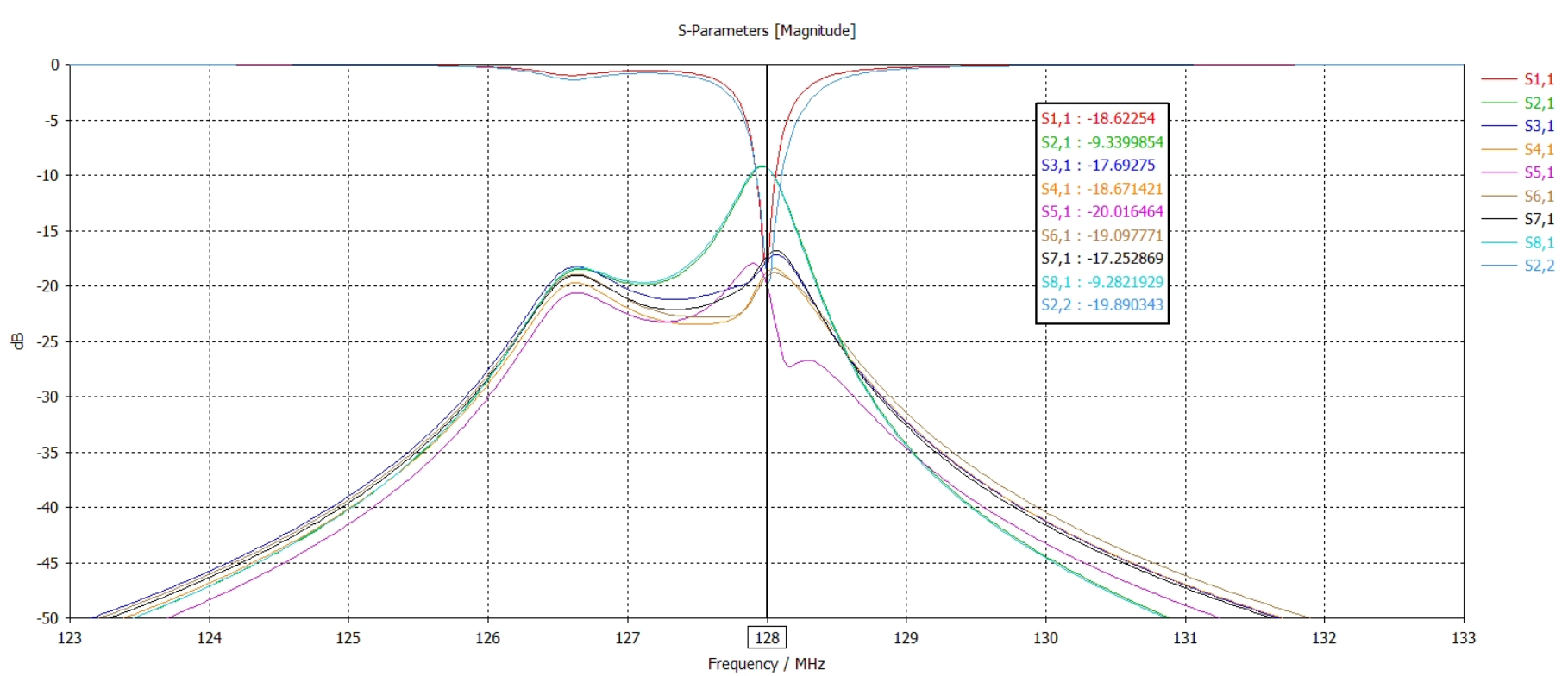


Figure 8: S-Parameters of the simulated array. Reflection factor for 2 elements are shown. Element 1 is oriented parallel to the mesh, element 2 is oblique.

Eigenmode analysis (2) shows that there are problematic modes with very high reflection. The reflection for the best-case mode is 1.74%, while the reflection for the worst-case mode is 95%. Furthermore, it is possible to reflect up to 2.32 kW on a single channel when a forward power of 1 kW is applied to each channel with appropriate phase. It is recommended to avoid modes with high reflection and a reflection matrix will be implemented in the control software of the STASIS project to ensure safe use of the array.

### B1+ field results

A transverse view of the B1+ field distribution for the birdcage mode and a stimulated power of 1W is shown in Figure 9. It shows the pattern typical for 3T body imaging with a high intensity in the center and two lower intensity bands.

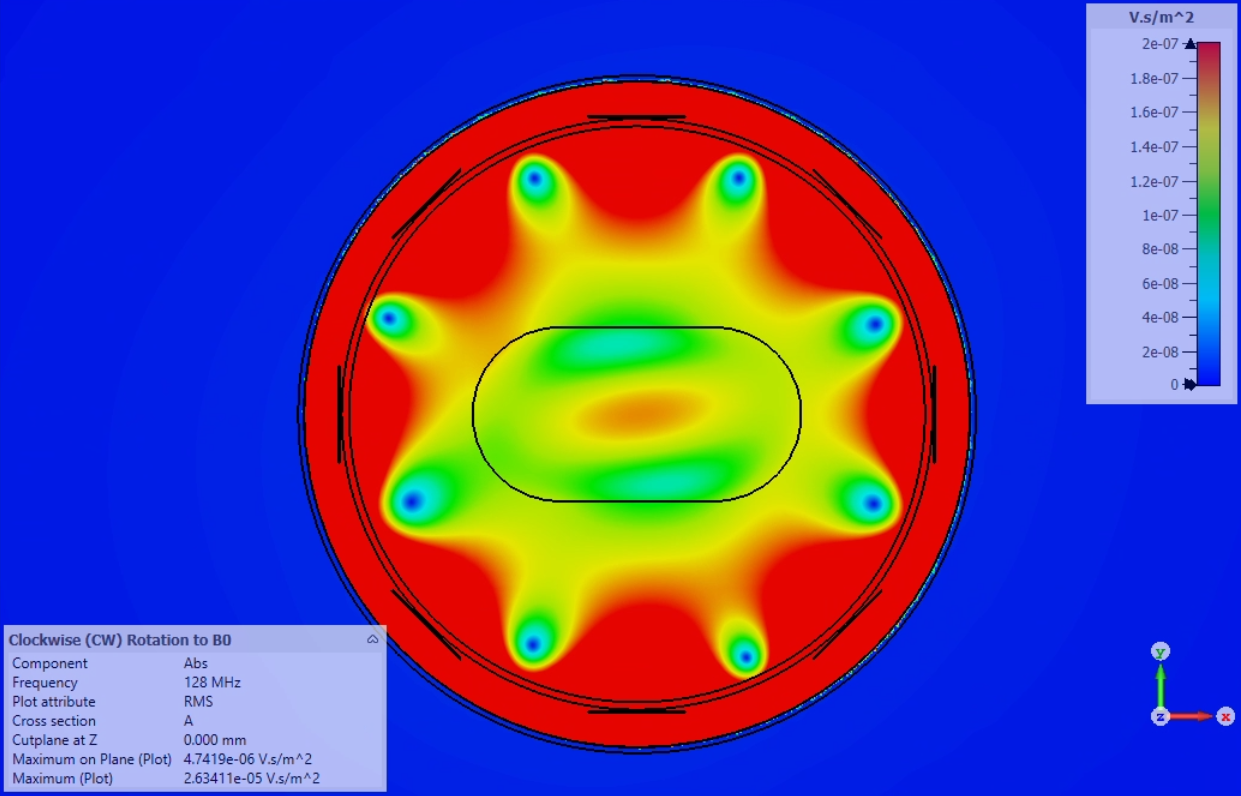


Figure 9: Simulated B1+ field distribution of the CP+ mode (birdcage mode) for stimulated power of 1W. The typical pattern with a high intensity center and two lower intensity bands as known from 3T body imaging is visible.

Figure 10 shows the B1+ for the birdcage mode and stimulated power of 8 kW on a central line on the z-axis within the phantom. The values vary between 18 µT and 22µT.

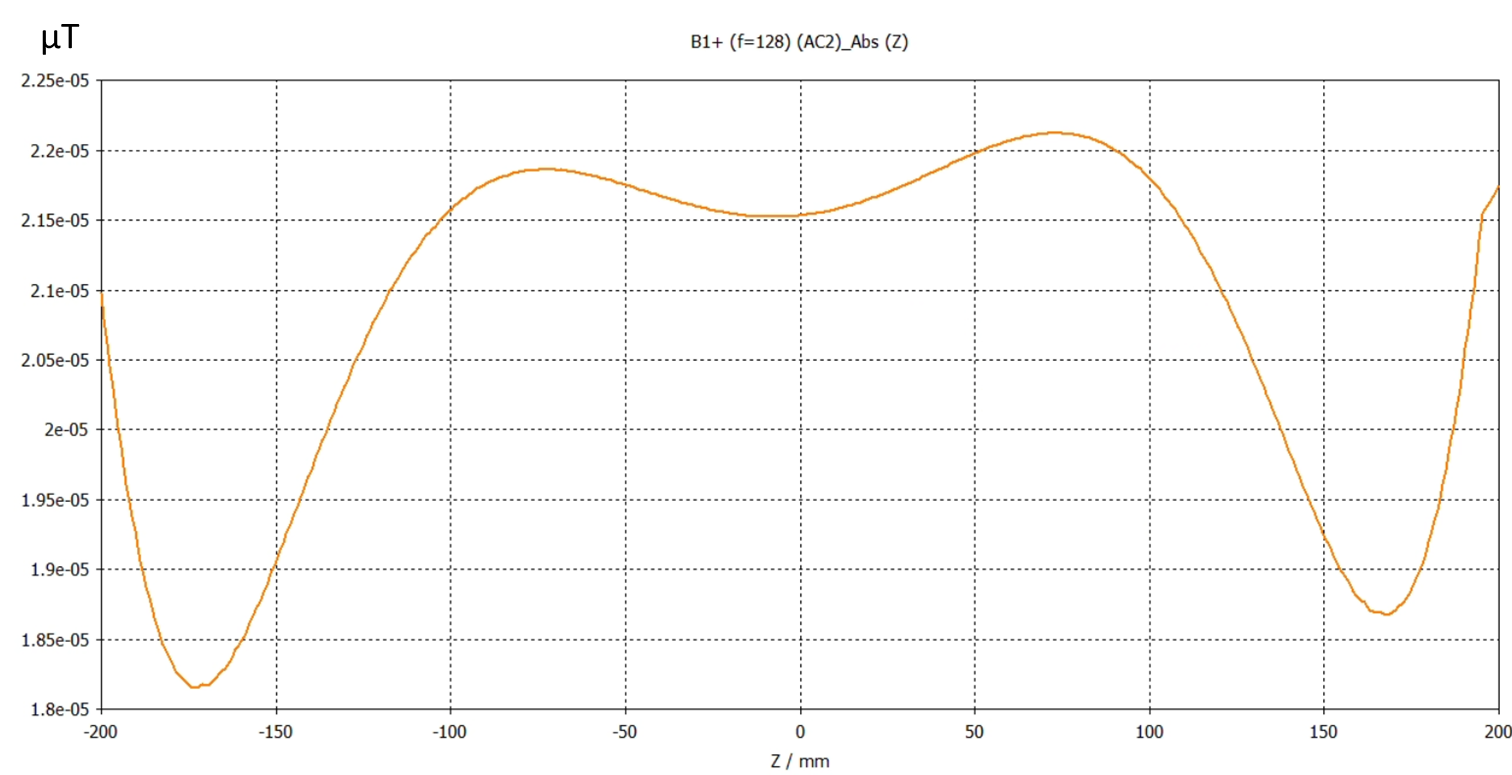


Figure 10: B1+ for the birdcage mode and a stimulated power of 8 kW on a central line on the z-axis through the phantom. The values vary between 18 µT and 22 µT.

## Measurement Results

To be performed…

# References

1. Vernickel P, Roschmann P, Findeklee C, Ludeke KM, Leussler C, Overweg J, Katscher U, Grasslin I, Schunemann K. Eight-channel transmit/receive body MRI coil at 3T. Magn Reson Med 2007;58(2):381-389.

2. Kazemivalipour E, Sadeghi-Tarakameh A, Atalar E. Eigenmode analysis of the scattering matrix for the design of MRI transmit array coils. Magn Reson Med 2021;85(3):1727-1741.