

Document ID	TITLE ISM AND GNSS ANTENNAS FINAL REPORT	VERSION 0.1	DATE 2021-04-21
AUTHOR André da Silva Frazão	DOCUMENT RESPONSIBLE Fredrik Löthgren	APPROVED BY Darko Knutsson	

ISM AND GNSS **ANTENNAS FINAL** **REPORT**

Subtitle

TABLE OF CONTENTS

1 REVISION HISTORY	3
2 GENERAL.....	3
3 TEST EQUIPMENT	3
4 THE TEST OBJECT	4
5 ANTENNA MATCHING AND PERFORMANCE	5
5.1 THE GNSS-ANTENNA	6
5.2 THE ISM-ANTENNA.....	11
6 ISOLATION BETWEEN ANTENNAS.....	15
7 COORDINATE SYSTEM OF THE SATIMO STARGATE 24 SYSTEM	16

1 REVISION HISTORY

0.1	First draft.	2021-04-21 André da Silva Frazão

2 GENERAL

Sigma Connectivity AB in Lund has been contracted by SAAB to design, trim and measure two antennas, one for ISM 868MHz, ISM 902-928MHz, ISM 2400-2500MHz and one for GPS and Glonass. The antenna on the WiFi module was not part of the test-scope and this antenna was made by the module vendor. The NFC antenna has been designed by SAAB and was not part of Sigma's verification.

The work has consisted of antenna-simulations with the CST simulation software and Optenni Lab v4.2 software for matching components simulations, antenna trimming and matching with mock-ups where parts were provided by SAAB, and finally efficiency and gain measurements for the antennas based on a more finalised build.

These measurements were done in Satimo Stargate 24 (large) for final measurements and in our in-house designed reverberation chambers (a.k.a. SFC (Scattered Field Chamber)). Measurements were done in free space and with the training vest and SPEAG SAM head phantom.

No measurements were performed with the radios active. Only passive antenna-efficiencies and -gains were measured, as agreed with the customer.

3 TEST EQUIPMENT

For antenna matching studies the following equipment and tools were used:

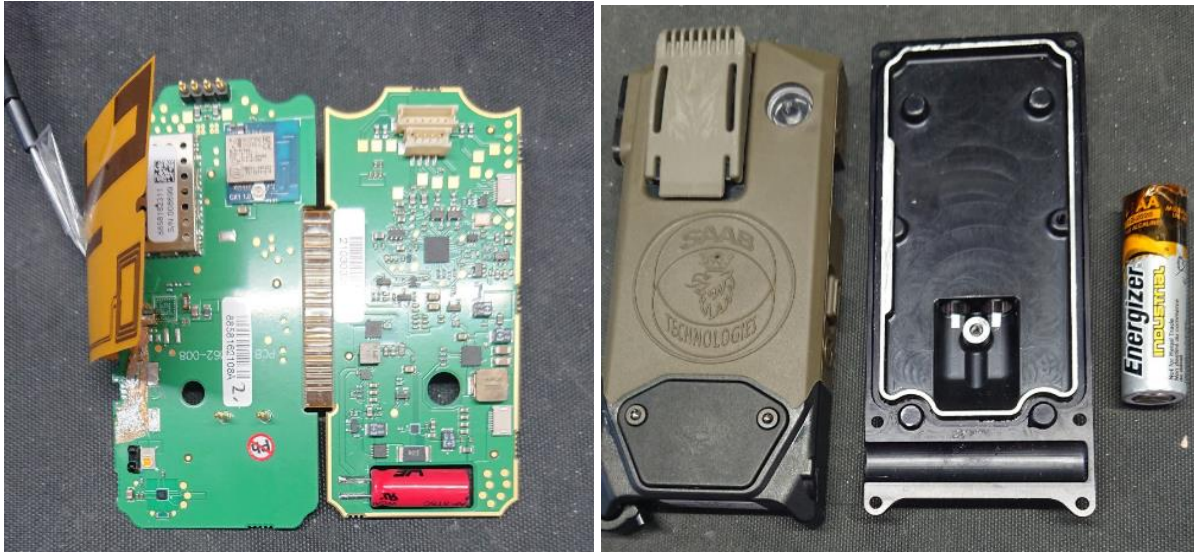
- Agilent VNA 5071C;
- Agilent electronic calibration module 85093-60010;
- Rosenberger HF cables for the VNA;
- IMS Connector Systems K-485 semi-rigid coaxial cables;
- Optenni Lab v4.2 simulation tool, used for simulation of matching network;
- SPEAG SAM head phantom.

Chambers used for passive antenna measurements, i.e. antenna efficiency and gain:

- Scattered field chamber (SFC), reverberation chamber used for quick antenna efficiency tests;
- Satimo Stargate 24, anechoic chamber used for passive antenna measurements.

4 THE TEST OBJECT





From the pictures above the parts used during the tests can be found. As can be seen above, the GNSS antenna and the ISM-antenna is part of the rigid flex. I.e. the core of the PCB, a polymer material, is sticking out from the RF-PCB and on this flex the antennas are located as wide copper traces. With this method no connectors are needed for feeding and grounding the antennas. The idea for this type of antenna placement was the customer's.

During the simulation phase it was found that an ISM-antenna located on the above describe flex/rigid flex was feasible and that it could co-exist with a NFC-antenna, the latter designed by SAAB. During the first half of the project the intent was to use a GNSS-antenna of ceramic type. Later the performance of this GNSS-antenna was found unsatisfactory. A request for designing a GNSS-antenna (GPS and Glonass) on the same flex as the ISM-antenna was issued from SAAB. Simulations showed that this should be feasible with a redesign of the NFC-antenna to a smaller version.

5 ANTENNA MATCHING AND PERFORMANCE

The matching components for the ISM-antenna and the GNSS-antenna was based on simulation results and the need to update the component values and even the topologies were likely to be needed.

During mock-up tests for the different builds Sigma and SAAB have not got the same matching results when measured by a network analyser. Hence, there are discrepancies between antenna matchings in different tests, as will be described below.

Two complete PCBs and a new mechanical metal back-cover were provided by SAAB for final matching and verification. During extensive lab-work one of the PCBs were unfortunately destroyed, meaning that most of the pads and traces for the matching components for the GNSS were ripped off the PCB. Hence, not all test could be performed with one unit.

5.1 THE GNSS-ANTENNA

From simulations and initial tests it was found that a single series components, an inductor of 3.8-3.9nH, was enough to match the GNSS-antenna. This was used for the first complete build. During SAAB's field-trials this solution was found satisfactory. Sigma's tests showed that a better antenna-matching could be found by a shunt inductor of 4.7nH closest to the GNSS-radio followed by a series inductor of 3.9nH before the antenna. This matching would result in better VSWR/return-loss especially for 1575MHz.

For the latest build the single series inductor was kept (no shunt component) and due to the findings during field-trials it was decided to keep the single component solution for the final product.

Since the close proximity to the ISM-antenna there is a risk that the two antennas affect each other. To test this the ISM-antenna needs to be properly matched. The factory matching of the ISM-antenna seems to be completely off when Sigma measures the ISM-frequencies. This cannot be verified by SAAB and SAAB has from field-trials found acceptable ISM-performance.

Unfortunately the GNSS patch on one of the PCBs was destroyed and on the other PCB with both the ISM and the GNSS paths intact Sigma could not get a proper ISM-match, even though several s-parameters were extracted and simulated in the Optenni matching tool. Only on the PCB with the broken GNSS could Sigma find acceptable ISM-matching. Hence, Sigma no longer has any PCB with both good GNSS-matching and acceptable ISM-matching.

Below are GNSS-antenna matching and performance (efficiency and gain) presented for both the single component solution and the 2-component solution.

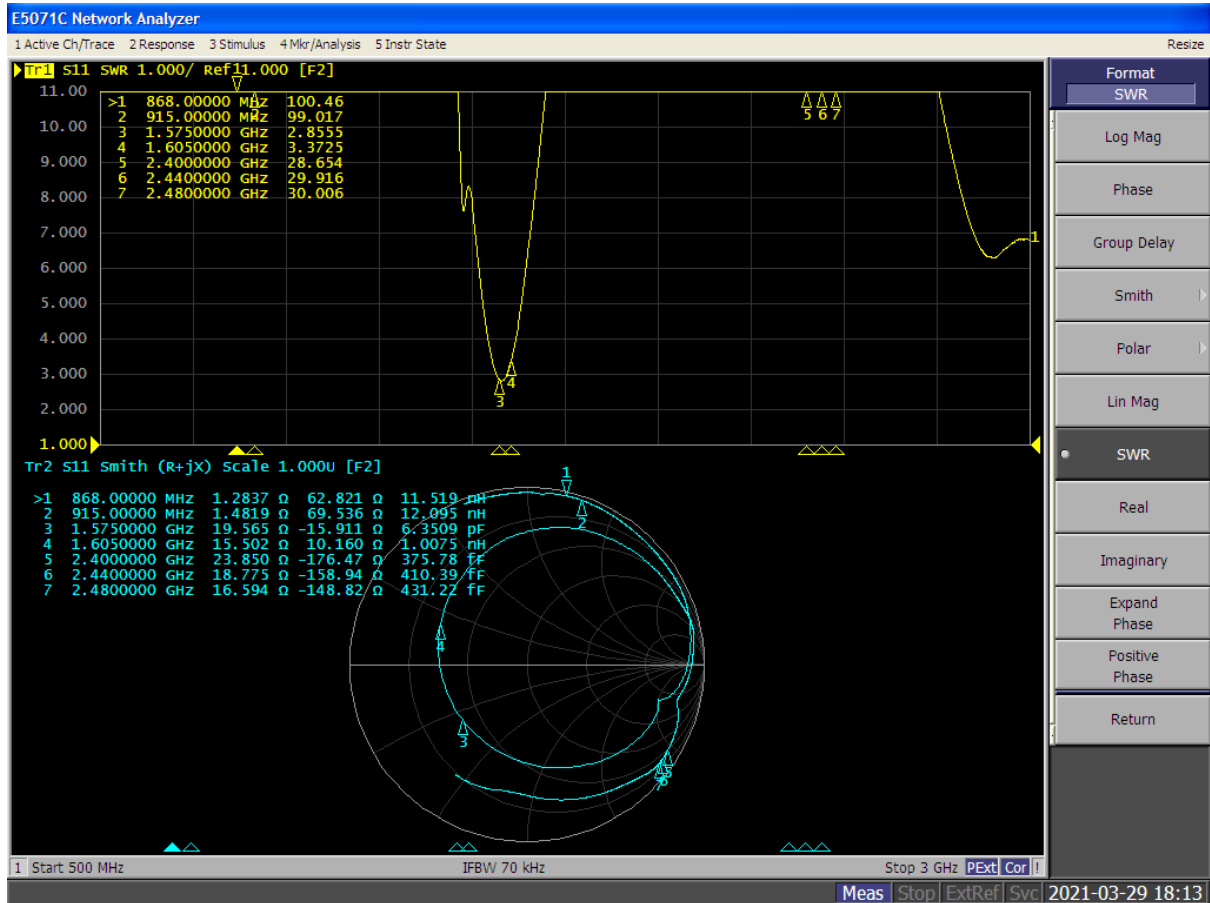


Figure 5.1: GNSS with 3.9nH series-inductor only and original matching for the ISM-antenna in free space.

As can be seen in figure 5.1 there is a distinct GNSS resonance with a single 3.9nH series component, but not 50 ohms. With an additional 4.7nH shunt-inductor closest to the GNSS-radio the matching will be more matched to 50 ohms and with a 1575MHz bias. See figure 5.2 below.

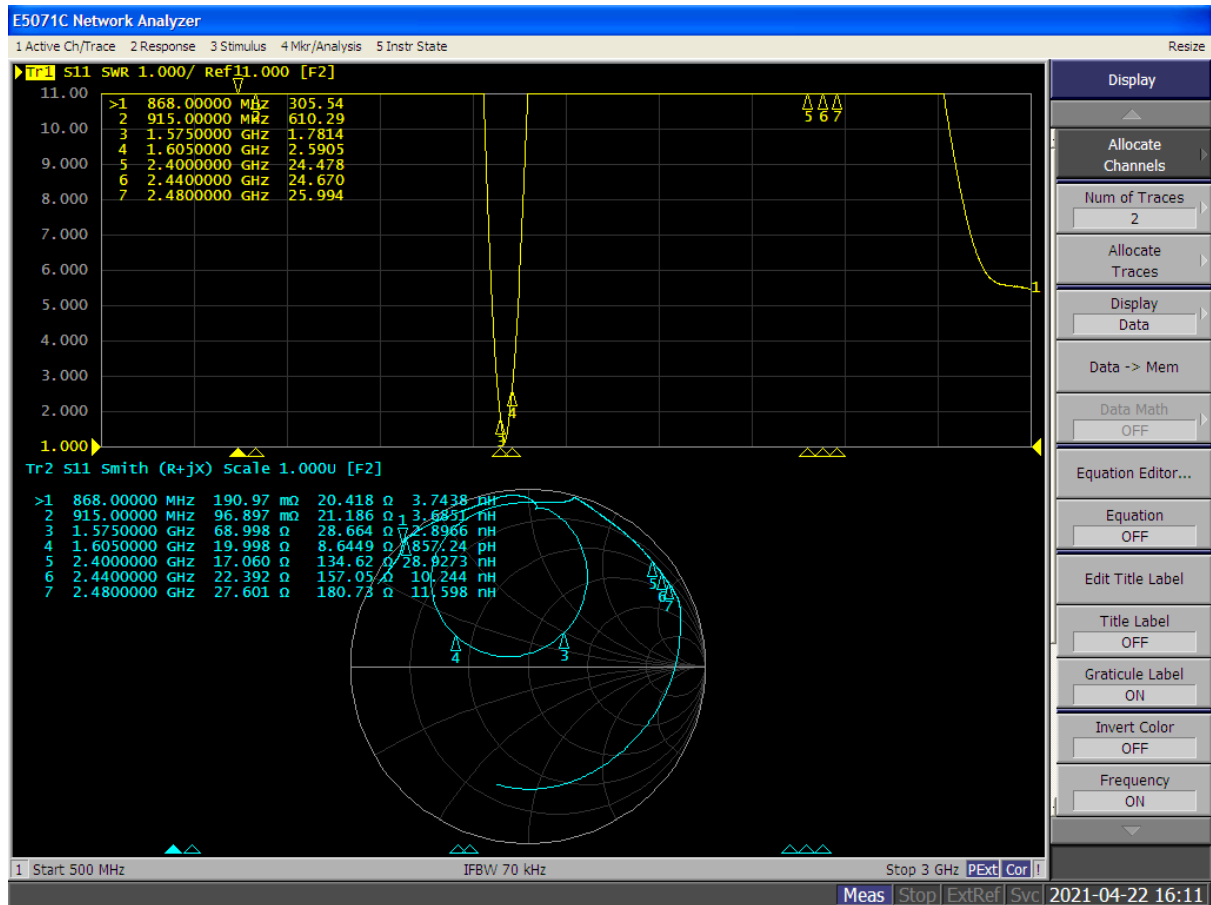


Figure 5.2: GNSS with 4.7nH shunt-inductor and a 3.9nH series-inductor and original matching for the ISM-antenna in free space.

FS (3.9nH series)		
Frequency	Efficiency	Gain
1563 MHz	-7.1	-2.9
1575 MHz	-6.9	-2.7
1587 MHz	-6.7	-2.4
1593 MHz	-6.9	-2.6
1602 MHz	-6.8	-2.4
1610 MHz	-7.1	-2.5

SAM and Vest (3.9nH series)		
Frequency	Efficiency	Gain
1563 MHz	-7.4	-1.5
1575 MHz	-7.2	-1.5
1587 MHz	-7.0	-1.4
1593 MHz	-7.2	-1.6
1602 MHz	-7.2	-1.7
1610 MHz	-7.4	-2.0

FS (4.7nH shunt and 3.9nH series)		
Frequency	Efficiency	Gain
1563 MHz	-6.5	-1.9
1575 MHz	-5.8	-1.3
1587 MHz	-5.8	-1.2
1593 MHz	-6.1	-1.6
1602 MHz	-6.6	-1.9
1610 MHz	-7.3	-2.6

SAM and Vest (4.7nH shunt and 3.9nH series)		
Frequency	Efficiency	Gain
1563 MHz	-7.0	-1.4
1575 MHz	-6.4	-0.5
1587 MHz	-6.4	-0.7
1593 MHz	-6.8	-1.4
1602 MHz	-7.4	-2.1
1610 MHz	-8.2	-2.9

Table 5.1: GNSS-antenna efficiency and gain with original single component match and the two components match, in free space and with vest and SAM phantom.

From some measurements done with a more optimum GNSS-antenna matching the results show that the benefit by doing so is not substantial. Some measurements have shown a bit better, but the benefit of changing to two component matching is marginal.

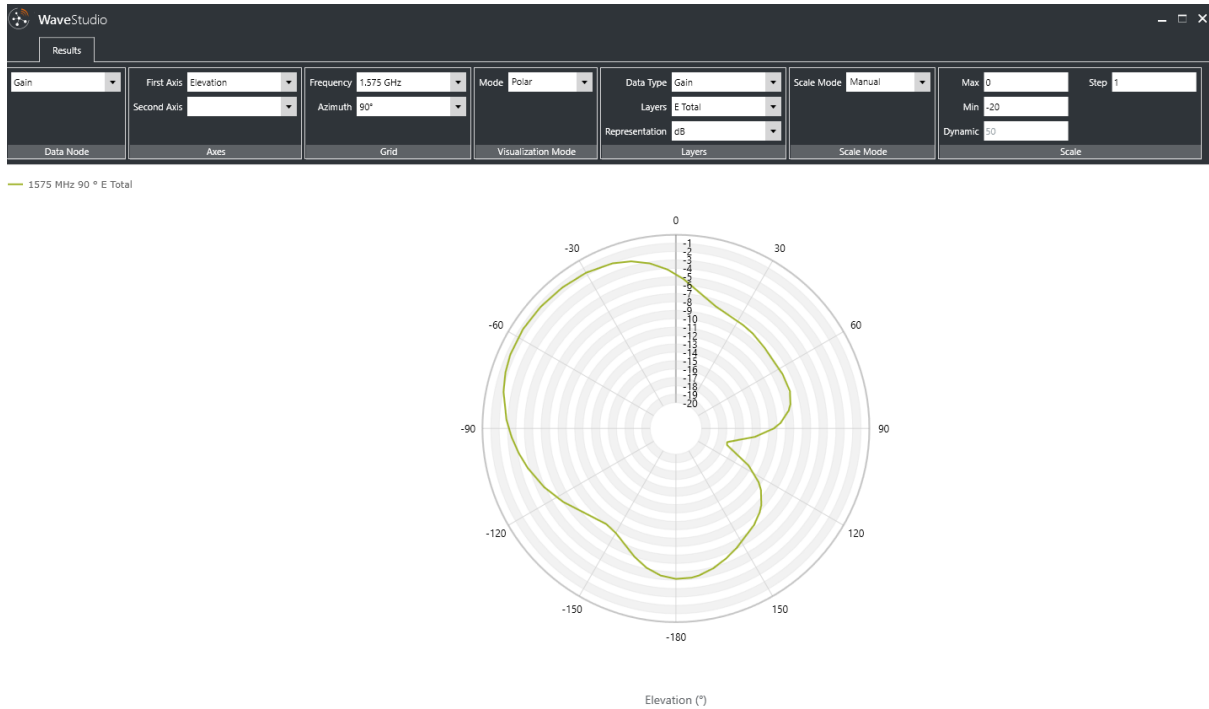


Figure 5.3: Y-Z-plane. See figures 7.1 and 7.2 in chapter 7. Gain along the DUT's elevation.

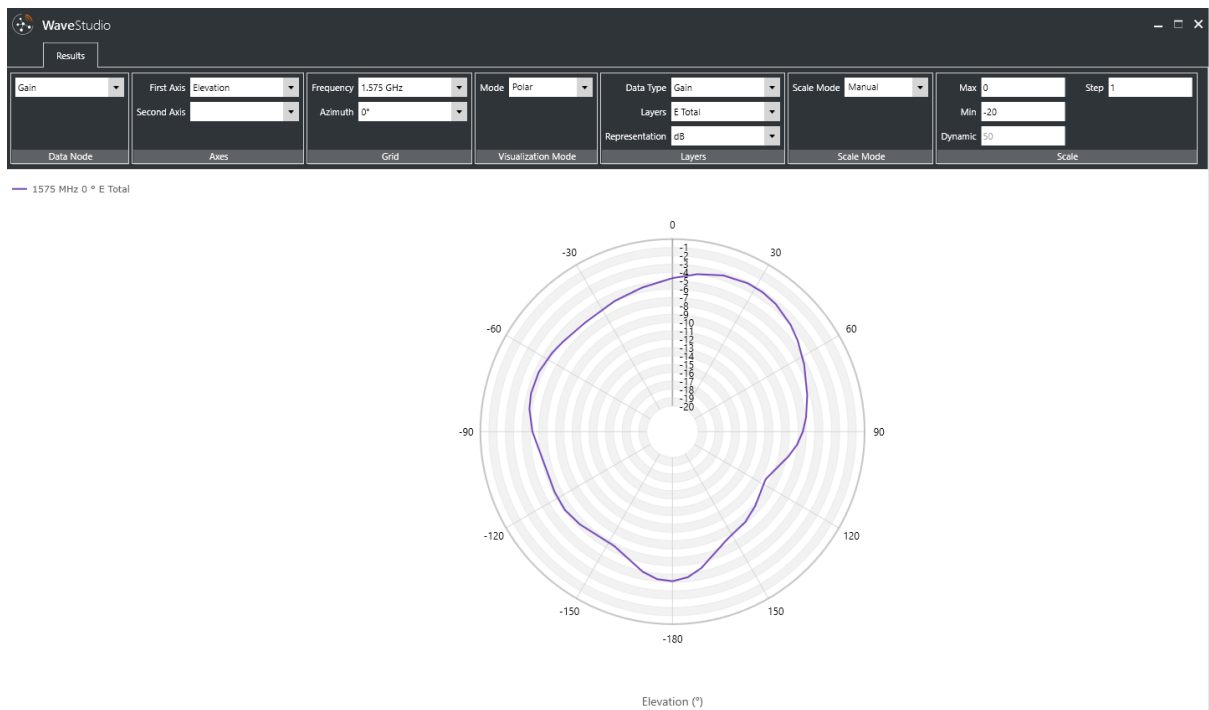


Figure 5.4: X-Z-plane. See figures 7.1 and 7.2 in chapter 7. Gain along the DUT's elevation.

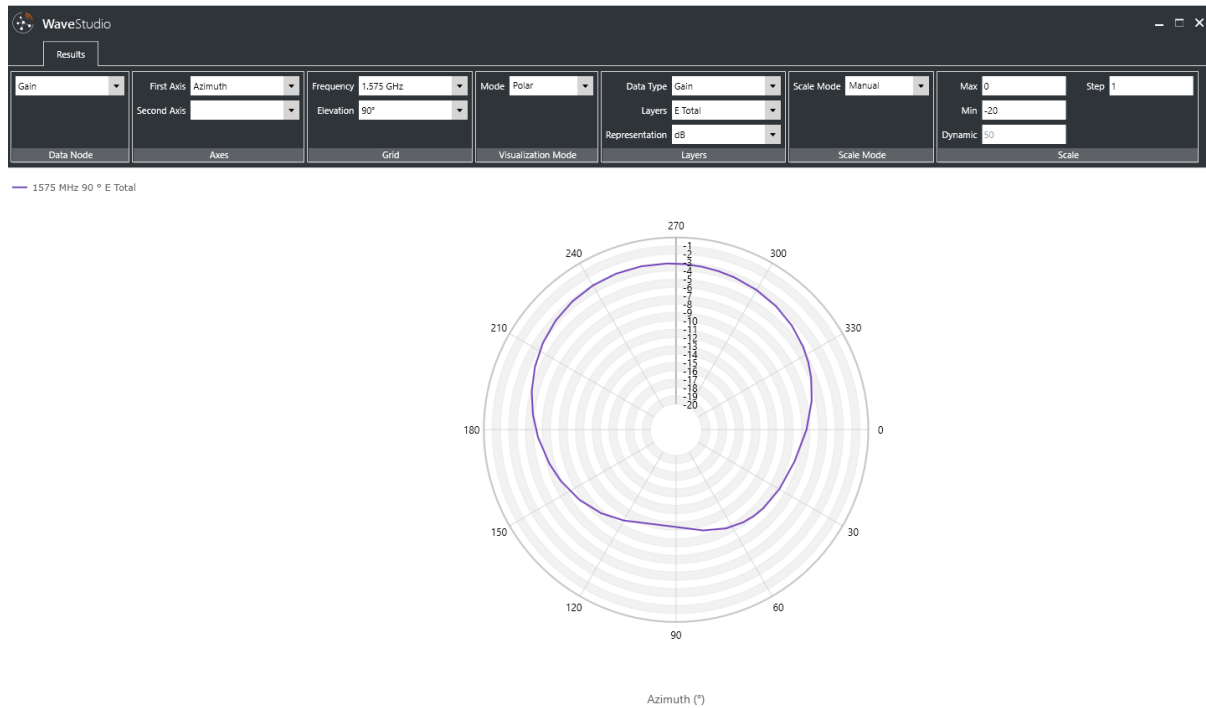


Figure 5.5: X-Y-plane. See figures 7.1 and 7.2 in chapter 7. Gain along the DUT's azimuth.

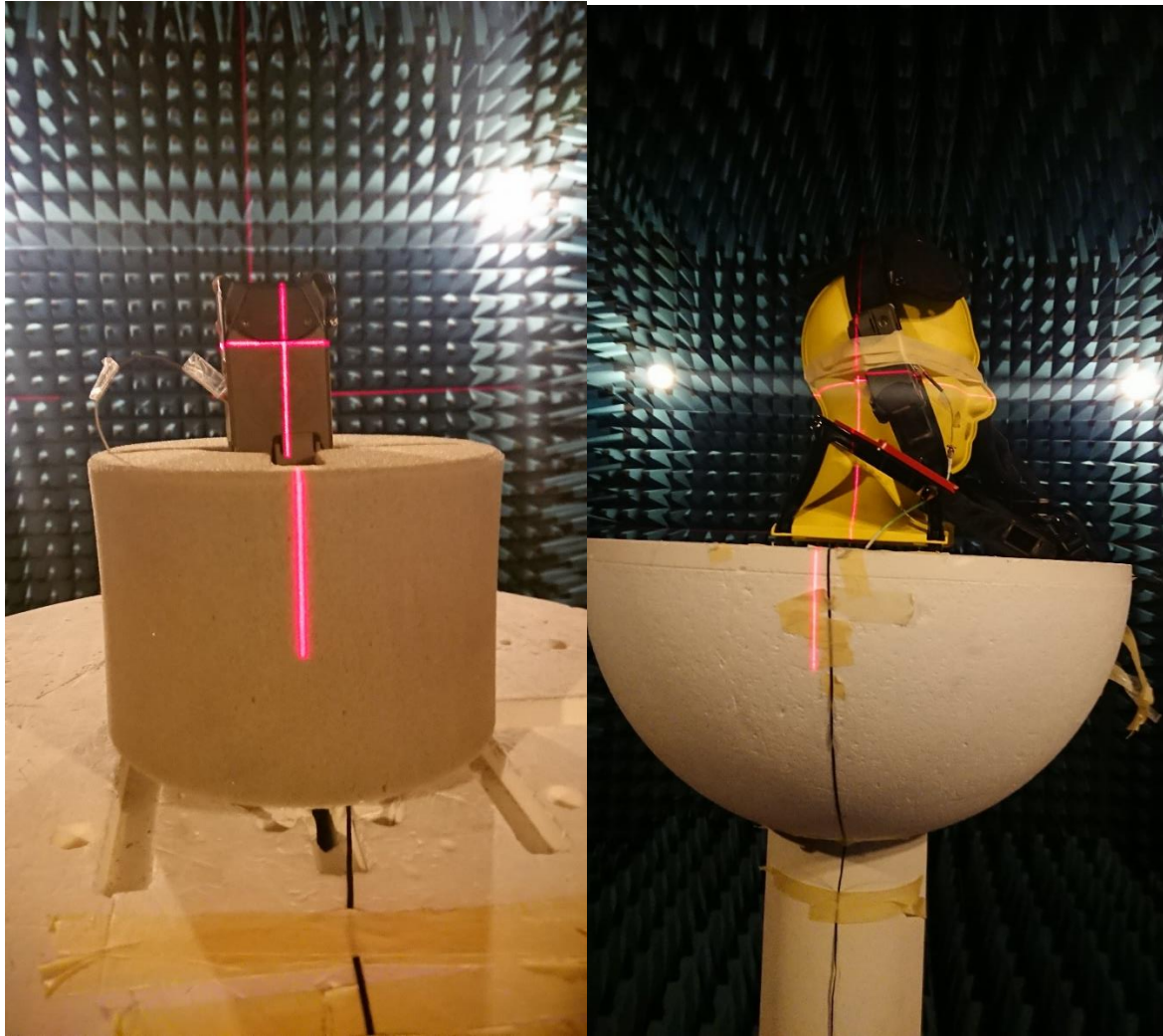
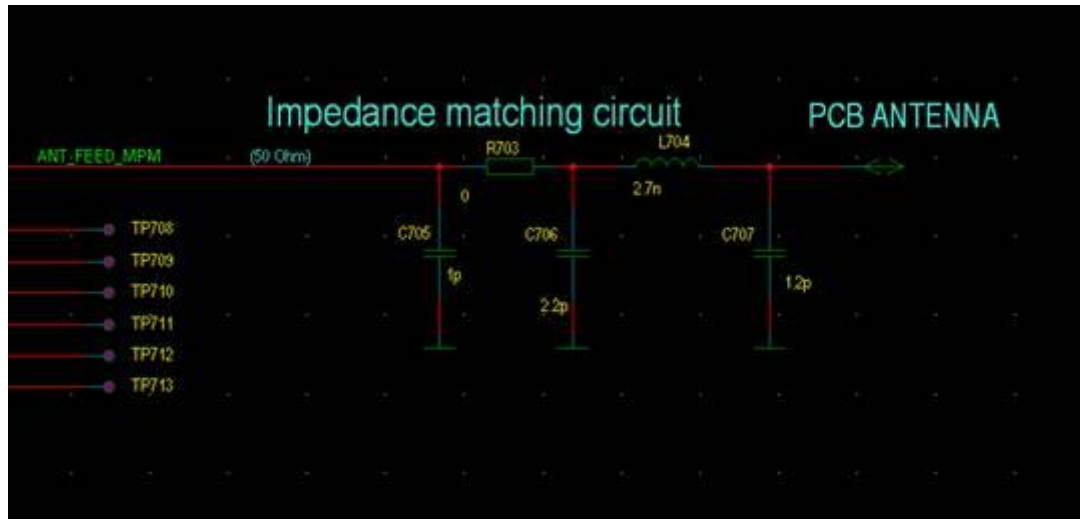


Figure 5.6: The DUT in free space and with the vest mounted on a SAM phantom head.

5.2 THE ISM-ANTENNA

The current factory ISM-antenna component matching is based on simulation results and initial mock-up tests. Its matching component network is described below.



Original matching:

C705 not mounted

R703 0ohm

C706 2,2pF

L704 2,4nH

C707 1,2pF

With this component matching Sigma cannot get any proper matching viewed on a network analyser. There are on Sigma's previous and latest mock-ups none to close to none ISM matching for 868MHz band and the 915MHz band. The 2.4GHz band has a distinct resonance, however. See figure 5.7 below.

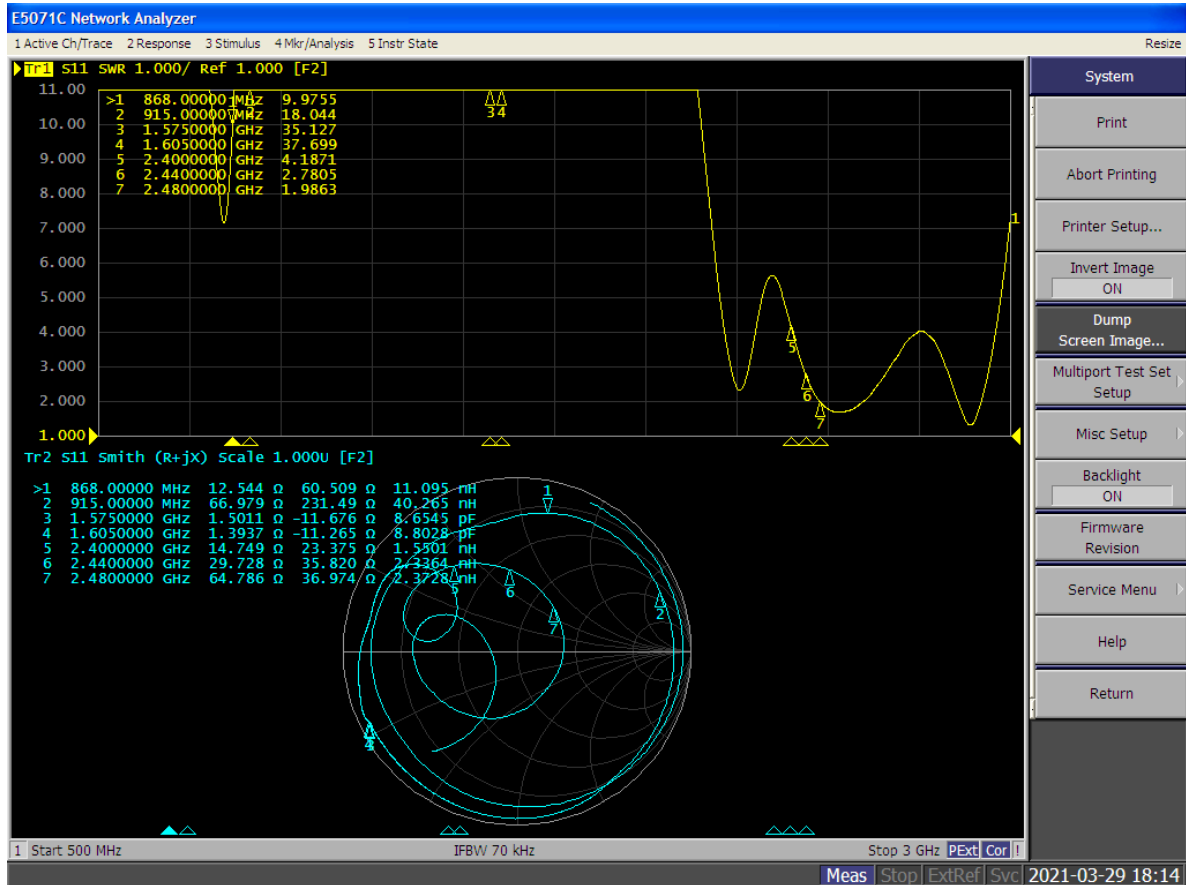


Figure 5.7: Sigma's latest mock-up with factory matching for the ISM-bands. Free space.

This very poor 868MHz band and 915MHz band matching does not seem to fully correlate with SAAB's field trail, where acceptable connection has been found. Sigma tried to find a more optimised matching for Sigma's mock-up. A simple two component network could improve the matching, especially for the low bands. Due to problems with the mock-ups and a screen dump seems to be missing, the Optenni-simulated VSWR and matching network are shown in figure 5.8 below. At least it is very representable with the actual network analyser measurement.

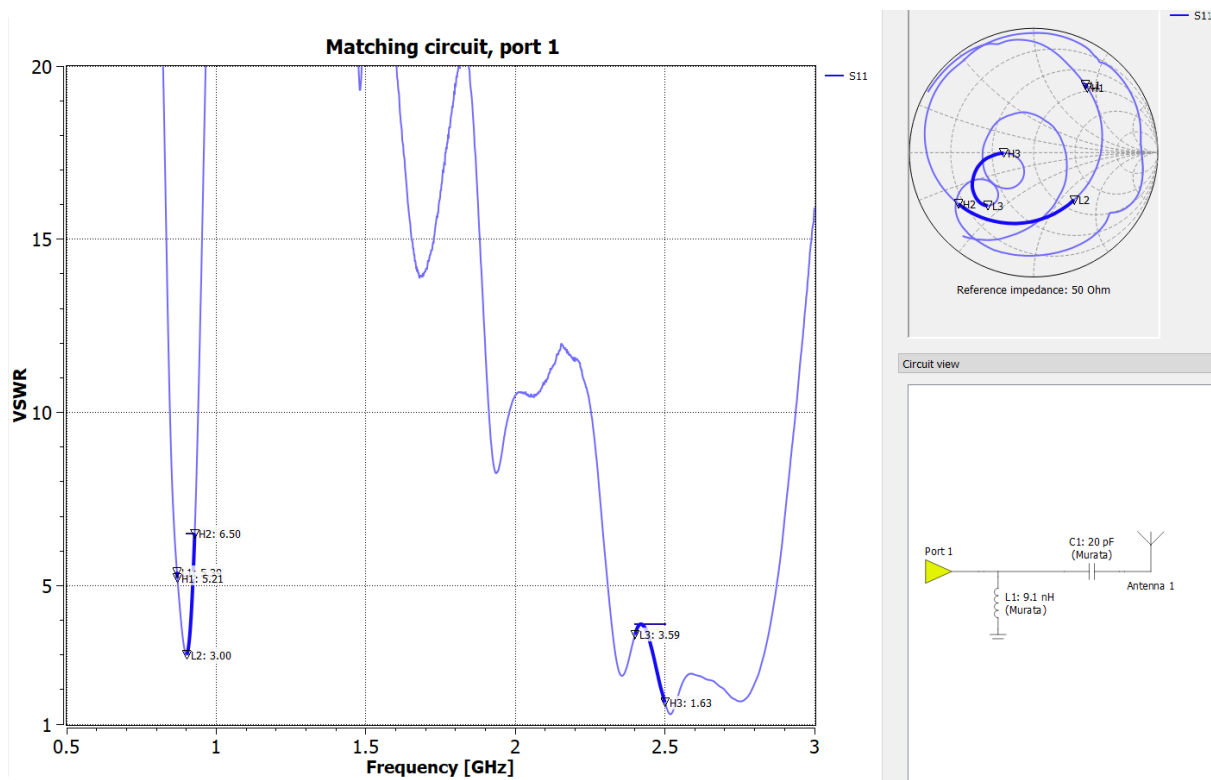


Figure 5.8: Optenni-simulated VSWR and matching network. Due to component availability a 22pF was used on the mock-up instead.

FS (factory matching)			
Frequency	Efficiency	Gain	
868 MHz	-13.0	-9.3	
902 MHz	-14.9	-12.1	
915 MHz	-15.7	-13.4	
928 MHz	-16.8	-14.4	
2400 MHz	-13.4	-7.8	
2440 MHz	-11.1	-5.9	
2480 MHz	-8.8	-4.2	
2500 MHz	-8.2	-3.8	
SAM and Vest (factory matching)			
Frequency	Efficiency	Gain	
868 MHz	-26.7	-20.7	
902 MHz	-26.4	-21.2	
915 MHz	-26.0	-20.7	
928 MHz	-25.7	-20.3	
2400 MHz	-14.1	-6.8	
2440 MHz	-10.5	-2.9	
2480 MHz	-9.0	-1.9	
2500 MHz	-8.7	-1.5	

FS (9.1nH shunt and 22pF series)			
Frequency	Efficiency	Gain	
868 MHz	-9.4	-6.7	
902 MHz	-13.7	-11.2	
915 MHz	-15.3	-12.9	
928 MHz	-16.7	-14.2	
2400 MHz	-12.0	-8.0	
2420 MHz	-11.6	-6.8	
2440 MHz	-10.9	-6.2	
2460 MHz	-9.7	-5.3	
2480 MHz	-8.8	-4.2	
2500 MHz	-7.7	-3.2	
SAM and Vest (9.1nH shunt and 22pF series)			
Frequency	Efficiency	Gain	
868 MHz	-14.1	-9.7	
902 MHz	-18.3	-14.0	
915 MHz	-19.6	-15.4	
928 MHz	-20.7	-16.6	
2400 MHz	-14.7	-8.1	
2420 MHz	-14.2	-7.8	
2440 MHz	-13.4	-6.8	
2460 MHz	-12.1	-5.3	
2480 MHz	-11.1	-3.6	
2500 MHz	-9.9	-2.3	

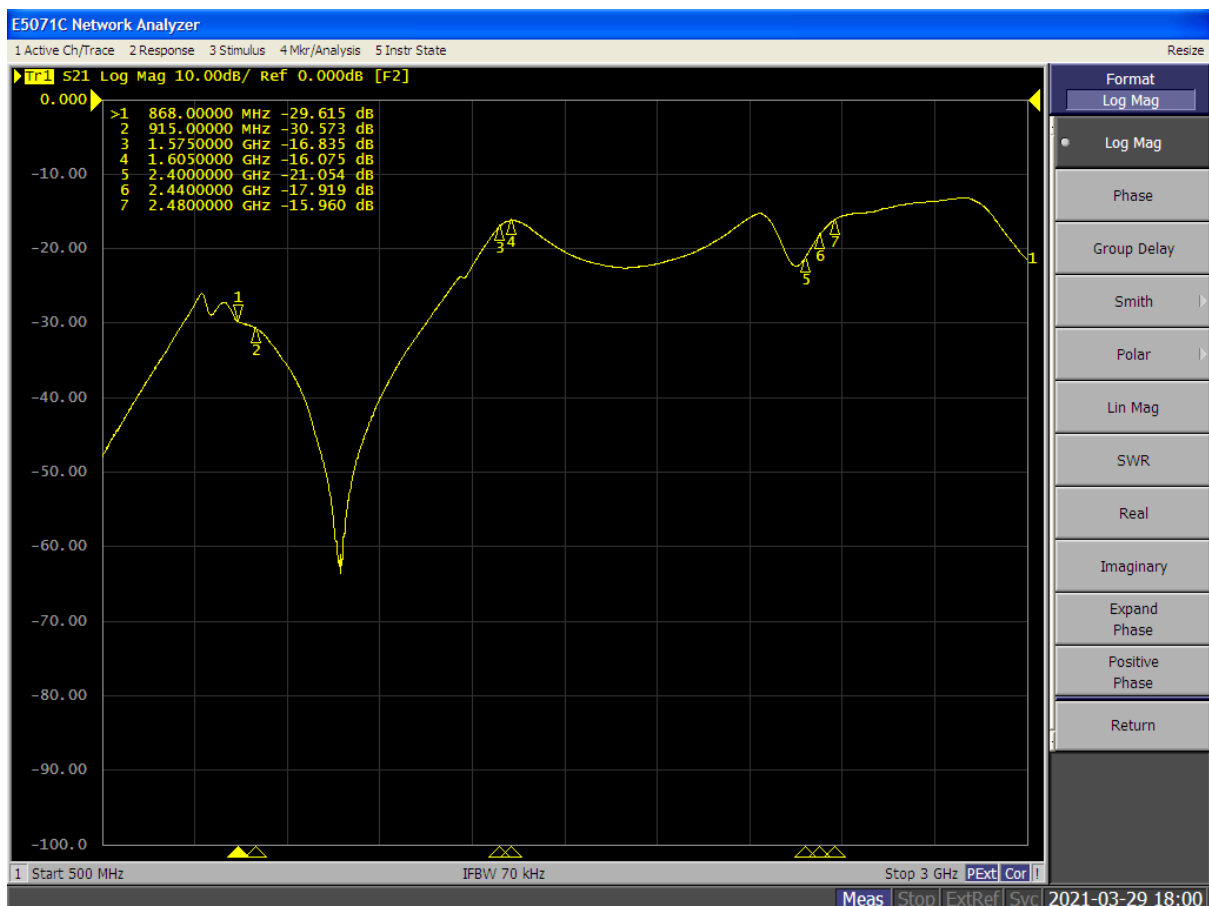
Table 5.2: ISM-antenna efficiency and gain with factory matching and the two components matching, in free space and with vest and SAM phantom.

It is worth noting that the two mock-ups (before one of them broke down) had quite different results with the factory performance. The other unit had about 10dB worse free space performance. And for one of the units a satisfactory low-bands matching could not be found.

Since there are such differences between Sigma's units and the performance differences between factory matched and re-matched DUTs polar plots might not be relevant. However, the low bands shows classic dipole radiation patterns and the 2.4GHz band shows more of a butterfly pattern (as expected).

6 ISOLATION BETWEEN ANTENNAS

Since there seems to be such differences between what SAAB experience from the field-trials and what Sigma measures on the factory matched units, the s_{21} /isolation between the GNSS-antenna and the ISM-antenna is most likely not representable with reality. Since the matching is so poor at the low bands for the factory matched units the isolation is most likely too good for some part of the total frequency-span. In figure 6.1 the isolation for one of the factory matched units is shown.



Picture 6.1: Graph with s_{21} /isolation between the GNSS-antenna and the ISM-antenna with original matching components from factory.

7 COORDINATE SYSTEM OF THE SATIMO STARGATE 24 SYSTEM

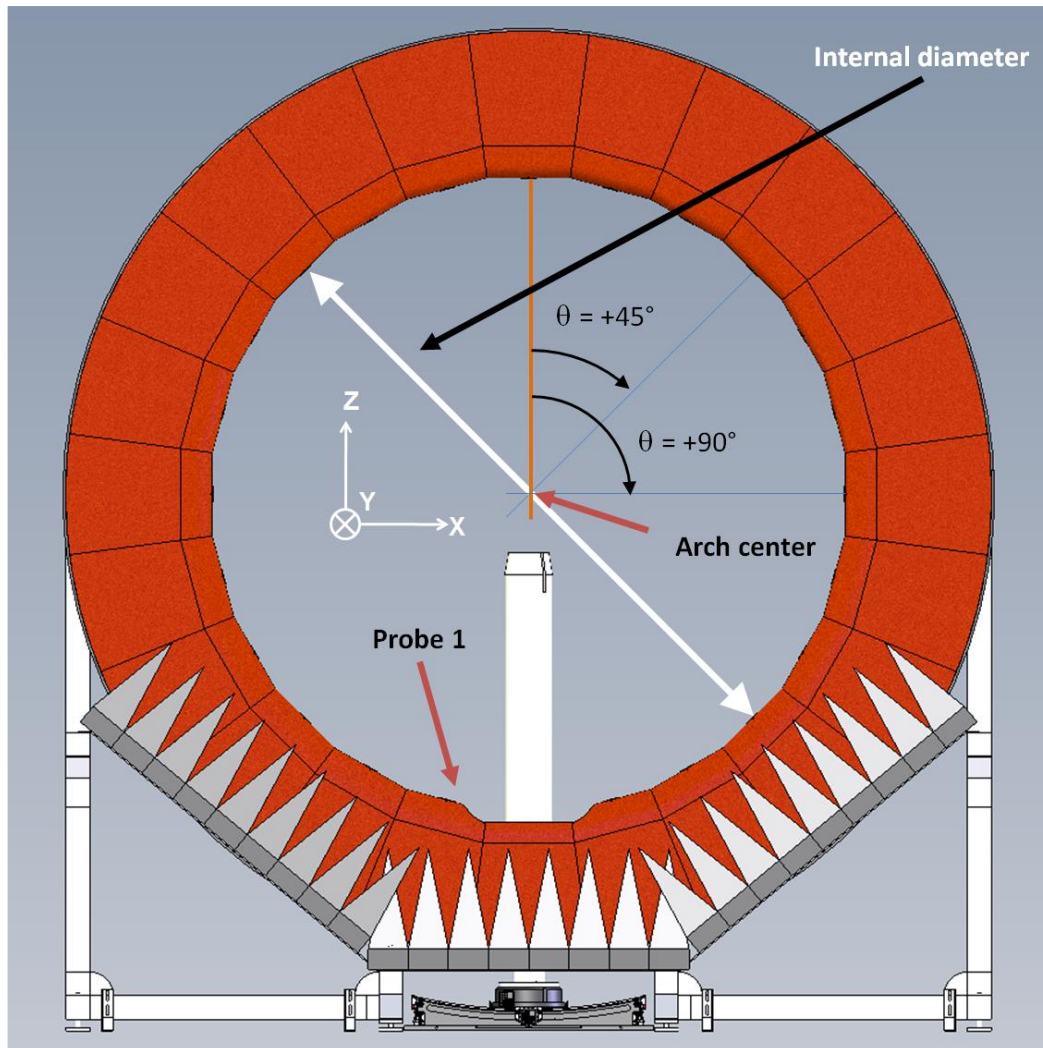


Figure 7.1: The Stargate 24 coordinate system.

Below is the explanation of the coordinate system of the Satimo Stargate 24:

+Z is towards the ceiling.

-Z is towards the floor.

+Y is towards the wall in front of you (the wall furthest away from you).

-Y is the wall behind your back.

+X is towards the wall with the door.

-X is towards the wall without the door.

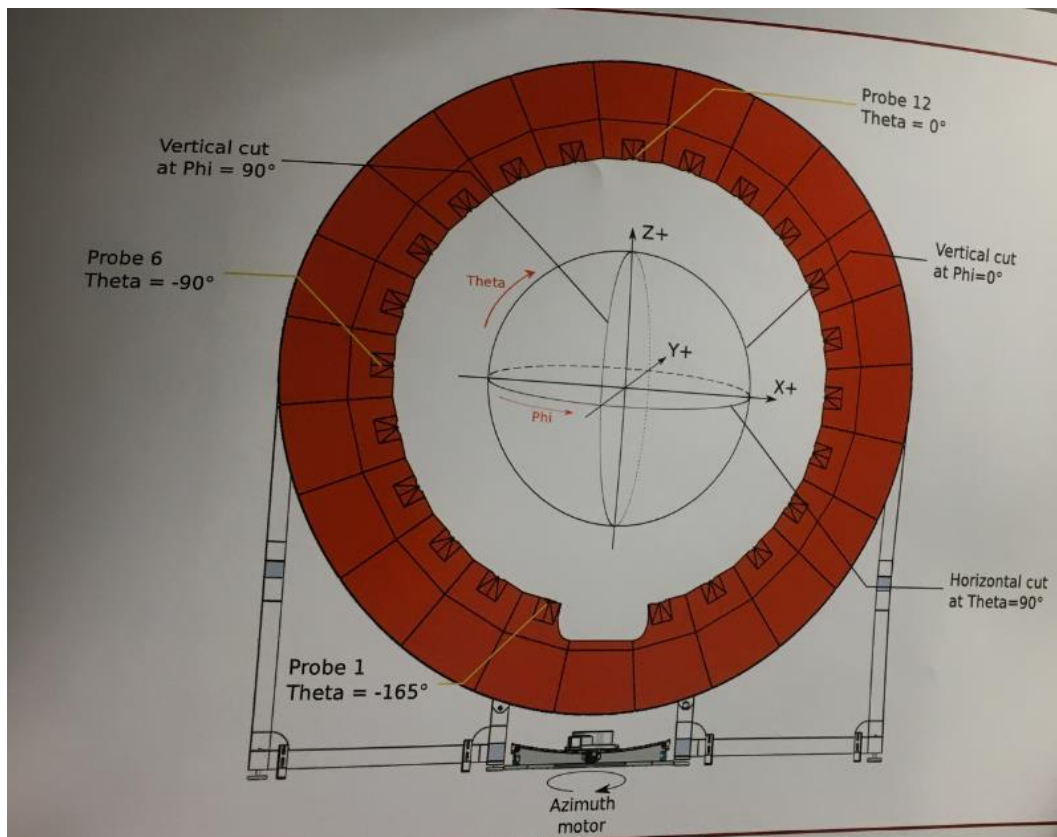


Figure 7.2: The Stargate 24 coordinate system.

Below is the explanation of the coordinate system of the Satimo Stargate 24:

+Z is towards the ceiling.

-Z is towards the floor.

+Y is towards the wall in front of you (the wall furthest away from you).

-Y is the wall behind your back.

+X is towards the wall with the door.

-X is towards the wall without the door.