

EISCAT 3D PREPARATORY PHASE PROJECT

DELIVERABLE 8.3:

*FIRST PROTOTYPE OF THE ANTENNA THAT WILL BE USED IN THE
EISCAT_3D SYSTEM*





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Introduction

This report presents the design of, and measurements on, the first antenna prototype developed in WP8 for the Eiscat_3D system. The work has been performed by Gelab AB together with Luleå University of Technology. Gelab is a contract manufacturer in Jämtland in the North of Sweden with two production sites, one in Gädde and one in Östersund. The company has over 30 years' experience in the manufacture of antennas, electronics, electro-mechanics, wiring and system integration.

The report covers two topics:

- The construction of an electric full-scale model of the "Gunnar Isaksson Antenna no:1".
- Measurements of S-parameters (S_{11} and S_{22} , Return loss) and radiation pattern of the above constructed full scale model.

The Cross-Polarized Antenna Element no:1

The EISCAT Cross-Polarized antenna element no: 1 was designed by Gunnar Isaksson at Luleå Technical University, LTU [1]. This model, termed "Antenna 1" is designed without its own reflector. The basis for the construction of the electric prototype is the drawing below.

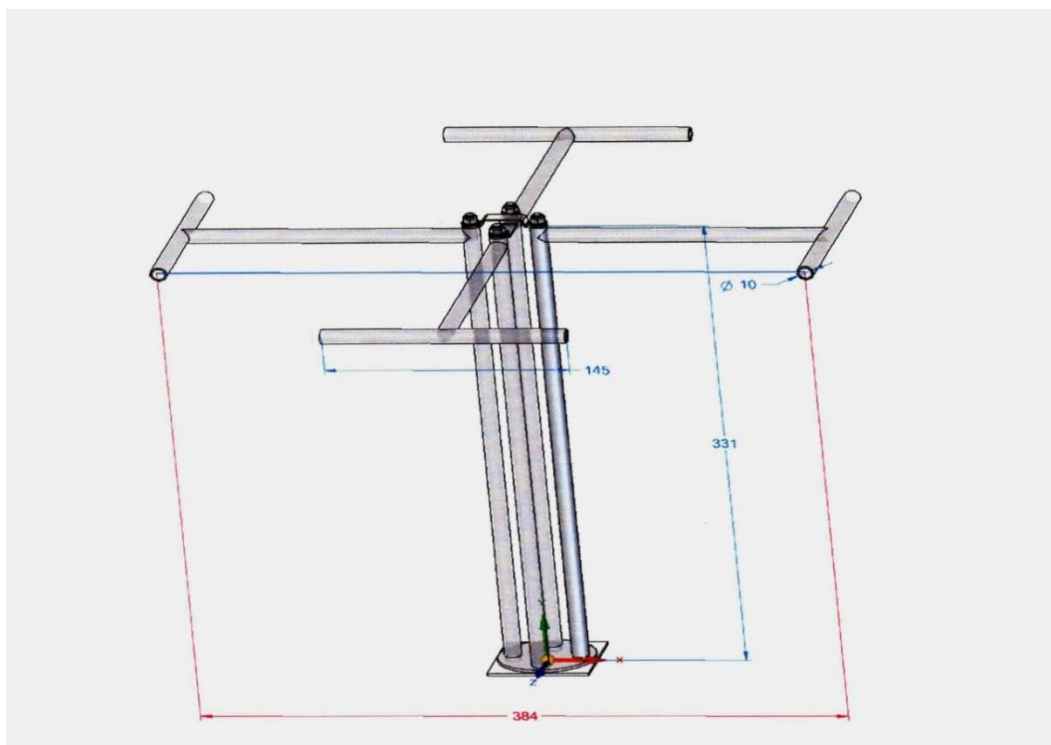


Figure 1. antenna element no:1 designed by Gunnar Isaksson at Luleå Technical University

The antenna has as driven elements crossed shortened dipoles mounted above a reflector made out of a Quad element. The driven element and the reflector can be designed in several ways and would create a lot of alternatives but only one of these is discussed here.

In the simulations, a Quad element (a closed square loop) is used as a reflector due to its small foot print. It works equally well for both polarizations and have a smaller foot print than normal crossed reflectors made out of straight wires/tubes. To make the Quad into a reflector it's resonant frequency is just made somewhat lower than the operating frequency.

For a driven element is a shortened dipole is used. It is cut a bit short and capacitively loaded at the ends to keep it's resonant frequency.

An alternative to fit a dipole into a small foot print is to bend the antenna tips down into an inverted V configuration. This element is sometimes also referred to as a PAW element [2]

Antenna construction

In order to verify the electrical performance made by Gunnar Isaksson, a full scale electric prototype of the antenna element was built. This electric antenna prototype has the been placed on a ground plane with a diameter of 1 lambda (Figure 2).

Frequency band 218-248 MHz, giving center frequency 232.5 MHz and lambda 1.29 m
A ground plane is thus necessary to verify the performance of the antenna, then the element does not have its own reflector, but uses in the future a much larger ground plane. This ground plane antenna has many elements in common with the ground plane. Here the circular ground plane with radius $\frac{1}{2}$ lambda form a good basis for the cross-polarized antenna element



Figure 2. Electrical full-scale model of antenna element no:1 mounted on a ground plane with a diameter of one wavelength (λ).

Measurements

Return loss and isolation

Instrumentation

The return loss of each antenna port and the isolation between them, were checked using a Hewlett and Packard Network Analyzer model 8753C. The two ports of the antenna (port 1 and 2) connect to the two orthogonal polarizations.



Figure 3. Hewlett and Packard Network Analyzer model 8753C used for return loss and isolation measurements

Results

Return Loss from both antenna ports, S_{11} and S_{22} , are shown in the upper half of figure 4. Markers 1 to 4 is the current frequency range 218-248 MHz. Scale 5dB/div. Marker 1, shows a RL of -15.9dB for 218 MHz.

The lower half of the figure shows the insulation between the antenna ports, ie, the cross-polarized antennas isolation S_{21} . Marker 1 shows where the isolation is -32.4 dB

In Figure 5 complex impedance results from return loss and isolation measurements are plotted in the Smith chart for the same measurement. Figure 5 (upper), shows the complex

impedance, related to the input terminal at the ground plane, and, Figure 5 (lower), shows the impedance of the dipole gap 350mm from the coax contact.

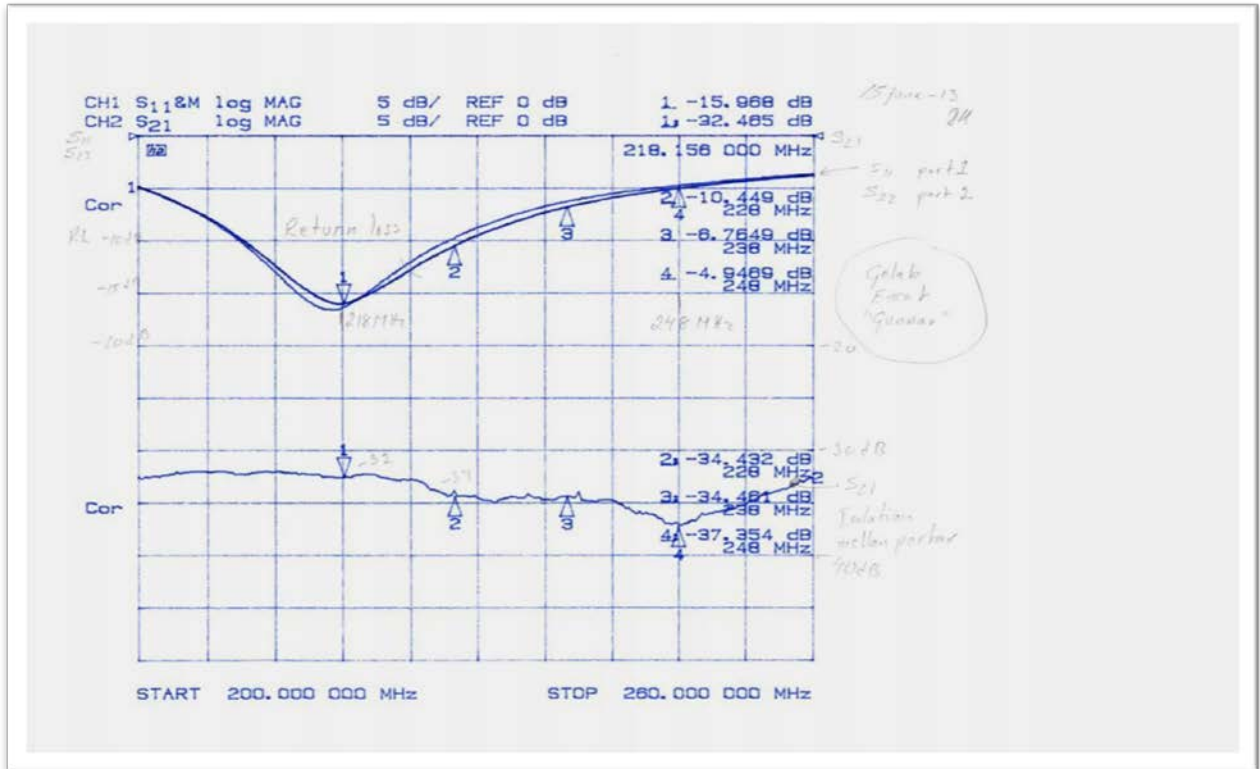


Figure 4. Results from return loss and isolation measurements

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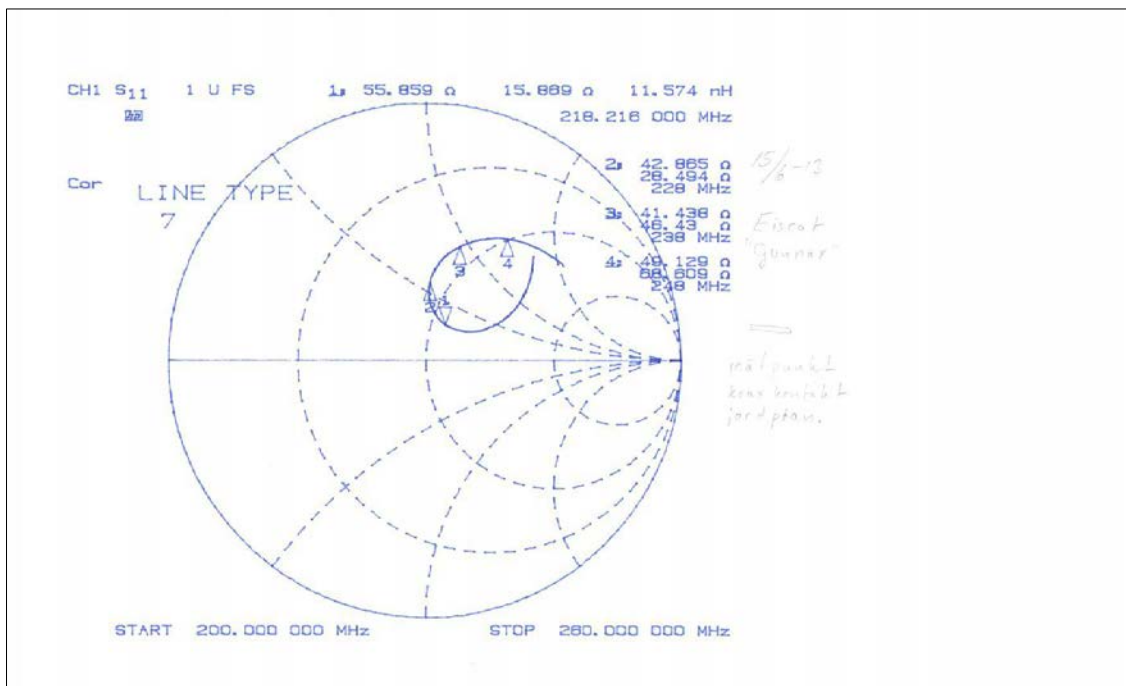
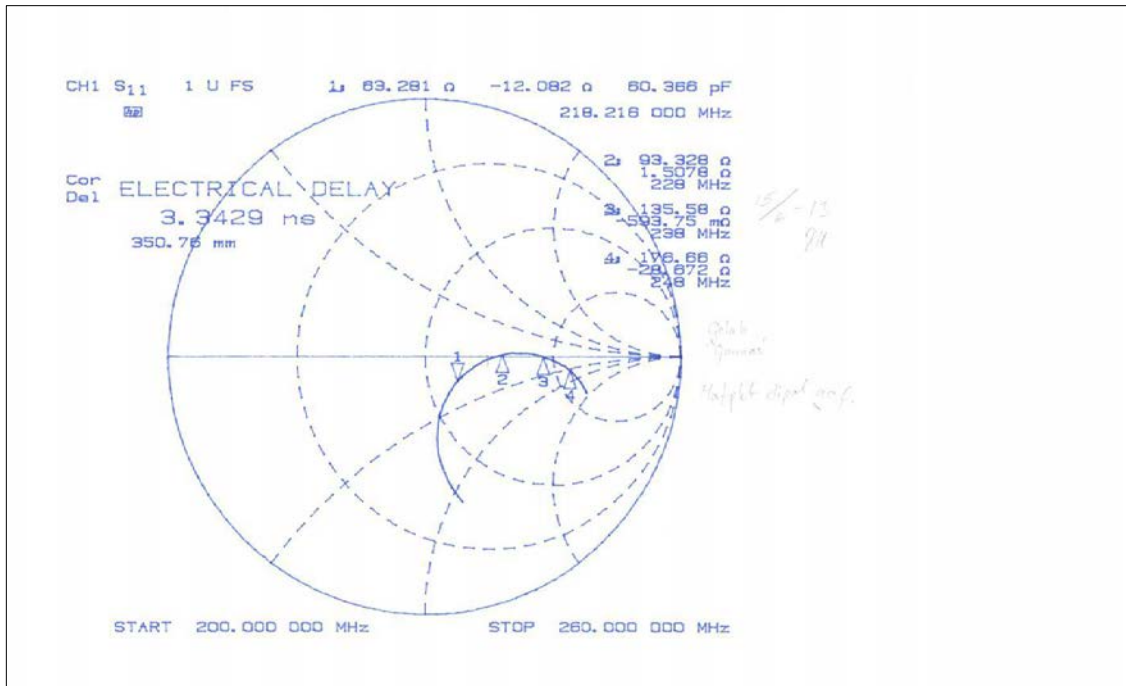


Figure 5. Complex impedance results from return loss and isolation measurement. The upper graph shows the complex impedance, related to the input terminal at the ground plane. The lower shows the impedance of the dipole gap 350mm from the coax contact.

Radiation pattern measurements

Measurement range

The Radiation patterns were measured in a non-echoic measurement chamber using an Orbit/Fr near field system. The size of the measurement chamber was 8 x8 x 8m

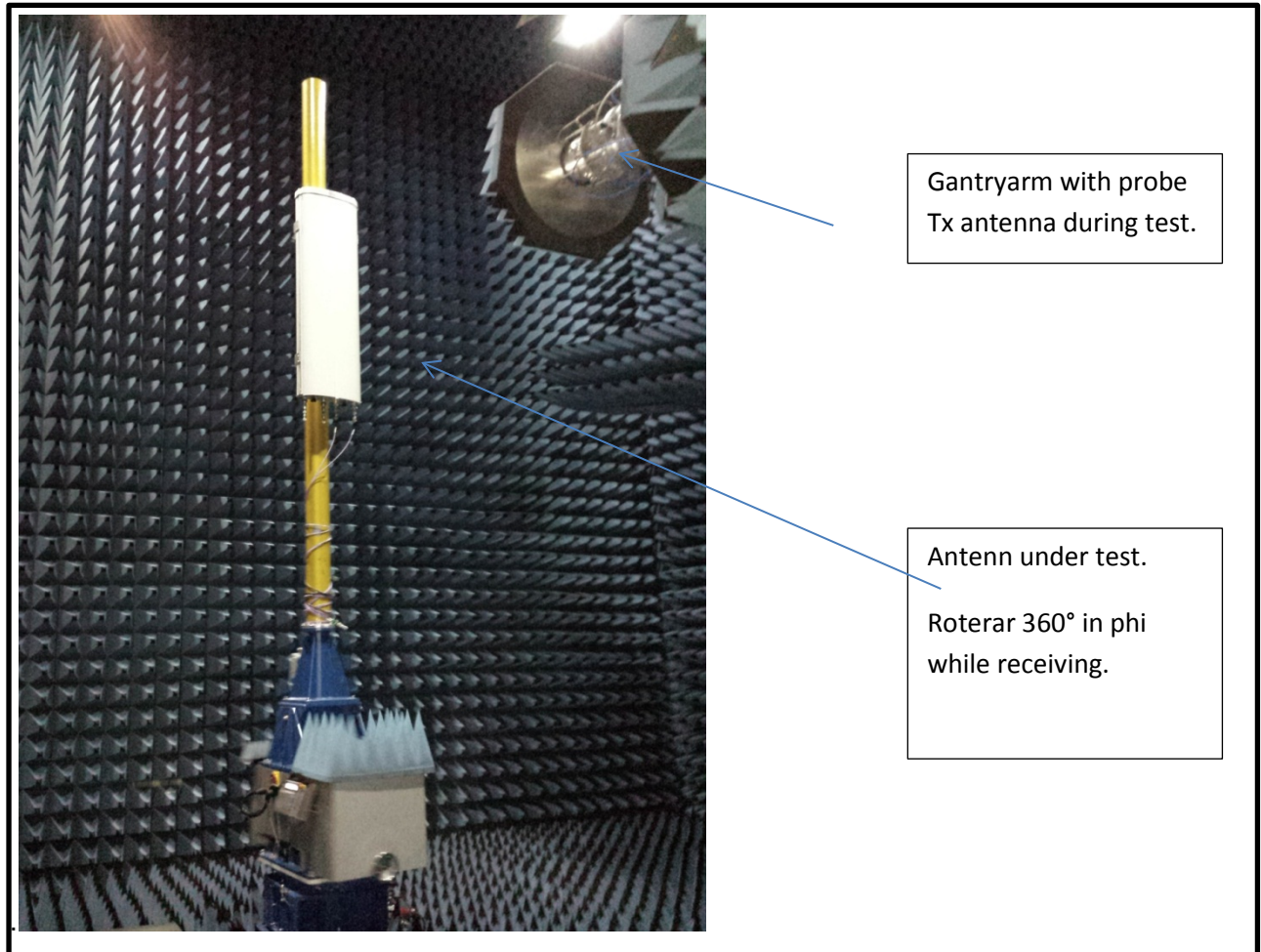


Figure 6. Photo taken from the inside of the test chamber showing an antenna being tested using the Orbit/Fr near field system

This particular set-up is designed to measure spherical near field from antennas in the frequency bands 680-980MHz and 1700-2800MHz.

Using the spherical measurement system, each amplitude and phase is at each frequency sampled vs. angle Elevation (Theta) and azimuthal (Ph) angle, in increments of half a wave length (λ), providing a basis for the transformation to the far field.

Unfortunately, the current system did not include any probes for 200-250 MHz, why a separate simple Yagi was manufactured and used as a probe during the measurement of the EISCAT Antenna 1.

Instrumentation



Figure 7. Measurement and analysis equipment for the Orbit/Fr near field system

Figure 7 presents the measurement and analysis equipment for the Orbit/Fr near field system. The Network Analyzer used is a Rohde & Schwarz ZVA8. In the test is is used both as the transmitter and receiver. Measurement analysis software was provided by Midas. The control system for the turntable was provided by Orbit

Measurements

Because of the unusual frequency range, a separate simple 3 element Yagi antenna was constructed and mounted at the arm of the near field scanner. This transmitt antenna that illuminates the object is not ideal, as it must be turned by hand to get the different polarizations measured. Yagi antenna is rotated between -45° , 0° , $+45^\circ$, and 90° for the different polarizations measured.

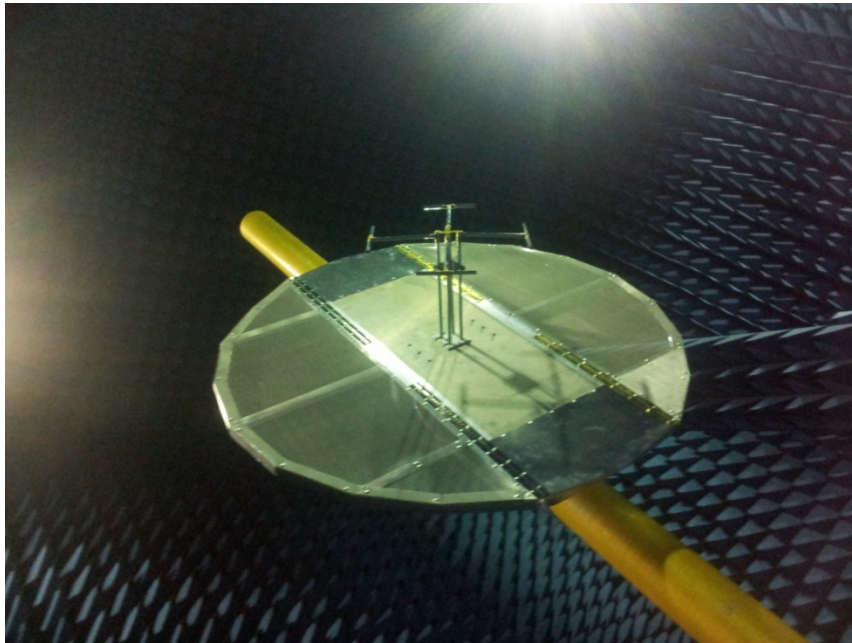


Figure 8. Antenna 1 mounted in the measurement chamber

The Measurement data is then transformed to the far field. Thus, we can plot a 3-dimensional view of the radiation pattern of the antenna 1 based on the near field data obtained by the system (For more details, see appendix). In order to easily analyze the radiation pattern, they are here below also presented in both polar and Cartesian plots.

Antenna 1 has been documented in the frequency range 215-250 MHz in 5 MHz steps. The entire frequency range of 8 frequencies are presented as overlay in all charts. Both antenna ports is measured N45 and P45

Note that the gain cannot be read because it is not calibrated for these frequencies. Directivity values is presentable as they represent an estimated volume of the measured antenna sphere and thus reasonably accurate for the ground plane size.

Discussion

In this report we have presented some test results of a full scale electrical model of an initial element design called "Antenna 1". The purpose of this first step of measuring a full scale prototype is to get a true measurement of the simulated antenna element design. However, there are some parameters that cannot be compared to the simulated data. Firstly, the ground plane for the practical model had to be limited to a manageable size. Secondly, the antenna model was design for an outdoor installation, which means that its mechanical strength had to be improved compared to the model in the simulations.

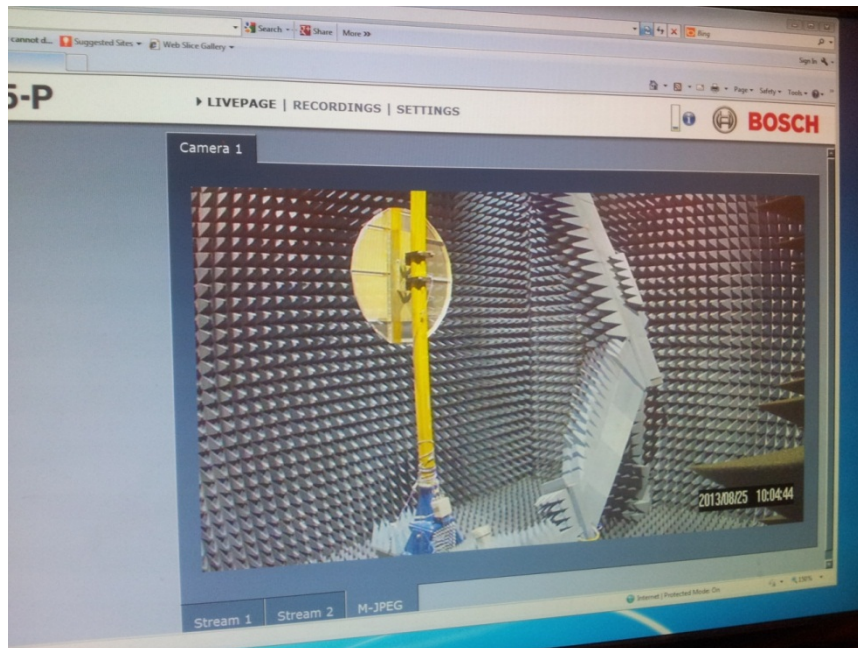


Figure 9. The EISCAT electric prototype antenna under test in the measurement chamber

What does this first step then contribute to the project? This individual element "Antenna1" is the building block of the entire large array with thousands of antenna elements. If this element can be accurately verified and compared with the calculated data, the probability is good that the properties of the total array may accurately be estimated [3].

As is evident from the initial results, "Antenna1" does not meet the existing preliminary spec requirements for individual elements. However, there are a number of different sources of error: E.g., when we compare estimated and actual measurement for radiation pattern we need to bear in mind that the ground plane size is smaller for the full scale model than in the simulations. Furthermore, S-parameters and radiation characteristics of a mechanical structure always requires great care in materials and manufacturing technology to get a stable antenna unit

Conclusions

The EISCAT3D consortium has come a small step on the road towards the planned massive phased array of thousands of elements. The ambition is to achieve an antenna with steerable beams over a wide range of angles from zenith down to ~30 degrees from the horizon.

The interaction between thousands of antenna elements requires that we are very familiar with the element performance, both individually and with other antenna elements in the

immediate vicinity. How does this mutual coupling affect performance is still to be investigated [3]

The whole antenna system must withstand tough outdoor environments for many years. Hence, it is essential that the building materials are chosen with care so that we can rely on the antenna element for many years to come.

Computer calculations is a must for this project in order to gain an understanding of the overall array performance [1,3]. However, in addition to these calculations already performed, it is of importance to simulate how material constants may change with temperatures etc., in order to see how the overall array performance changes. Cabling etc. follow the laws of physics and it must enter into the calculations.

A system is only as strong as its weakest link, which for an array antenna is the individual element performance .

Next steps

The work conducted in this project has to a large extent been based on the experience from the development of military, and base station antennas for mobile systems.

With this background in mind we would first of all like to point out that building antennas to be constantly in operations, without maintenance for at least 10 years, regardless of climate and installation, puts great requirements on both the design as well as the choice of materials and components.

Therefore, we believe that more work has to be done on the individual antenna element's electrical and mechanical design and performance. Before moving forward with studies on the performance of several antenna elements in an arrays, we need to an antenna element which is closer to the final design.

In order to get to an element closer to the final design we need to start evaluating various material choices, dimensions etc, and also perform environmental testing. Typical such environmental testing takes some 5 to 8 weeks, during which the aging is accelerated, equivalent to many years of use in the installation. The testing need also to include mechanical vibration, chock etc.

When the design of the individual antenna element is fixed, it is of importance also to evaluate the influence of neighboring antenna elements in a practical experiment and compare the results with simulations.



Unfortunately, such an experiment will require very large mechanical devices at the low frequencies of 230 MHz, that are difficult to manage and difficult to measure with existing test ranges. We therefore propose to build antennas in 1:3 scale (750 MHz band). At this band there are plenty of resources to measure both the electrical performance of the antenna as well as the radiation characteristics.

An array of 3x3 antenna elements or greater is mechanically manageable and extremely valuable to compare with simulations. For example, an array of 4x4 elements is only about 1x1m at 750MHz and thus manageable. Based on measurements of the full-scale "Antenna1" presented here, a model with 16 elements is expected to provide about 20 dB directivity. However, the magnitude of side lobes and grating lobes that is the result also of the mutual coupling, we may only get hold of after measurements of an actual array.



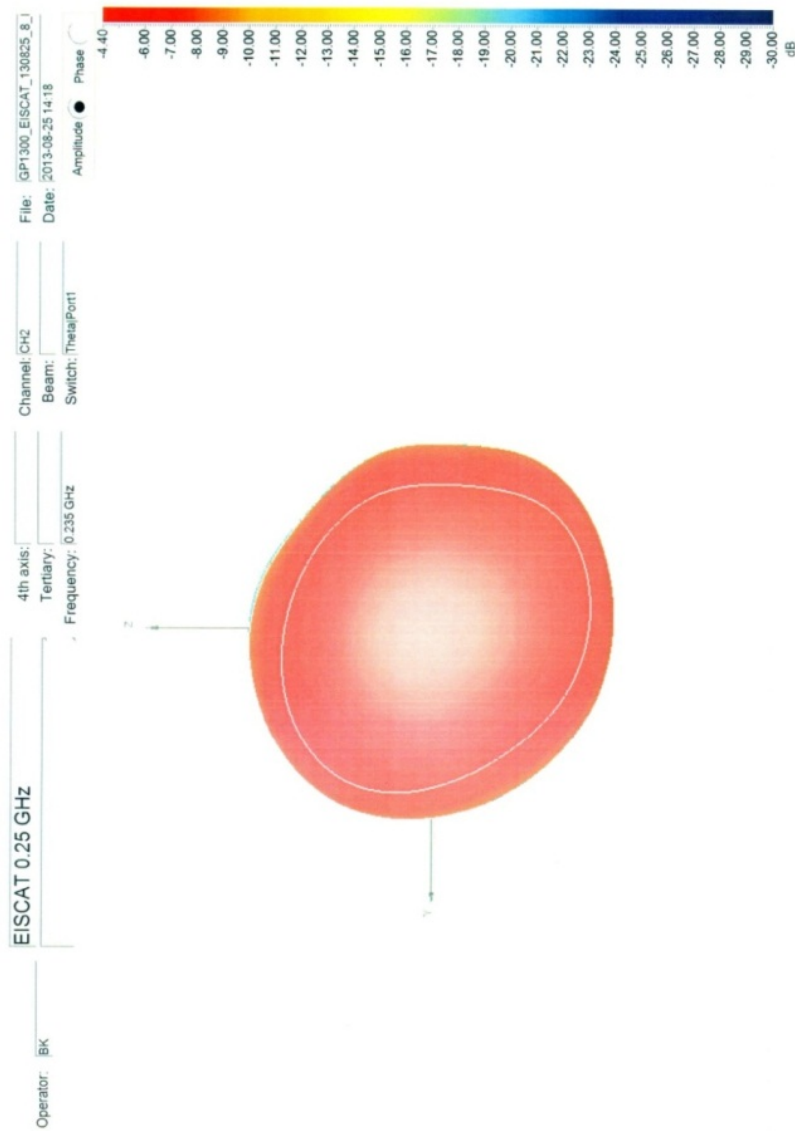
References

- [1] Gunnar Isaksson. "Design of Antenna Elements for EISCAT 3D's Phased Arrays". Luleå University of Technology, Technical Report, September 5, 2012
- [2] Eli Brokner et al "Demonstration of Accurate Prediction of PAVE PAWS Embedded Element Gain"
- [3] Irina Tecsor "Mutual Coupling effects and Optimum Architecture of a sparse array". Master of Science Thesis. Royal Institute of Technology, KTH. 2013

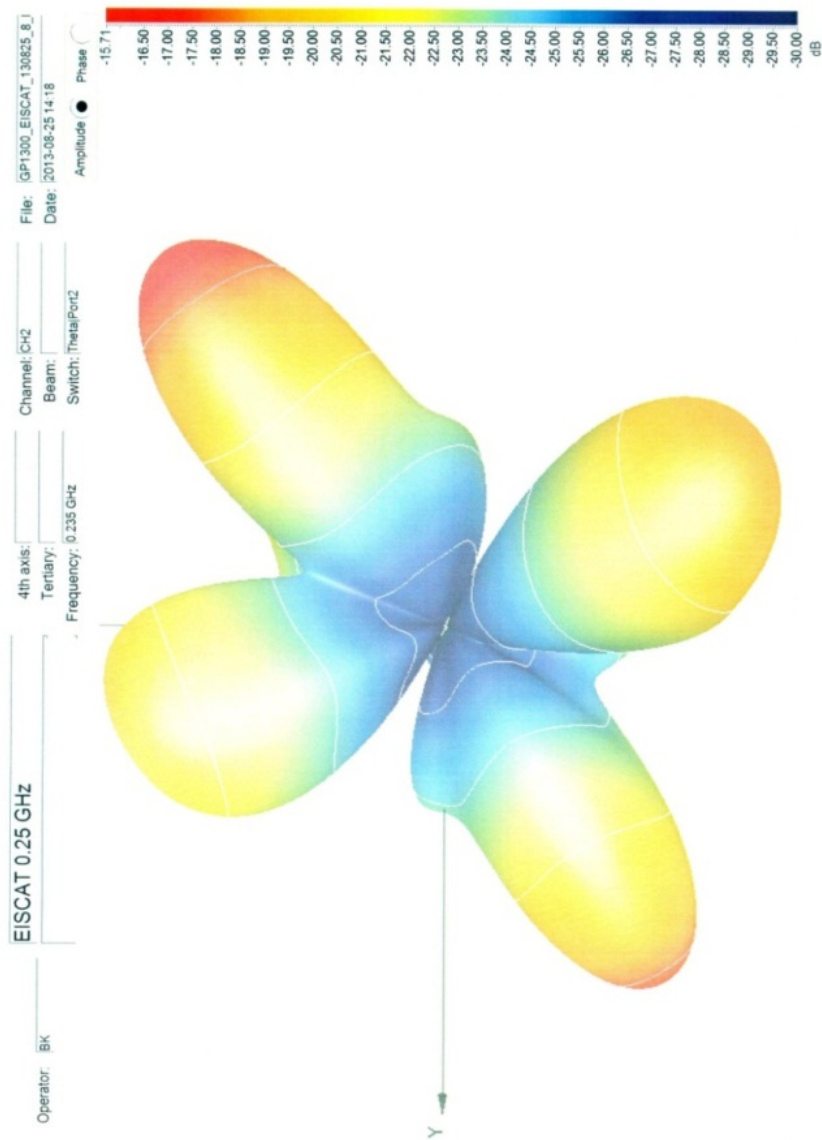


Appendices

Appendix 1.: Antenna1_ N45_3D_Copolar.

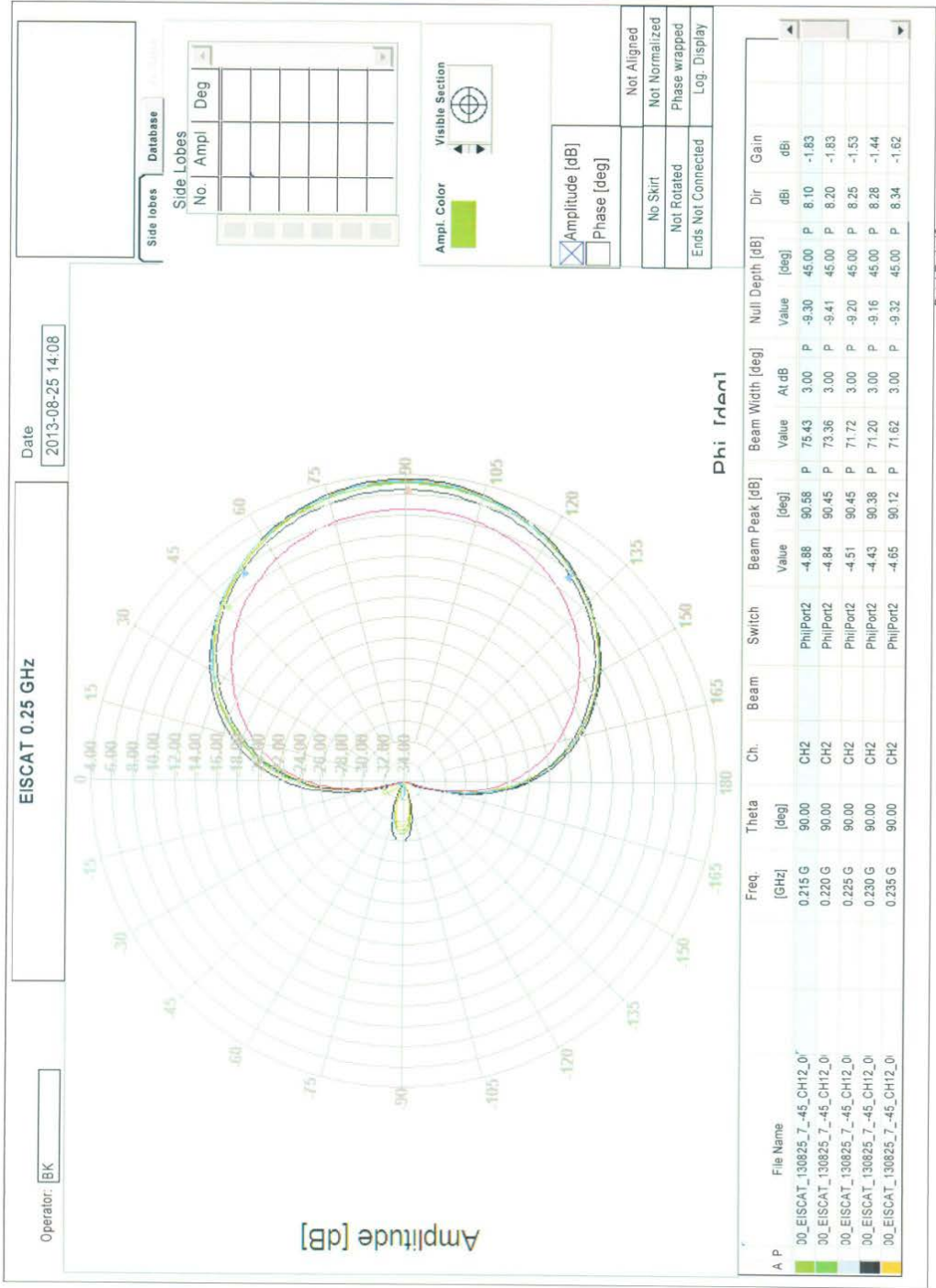


Appendix 2: Antenna1_N45_3D_Crosspolar.



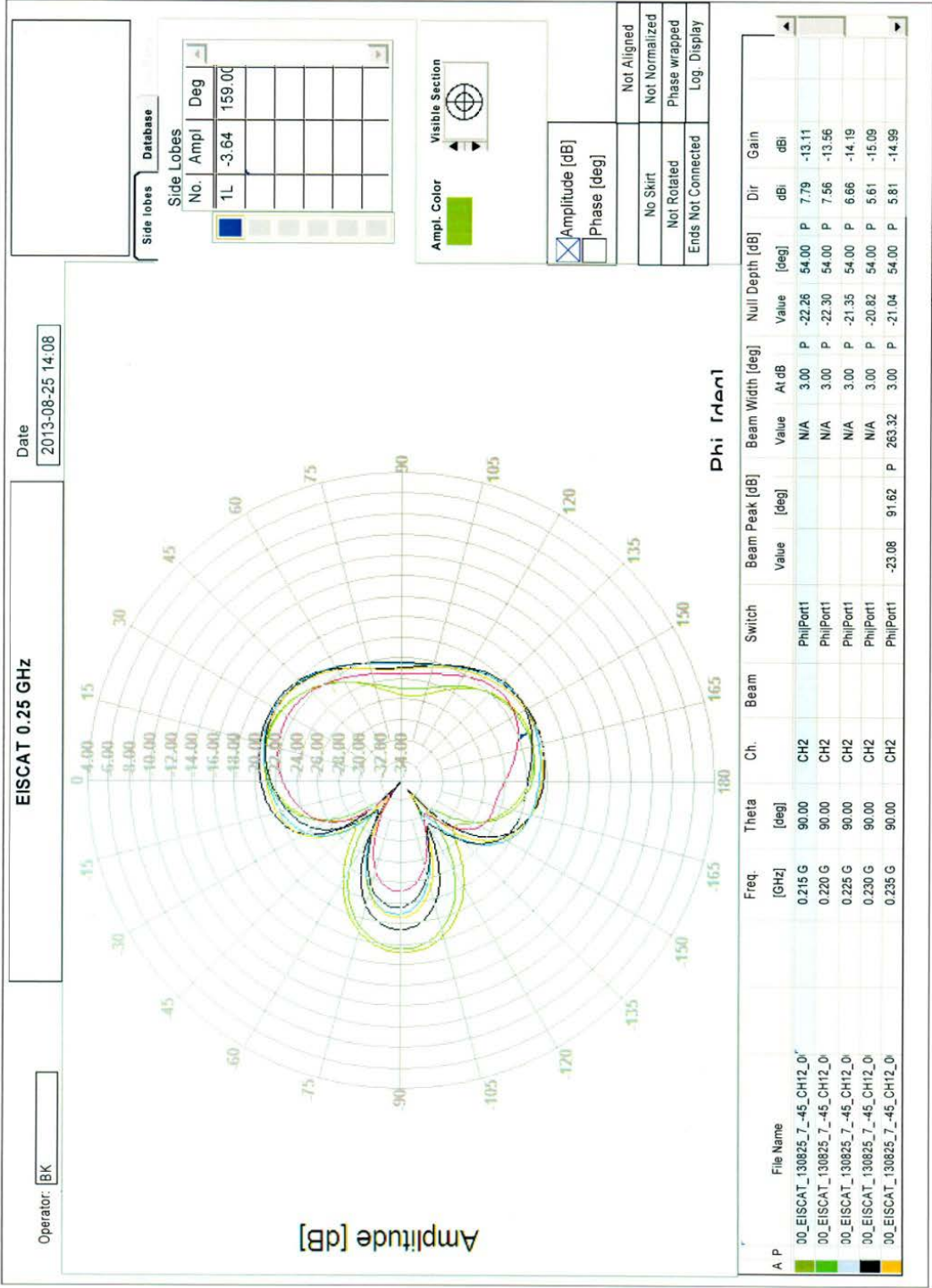


Appendix 3: Antenna1_Pol_N45_Phi_Copolar.



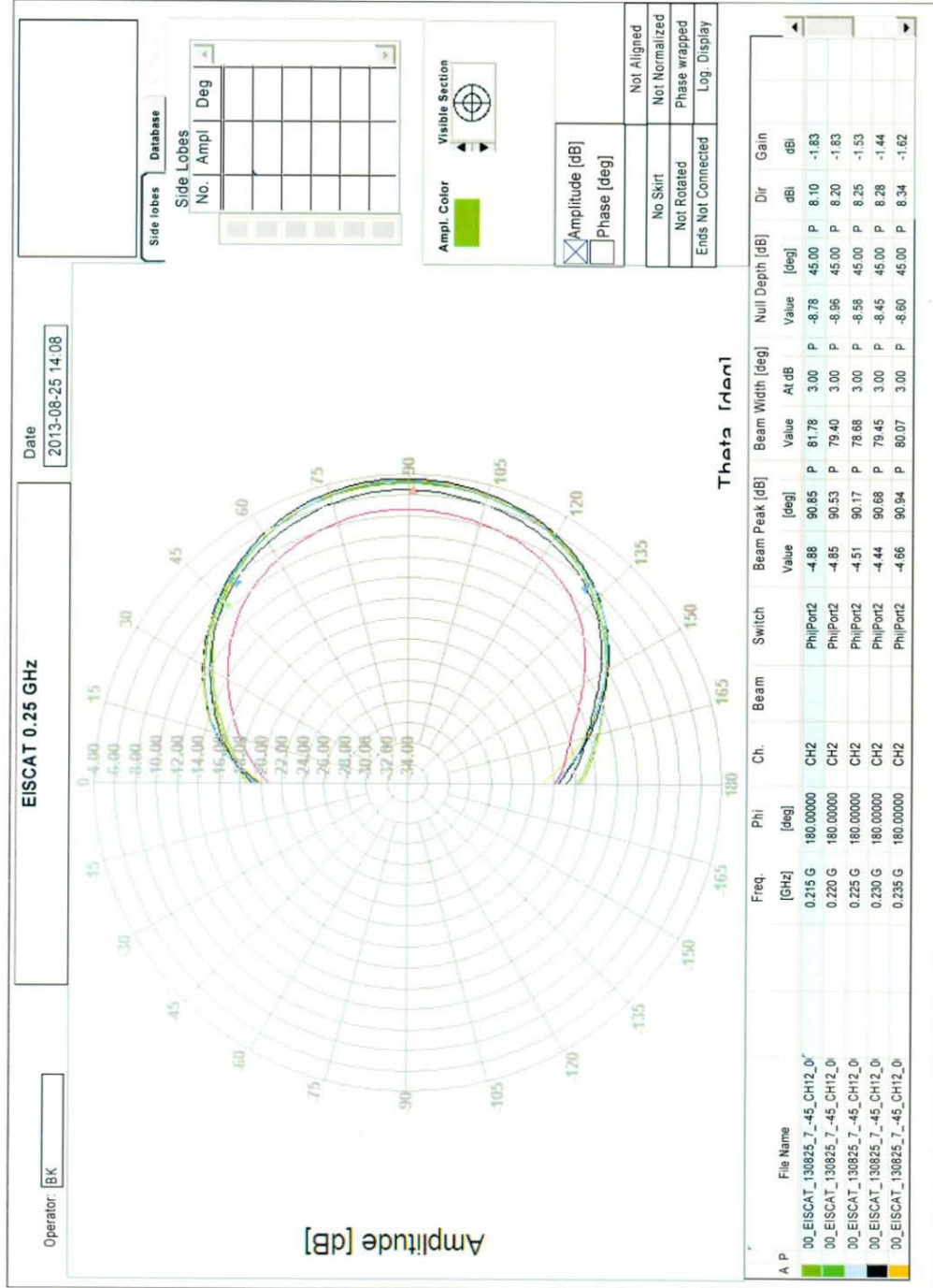


Appendix 4. Antenna1_Pol_N45_Phi_Crosspolar.



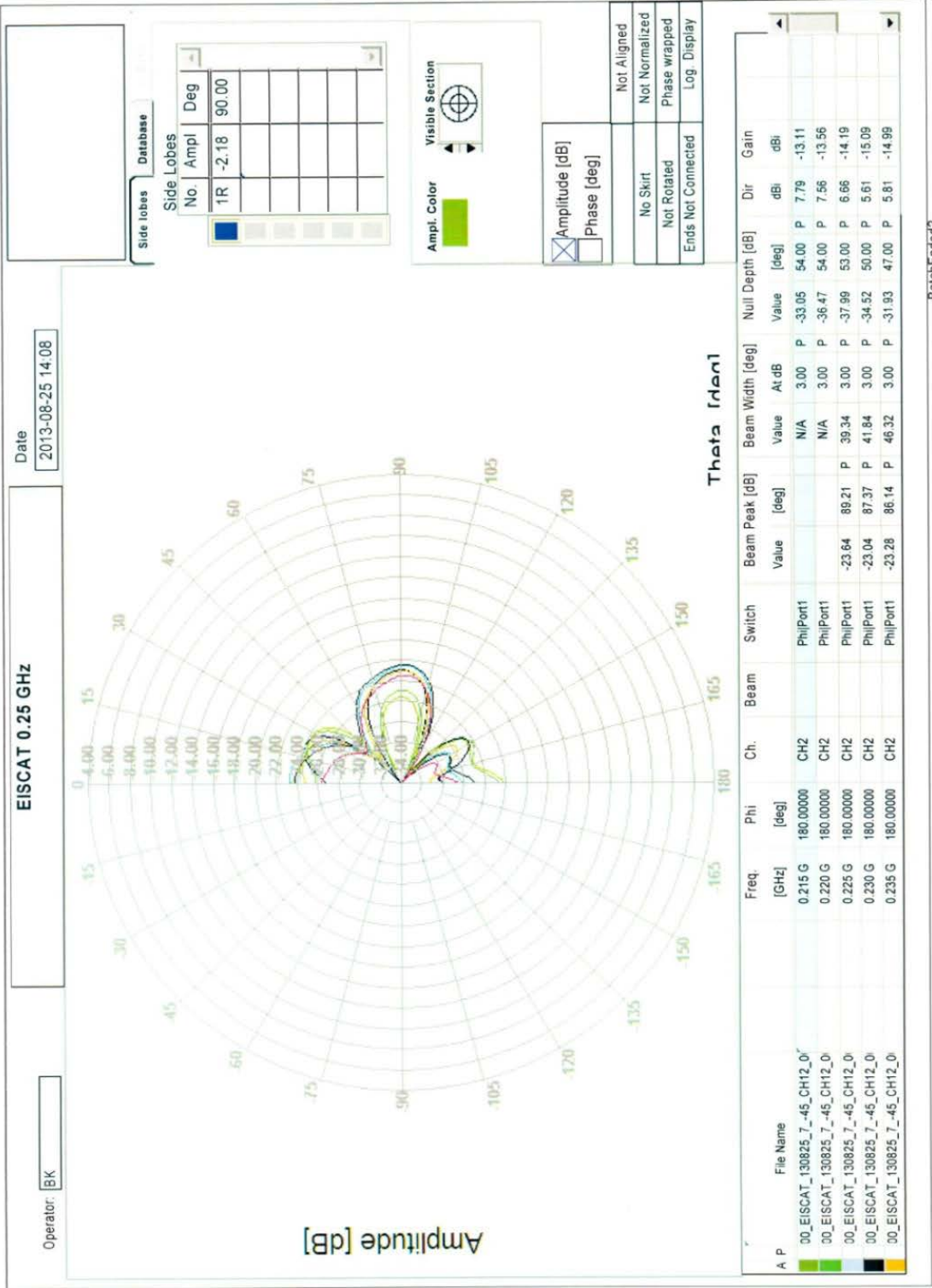


Appendix 5. Antenna1_Pol_N45_Theta_Copolar



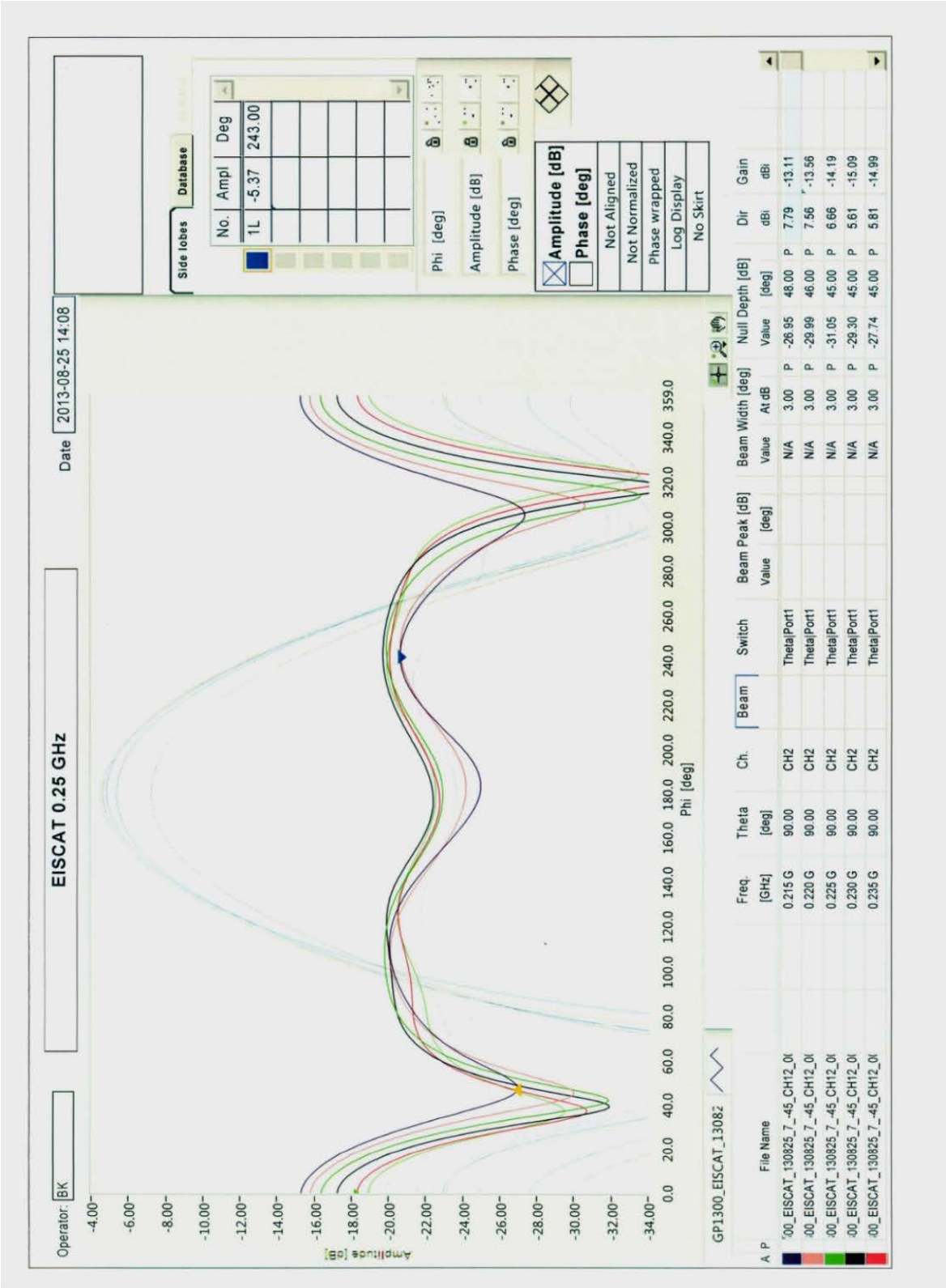


Appendix 6. Antenn1_Pol_N45_Theta_Crosspolar

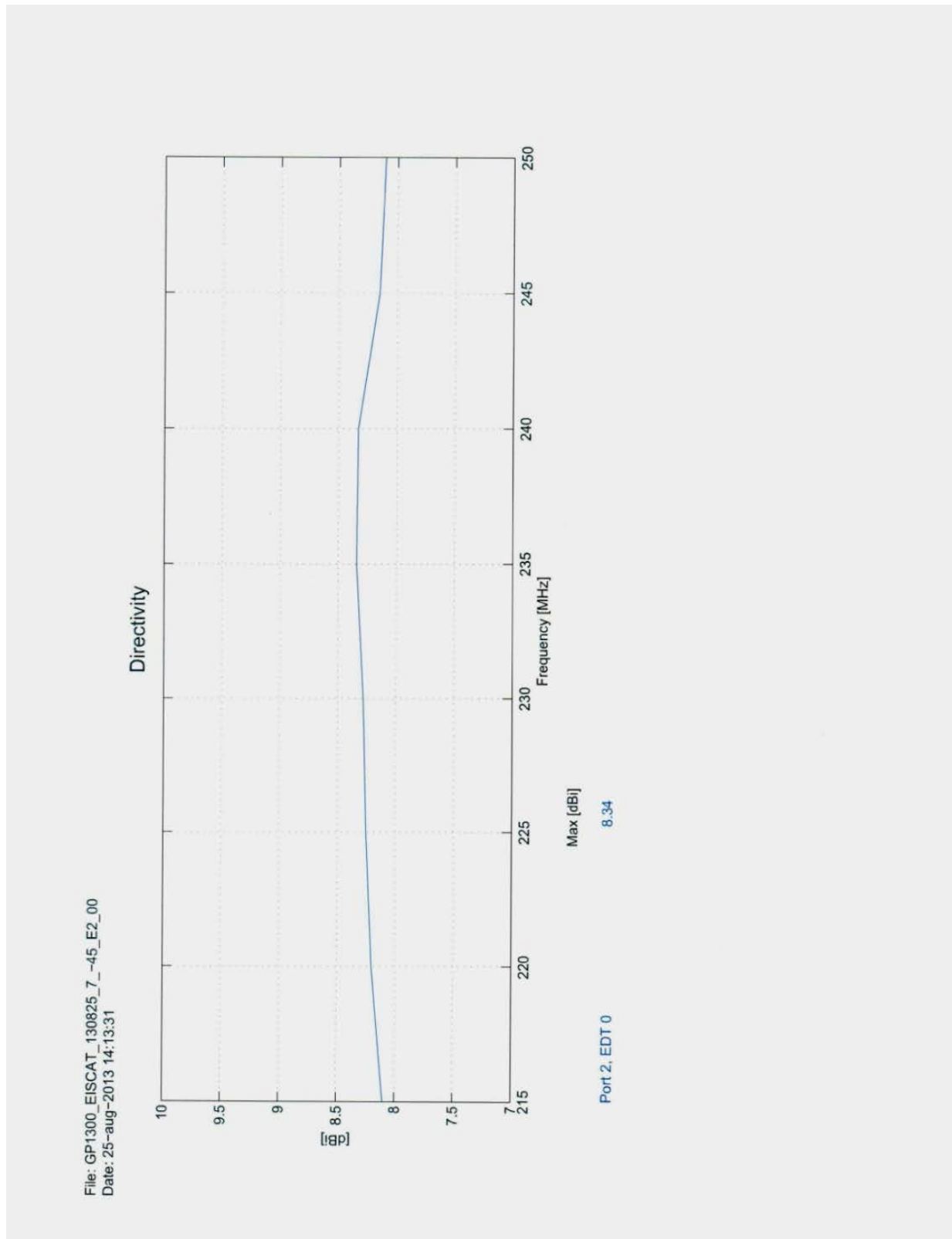




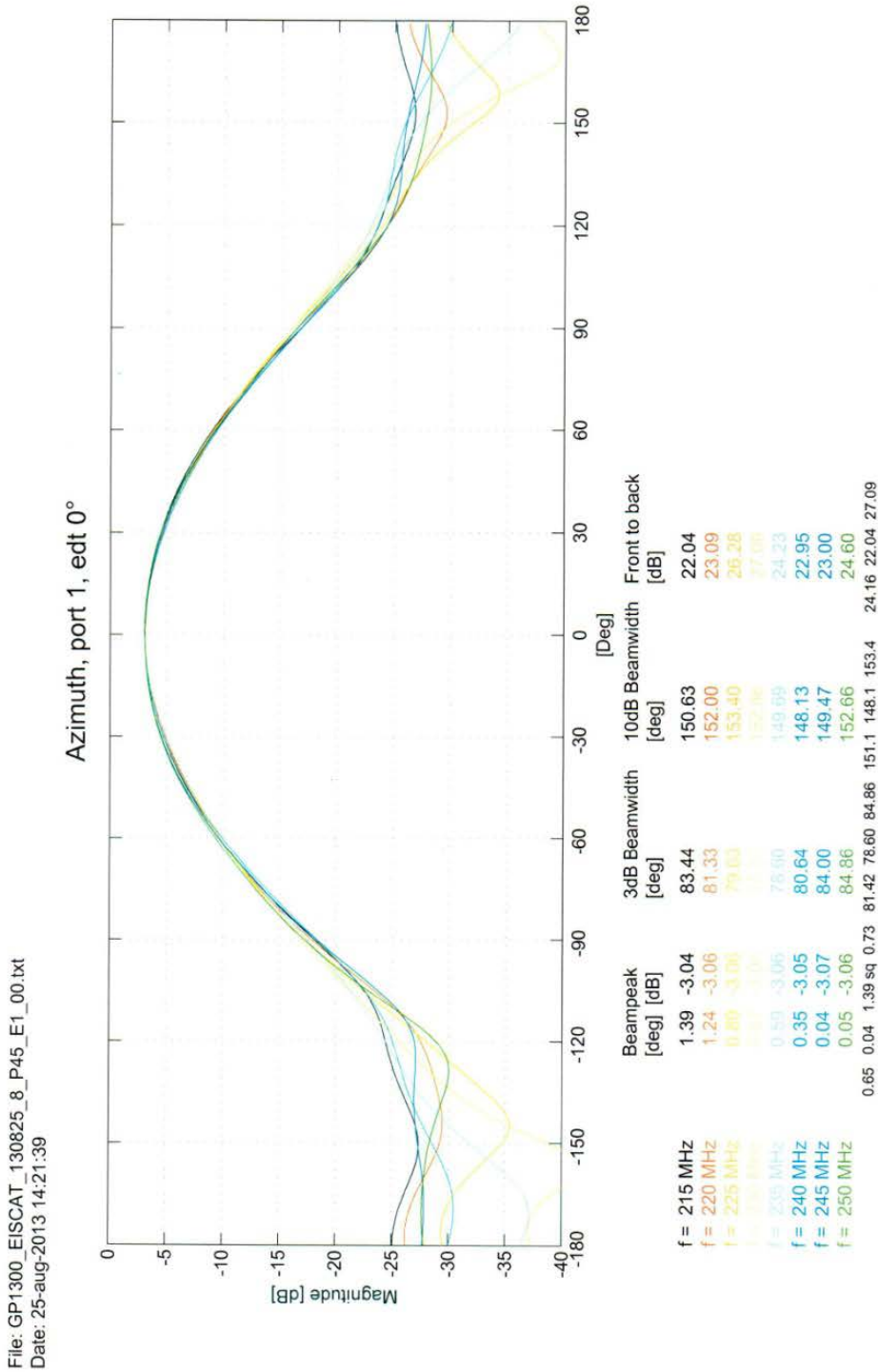
Appendix 7. Antenn1_Cart_N45_Phi_Co/Crosspolar



Appendix 8. Antenn1_Cart_N45_Direktivty

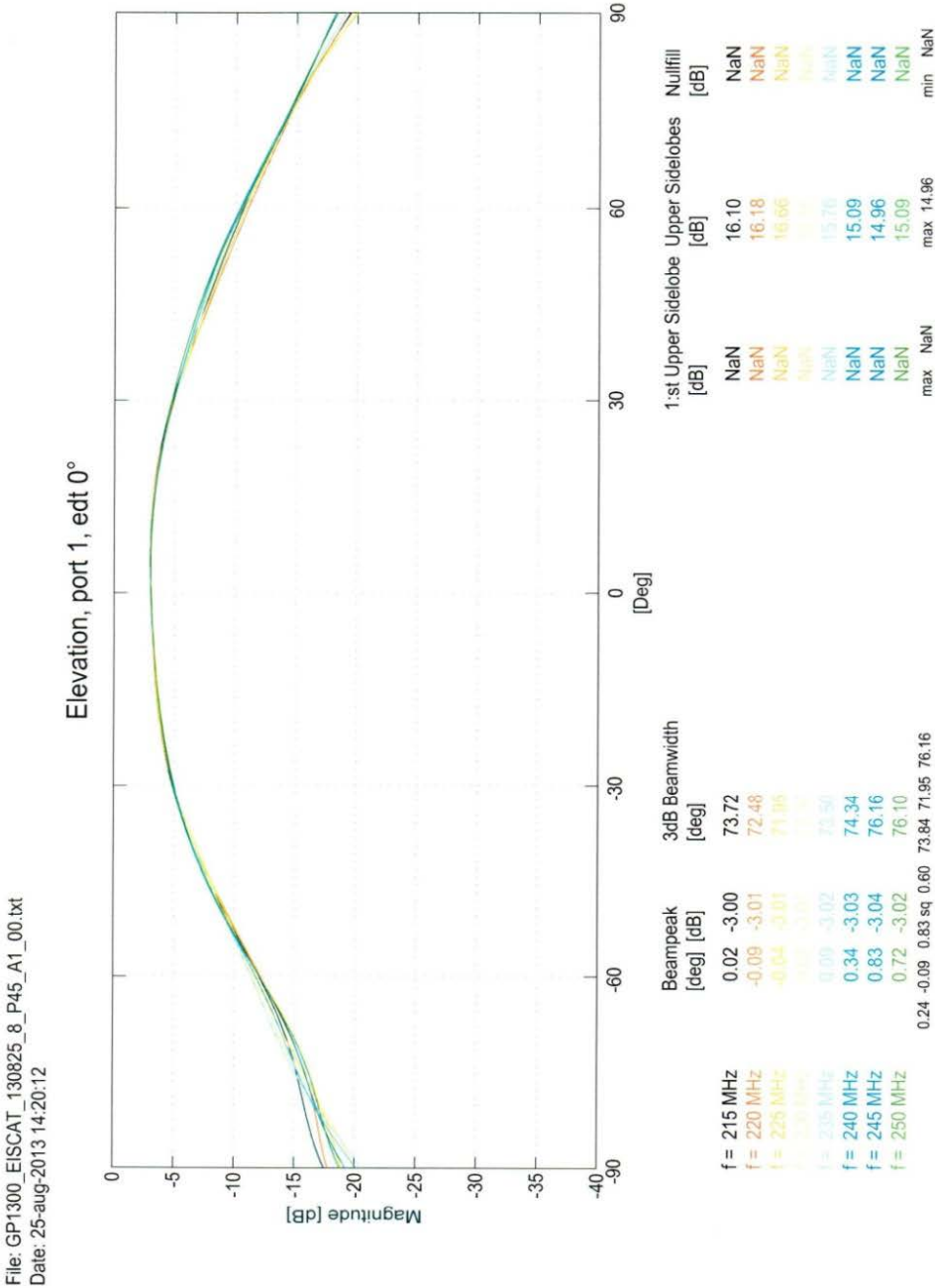


Appendix 9. Antenn1_Cart_P45_Phi_Copolar



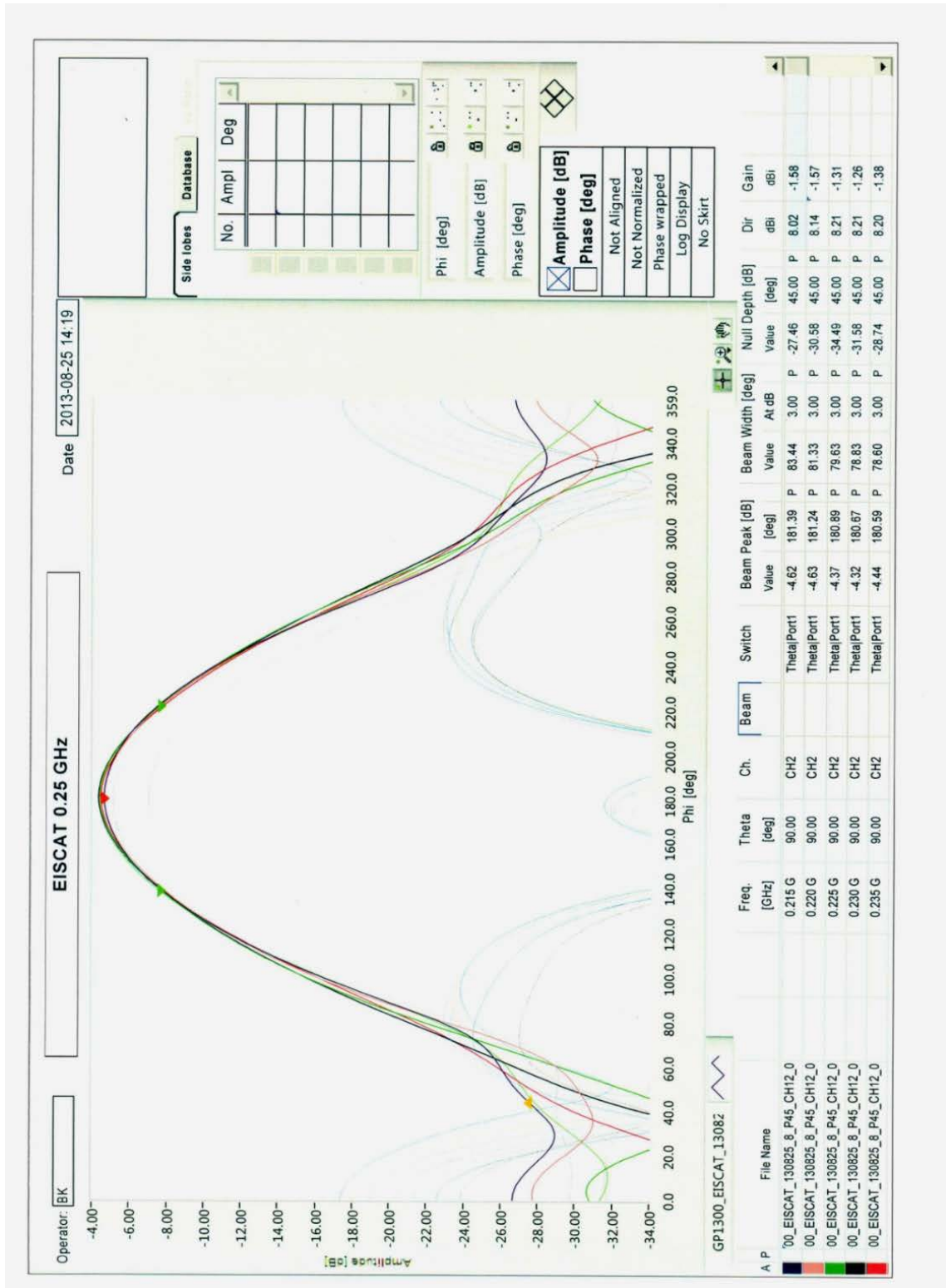


Appendix 10. Antenn1_Cart_P45_Theta_Copolar





Appendix 11. Antenn1_Cart_P45_Co/Crosspolar



Appendix 12. Antenn1_Cart_P45_Direktivty

