ABSTRACT

A major new research European infrastructure will be constructed in Northern Scandinavia, combining several very large phased-array transmitters/receivers with multiple receiver arrays. The new EISCAT 3D radar system has a design goal of ten times higher temporal and spatial resolution than the present radars, a volumetric radar imaging capability with simultaneous full-vector drift velocities, continuous operation modes, short baseline interferometry capability, real-time data access and extensive data archiving facilities. Some arrays are very large, in the scale of 16 000 individual antenna elements. The receiver arrays will be located at 110-250 km distance from the illuminators, so that the total system will comprise in the order of several tens of thousands of antenna elements.

1. INTRODUCTION

EISCAT Scientific Association operates currently three incoherent scatter radars in Northern Scandinavia on behalf of its associate members in Finland, China, Germany, Japan, Norway, Sweden and United Kingdom, as well as currently supporting partners in France and Russia. The current facilities include the 2-dish monostatic radar at 500Mhz at Longyearbyen, Svalbard, the 224 MHz monostatic VHF radar in Tromsø, Norway, a tristatic UHF radar at 930 Mhz with transmitter/receiver in Tromsø and receivers in Kiruna, Sweden and Sodankylä, Finland, a high-power HF heating facility in Tromso, as well as 2 dynasondes in Tromso and at Svalbard. Incoherent scatter radar (ISR) is known to be the most versatile ground-based remote sensing method of the upper atmosphere and near-Earth space, being able to measure 4 parameters, electron density, electron temperature, ion temperature and line-of-sight plasma velocity simultaneously. With assumptions, even more parameters can be deduced. Also weak coherent targets, such as meteors and very small space debris can be measured since the ISR is essentially a high-power, large-aperture radar.

Since 2005 EISCAT has coordinated a technical feasibility study of a third generation incoherent scatter radar facility, as an EU framework 6 supported project “EISCAT_3D Design Study”, which ended in April, 2009. The project had 5 participating institutions from 3 countries, EISCAT Scientific Association, Luleå University of Technology, Swedish Institute of Space Physics and Rutherford Appleton Laboratory, technical leader Dr. Gudmund Wannberg, Swedish Institute of Space Physics, Box 812, SE-981 28 Kiruna Email: gudmund.wannberg@irf.se

EISCAT 3D was accepted on the European Roadmap for Research Infrastructures by the European Strategy Forum on Research Infrastructures in December 2008. The proposal to ESFRI was prepared by the Swedish Research Council, and it adds conceptually to the Design Study the concept of having several active sites. Thus one would be able to produce volumetric imaging radar data with full vector field velocity measurement capability in an extended spatial region, thus supporting all the existing well-developed ground based research infrastructure and facilities. This concept will open up a unique European window to atmosphere and geospace in Northern Scandinavian Arctic.

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2. THE EISCAT_3D DESIGN STUDY

The design goal for the EISCAT_3D Design Study was set up during the year 2005, according to a summarized wish list of the user community of the present radars at that time. It appeared that only a multi-static phased array system could reach or approach the performance demanded by users. Accordingly, the target system specified comprises a central active (transmit-receive) site, the core site, and four receive-only sites, located on two approximately 250 km long baselines oriented N-S and E-W respectively.

Figure 2. Geographical layout of the sites in the EISCAT_3D Design Study

The proposed system design incorporates a number of innovative, ground-breaking concepts, e.g.

- Direct-sampling receivers
- Digital time-delay beam-forming
- Multiple simultaneous beams from each receiving array
- Adaptive polarisation matching and Faraday rotation compensation
- Digital arbitrary-waveform transmitter exciter system
- Full interferometry and imaging capabilities
- Amplitude-domain data recording at full sampling rate

During the four-year study, all mission-critical technical concepts were modelled, investigated by simulations, in critical cases also by full-scale tests, and found to be realizable. Array sizes, transmitter power levels and receiver noise performance required to reach the desired time and space resolutions were also established. The target system should have the following technical characteristics:

The core site is proposed to comprise a 230 Mhz transmitter/receiver facility as:

1) a 120-m diameter filled circular aperture array with 16000 elements, laid out on an equilateral triangular grid, and
2) a number (6...9) of smaller outlier receive-only arrays.

It would provide:

- a half-power beamwidth of ≈ 0.75°, i.e. comparable to that of the EISCAT UHF,
- a power-aperture product exceeding 100 GW m², i.e. an order of magnitude greater than that of the EISCAT VHF,
- grating-lobe free pattern out to 40° zenith angle,
- graceful degradation in case of single-point equipment failure.

Each core array element would be made up of a radiator, a dual 300+300 watt linear RF power amplifier, a high performance direct-digitising receiver and support electronics. The recommended radiator is a crossed Yagi antenna with a minimum directivity of about 7 dBi.

Figure 2. The proposed Yagi antenna

Two filled 8000-element receive-only arrays are proposed to be installed on each baseline at distances of respectively ≈ 110 and ≈ 250 km from the core. Their radiating elements would be 3- or 4- element X Yagis, essentially identical to those used in the core. The Yagis are directed towards the core field-of-view and elevated to 45°. Outlier arrays for interferometry should also be installed.

Advanced digital beam-forming systems allow the generation of a large number of simultaneous beams from each array, thus eliminating the time/space ambiguity plaguing present incoherent scatter systems and making true volumetric imaging of vector quantities possible for the first time.

The design study verifies that a system meeting the performance requirements put forth in the EISCAT_3D
performance specification could be built today, using existing technology, if cost were not an issue. Advances in semiconductor technology, signal processing and data storage between now and the time of placing a contract are expected to reduce component and subsystem costs to the point where a full-size core would cost about 60 MEUR and each receive-only site 20 MEUR. As designed, the system would be highly modular lending itself excellently to gradual expansion, if funding should only be forthcoming in instalments. In this case, one could start constructing in the first phase a 5000-element, 70-m diameter core array and at least two, 1500-element receiver sites. Such a configuration would already exceed the performance of the current VHF system, providing a 1.3° half-power beamwidth, a power-aperture product of 10 GW m², and full beam steerability at the transmitter site. Modular construction to a full-scale system could be taken according to funds becoming available.

Figure 3. summarises the technical concept of EISCAT_3D as defined in the Design Study. The beam steering in the antenna arrays is achieved with digital time-delay beam forming in two steps, first a whole sample delay of the signals from the directly sampling receivers and second a fractional sample delay using FIR filters implemented with FPGA technology. When needed, FPGAs can be reconfigured in the field by reprogramming. This would facilitate continuous development of the system when improved algorithms become available.

The data processing and archiving task of the system is non-trivial, especially when interferometric and amplitude domain data is to be archived. The Design Study addresses this by investigating currently available stand-alone central archive solutions. If data connections to the sites were not an issue, distributed systems could also be considered. There are 3 types of archives proposed. A Ring Buffer with a high-volume (~100 TB) short-duration (hours to days) storage records continuous IS data and interferometry data when events are detected. Data accumulate constantly and oldest data is overwritten. Interferometry System is a small storage area (~100 GB), holding only the past few minutes of data. Here data accumulate constantly, and are tested against a threshold. If event is detected, data flow is diverted, otherwise deleted. Permanent archive has a large capacity (~1PB) for mid and high-level data expected to accumulate 200 TB/year. This is a tiered storage, connected to a multi-user computing facility.

Figure 3. Conceptual level block diagram of EISCAT_3D as described in the Design Study in April 2009

Technical details are summarised in the Design Study technical documentation [1], available in public, and not reproduced here. It is worth mentioning that many of the concepts were actually tested in a constructed hardware test facility, called the EISCAT_3D demonstrator array. The array used cheap off-the-shelf Yagi-antennas, in a configuration of 48 elements. This antenna field has too small aperture for a meaningful standard ISR work, but ISR spectra were nevertheless measured using the Tromso VHF transmitter with a fixed phasing of the antennas. Also the whole signal path from antennas to current EISCAT receiver system was demonstrated.

Figure 4. The demonstrator array at the Kiruna EISCAT site, Sweden.

3. THE ESFRI ROADMAP PROJECT

ESFRI, the European Strategy Forum on Research Infrastructures, acts on issues related to the development of high scientific quality European research infrastructures. ESFRI’s delegates are nominated and mandated by the Research Ministers of the Member States and Associated Countries, and include a
representative of the European Commission. The Swedish Research Council proposed EISCAT_3D to be included on the ESFRI Roadmap of large European Research Infrastructures. ESFRI accepted the proposal in December 2008.

The ESFRI proposal was based on the success of the Design Study, but enhances the concept of the Design Study essentially. The ESFRI EISCAT_3D proposal emphasises modular construction of a large distributed radar facility, with a possibility to have several active sites in the final concept.

In fact, the sites in such a collection of new generation radar transmitters and receivers need not to be similar or same scale, they can be very different once the data can be processed to products suitable for different applications. Modular construction would allow a part or whole of the facility to be constructed, according to funds available.

Figure 6. Possibility of a collection of active (green) and passive (red) sites to support existing research infrastructure for different purposes in whole Northern Scandinavia, including Kola Peninsula.

Such a distributed phased-array radar facility would be able to produce volumetric imaging radar data with full vector field velocity measurement capability in an extended spatial region. In Northern Scandinavia EISCAT_3 would form a unique combination with all the existing well-developed research infrastructure, including the rocket ranges at Esrange, Sweden and at Andoya, Norway, the current high-power Heating Facility in Tromso operated by EISCAT, the extended optical network for auroral research, lidars, spectrometers, and interferometers, the several other radar facilities, networks of magnetometers and pulsation magnetometers, riometers and the imaging riometer IRIS, satellite tomography and GPS satellite receivers. This concept will open up a fascinating research opportunity: European window to atmosphere and geospace in Northern Scandinavian Arctic.

The timeline and rough cost estimate proposed for the ESFRI EISCAT_3D is given below:

**Timeline:**
- Preparatory phase: 2009-2011
- Operation: 2015-2045

**Estimated costs:**
- Preparation: 6 M€
- Construction: 60 M€ one active site
  250 M€ all sites
- Operation: 4-10 M€/year
- Decommissioning: 10-15%

4. CONCLUSIONS

The extremely large-scale atmospheric and space environment radar arrays open up unprecedented science opportunities, well beyond the traditional ground-based ionospheric remote sensing role of the old incoherent scatter radars. Locations of the sites will be selected to support the combination of sounding rocket and ground based radar observations. Science applications include continuous measurements of the space environment - atmosphere coupling at the statistical southern edges of the polar vortex and the auroral oval. Studies of space weather, plasma physics, atmospheric structure, chemistry and dynamics, couplings between lower, middle and upper atmosphere, meteoroids, dust particles and near-Earth objects will benefit of the higher power and resolution than available today, but specially of the volumetric imaging and built-in interferometry capability as well as of the continuous measurement opportunity. The basic scientific purpose of the facilities will be complemented by service-type operation modes to support space debris and orbit detection, as well as by navigation application support with continuous direct ionospheric 3D imaging and geomagnetic disturbance detection service.

5. REFERENCES