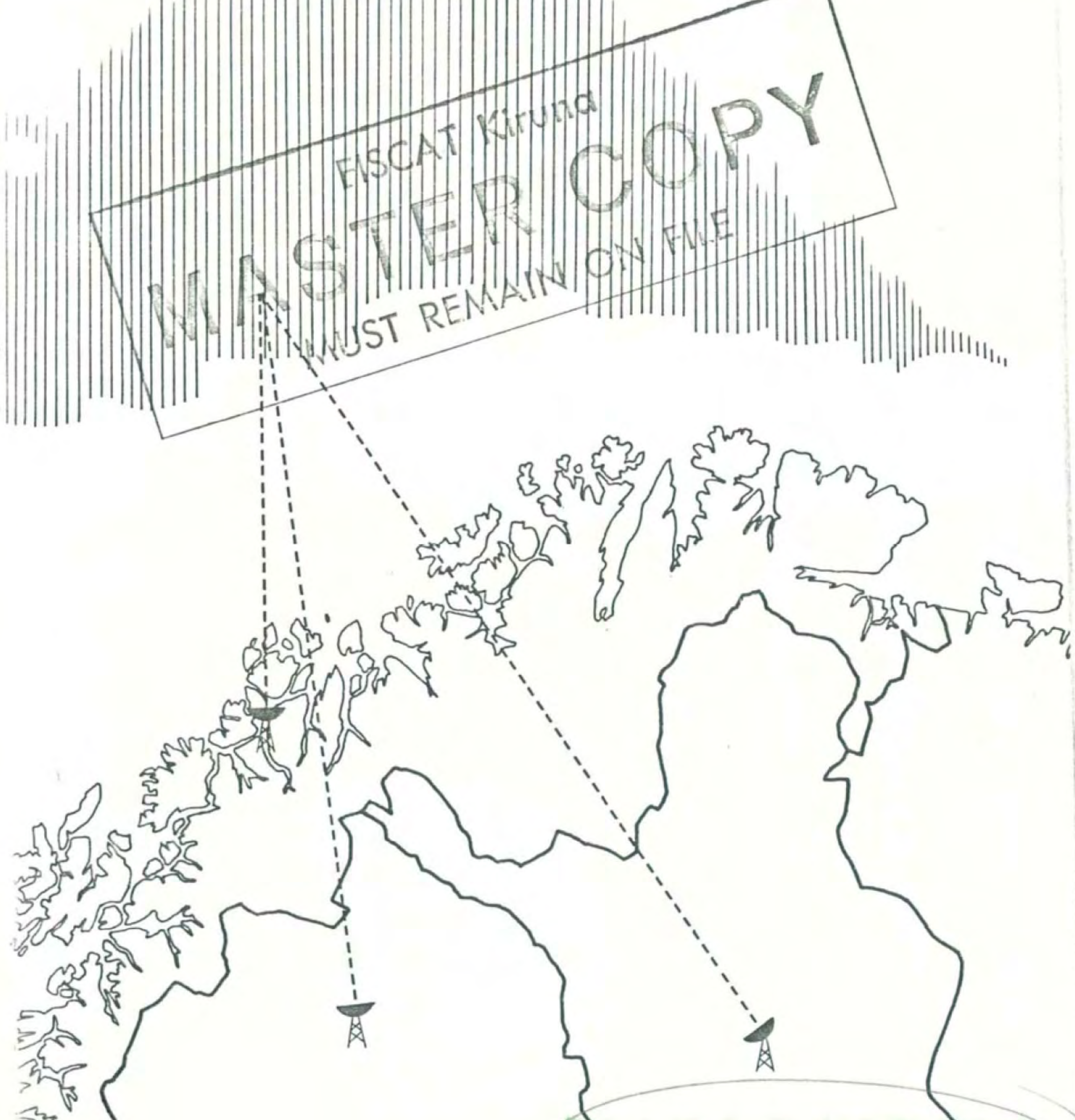
A European incoherent scatter facility in the auroral zone



A FEASIBILITY STUDY

Proposal for

A EUROPEAN INCOHERENT SCATTER FACILITY IN THE AURORAL ZONE (EISCAT)

Presented by

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June 1971

Published by the Auroral Observatory, Tromsø, Norway.

Printed by Nordoffset, Tromsø, Norway.

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FOREWORD

The proposal presented in this report is the result of five meetings; Stockholm, September 1970, Nancay, October 1970, Tromsø, March 1971, Helsinki, May 1971 and Titisee, June 1971 and of numerous discussions and feasibility studies carried out in Finland, France, Germany, Norway and Sweden. We have also drawn on the experience and advice of incoherent scatter workers from USA and Great Britain, particularly Dr. T. Hagfors, MIT, Lincoln Laboratory, Lexington, Mass., who has been the main writer for sections 4.3, 4.5 and 4.9 of this report and has also contributed Reference Reports Nos. 7, 10 and part of No. 2, and Dr. G.N. Taylor, RRE, Malvern, who has assisted in drafting large portions of the main report and has edited, and partly written, Reference Report No. 2.

A number of other consultants have assisted in carying out feasibility studies. These are included in the following reference reports:

Dr. A. Egeland, Oslo, Reference Report No. 1.
Dr. G. Svennerus, Stockholm, Reference Report No. 6.
Allmänna Ingenjörsbyrån AB, Stockholm and Umeå (Mr. G. Sørensson), Reference Report No. 11.
Thomson - CSF, Division R.S., Bagneux (Mr. B. Daveau), under CNET contract, Reference Reports Nos. 3,4.

(For a complete list of Reference Reports see Appendix 2).

Important contributions have also been provided by the following members of interested scientific groups in Finland, France, Germany, Norway and Sweden:

R. Armstrong, Auroral Observatory, Tromsø
P. Bauer, CNET, Issy-les-Moulineaux
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G. Haerendel, MPI für Extraterrestrische Physik, Garching
R. Lindquist, Research Institute for National Defence, Stockholm
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To all contributors we express our sincere thanks.

Titisee, 18 June 1971

F. du Castel
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RESOLUTION

The undersigned representatives for research organizations in Finland, France, Germany, Norway and Sweden
having considered

- the great scientific interest of exploiting the incoherent scatter technique in auroral zone and polar cap conditions (see Chapters 2 and 3),

- that no incoherent scatter installation of this kind exists or is planned elsewhere at these latitudes,

- that the three observatories at Tromsø, Sodankylä and Kiruna are well located to accommodate and operate the three stations which will constitute the incoherent scatter facility,

- that the cooperative efforts of the scientific communities of several European countries are necessary to ensure the optimum scientific usage of such a facility,

- that the investments needed to achieve the scientific objectives satisfactorily are about 10 MAU and are thus prohibitively high for any single European country or for the Scandinavian countries together.

propose

- that European scientific groups cooperate to establish a European Incoherent Scatter Facility in the auroral zone (EISCAT),

- that the facility shall have a transmitter station in the Tromsø area and receiver stations near Sodankylä and Kiruna,

- that the most important parameters of the facility shall have the following values:

Frequencies around	958 MHz and 240 MHz
Transmitter peak pulse power	5 MW(UHF) and 5 MW(VHF)
Pulse lengths	10 μsec to 10 msec
Transmitting antennae	50 m fixed parabola (UHF) 100 x 100 m^2 steerable array antenna (VHF)
Receiving antennae (UHF)	25 m steerable parabola at Kiruna 30 m steerable parabola at Sodankylä

- that the capital and running costs be distributed between the participating countries, Finland, France, Germany, Norway and Sweden in the manner shown on the accompanying table.

- that member organizations of EISCAT shall be national agencies such as research councils and/or national research institutes,

- that the governing body of EISCAT shall be a Council which will have overall responsibility for the facility, scientifically and technically as well as for finance and administration and be composed of 2 members from Finland, 4 from France, 2 from Germany, 2 from Norway and 2 from Sweden, nominated by the respective member organizations,

- that the prospective member organizations shall negotiate a formal Agreement,

- that facility shall be operational in time for the International Magnetospheric Study (1975 - 1977).

	Capital cost, MAU		Running costs, MAU		Sum capital and runnings costs over 10 years, MAU
	First stage	Second stage	per year	in 10 years	
Finland	Finnish receiver station 0,5	1/3 of VHF antenna 0,2	0,06	0,6	1,3
France	UHF transmitter 3,6	-	0,04	0,4	4,0
Germany	UHF antennae 1,8	-	0,04	0,4	2,2
Norway	Transmitter station 0,9	Extension of station 0,2	0,08	0,8	1,9
Sweden	Swedish receiver station 0,7	2/3 of VHF antenna 0,4	0,10	1,0	2,1
Possible other sources		VHF transmitter 1,2	0,08	0,8	2,0
TOTALS	7,5	2,0	0,40	4,0	13,5

MAU = Million Accounting Units

The accuracy of the Totals is estimated to be ± 10 %.

DISTRIBUTION OF CAPITAL AND RUNNING COSTS

1 INTRODUCTION

1.1 INCOHERENT SCATTER MEASUREMENTS IN THE AURORAL ZONE

This report presents a proposal for a new international project, an auroral zone incoherent scatter radar situated in Northern Scandinavia. This radar will study the upper atmosphere from the ground, by means of the relatively new and very powerful technique of ionospheric incoherent scatter (sometimes known as Thomson scatter). The proposed equipment will be the only one of its kind in the world in either auroral region, and is expected to produce new and uniquely important measurements of upper atmospheric and auroral phenomena. It will give the scientists of the participating countries an opportunity of working t the very forefront of research in this field for at least a decade.

Studies of the upper atmosphere are important from several points of view. Measurements leading to elucidation of the basic physics of this region give an understanding of its structure and dynamics, and hence an understanding of the way it interacts with the lower atmosphere, and of the way it is acted upon by extraterrestrial influences; many plasma processes can be observed that ould be difficult or impossible to reproduce in the laboratory. Upper atmospher-ic science thus contributes basic knowledge at the same time to meteorology, astronomy and plasma physics. Advances in knowledge of the upper atmosphere can also be expected to affect several applied sciences, for example weather forecasting, through better understanding of global atmospheric circulation and energy balance; thermonuclear fusion research, through the opportunity of studying the behaviour of both trapped and non-trapped natural plasmas, and their interaction with the ambient neutral gas; radio propagation, through better forecasting of the occurrence and effects of Solar disturbances and more effective use of available propagation paths. The latter is particularly important for the improvement of long distance communications and navigational systems at high latitudes.

What then is the special importance of the auroral region to upper atmosphere physics ? The answer to this question lies in the fact that this region is near the boundary between the open and closed field lines of the earth's magnetosphere. The polar cap region north of the boundary is open to bombardment by energetic particles and to other disturbances originating from the Sun or from the magneto-tail. The ionosphere in the polar cap, and especially in the auroral region, is thus highly disturbed, and this can sometimes produce big effects in the ionosphere and netural atmosphere at lower latitudes, through the generation of internal gravity waves and abnormal neutral air winds. As an indication of the relative importance of high latitude effects, the energy dissipated as heat in the auroral regions can sometimes be as large as that generated by Solar XUV radiation over all the rest of the earth.

Techniques for making measurements in the upper atmosphere divide broadly into two categories: (1) ground-based methods, involving the observation of electro-magnetic waves emitted from or interacting with the atmosphere, (2) direct sampling methods, involving the use of instruments carried on spacecraft, sounding rockets or balloons. Ground-based techniques give measurements as functions mainly of time and altitude at fixed stations, and usually give very little information about horizontal variations. Instruments on satellites make measurements as functions mainly of horizontal position, and changes with altitude and time can only be obtained by averaging data taken over long periods. In order to get a complete picture of how any parameter varies in both space and time it is thus necessary to use both ground-based and satellite techniques. Sounding rockets are important for getting very detailed information difficult to obtain by other methods, but are too inconvenient and expensive for use in long term synoptic measurements.

The incoherent scatter technique, first suggested by Gordon (1958) and experimentally verified by Bowles (1958) is able to measure more parameters over a greater range of altitudes than any other ground-based technique, typically between 85 and more than 1000 km. It depends on the scattering of VHF or UHF radio waves by random thermally induced irregularities of electron density in the ionosphere. As well as the electron density itself, the temperature of the electrons and positive ions in the plasma can be measured separately, from the shape and degree of thermal doppler broadening of the frequency spectrum of the scattered signal, and, most important, the line-of-sight velocity of the plasma can be determined from the doppler shift of the centre of the spectrum. While these fundamental measurements relate only to the ionised component of the atmosphere, many other quantities can be deduced, such as the temperature, composition and wind speed of the neutral gas. Furthermore, measurements can be made in conditions which defeat other methods, for example electron density profiles can easily be obtained in the presence of blanketing sporadic-E layers or high HF absorption, which hamper ionosonde operation. Incoherent scatter is unique in its ability to measure plasma winds, and also in obtaining routine temperature and composition data for the important altitude range between 100 and 200 km, which is below the perigee height of most satellites.

The equivalent scattering cross section of all the electrons in a typical sampled volume of the ionosphere at 300 km altitude is $\gtrsim 10^{-4}\ m^2$, which is about the size of a small coin, and so it is clear that a very sensitive radar system is needed for this work. Typical peak transmitter powers of several megawatts and antenna diameters of several tens of metres, together with a very low noise receiver, are required. The data rate at the receiver output is very large, and special high speed on-line signal processing equipment is needed, together with a large off-line computer for extracting the required parameters for the pre-processed data. Indeed, most components of the system should have as near as possible 'state-of-the-art' performance, and thus interesting and challenging tasks are available for the contractors who undertake the design and constructional work. While the total capital cost of the system is much larger than is usual with ground-based equipment for upper atmosphere research, it should be realised that it is no greater than the cost of a single typical scientific satellite, excluding the launching vehicle. Moreover, the value for money is arguably much better for most satellites, as malfunctions and deterioriation of equipment performance can be corrected; thus a system, once built, can be run intensively for an indefinite period of time, during which it will produce a very large quantity of important scientific results, as well as contributing to the training of graduate scientists.

It is thought that many unknown phenomena occur in the atmosphere above the auroral zones and the polar cap (see Chapter 3), and so, the establishment of an auroral incoherent scatter station has been strongly recommended in a resolution of URSI, Ottawa 1969 (see Appendix 1). Northern Europe is in many respects an ideal location for such a facility, as its climate is relatively mild, and it is not too remote from populated areas. In addition, there are already several well-established and active geophysical observatories there. With this in mind, a group of scientists from Finland, Norway and Sweden made a preliminary proposal in 1969 for building a new incoherent scatter facility in the area. A related resolution of the same URSI General Assembly endorsed an earlier French proposal for a mobile incoherent scatter facility, (Waldteufel, 1968) intended for successive use at several locations of scientific interest, and set up a Working Group to study it. The present proposal subsumes the original Scandinavian and French projects, and includes contributions from German scientists, who have recently acceded to the joint project. The groups from the five European countries now actively involved have been able to draw on the experience and advice of incoherent scatter workers from the USA and Great Britain, as well as those in France. This report is the result of several meetings, discussions and feasibility studies carried out in these various countries.

1.2 THE PROPOSED INCOHERENT SCATTER SYSTEM

The proposed European Incoherent Scatter facility (referred to in the report as EISCAT), consists of two radar systems: a tristatic UHF radar operating on a frequency near 960 MHz, and a monostatic radar operating at about 240 MHz. The tristatic system is necessary in order to utilize the advantages of the incoherent scatter technique for studying the dynamics of the upper atmosphere, making it possible to measure three independent velocity components of the moving plasma. The three existing geophysical observatories close to the auroral zone in Scandinavia - Tromsø in Norway, Kiruna in Sweden and Sodankylä in Finland - are fortunately situated such that they are suitable locations for the three stations. This will minimize the costs, and ease the operation of the system. It is proposed that the UHF transmitter and the complete VHF radar should be situated in Tromsø, and the UHF receiving stations at Tromsø, Kiruna and Sodankylä. Putting the transmitting station at Tromsø places the line of sight of the radars almost at the northern edge of the auroral oval; on some occasions, when the oval has expanded, it should even be possible to see the polar cap regions north of the auroral oval. The station will also be near the field lines which will be covered by satellites in geostationary orbit, and particularly by the planned European magnetospheric satellite GEOS. It would be technically possible to site the transmitters at Kiruna instead of Tromsø (with receiving stations at Tromsø and Sodankylä), but this arrangement is not so advantageous scientifically for studying both auroral and polar cap phenomena. Two radar systems operating on a high and a low frequency are necessary in order to study the various parameters over the whole altitude range of interest.

The main characteristics of the incoherent scatter radars are:

	UHF	VHF
Frequency	958 MHz	240 MHz
Transmitter power	5 MW peak) 150 kW mean)	5 MW peak) 150 kW mean)
Modulation	10 μs - 10 ms pulsed	10 μs - 10 ms pulsed
Transmitting antenna	50 m paraboloid	100 x 100 m^2 steerable array
Receiving antennae:		
Kiruna	25 m steerable paraboloid	
Sodankylä	30 m " "	

1.3 COOPERATIVE ASPECTS OF THE PROJECT

The building of an incoherent scatter radar is a major undertaking, and most equipments up till now have been built either with radio-astronomical support or with some components designed originally for other purposes. In this case we intend to build a radar for auroral research only. The aurora is such a complex and fundamental phenomenon that it demands a more complicated system than has been built hitherto, and we believe will not allow sharing with another discipline. We are fortunate that the three Scandinavian countries, Sweden, Norway and Finland, lie close to the auroral zone, and that there are in fact convenient sites in each country fulfilling the requirements for an incoherent scatter radar system.

However, such a system will be expensive, and its cost is unlikely to be covered by the research funds available from any single European country, or even from the combined resources of the three Northern countries. Thus we in Europe are fortunate in that there is an advanced incoherent scatter equipment already working in France and that France and Germany, each having a long term interest in high latitude research, are both willing to share their expertise in establishing this cooperative facility. It is particularly fortunate that the requirements of the proposed multistatic system are such that each Scandinavian country can have a receiving station and a large antenna on its own soil.

Upper atmosphere research activity is already well established in the area of the proposed facility; in particular, Kiruna Geophysical Observatory is a constituent part of the Swedish Academy of Science and of the University of Umeå; Tromsø has its own University, founded in 1969 and now in active development, besides the well established Auroral Observatory; Sodankylä is an active and expanding geophysical centre. It must not be lost sight of that these northern areas are not as affluent as the southern regions of their respective countries, and the construction of a facility such as we propose here will be of considerable importance in stimulating industrial and educational activity.

The opportunities for fruitful scientific collaboration involving EISCAT are excellent. As well as the upper atmosphere research centres at Kiruna, Tromsø and Sodankylä the sounding rocket ranges at Kiruna and Andøya lie very close to the observational sites, a circumstance which should allow cooperative work with any of the scientists who use these ranges. In particular, the apogee of many rockets fired from Kiruna range will lie only about 100 km distant horizontally from Tromsø. Rockets launched from Andøya enter the D and E regions of the ionosphere at about 120 km distant horizontally from Tromsø. The fact that the transmitter site will lie on almost the same L-shell as the forthcoming European satellite GEOS, or as any other geostationary satellite near this longitude, has already been mentioned: this circumstance will allow unique opportunities of making simultaneous measurements as functions of time at two widely spaced fixed points on nearly the same geomagnetic field line. EISCAT will also be strategically placed for participating in the International Magnetospheric Study (IMS) 1975-1977, being situated near the earthwards boundary between open and closed magnetic field lines. The influence of EISCAT should also be felt in the work of the existing network of ground-based geophysical stations in Europe, which cover the latitude range from about 70° N to 35° N, and to which it will be a very significant addition. Previously, it has been possible to observe the development of disturbances travelling South from the auroral region: now it will also be possible to get uniquely detailed information about their origin.

It is becoming increasingly true in all branches of experimental science that the important advances are being made by teams, and not by individual workers. This is certainly true of incoherent scatter measurements, for which the co-operation of experts in several disciplines is essential. It is thus important that EISCAT will be organized in such a way as to make it easy for teams of scientists from more than one country to operate the equipment and to work on the results. Thus it offers the opportunity of getting the maximum scientific output, and in particular of stimulating interaction between experimental and theoretical research in the upper atmospheric sciences, whose practitioners are well represented in the participating European countries.

1.4 EDUCATIONAL AND TECHNICAL ADVANTAGES FOR THE PARTICIPATING COUNTRIES

A project of this sort will bring much added benefit to the study of the physical and engineering sciences from the lowest technical level to the postgraduate university level for all participating countries. In the fabrication of the equipment there will be scope for industrial activity of useful and advanced types, and this activity can be spread, we believe over all the countries involved in the study. Furthermore, for the Scandinavian countries, this project will occur in the region where development and activity of this sort has lagged behind the more affluent southern parts of the countries concerned. An Incoherent Scatter Installation will meet the need of facilities for advanced graduate training and research in physics and electrical engineering, which, in particular, the new northern universities in all three countries are short of.

In the past it could be argued with some justice that much research activity was oriented and carried out in a way which bore little relation and offered little training for the more applied work of everyday life. Today this can probably be dismissed as inaccurate particularly for a project of this sort: the electrical high frequency applied interests are now very large indeed and enter many different industries. In addition, computer data handling which is such an important aspect of the project, is now widespread and rapidly becoming more and more developed in the business and industrial world.

1.5 COMPARISON WITH OTHER HIGH LATITUDE RADARS

It is appropriate to conclude this introduction with some brief remarks about other high latitude incoherent scatter radars, existing or planned. The earliest of these was the one at Prince Albert, Canada. This site has a Mc Ilwain shell parameter L (Mc Ilwain, 1961) equal to 4.7. This was not designed primarily for incoherent scatter work, though it gave some useful results. Unfortunately it ceased working in 1967. Another radar is about to come into use at College, Alaska ($L = 5.4$) as a joint project of Stanford Research Institute and the Geophysical Institute, University of Alaska. This system will operate at 1300 MHz and be monostatic, with a 27 m steerable antenna and a peak transmitted power of 5 MW. A new incoherent scatter system is also being planned as a joint US/Canadian project; this will be situated in the Northeastern US, at a location where $L \approx 4$. This project so far exists only as a proposal; but it is known that the radar is intended to be multistatic, to have a fully steerable antenna, and to work at a frequency near 400 MHz. It can safely be assumed that the antenna dimensions and transmitted power will be at least as large as those proposed for the EISCAT system. (National Academy of Sciences, 1971; University of Illinois, 1971).

Of these three radars, the Prince Albert and $L = 4$ systems are in no way to be compared with EISCAT, as their locations are some distance south of the true auroral region. The L-value at College is the same as at Kiruna, so that system is perhaps competitive with EISCAT. However, the capabilities of the Stanford radar at College are much more limited than those of the proposed EISCAT facility, which latter will also lie significantly further north ($L = 6.3$), and will have opportunities of sometimes looking along open field lines, a circumstance that will arise only rarely at College (or at Kiruna). Moreover, the two independent systems included in the EISCAT scheme will allow much greater flexibility of operation, and much more complete information, especially about the plasma velocities. Thus we feel that the statement made at the opening of this Introduction, about the uniqueness of the measurements to be made with the EISCAT facility, is well justified.

2 THE INCOHERENT SCATTER TECHNIQUE

2.1 GENERAL CONSIDERATIONS

The incoherent scatter technique for the observation of ionospheric quantities of physical interest is based on the theory of thermal density fluctuations in a plasma. A very simplified picture of the fundamental processes at work may be had from the following description: The ions and the electrons of a fully ionized plasma where two-body collisions are unimportant to first order travel as if completely free and non-interacting. The first order correction to this motion can be obtained by considering an individual particle to still be travelling along on an unperturbed path, but to be surrounded by a cloud slightly depleted in particles of like sign and by a cloud slightly enriched in particles of the opposite sign. In a plasma consisting of electrons and one type of positive ions the electron density fluctuation can be thought of as consisting of three contributions, one contribution is caused by the density fluctuation associated with the fact that the electron is a point particle in space. A second contribution is one associated with the cloud surrounding the electron of an electron density depletions. Note that when looked upon on a reasonably large scale, as compared with the cloud size, the two contributions to the electron density fluctuation mentioned so far counteract each other. A third contribution is associated with the electron cloud surrounding an ion. There will be no intrinsic counterpart to counteract this contribution and this will be the important part of the fluctuation in electron density at least in the low frequency region of the fluctuation spectrum.

The original proposal for investigating the scattering did not realize how dominant a part the ionic interaction with the electrons plays. In fact, incoherent scattering from individual electrons (Thomson scattering) has only been observed in the laboratory.

The ionospheric plasma can support wave motions and then the probability of scattering is much increased. Wave motions are not possible with single electrons, and it is the presence of ions which leads to the partial coherence responsible for the ionic spectrum and the plasma line. The wave motions involved are ion acoustic waves and plasma oscillations, respectively. Furthermore should other wave motions be induced in the plasma, eg. by instabilities known to occur in auroral regions, then further scattering at possibly other frequency offsets to the transmitted frequency can be expected.

In the following sections of this chapter we discuss in greater detail the quantitative aspects of an incoherent scatter system with particular emphasis on the ionic spectrum and the plasma line. We discuss also the geometries of the monostatic and the bistatic systems and the signal to noise ratios which may be encountered in practice are given.

2.1.1 The scattered signal

The Thomson scattering cross section for electrons, is given by $\sigma_0 = r_e^2 \sin^2\chi$ where r_e is the electron radius ($2{,}82 \times 10^{-15}$m) and χ is the angle between the electric field vector of the incident wave and the direction of scattering.

When $\alpha = 2\pi\,\lambda_D/\Lambda < 1$ the scattered spectrum separates into a central part (referred to as the ionic spectrum) and lateral lines (electronic spectrum) (Evans, 1969). λ_D is the Debye length and Λ is the wavelength of the thermal density fluctuations responsible for the scattering and is related to the radar wavelength, λ, through $\lambda = 2\Lambda\cos(\beta/2)$, where β is the angle between the direction of the incident wave and the scattering direction. The bandwidth of the ionic spectrum is determined by the thermal motion of the ions and the consequent Doppler frequency shift. The half power bandwidth of the ionic spectrum we shall call b_i. It is equal to $4\,(2kT_i/m_i)^{\frac{1}{2}}/\Lambda$ where k is Boltzmann's constant and m_i and T_i are the ion mass and temperature; being determined by the Doppler effect. When the ion-neutral mean free path becomes of the order of the radio wavelength then the bandwidth is decreased and is taken to be $0.5b_i$ at 90 km altitude in the following quantitative work.

The scattering cross section is now found to be (Bunemann, 1962)

$$\sigma_o\left(\frac{1}{1+\alpha^2+(T_e/T_i)}+\alpha^2\right)\frac{1}{(1+\alpha^2)}$$

The electronic component of the spectrum consists of two lines separated from the transmitted frequency by $\Delta f = \pm f_N(1+3\alpha^2)^{\frac{1}{2}}$ where f_N is the plasma frequency. The plasma lines, as they are termed, are enhanced when the distribution of electron energies has more electrons at higher energies than corresponds to a Maxwellian distribution. The energy of electrons causing a plasma line at a frequency offset of Δf is given by

$0.7\,(\Delta f\cdot\lambda)^2$ in e.V. if Δf in MHz and λ in m and is

the radio wavelength. Landau damping and electron-ion collisions impose limits on the possible range of Δf.

2.1.2 Incoherent scatter systems

Two geometries are of interest in the present content: viz back scatter (monostatic) and lateral scatter (bistatic). A monostatic system necessitates pulse operation, and the size of the scattering volume V and its extension in the direction of the radar beam are determined by the pulse length. In a bistatic system however, the intersection of the main lobes of the transmitter and receiver antennae can determine the scattering volume, and pulse operation is not demanded for reasons of geometry alone.

At a distance d_T from the transmitter the power density is given by

$$\frac{a\,G_T P}{4\pi\,d_T^{\,2}}$$

Here P is the transmitter power, a is a correction for feeder losses and G_T is the transmitter antenna gain. The scattered power from a volume element dV, where the electron density is N_e, can be written as

$$a_T\cdot\frac{G_T\ P}{4\pi\,d_T^{\,2}}\ \sigma N_e\,dV$$

and the power received by the receiver antenna (which may be the same as that of the transmitter), as

$$dP_S = a_T\,\frac{G_T\ P}{4\pi\,d_T^{\,2}}\quad \sigma N_e\,dV\,a_R\,\frac{G_R\,\lambda^2}{4\pi\,d_r^{\,2}}$$

Integrating over the scattering volume, one obtains the general result for the power at the receiver P_S as

$$P_S = a_T \frac{a_R P \sigma N_e}{(4\pi)^2} \cdot \int_V \frac{G_T \; G_R}{d_r^2 \; d_T^2} \, dV$$

This formula is applicable to both the bistatic and monostatic systems.

The noise power P_n is given by

$$P_n = k\,T\,b$$

where k is Boltzmann's constant, T the system temperature and b the receiver bandwidth.

2.1.3 System sensitivity

The relative uncertainty in power is $\delta P_S/P_S$ where P_S is the power at the receiver and δP_S the RMS error. It can be shown that this quantity for CW and single pulse conditions is given by

$$\left[(1 + 2/R + 2/R^2)/bt\right]^{\frac{1}{2}} \qquad \text{(CW)}$$

$$\left[(1 + 2/R + 1/R^2)/b\,nt\tau\right]^{\frac{1}{2}} \qquad \text{(single pulse)}$$

where R is the signal to noise ratio at the receiver, b is the receiver bandwidth, t the integration time, τ the pulse length and n the repetition rate. In the limiting case of a small signal to noise ratio this gives an advantage in sensitivity for the pulse system of $(n\tau/2)^{\frac{1}{2}}$.

However, this result is only a first approximation; equal transmitted powers and filter bank spectral analysis have been assumed.

We turn now to the more complex case of double-pulse modulation. We consider a very simple model situation where the correlation function is calculated from two pulse signals of duration τ successively delayed by t_o, $2t_o$ ..... , pt_o.

Under reasonable conditions the error in the correlation function is

$$\delta\rho \sim \frac{k_2}{R} \; \frac{1}{\sqrt{nt}}$$

where k_2 has a value close to unity and depends on the value of ρ and the modulation used. (Farley, 1969 b). As discussed by Farley (1969 a) the two pulses should have orthogonal polarisations for optimum signal to noise ratio.

It is now necessary to consider how the errors we have discussed carry over into the determination of electron density and temperature (T_e and T_i). If the ion composition is known, Petit (1967) has shown that percentage errors on power received and electron density are about equal but that temperature errors are about twice as great. The double pulse method leads to approximately equal correlation function and temperature errors while electron density errors are about one half as large.

In all cases, if the ionic composition is unknown, the errors must be multiplied by about 2 or 3. Banks (1967) has suggested that there may be on some occasions different ionic temperatures. This will further increase the error.

The error on the determination of the plasma drift velocity may be written in the bistatic and monostatic (single pulse) cases as

$$\delta v = \frac{\Lambda}{2} \left(1 + \frac{2}{R}\right) \sqrt{\left(\frac{b_i}{2nt}\right)}$$

b_i is the bandwidth of the ionic spectrum as defined before and the other symbols have unaltered meanings.

For the double pulse method the error in the plasma velocity is given by

$$\delta v = \frac{1}{\sqrt{2nt}} \quad \frac{\Lambda}{4\pi} \quad \frac{\sqrt{1 - S^2}}{S t_1}$$

where S is the ratio of the correlated receiver power in the two pulses to the total power, and t_1 is the time delay between the pulses.

Further $S = \frac{\rho(t_1)}{a + R}$ where a = 1 for orthogonal polarisations and equals 2 for similar polarisation, (University of Illinois, 1971). Minimum δv is found to occur at $\rho(t_1) \sim 0.5$.

2.2 DEDUCED QUANTITIES AND COMPARISON WITH OTHER METHODS

By means of the incoherent scatter radar (hereafter written ISR) technique, several parameters of an ionised medium can be measured simultaneously. In addition, other parameters such as neutral temperature, density, drift velocity, electric field, and soft electron fluxes, can be deduced indirectly. These quantities are listed in Table 2.2.1. In this respect the ISR technique is much more powerful than any other ground-based technique. Again, a satellite gives in general horizontal coverage along its trajectory while ISR observations provide measurements at a given location, complementing in a most valuable manner satellite measurements.

In 2.2.1 to 2.2.5 the different parameters obtainable are considered in turn and their determination compared with other techniques available.

2.2.1 Electron concentration

In the altitude range 85 to 2000 km, the incoherent scatter technique is the only way of measuring continuously the electron density below and above the electron density maximum.

The determination of the electron concentration from the scattered signal may be obtained in various ways. The power of the ionic part of the returned signal gives only a relative measurement of this electron concentration. The observation of the electronic part of the signal (plasma lines) allows an absolute measurement of the electron density; however, it is possible only in a limited height range. Absolute determination of the electron density is also possible using the observation of the Faraday effect which can be used only for low frequency systems. Both the plasma line and the Faraday observations may serve as a continuous calibration of the power profile measurements.

Table 2.2.1 Parameters measurable by an ISR facility

Electron density	N_e
Electron temperature	T_e
Ion temperature	T_i
Ionic mass composition	
Neutral temperature	
Neutral density	
Plasma drift velocity	
Electric field	
Soft electron precipitation	
Ion neutral collision frequency	ν_{in}
Electron neutral collision frequency	

In the D region, below 100 km, the partial reflection technique becomes competitive with incoherent scatter technique since it can measure extremely low electron densities. But provided the electron density exceeds about 10^9 m^{-3} there is no doubt that the ISR technique is good above 85 km.

2.2.2 Temperatures

The incoherent scatter technique is the only ground based technique giving measurements of both the electron and ion temperatures. Langmuir probe measurements on rockets or satellites performed so far often produce erroneous results. For ionic temperatures, in situ measurements using retarding potential analysers are very difficult to interpret because the space vehicle velocity is of the same order as the ion thermal velocity.

Neutral temperature (and density) can be deduced from measurements of N_e, T_e and T_i as obtained from the ionic spectrum. In the upper thermosphere - for example between 200 and 400 km - to a first approximation the electrons heat the ions, which, in turn, give their energy to the neutral particles. The heat transfer of electrons to ions is therefore equal to the heat transfer from ions to neutrals.

The neutral temperature T_n may also in special circumstances be obtained from ground based or satellite measurements of the spectral width of some naturally excited optical lines (630 nm or 557.7 nm). The agreement of the results is quite satisfactory. The neutral density deduced from incoherent scatter measurements has also been compared with values obtained from satellite drag data. The agreement here is in general acceptable but there are serious discrepancies.

2.2.3 Composition

The determination of the ionic composition using the ionic spectrum is a difficult problem. At low altitudes, where O_2^+, NO^+ and O^+ ions are dominant, only the relative proportion of atomic and molecular ions can be obtained. In the exosphere, $He^+$and $H^+$are also of importance. It is difficult to distinguish between the two lighter ions. Nevertheless the transition altitude between O^+ predominance and light ion predominance is deducible. Although incomplete in this regard the incoherent scatter technique is the only ground based method which enables any quantitative determination of ion composition in the ionosphere.

The composition of the neutral atmosphere cannot be obtained directly by the incoherent scatter technique. In the lower E region, the ionic spectrum is narrowed because of ion neutral collisions. The ion neutral collision frequency, ν_{in}, deduced from this observed spectral contraction is related to the concentration of the atmospheric neutral constituents by the equation:

$$\nu_{in} = 9 \cdot 10^{-6} \left[N_{N_2} + N_{O_2} + N_O\right]$$

These determinations and considerations involving the production and recombination processes in the ionospheric F_1 and F_2 layers, yield information concerning the diurnal and seasonal variation of various atmospheric constituents. Much more precise measurements may be obtained from in situ mass spectrometry observations. However, it is found in general that these measurements must be calibrated; moreover monitoring (continuous observation) of the upper atmosphere is not practicable using vehicle borne instruments.

Finally, the electron neutral collision frequency may be obtained below 100 km using incoherent scatter observations through heating of the medium by interaction experiments.

2.2.4 Movements

Ionization movements along the bisector of the incident and scattering directions can be deduced from the small frequency shift of the measured ionic spectrum.

There are some other techniques which provide information on the movements of ionization or of the neutral atmosphere. Optical observations of artificial clouds released from rockets (sodium or trimethyl-aluminium) can give the neutral wind velocity between 80 and 200 km; this method, however, is limited to a very short period at twilight. Optical observations of the Doppler effect from naturally emitted lines (630 and 557.7 nm) have also been used to deduce neutral winds. This method is useful only during particularly favourable periods. Radio observation of meteoric trails gives a measurement of winds in the range 75 to 110 km. The "fading method" which has been extensively used over the last twenty years appears to be very difficult to interpret.

Techniques for measuring electric fields using rockets and satellites have also been developed. They all suffer,of course , from the temporal and spatial limitations of rockets and satellites, compounded in the case of measurements close to the travelling vehicle by shock and plasma sheath difficulties.

2.2.5 Soft electrons

Electrons with energy in the range 1 to 100 eV can be detected from analysis of the electronic component of the spectrum (plasma lines). These electrons would be present in the ionosphere as photoelectrons or as secondary auroral electrons at high latitude. Using an incoherent scatter facility with one frequency it is only possible to observe the flux corresponding to one particular energy, the value of which depends on the local plasma density; the energy distribution of these electrons is therefore not measurable with such a facility.

Electron fluxes with energy in the range mentioned above can also be detected by electron traps on space vehicles. Ground based observation of the 630 nm line of atomic oxygen emitted in the F-layer has also been used to obtain some information on the precipitation of such electrons, but the interpretation of the measurements is difficult.

In the auroral zone optical auroral observations permit indirectly the detection only of the primary particles responsible for auroral events. These observations are clearly very complementary to those made with an incoherent scatter system.

2.2.6 Conclusions

The potential of the incoherent scatter technique appears then very great because of the possibility of simultaneous measurement of a number of upper atmospheric parameters. The added benefit of complementary measurements available on the site or close by, is stressed (see section 4.10).

2.3 IONOSPHERIC MODELS

A model of the parameter of the ionosphere must be available to enable assessment of the performance of a proposed system. The information available is not extensive but in Reference Report No. 9 proposals for mean and limiting cases are given. These proposals are summarized in Figure 2.3.1 and in Tables 2.3.1 and 2.3.2 for mean and minimum conditions respectively. In addition a curve for ionic mass variation such as could be expected in Polar Wind conditions is also shown.

Table 2.3.1 Mean ionospheric model.

h (km)	N_e (m^{-3})	T_e (°K)	T_i (°K)	$\overline{m}_i$ (amu)	λ_{in} (m)	λ_D (m)
85	$1.0\ 10^{10}$	200	200	31	0.0035	$1.0\ 10^{-2}$
100	$4.0\ 10^{10}$	250	250	31	0.043	$5.5\ 10^{-3}$
120	$1.5\ 10^{11}$	300	300	31	1.20	$3.1\ 10^{-3}$
200	$5.0\ 10^{11}$	1000	700	20		$3.1\ 10^{-3}$
500	$3.0\ 10^{11}$	3000	1150	16		$7.0\ 10^{-3}$
1000	$7.0\ 10^{10}$	3000	2300	13		$1.4\ 10^{-2}$
2000	$1.1\ 10^{10}$	3000	3000	10		$3.7\ 10^{-2}$

Table 2.3.2 Minimum ionospheric model

h (km)	N_e (m^{-3})	T_e (^oK)	T_i (^oK)	$\overline{m}_i$ (amu)	λ_{in} (m)	λ_D (m)
85	$3.0\ 10^7$	200	200	31	$3.5\ 10^{-3}$	$1.5\ 10^{-1}$
100	$3.0\ 10^9$	250	250	31	$4.3\ 10^{-2}$	$2.0\ 10^{-2}$
120	$2.0\ 10^{10}$	300	300	31	1.2	$8.5\ 10^{-3}$
200	$6.0\ 10^{10}$	1000	700	20		$5.0\ 10^{-3}$
500	$3.0\ 10^{10}$	3000	1150	16		$2.2\ 10^{-2}$
1000	$1.6\ 10^9$	3000	2300	13		$9.5\ 10^{-2}$
2000	$1.0\ 10^8$	3000	3000	10		$3.0\ 10^{-1}$

2.4 INTERFERENCE PROBLEMS OF SPECULAR AND NON-SPECULAR CLUTTER

2.4.1 Introduction

Clutter in a radar system is defined as any detectable signal caused by an echo from a target other than the wanted target.

Incoherently scattered signals from the ionospheric plasma are extremely weak (see sect. 2.2). Scattering of the same radio waves from other ionospheric sources may therefore cause interference problems and even destroy the measurements.

The most serious source of interference at high latitudes is specular auroral clutter or radio-aurora. This problem is discussed in detail in Reference Report No. 1 and a brief summary of the report is given in the next section. Various forms of non-specular clutter may also give rise to interference with the incoherent scattered signals. These effects are described in Reference Report No. 2, and the main conclusions are given in section 2.4.3.

2.4.2 Interference of radio-aurora with an auroral zone ISR system

Our knowledge of radio aurora, based on more than 20 years of observations, is almost completely unambiguous. It is therefore possible to predict fairly accurately the volume cross sections of auroral clutter as functions of frequency, aspect angle, latitude and time. The Doppler shift and frequency spread of radio aurora can also be estimated as functions of the same parameters. Based on such calculations for different places in Northern Scandinavia the suppression of interference due to auroral clutter on incoherently scattered signals is discussed.

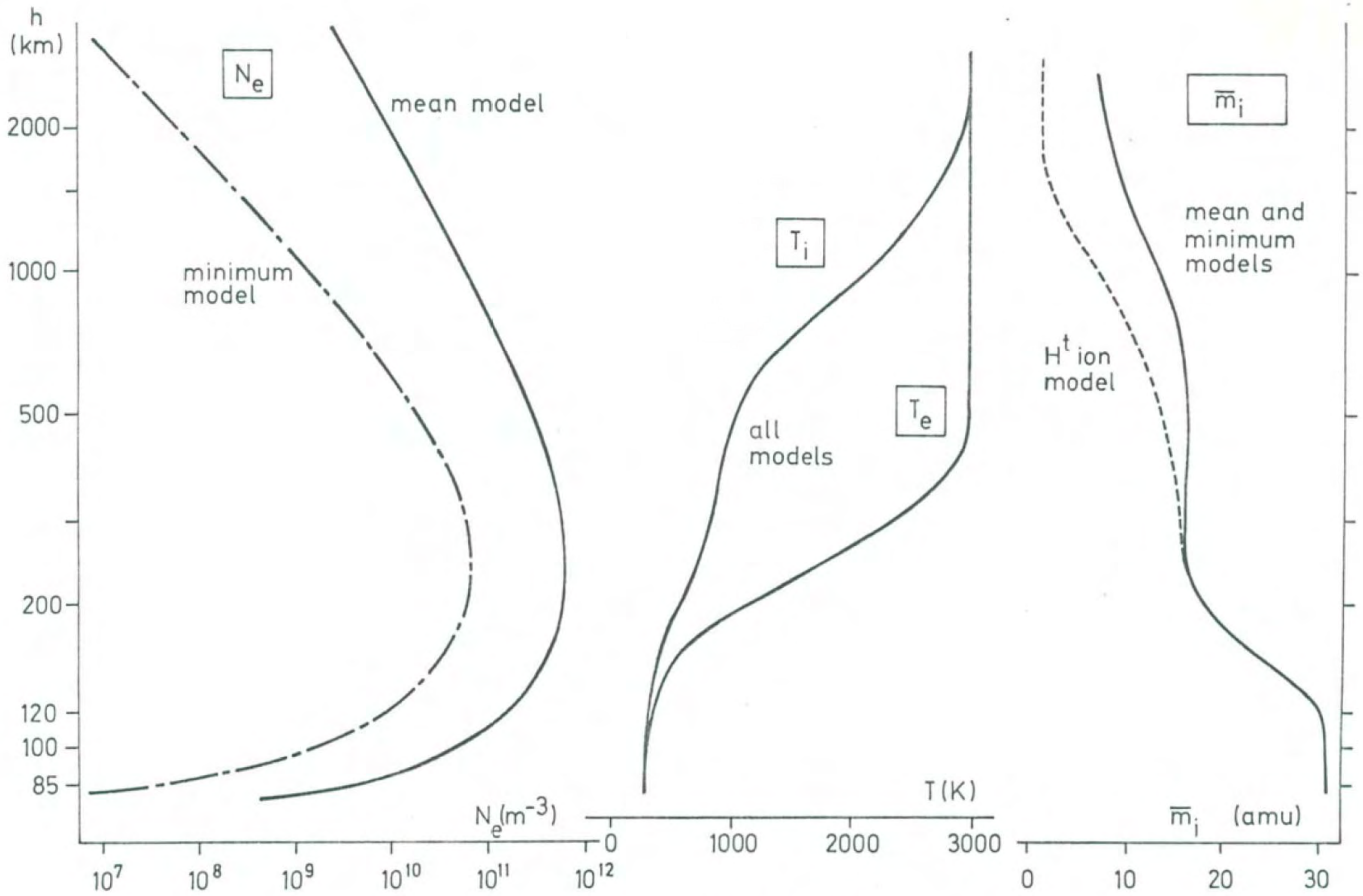


Figure 2.3.1 Ionospheric models

The computations are based on the fact that the auroral clutter will be received via the far-out antenna sidelobes of the incoherent scatter radar. The auroral echoes can be sorted out by the two-way front-to-sidelobe gain ratio, by antenna screening from the northern sector and by increasing the operating frequencies. It is assumed that the volume cross sections for incoherent scattering at altitudes below 1200 km can vary between 10^{-17} and $10^{-20} m^2/m^3$ (see sect 2.2). Furthermore, the radar antenna should be pointed to within ± 30 degrees of magnetic zenith.

Some results of these calculations are summarized below: (for more details the reader is referred to Reference Report No. 1).

1. On account of the limited spatial extent of auroral echoes no interference will occur for altitudes above 1200 km.

2. If the antenna is screened from the northern horizon to 10 degrees elevation, the strongest possible requirement for the sidelobe sensitivity will be 56 dB below the main lobe at 240 MHz and 30 dB for 1GHz. For medium strong auroral reflections and very weak incoherent scattering, the requirements above may be reduced by more than 10 dB. If the antenna is placed so that it is screened from the northern horizon to 20 degrees elevation the requirements given above will be reduced by 35 dB.

3. The worst possible case is no antenna screening, very strong auroral echoes together with weak incoherent signals. In order to avoid interference in this situation, antenna sidelobes at about 90° to the main beam of -70 dB at 240 MHz and -45 dB at 1 GHz are required.

4. The figures given here are believed to be somewhat conservative. It may well be that an incoherent scatter system in Northern Scandinavia will experience no interference even if the values above are reduced by 5 to 10 dB.

From these computations the following conclusions may be drawn:

a) For an incoherent scatter radar operating at 1 GHz it should be fairly easy to sort out the auroral clutter by the two-way front-to-sidelobe gain of the antenna. Thus, screening from the northern horizon is not essential.

b) If the antenna sidelobes at 240 MHz are 56 dB, an additional requirement of screening from the northern horizon to 10 degrees elevation must be fulfilled in order to avoid interference. If the antenna is screened from the northern horizon, the requirement on the sidelobes is reduced by 10 dB. This is a fairly realistic requirement for a VHF antenna (see Chap. 4).

2.4.3 Interference of non-specular clutter on incoherent scattered signals

The following non-specular types of clutter may interfere with ISR measurements: Spread-F, scattering and scintillation from electron density irregularities in the ionosphere, tropospheric scattering, echoes from meteors and aircraft and ground clutter. In addition, signal distortions not related to clutter phenomena are also mentioned.

A very brief summary of the different phenomena which might cause interference follows here.

Coherent non-specular F-region scattered signals are observed at the Jicamarca ISR. Spread-F is probably more intense in the auroral regions than over Jicamarca. Furthermore, strong electron density irregularities with small (order of 10 m) dimensions are observed at high latitudes. A pessimistic assessment is that these sources could give fairly strong scattered signals at 1 GHz and cause severe interference at 240 MHz. With more optimistic assumptions these coherent signals will be negligible at 1 GHz and only about as strong as the incoherent at 240 MHz. We still do not know for what proportion of the time such conditions are likely to be present.

It is likely that the most troublesome periods will occur during "radio-star fadeout" conditions, which have limited duration and only happen during the winter nights. Thus, it might be worthwhile to run a short baseline radio-star interferometer as a permanent auxiliary instrument to help with "post facto" indentification of very disturbed periods.

Besides scattering, amplitude scintillation is likely to occur. The power scintillation index is unlikely to exceed 10% in the worst case at 240 MHz and its only significant effect will be to degrade the statistical accuracy of measurements of incoherently scattered power.

When horizontal currents are flowing in the E-region, it is possible that enhanced field aligned density fluctuations will cause trouble when viewed along the fieldlines. This condition will be present in the main beam of the radar for quite a small proportion of the time, and if scattering does occur, it will be a new phenomenon and might be expected to yield new information.

Apart from ensuring that the aerials have well shielded sites and low side-lobe levels, there is little that can be done to reduce other types of clutter. If time-domain processing is used for reducing the signals from a distant CW transmitter, then the coherent troposcatter signal must be filtered out before the signal is sampled.

3 THE SCIENTIFIC OBJECTIVES OF THE NEW FACILITY

3.1 THE PRESENT STATUS OF IONOSPHERIC RESEARCH IN THE AURORAL ZONE AND THE PROBLEMS TO BE SOLVED

It is probably true to say that the gross features of the structure of the ionosphere are quite well mapped. The techniques used for studying these features include ground based observations as well as rocket and satellite instruments. All these techniques can be improved in various ways and there are, no doubt, many details of ionospheric structure yet to be revealed. The electron density is the parameter which has been most extensively studied, and its diurnal, seasonal and sunspot cycle variation at various latitudes and altitudes is now known in much detail. Irregularities in the electron density have also been the subject of study but are less well understood. Only recently have in situ reliable measurements of small scale structure been made.

Information on ion densities and composition are less readily available from ground based observations. Progress has been mainly due to the use of a variety of probes and mass spectrometers flown in rockets, and to various plasma resonance phenomena observed from satellites. Direct observations of this sort have also led to measurements of electron and ion temperatures. The density of the neutral atmosphere has been determined from satellite drag observations. Electrons and ions interact with the neutral atmosphere through collisions, and collision frequencies are important parameters studied in many experiments. Practically all the parameters we have mentioned here can be studied by the incoherent scatter technique though normally not all at the same time or with the same equipment.

Less well known than the structure of the upper atmosphere, or the ionosphere is its dynamical behaviour, i.e. the movements or winds in the neutral and ionized atmosphere above say 80 km and far out into the magnetosphere. There are three main energy sources determining the dynamical behaviour of the upper atmosphere: gravity and tidal waves (which also provide a coupling to the lower atmosphere) solar electromagnetic radiation absorbed in situ and precipitation of energetic particles (mainly electrons and protons). In the latter source should also be included energy provided by the solar wind through interaction with the magnetospheric boundary. This gives rise to large scale circulation in the magnetosphere, which in turn drives winds lower down in the ionosphere, constituting one dynamical system of very large extent. We would stress that this domain of dynamics is one in which considerable work remains to be done, and where we can expect interesting developments of our understanding of basic plasma phenomena.

The auroral zone is the site of considerable energy input and the relation of this energy source to the thermal balance in the global atmosphere has not been made clear. Moreover, movements and electric fields in the auroral zone map into regions of the magnetosphere with L values of about 5 to 7, very close to where geostationary satellites are situated in the equatorial plane.

Although we have stressed the measurement of movements as an objective of great interest for our system, the determination of electron densities, ion and electron temperatures and ionic masses in the auroral zone will also be very important for understanding the auroral process. To this day, for example it has not been possible to obtain vertical profiles of these parameters through an auroral arc. The Polar Wind has not been experimentally confirmed.

In addition the neutral structure of the atmosphere in the auroral zone is not known. The incoherent scatter instrument may contribute here through measurements of the frequency of collisions of ions with neutral particles and perhaps of the electron collision frequency in artificial heating experiments. Inter alia the results of such measurements of the neutral atmosphere may contribute to the understanding of circulation processes in the atmosphere. This could have repercussions on even lower altitudes than that at which measurements are possible.

Finally we would emphasize that the incoherent scatter facility yields profiles over a great height range for many quantities of great physical interest. Satellites can not compete with this capability but can complete it (see section 1.1).

It is regrettable that polar orbiting satellites are not more numerous. But satellites can only give horizontal cover and only at discrete times. This situation is not satisfactory or adequate for rapidly fluctuating and localized events.

We can state unequivocally that the scientific results obtainable from this facility will be far reaching for aeronomy as a whole and in particular for the understanding of the magnetospheric interaction with the ionosphere so forcefully demonstrated in the auroral zone.

Various problems that could be undertaken by an incoherent scatter facility in Northern Scandinavia will be discussed in the following sections of this chapter.

3.2 THE RESEARCH PROGRAMME OF THE FACILITY

3.2.1 Interaction of the magnetosphere and the ionosphere

The precipitation of electrons and protons in the auroral zone is generally believed to be caused mainly by magnetospheric processes possibly involving an acceleration mechanism in or near the equatorial plane of the magnetosphere. The auroral electrojet is an intense and complex current system which is associated with auroral precipitation. It has also been established that there are often strong field aligned currents. These currents may indicate a direct connection between the ring current and the auroral electrojet. The presence of electric fields in the auroral oval and in the polar cap region are also evidence of magnetospheric interaction with the ionosphere.

The discussion of the detection of the currents and electric fields is deferred to the following section. However, in this connection we can expect very fruitful collaboration with the ESRO geostationary satellite (GEOS) which will be situated on a field line reaching the ionosphere a short distance north of the Norwegian coast near Tromsø. GEOS will measure magnetospheric plasma convection at 6.6 R_e. The incoherent scatter installation will also measure plasma motions and the comparison of the corresponding electric fields will be of the greatest importance for the understanding of the interaction of the hot magnetospheric plasma with the cold ionosphere.

It is obvious that the changes in electron density and temperatures produced by particle precipitation can and should be direct observables of an adequate incoherent scatter facility. But there are at least two other ways in which effects of particle precipitation may be found.

Firstly, the plasma line may be enhanced by the secondary electrons produced by the primary particles. This is a process analogous to the well known closed field-line photoelectron enhancement of the plasma line at mid-latitudes. Auroral protons may also directly enhance the plasma line, but the more abundant primary auroral electrons are believed to travel too fast to couple with the plasma wave.

The other possible way in which precipitation could be detected is through the excitation of instabilities. The instabilities considered are believed to set up plasma fluctuations which should be detectable by the incoherent scatter facility, ideally as a line spectrum displaced in frequency from the ionic spectrum. Examples of such instabilities are the two stream instability (discussed in the next section) and the instability described by Perkins (1968).

This latter instability is predicted to occur when electrons of energy about 10 keV are precipitated in the topside ionosphere. If the monoenergetic flux exceeds about 10^{14} particles m^{-2} sec^{-1} $ster^{-1}$, then plasma waves with frequency close to the upper hybrid resonance may grow to large amplitudes, accelerating some electrons to energies as high as 100 keV. These plasma waves should be detected as a line in the power spectrum displaced in frequency from the ionic spectrum.

Instability of the type we are considering may lead to electron density irregularities which in turn may be detectable directly or may possibly cause coherent scattering (see section 3.2.2).

The Polar Wind is a concept developed to explain the large values of the mean ionic mass and the low plasma densities observed at heights of 1000 km or more above the auroral zone. It is surmised by the proponents of the Polar Wind hypothesis that an evaporation at supersonic speeds of the low mass ions, such as H^+ and He^+, can occur along open field lines. This leads for example to a preponderance of O^+ ions, even at distances as great as 3000 km, at the latitudes of open field lines. At other latitudes H^+ is the predominant ion at these heights.

In the region where the Polar Wind is believed to exist it is thought that the O^+ ions also have a large velocity, (but not as great as that of the lighter ions) directed away from the earth along the field lines. The Doppler shift produced by such a motion should be measurable by the system as a displacement of the ionic spectrum in the topside ionosphere up to about 1000 km. The tiltable antenna provision will permit measurements at higher L-values than that of Tromsø, although at somewhat lower altitudes.

The physical phenomena occurring inside the auroral region, i.e. in the polar cap, are little understood and have been studied only to a limited extent. The opportunity of carrying out incoherent scatter measurements in the polar cap, which will sometimes exist for an incoherent scatter radar located in Tromsø, is therefore one of the attractions of the proposed facility.

3.2.2 The dynamics of the ionosphere

Until now electric fields in the ionosphere have been measured by probe techniques or by means of artificial ion clouds whose drift could be observed during twilight. However, electric fields can also be derived from ISR measurements of the ionization velocity. The advantage of an ISR is that it is not restricted to specific hours of the day. It can, if desirable, monitor true electric fields continuously.

Electric fields will produce height changes of the F-layer, which may be reflected in the $N_e(h)$ profiles observed simultaneously. Although investigations at medium latitudes have revealed that F-layer height variations are mostly due to the action of neutral air winds, the situation may be different at high latitudes where, particularly during periods of magnetic disturbance, strong electric fields may be present.

Such fields will also produce horizontal electric currents in the altitude range around 100 km as well as field aligned currents at greater heights. It is expected that these currents will lead to an asymmetry in the observed spectrum. This asymmetry can be detected by an ISR system, and it is possible that, in an auroral electrojet, it is large enough to lead to a measurable effect. If the current exceeds a certain value, plasma instabilities will occur, which may be detectable by the coherent scatter signal they will produce. For further discussion of this effect see Reference Report No. 2.

There is experimental evidence that neutral air winds in the height range from 200 to 250 km may be different from what is expected from model calculations, during periods of disturbance. This may be caused by changes in the structure of the thermosphere or by electric fields setting the ionization into motion, which in turn will drag the neutral air with it. A decision between these alternatives can be obtained by measuring wind and ionization velocity together with other ionospheric parameters.

3.2.3 The behaviour of the neutral thermosphere during quiet and disturbed conditions

Air densities in the thermosphere have so far been deduced mainly from satellite drag observations above 180 km altitude. Little is known about density variations in the lower thermosphere, but as an ISR can measure collision frequencies at about 100 km altitude, information on density changes can be obtained there.

The global distribution of thermospheric temperature has also been inferred from satellite drag measurements, using reasonable assumptions. However, temperatures derived from ISR observations at medium latitudes deviate in some respects from the global picture. It is important, therefore, to have additional temperature measurements also at high latitudes in order to obtain more information that may be fed into atmospheric models. Motions of ionization observed in the lowest part of the thermosphere can be interpreted in terms of neutral air movements as it is believed that the velocities of the neutral and ionized gas are equal there. Hence, it should be possible to detect tidal oscillations and gravity waves in this region; as it is also believed that neutral and ion temperature are equal there, the same phenomena may be present in the ion temperature measurements.

At altitudes above 150 km the situation is more complicated, as the velocity of the ionization is no longer equal to the neutral air velocity, since electromagnetic forces and diffusion become involved. Nevertheless, studies at medium latitudes have shown that also neutral air velocities can be derived from ISR observations at F-region heights. It is very important to know these winds, as they may transport a large amount of energy by thermal convection and are, therefore, of major interest for the understanding of the thermal balance of the thermosphere.

During disturbed conditions the thermal balance is also influenced by precipitating particles and by electric currents associated with them. As a consequence densities and temperatures during geomagnetic disturbances are larger than during quiet conditions.

The auroral particle precipitation heats the ionosphere and creates local high-pressure regions. This effect may produce local neutral wind systems in the F-region responsible for the formation of the F-region trough equatorward of the precipitation region. It is extremely important to exploit the full capabilities of an ISR to obtain as much information as possible about neutral temperatures, densities, winds and also about the other ionospheric parameters which are of vital concern to the understanding of the behaviour of the neutral atmosphere.

3.2.4 The structure of the quiet and disturbed ionosphere

The distribution of ionization is intimately related to the behaviour of the neutral atmosphere, for the production and loss processes of ionized particles depend on neutral air density, composition and temperature. It is, therefore a very fortunate circumstance that information on both the neutral and ionized part of the atmosphere can be drawn from incoherent scatter observations.

One problem, which is not restricted to high latitudes, is the so-called seasonal anomaly of the F-layer, which is also observed at auroral zone latitudes at sunspot maximum. It can be expected that the large amount of data that will be available from ISR observations will help to explain this phenomenon.

It is also not yet clear how F-layer ionization is produced during the polar night. It has been suggested that magnetospheric particles in the keV-range precipitate into the ionosphere and ionize the neutral gas. If this is so, then we can expect that even in the absence of solar EUV-radiation hot "photo"-electrons are present in the F-layer, which may be detected by observation of the plasma line, and also that an increase in the electron temperature will be observed.

At polar latitudes various troughs and crests appear in the latitudinal distribution of electron density. An ISR at a location of L = 6.3 will often lie towards the northern edge of the auroral oval, and it can be expected that the F-layer is sometimes linked to the geomagnetic tail. This circumstance will be associated with a depletion of ionization in the F-layer (polar cap cavity). During less disturbed conditions, however, this location will be inside the auroral crest, which means that ionization is produced by precipitating particles. It will be interesting to study the ionosphere during such varying conditions.

In the auroral zone E-region a fairly thick layer is often observed, which is produced by precipitating particles and shows a very irregular structure. As mentioned in 3.2.2 and 3.2.3 the temperatures, densities and perhaps the currents associated with this precipitation are of great interest. In this connection ground based optical observations of the aurora should also be made.

The D- and lower E-regions are very significant parts of the ionosphere, but they comprise a region uniquely difficult for research. For example they are both inaccessible by satellite or by the conventional ionosonde. Auroral precipitation and polar cap absorption (PCA) events produce very large electron densities in this height range. Because of this, the ISR may be able to probe these events with precision down to 80 km; at least for electron density measurements. We do not consider it possible at present to measure ionic masses or temperatures at this height level. It has been demonstrated that in certain conditions it is possible to measure electron densities by the ISR technique to even lower altitudes at a mid-latitude site.

The height range from 80 to 90 km is proving to be exceedingly interesting in the field of aeronomy. To emphasize the importance of this region we list some of the phenomena which occur in this height range:

1. the winter anomaly increase in electron density,
2. the transition between hydrated ions and ions such as NO^+ and O_2^+,
3. the mesopause temperature minimum,
4. noctilucent clouds,
5. sharp gradients in electron density, which are believed to be associated with changes in the composition of the neutral atmosphere.

The availability of an ISR system capable of measuring electron densities to the low altitudes mentioned here, will be of great use in the solving of the many problems surrounding these phenomena.

3.3 REQUIREMENTS FOR THE NEW FACILITY

In section 3.2 the scientific objectives of the project were outlined. We will now try to define more accurately the capabilities of the system, which will be needed for these studies.

3.3.1 Overall capability of the system

The parameters which can be obtained from incoherent scatter measurements were listed in Chapter 2. Many of these parameters are deduced from the ionic part of the frequency spectrum of the scattered signal. Faraday rotation and plasma line measurements are also very important since they can give the absolute value of the electron concentration. Moreover, from plasma line observations, the flux of soft particles at particular energies can be determined. The possibility that other discrete spectral features, at frequencies well removed from the ionic spectrum, may exist must also be remembered.

The physical parameters to be extracted from the ionic part of the spectrum are the electron density, electron and ion temperatures, ion-neutral collision frequency and also the ion velocity vector. Moreover, an asymmetry of the ionic spectrum associated with electron currents may be detectable. In order to obtain the ion velocity vector, the simultaneous use of (at least) three receiving stations giving 3 independent components is necessary. Only with such a configuration will it be possible to separate the ion drift components parallel and perpendicular to the magnetic field.

Table 3.3.1 gives a summary of the accuracy, altitude and time resolution which would be considered satisfactory for scientific purposes. The various parameters listed in this table are discussed in the following subsections.

3.3.2 Sensitivity of the system

The sensitivity of an incoherent scatter equipment is not easy to quantify because the accuracy of the results can be considerably improved by integrating for a long time. When the medium is not changing too rapidly, integration times of some ten minutes may be acceptable. However, in the auroral zone, significant changes are known to take place with time scales of the order of 1 second or even less. An incoherent scatter radar cannot make measurements on such a short time scale with useful accuracy.

Thus the criterion for the desired facility can be stated as follows: in the accessible altitude range, an accuracy of 1% in the signal to noise ratio must be achieved after an integration time less than 10 minutes. An integration time of less than 1 minute for this accuracy is considered as very satisfactory, as shown in Table 3.3.1. For specific studies, however, it should be remembered that greater accurary can be achieved with longer integration times.

3.3.3 Altitude coverage

The signal to noise ratio is a function of various parameters of the medium observed and in particular of the electron concentration, which varies with time and altitude. In Reference Report No. 9, models of the altitude profile of electron density and other parameters are given for various conditions.

An optimum facility would be designed to obtain the required accuracy over the range of interest, i.e. between 85 km and several thousands of km. From Debye length considerations, however, it is absolutely unrealistic to expect any useful results for a reasonable operating frequency when the electron density is lower than about 10^9 m^{-3}. Because of the scientific interest of the lowest and highest altitudes, the equipment parameters must be chosen to obtain information in conditions of the lowest possible electron densities.

In the facility it seems appropriate to make measurements along the direction of the magnetic field (about 13° off vertical), since most auroral phenomena are field aligned. This is in contrast to most of the existing equipments which observe in the vertical direction.

Table 3.3.1 AN ASSESSMENT OF THE DESIRABLE PRECISION, IN MEASUREMENT UNDER AVERAGE CONDITIONS, OF THE FACILITY

Height range (km)	Precision of electron density (%)	Precision of T_e and T_i (%)	Precision of drift measurements (ms^{-1})		Relative composition of ions in the three mass ranges 1-4, 16, 30-32 Precision (%)	Ion neutral collision frequency (ν_{in}) Precision (%)	Altitude resolution (km)	Integration time (minutes)
			$V_{\parallel} \overline{B}$	$V_{\perp} \overline{B}$				
85-100	2	-	2	10	-	20	1	4
100-120	2	5	5	10	-	20	2	4
120-220	1	2 (Composition problems)	3	10	10	-	15	1
220-500	1	2	5	10	10	-	15	1
500-1000	5	10	10	-	10	-	75	10
1000-2000	10	30	30	-	-	-	150	30

3.3.4 Spatial resolution

The altitude resolution must be such that the electron density and other parameters do not vary significantly within the sampled range. A physical criterion for this is that the altitude resolution should be less than the scale height of the more rapidly varying constituent of the upper atmosphere, which is generally the neutral one. The figures for height resolution given in Table 3.3.1 are derived essentially from this criterion: below 500 km the height resolution must be less than half the scale height of the neutral atmosphere. Above 500 km the ionization concentration is likely to vary less rapidly and an altitude resolution of about 100 km is acceptable.

Below 120 km, however, the altitude variation of the electron concentration may be more rapid than that of the neutral concentration, because ion production by fast particles may cut off very rapidly with altitude. Variations of loss processes have also been shown to produce sharp gradients in electron concentration. The detection of such sharp gradients by incoherent scatter appears to be difficult though not hopeless.

The horizontal dimensions of the scattering volume are also important, because of the presence of horizontal gradients. A near-vertical transmitting beam, 0.5^{o} wide, has a cross section of about 1 km at 200 km altitude. Irregularities of about this size should thus be detectable with appropriate integration times. Moreover, if the transmitter beam could be rapidly tilted by a few beam widths from its mean position, horizontal gradients on a scale of a few km could be investigated.

3.3.5 Geomagnetic location of the stations

The choice of the location of the incoherent scatter network of stations with respect to the geomagnetic field and auroral phenomena was governed primarily by the following considerations.

It would be desirable to have the auroral oval (Akasofu, 1968) sweep over the stations when the particle precipitation into the oval is strong. Northern Scandinavia is in a favourable position for this to occur.

A location near Tromsø would permit the observation of both the southern and the northern boundaries of the auroral oval, depending on the magnetic activity, and it would at times be suitable for observations of polar cap phenomena. The North American $L = 4$ station would, during most of the time, observe midlatitude ionospheric phenomena and the southern boundary of the auroral oval at some times. The stations in Northern Scandinavia and the American installation will then in a very real sense be complementary to one another.

In addition, the ESRO geostationary satellite (to be launched in 1976), and possibly others at a later date, will lie on a line of force which, at ground level, is just north of Tromsø during part of the day. The possibility of linking observations from geostationary satellites with those of the proposed incoherent scatter system is an important factor in deciding the location of the latter, and is discussed elsewhere in this proposal. Yet another consideration in favour of Tromsø is the important part that observations from this site may play in the International Magnetospheric Survey (1975-77).

4 THE DESIGN OF THE FACILITY

4.1 MAIN CRITERIA

There are several ways in which the scientific objectives described in the previous sections could be attained. The proposed facility is intended to be used in a very flexible way whilst keeping the cost at a reasonable level. It would not be satisfactory to merely copy existing facilities, designed a decade ago, without trying to incorporate new possibilities, desirable in the light of experience, and which are now technically feasible.

The main considerations influencing the design of the incoherent scatter facility are the relation between the monostatic and the multistatic systems, and the emphasis to be devoted to the signal processing system and to the other parts of the facility.

4.1.1 Monostatic and multistatic systems

A tristatic system is the only configuration giving a complete measurement of the plasma velocity vector at a given place. Multistatic systems can also give a better altitude resolution in the lower ionosphere than a monostatic system. The scientific priority given to the dynamical processes in the high latitude area and the importance of space (and time) resolution necessitate the use of a multistatic configuration.

Nevertheless a monostatic system has advantages; higher sensitivity and the possibility of simultaneous measurements over all the altitude range. It will thus be very desirable to combine the advantage of both systems, by using pulse modulation with different pulse lengths, from very short to very long, appropriate to the monostatic and multistatic systems respectively.

4.1.2 Choice of operating frequencies

To achieve the required altitude resolution, a multistatic system predicates a choice in the UHF frequency range, in order to obtain adequate directivity for the steerable antennae, which in turn governs the altitude resolution. The UHF range also ensures better protection against spurious signals, originating from specular or diffuse echoes.

But the use of a high frequency introduced a limitation in the altitude range, because of the Debye length condition (see Chap. 2). To be able to observe the polar wind, for example at an altitude higher than 1000 km, a lower working frequency, in the VHF range, will be necessary.

Furthermore, the limitations introduced by Landau damping and by electron-ion collisions show that the plasma lines cannot be observed on a UHF frequency, except during conditions of high ionization density, and that a VHF frequency detects them with reasonable resolution when the ionization density is low. The use of two operating frequencies simultaneously will allow a full coverage. Furthermore, the use of two frequencies will permit the calculation of the energy spectrum of the electron flux, although this may be rather coarse.

Considering all factors affecting the choice of working frequency, it appears that only the use of two well separated frequencies will satisfy the main requirements. Restriction to a single intermediate frequency will seriously impair the performance of the facility. Thus the proposal in this document calls for a complete facility, comprising a tristatic pulse modulated UHF system (approximately 958 MHz) together with a monostatic VHF system (approximately 240 MHz).

Moreover the ionosphere is essentially field-aligned in the auroral regions and this makes it very advantageous to point the transmitter beams of both systems along the direction of the magnetic field line, or more precisely along the mean value of the direction in the 300 - 500 km range (e.g. at Tromsø, inclination 77°, declination 0°).

4.1.3 Frequency allocations

A preliminary study of the frequency allocations in Northern Scandinavia indicates that permission can probably be obtained to use frequencies in the band: 235 to 267 MHz used for fixed and mobile traffic and in the band 952 - 962 MHz. For the purpose of this study frequencies of 240 MHz and 958 MHz are considered.

4.2 THE DESIGN OF THE UHF SYSTEM

The proposed UHF radar is a pulse-modulated multistatic system, working at the frequency near 958 MHz. It comprises a pulse-modulated transmitter, a fixed transmitting antenna oriented along the mean magnetic field line direction (77° elevation, 180° azimuth), a receiver and data analysis equipment at the transmitting station, for the monostatic mode of operation. For a tristatic operation two additional receiving stations are needed, each of them equipped with an antenna steerable in one direction, a receiver and a data analysis system.

4.2.1 The transmitter

A fairly detailed study of the UHF transmitter has been made and it is clear from this work that the final stage output tube (or tubes) and the modulation system pose the only significant problems.

The power amplifier tube must be able to transmit pulses, of duration from about 10 microseconds up to several milliseconds, with a peak power greater than 1 MW and a mean power of several hundred kW. The only suitable tube in the frequency range, without a costly new development, would appear to be a Varian klystron, VA 862 K, derived from the existing tube VA 862. The provisional characteristics of the new VA 862 K tube are

Frequency 958 MHz	Bandwidth ± 10 MHz
Peak power 2 MW	Mean power 250 kW
Pulse length 10 μs to 10 ms	
Gain 47 dB	

This klystron is an anode modulated tube. By using a floating type modulator, requiring two power triodes of type ML-2PT, it is possible to produce pulses with straight edges (rise time less than 2 μs) and low phase variations (equivalent frequency shift less than 4 Hz during 10 ms). These constraints on the quality of the pulses at maximum power, imply considerable complexity of the modulator, a very high value of the energy storage capacitance (0.4 mF) and a powerful cooling system. The maximum output from the transmitter is limited by the electronics of the klystron beam and by the maximum power dissipated at the grids of the modulating tubes. If maximum peak power is required, these limitations lead to a maximum pulse length of 10 ms, with a repetition frequency of 10 Hz, and to a maximum repetition frequency of 4 kHz, for pulses shorter than 30 μs. (The latter condition will introduce a constraint on the short pulse modulation mode considered below).

The use of two power klystrons in parallel is planned. In Reference Report No. 3 detailed characteristics of the transmitter are presented, with some estimates of the sizes of the various elements (power stages, modulator, capacitors and power supply) and of the required dimensions of the building.

4.2.2 Modulation

The multistatic mode is first considered. Here the longest pulses will be used (τ = 10 ms) with the lowest repetition rate (n = 10 Hz). The altitude resolution will depend only on the receiving antenna sizes. The accuracy of the measurements will be proportional to $(n \tau)^{\frac{1}{2}}$

For special purposes, an alternative short pulse modulation mode, suggested by Storey (Moorcroft, 1968), may be attractive. The objective would be to achieve an altitude resolution of a few hundred meters. However, the method leads to a loss of sensitivity so that it is only usable when the ionization density is high. It would be possible to overcome this decrease in sensitivity by exploiting the coherence between signals at close but discrete frequencies, e.g. by using pulse compression techniques. Such a technique is possible with the proposed transmitter, but needs further detailed study.

Turning now to the monostatic mode, single pulse modulation will be used for the high altitude range, choosing the best compromise between altitude resolution and sensitivity. For the low altitude range, when the resolution becomes too poor, a double pulse modulation will be employed, using the correlation between two successive pulses. The repetition rate being fixed by the maximum return delay of echoes, the transmitter will not be working at its full duty ratio and several pairs of pulses may be used at different frequencies, or even more complex coded modulation systems may be considered. The proposed transmitter is flexible enough to accept many types of modulation. The choice of the best arrangement needs further study.

4.2.3 The transmitting antenna

The size of the transmitting antenna will control the performance in the monostatic mode, which will depend on the receiving antenna. In order to maintain a compatibility between the two modes, the transmitter and receiver antennae should not be very different in size. A 50 m diameter paraboloidal reflector may be considered suitable a priori for the fixed transmitting antenna. Several types of feed can be envisaged, for instance direct Cassegrainian or modified Cassegrainian types. The parabolic surface may be symmetrical or asymmetrical. The main requirements are to achieve low levels of the first side lobes as well as of the far out sidelobes in the direction near by normal to the earth's magnetic field lines. This is necessary in order to minimize coherent auroral echoes. Some possible designs are discussed in Reference Report No. 6.

The main beam will be directed parallel to the magnetic field (site dip angle 77° North). It is planned to have a mechanically operated tilt of the main beam in the magnetic meridian. The magnitude will be small, only of the order of a beamwidth either way.

Actual performance at 958 MHz with a modified Cassegrainian feed, with a symmetrical paraboloidal main reflector, of 50 m diameter, a focal distance of 17.5 m, and an auxiliary reflector, 5.20 m diameter, will have the following minimum values:

Main lobe: gain 52 dB; half power width 0.4° (at 3 dB)

This figure allows for 60% aperture efficiency, 0.5 dB loss caused by random reflector errors, 0.2 dB reflector transmission loss and 0.3 dB waveguide attenuation.

First side lobe levels less than -20 dB, separation 0.75°

Second side lobe levels less than -25 dB, separation 1.5 °

Noise temperature (sky and antenna): 25° K

For the directions nearly perpendicular to the magnetic field, the side lobe level will be more than 50 dB below that of the main beam. Movement of the beam can be achieved by moving the feeder slightly or by changing the inclination of the secondary reflector (for a Cassegrainian system).

The reflecting surface must stay within ± 1,5 cm (rms) of the true paraboloidal form.

The polarization of the radiation will be circular, reasons for this are given in Reference Report No. 3.

The frequency dependence of the radiation pattern of the antenna has to be known up to 10 MHz on either side of the centre frequency, because the plasma line measurements require this information.

4.2.4 The receiving antenna

Three possible constructions have been considered for the receiver antenna. They are

1. Paraboloidal reflector movable in one direction.
2. movable paraboloidal reflector with a multiple Cassegrainian feed.
3. fixed Cassegrainian toroid with multiple sources, or a mobile source along the main reflector axis.

A fourth solution involving an interferometer array has been discarded because the interaction between the individual elements will vary with changing primary direction.

This work is given in detail in Reference Report No. 3 and we summarise the possible characteristics of the second solution in Table 4.2.1. The first construction would in fact correspond to a very slow height scanning operation and will not be considered further.

The third system, while most complex, would allow the most rapid information procurement. It would require a 45 m. diameter primary reflector to produce an effective 25 m aperture at all elevation angles between 20 and 55 degrees.

Table 4.2.1 Case 2: parameters of a movable paraboloidal reflector with a multiple Cassegrainian feed.

Main reflector	Diameter	25 m
	Focal length	8.75 m
Secondary reflector	Diameter	4 m
Gain	(Primary and lateral beams)	46 dB
Side lobe level	(Primary and lateral beams)	-20 dB
Beam width	(3 dB level): Primary, lateral	0,65°, 0,9°
Noise Temperature	(with liquid nitrogen or Helium)	100° K

4.2.5 Geometry of the multistatic system

The choice of the sites should consider the location of existing geophysical laboratories in Northern Scandinavia for obvious practical reasons. The problem is then essentially to consider the possible use of the three sites in the vicinity of Sodankylä (Finland), Tromsø (Norway) and Kiruna (Sweden). Many arguments favour selecting the highest latitude station for the transmitter and monostatic operations. (see section 3.3.5).

With the transmitter near Tromsø, pointing to the south with an elevation angle of 77°, the receiving stations will then be Kiruna at a horizontal distance 210 km and azimuth equal to 167°; Sodankylä at a much larger distance of 400 km and an azimuth of 128°. The possibility of having the Finnish station at a closer distance, eg. at Muonio, has been considered. However it is shown in Reference Report No. 5 that Sodankylä provides better accuracy.

It is desirable that all antennae must be shielded in the northerly direction, in order to obtain some protection against coherent echoes.

4.3 THE DESIGN OF THE VHF SYSTEM

The choice of frequency in an incoherent scatter system depends on a large number of factors and no unique answer to the frequency choice exists. The boundary conditions which determine the frequency choice are set by the parameters one is interested in measuring. If, as was discussed in the section 4,1, one is interested in measuring the wind and electrodynamic drift velocities with good height resolution, one must strive to make the beams exceedingly narrow and this dictates a high frequency so that antenna dimensions may be kept reasonable. If, on the other hand, one would like to observe electron density and temperatures with good time resolution over a wide height interval a frequency in the upper VHF band appears to be optimum. The one serious unknown in the choice of frequency for an incoherent scatter facility in the auroral zone is the effect of clutter. VHF frequencies are much more susceptible to clutter problems than UHF frequencie, since the clutter cross section per unit volume probably varies as λ^5, λ being the wavelength (see Reference Report No. 1). The installation of an incoherent scatter station of a VHF frequency in the auroral zone, therefore requires special steps to be taken to avoid clutter. We shall only consider a monostatic system in what follows, since the bistatic configuration at VHF cannot give adequate height resolution for wind measurements in a bistatic mode. In a VHF system the choice of frequency is guided by considerations of sensitivity for the detection of scattered energy from electrons.

If Debye length considerations are ignored for the time being, and one attempts to optimise the signal to noise ratio either on the basis of a fixed aperture or on the basis of a fixed gain antenna, one is led to a frequency in the vicinity of that where to cosmic background noise equals the receiver noise. If this is taken as 100 to 200° K, a frequency from 200 to 300 MHz is found as the optimum. Both a desire to measure densities by the Faraday rotation technique and a wish to measure densities above 1000 km where Debye length problems become serious under extreme conditions, at a 1 m wavelength or so, would tend to dictate an even somewhat lower frequency. However, frequency allocation problems and the fear of serious clutter problems have caused us to settle for a frequency near 240 MHz. For further details see Reference Report No. 7.

4.3.1 The transmitter

No very careful and accurate study of the transmitter has been made so far. A transmitter capable of several hundred kW average power with peak of 5 to 10 MW is available in the USA. This transmitter would be based on one of several available RCA very high power triodes.

One of the main reasons for locating the two transmitters at one site would be the possibility of sharing the power supply. This part of the transmitter is very costly and it is believed that at least 30% of the transmitter cost can be saved if the VHF transmitter can use the UHF transmitter power supply.

4.3.2 The antenna

Studies have been made of an antenna design based on an array of travelling wave elements. A size of the order of 100 x 100 m^2 has been considered. Each travelling wave element would produce a linearly polarized wave, but by interspersing orthogonally polarized elements and phasing them appropriately, cicular polarization can be achieved. In order to be able to study the ionosphere over a certain range of magnetic latitudes a scheme for tilting the elements by means of hydraulic jacks and rephasing them has been devised. This antenna has been subjected to model studies discussed in Reference Report No. 8.

4.3.3 The receivers and data handling system

The receivers should consist of low noise front end amplifiers, several IF stages and phase detectors with subsequent analogue to digital converters in order to couple into the digital data handling system. One or more IF stages could be common between the VHF and the UHF system and the phase detectors, A/D converters and digital data analysis system should be common to the two systems. All the local oscillator frequencies must be derived coherently from a station frequency standard. Provision should be made for at least one local oscillator to be programmed from the computer so that arbitrary frequency offsets can be obtained, particularly in connection with plasma line studies.

The front ends of the receivers should be low noise amplifiers, preferably uncooled. Both parametric and transistor amplifiers might be suitable. The bias is in favour of the former for noise reasons. Cost and ease of operation would favour the latter solution. No price has yet been placed on the additional hardware required by the VHF receiver system. It is quite clear, however, that the cost will be insignificant compared to the cost of both the transmitter and the antenna systems (Reference Report No. 10).

4.4 THE PERFORMANCE OF THE UHF SYSTEM

4.4.1 Geometry and parameters of the UHF system

Table 4.4.1 Locations and parameters for UHF system performance

Location	Transmitter	Ramfjordmoen near Tromsø
	Receivers	Saurusvaara near Kiruna Oratunturi near Sodankylä
Frequency		958 MHz
Antennae	Tromsø	diameter 50 m, gain 52 dB
	Kiruna	" 25 m, " 46 dB
	Sodankylä	" 30 m, " 47.5 dB
Transmitted power		Peak 5 MW, mean 150 kW
Polarization		Circular
Transmitter orientation		elevation 77°, azimuth 180°
Maximum repetition frequency		$0.125 \times \tau^{-1}$, where τ is pulse length
Noise temperature		100 °K
Feeder loss factor		0.8

The locations and parameters used in this section for performance calculations are listed in Table 4.4.1. Full details may be found in Reference Report No. 5, while the basic theory has been given in Chapter 2.

4.4.2 Ionic spectrum measurement in the monostatic mode

The altitude ranges above and below 220 km must be considered separately. Below 220 km it is found to be advantageous to use a double pulse scheme and measure the autocorrelation function (ACF) of the returned signal. In Tables 4.4.2 and 4.4.3 is shown the percentage uncertainty in the measurements of the ACF and the plasma drift under what are considered to be reasonable and feasible operating conditions.

Following section 2.1 the errors of measurements of electron density and temperatures are given approximately by the following equation:

$$\frac{2\delta N_e}{N_e} = \frac{\delta T_e}{T_e} = \frac{\delta T_i}{T_i} = \delta\rho$$

provided the ion composition is known. If it is not, the percentage errors are certainly at least twice as great.

The corresponding results for heights above 225 km are given in Tables 4.4.4 and 4.4.5. Here it is supposed that a single pulse scheme can be used because the altitude resolution demanded is usually not too exacting.

In all the calculations an integration time of 10 minutes is assumed. The repetition rate has been chosen so that the interval between pulses corresponds to 2000 km altitude for the mean and H^+ model ionospheres and to 750 km for the case of the minimum model.

Table 4.4.2 Percentage uncertainty of measurements of the autocorrelation function of the receiver power (where no value is specified, then the measurements are very inaccurate indeed).

Altitude (km)	85	100	120	150	200
Altitude resolution (km)	3	3	3	6	6
Mean model	30	12	5	1.6	3
Minimum model	-	-	25	8	9

Table 4.4.3 Precision attainable with plasma drift measurements in $m.s^{-1}$.

Altitude (km)	85	100	120	150	200
Mean model	7	8	7	4	5
Minimum model	-	115	25	9	13

Table 4.4.4 Percentage accuracy of power measurements using a single pulse method.

Altitude (km)	225	300	500	800	1000	1500
Altitude resolution (km)	15	15	15	75	75	150
Mean model	0.25	0.35	0.9	0.5	1.2	3.0
Minimum model	0.5	1.0	9.0	-	-	-
H^+ model	0.25	0.35	0.9	6.0	1.5	6.0

Table 4.4.5 Precision attainable in measurement of plasma drift velocity parallel to the direction of the magnetic field in ms^{-1}.

Altitude (km)	225	300	500	800	1000	1500
Mean model	4	6	19	10	25	160
Minimum model	8	18	220	-	-	-
H^+ model	4	6	19	12	40	400

Improvement in these figures may be had by using coded pulses. Essentially this technique will prevent the loss of identity of the pulse when the repetition rate is increased. The results obtainable are shown in Table 4.4.6.

Table 4.4.6 Performance of the monostatic system using coded pulses.

Altitude (km)		85	120	200	300	500	1000	1500
Altitude resolution (km)		3	3	6	15	15	75	150
D = double pulses		D	D	D	-	-	-	-
Minimum model	Number of coded pulses	15	15	7	6	6	/	/
	$\delta N_e/N_e$(%)	/	3	1.6	0.3	4	/	/
	δV (ms^{-1})	/	4.1	4.8	7.5	93	/	/
Mean model	Number of coded pulses	41	41	20	16	16	3	1
	$\delta N_e/N_e$ (%)	3	0.4	0.3	0.08	0.25	0.6	3
	δV (ms^{-1})	1.0	0.8	1.4	1.4	5.4	16.0	80
H^+ model	$\delta N_e/N_e$(%)	3	0.4	0.3	0.08	0.25	0.7	5
	δV (ms^{-1})	1.0	0.8	1.9	1.4	6	23	260

The error on the electron density measurement is then less than 1% between 100 and 1200 km for the mean model and between 200 and 400 km for the minimum model. The velocity measurement error is less than 10 ms^{-1} below 800 km for the mean model and for the minimum model between 100 and 350 km. The results obtained are deemed to be encouraging but the integration time of 10 minutes considered here may be too lengthy for some auroral situations.

4.4.3 Ionic spectrum measurement in the bistatic mode

We turn now to a consideration of the tristatic system with transmitter near Tromsø and receivers near Kiruna and Sodankylä. Table 4.4.7 gives, for Kiruna and Sodankylä at various altitudes, the range to the scattering volume, the angle between the transmitting and receiving beams, a polarization factor due to the anisotropy of the elementary scattering volume, the altitude resolution and the elevation angle of the antenna.

Table 4.4.7 Characteristics of the tristatic system.

	Altitude (km)	85	120	200	300	500	1000	1500
Kiruna	Scattering distance (km)	224	234	272	343	517	1003	1503
	Half angle between beams (°)	79	72.4	53.8	40.0	25.2	12.6	8.4
	Polarization factor	0.51	0.55	0.67	0.79	0.90	0.97	0.98
	Height resolution (km)	4.3	4.7	6.3	9.6	20.1	69	150
	Elevation angle (°)	21.4	30.1	46.5	60.5	75.2	87.7	86
Sodankylä	Scattering distance (km)	404	410	435	483	621	1064	1550
	Half angle between beams (°)	83.0	78.0	67.4	56.0	40.2	22.2	15.0
	Polarization factor	0.50	0.52	0.57	0.65	0.79	0.92	0.96
	Height resolution (km)	5.7	6.0	7.1	9.0	14.6	39	78
	Elevation angle (°)	10.6	15.6	16.2	37.5	53.3	71.4	78.5

Using 10 ms pulses, it is possible to compute the receiver signal power accuracy, using an integration time of 10 min. and these calculations give the results summarized in Table 4.4.8.

Table 4.4.8 Receiver signal power accuracy (%) as a function of height for three ionospheric models.

Altitude (km)		85	120	200	300	500	1000	1500
Mean model	Kiruna	1.9	0.47	0.2	0.24	0.42	1.7	7
	Sodankylä	4.3	0.52	0.31	0.3	0.7	2.5	11
Minimum model	Kiruna		2.9	1.5	1.7	7		
	Sodankylä		3.1	2.3	2	12		
H^+ model	Kiruna	2.9	0.47	0.2	0.24	0.42	2	10
	Sodankylä	4.3	0.52	0.31	0.3	0.7	2.4	15

Alternatively if an accuracy of 1% (corresponding to $\delta N_e/N_e = 1\%$ and $\delta T_e/T_e = \delta T_i/T_i = 2\%$) can be considered as satisfactory, the integration time necessary to attain such an accuracy may be computed. For the two stations this integration time is less than 10 min for the mean ionosphere between about 120 and 500 km. At 200 km for example, this integration time would be 30 s for Kiruna and 70 s for Sodankylä for the conditions of the mean ionospheric model.

For the two receiving stations, the velocity components measured are in the direction of the bisectors of the transmitting and receiving beams. The errors on these measurements are shown in Table 4.4.9.

Table 4.4.9 Precision in ms^{-1} obtainable with tristatic system for plasma drift measurements for three reference ionospheres.

Altitude (km)		85	120	200	300	500	1000	1500
Mean model	V Kiruna	2.3	1.7	1.5	2.2	4.4	29	150
	V Sodankylä	2.6	1.9	1.7	3.1	73	45	250
Minimum model	V Kiruna	-	12	11	17	77	-	-
	V Sodankylä	-	18	19	30	126	-	-
H^+ model	V Kiruna	2.3	1.7	1.5	2.2	5.1	45	500
	V Sodankylä	2.6	1.9	1.7	3.1	8.5	71	800

It may be seen that, for the mean model, the velocity error remains less than 10 ms^{-1} up to 500 km for both components

4.4.4 Total velocity determination and components parallel and perpendicular to the direction of the magnetic field.

To determine the total velocity and components relative to the magnetic field, it is necessary to combine the monostatic and tristatic observations.

Formally the total velocity can be written in matrix form as

$$\begin{vmatrix} V_1 \\ V_2 \\ V_3 \end{vmatrix} = M \begin{vmatrix} V_M \\ V_{T1} \\ V_{T2} \end{vmatrix}$$

where V_1, V_2 and V_3 are components of the plasma drift; V_1 is perpendicular to the magnetic field direction and in the meridional plane, V_2 is perpendicular to the magnetic field direction and perpendicular to the meridional plane and V_3 is parallel to the magnetic field direction. The matrix M depends on the altitude considered but is determined solely by the geometry of the system. V_M represents the monostatic velocity determination and V_{T1} and V_{T2} represents the two tristatic velocities.

The following experimental procedure has been assumed for the purpose of the calculations. Operation is monostatic for 10 minutes with an appropriate pulse length and repetition rate for the altitude considered. Then, tristatic observations are carried out for another 10 minutes using 10 ms pulses.

In Table 4.4.10 the results of the computations are shown both for coded and uncoded pulses. It is seen that the error values for the velocity components are low in general below the F-region ionization peak, but that the use of coded pulses significantly improves the determinations.

Table 4.4.10 Errors in $m.s^{-1}$ of plasma drift velocity determinations for 3 orthogonal directions, perpendicular and parallel to the magnetic field using coded and uncoded pulses and with 10 minutes integration time (see text for further details).

Altitude (km)	85	120	200	300	500	PULSE	MODEL
δV_1	5.3	4.3	5.4	10.0	48.0		
δV_2	7.9	6.5	6.9	12.9	52.0	Coded	mean
δV_3	1.0	0.8	1.4	1.4	5.0		
δV_1	8.6	7.8	12.5	18.3	106.0		
δV_2	8.9	7.2	7.7	13.1	13.1	Uncoded	mean
δV_3	6.5	5.1	6.1	5.8	22.0		
δV_1		37.0	43.0	89.0			
δV_2		48.0	55.0	105.0		Uncoded	minimum
δV_3		16.0	13.0	19.0			

4.5 THE PERFORMANCE OF THE VHF SYSTEM

Table 4.5.1 is taken from the mean ionospheric model given in Reference Report No. 9.

Table 4.5.1 Typical ionospheric parameters

Height (km)	N_e (m^{-3})	T_e (^oK)	T_i (^oK)	$\overline{m}_i$ (amu)	b_i (kHz)	$\lambda/(4\pi\lambda_{in})$
80	$10^9 - 10^{10}$	250	250	31	~ 0.1	35.
100	$4 \cdot 10^{10}$	300	300	30	~ 0.5	2.0
500	$2.5 \cdot 10^{11}$	3000	1000	15	5.1	~ 0
1000	$6 \cdot 10^{10}$	3000	2500	14	8.3	~ 0

The following parameters for the VHF radar system are assumed for the purpose of calculation.

Receiver temperature	200 ^oK
Transmitter power (peak)	5 MW
Effective antenna aperture	5000 m^2

We obtain for the ratio of signal power to noise power at the output of the receiver:

$$R = 2.5 \times 10^9 \frac{N_e \tau}{h^2 \cdot b} \qquad \text{(MKSA units)}$$

where

N_e = electron density

τ = transmitter pulse length

h = height

b = bandwidth

Note that we must have $b > 1/\tau$ for all the signal power to be encompassed. With the parameters in the table we obtain the result shown in Table 4.5.2.

Table 4.5.2 Signal to noise ratio for electron density determination using power method. Asterisk denotes $b_i < 1/\tau$, and b replaced by $1/\tau$.

Height (km)	Height resolution (km)	P_S/P_n
80	1.5	0.04* - 0.4*
100	15	100.*
	1.5	1.*
500	15	25.*
	1.5	0.25*
1000	150	19.
	15	1.5*

If the electron density is determined from the signal power returned one can formally establish a relative uncertainty which is not very meaningful since the absolute calibration of the radar system (i.e. the systematic error) is not known. The formal relative uncertainty in power, after integration over n pulses is:

$$\frac{\delta P_S}{P_S} \approx \left(1 - \sqrt{2}\,\frac{P_n}{P_S}\right) / \sqrt{n}$$

A better method may be the determination of electron density by Faraday rotation from the formula:

$$\frac{\Delta\varphi}{\Delta h} = \frac{4\pi}{c} \frac{f_p^2 f_H}{f^2}$$

where φ is relative phase change, c velocity of light, f_p the plasma frequency, f_H the gyro frequency and Δh is the height interval. An approximate general formula for the relative uncertainty in electron density determination with a height resolution of Δh is, assuming $P_S/P_n \gg 1$:

$$\frac{\delta N_e}{N_e} = \frac{\delta P_S}{P_S} \frac{cf^2}{4\pi f_p^2 \cdot f_H \cdot \Delta h}$$

Returning to the ionospheric model in Table 4.5.1, one obtains for 10 min integration time the relative uncertainties given in Table 4.5.3 (repetition rate equal to 50 Hz).

Table 4.5.3 Relative uncertainties in N_e using the Faraday technique and 10 min. integration time.

Height (km)	Height resolution (km)	$\delta N_e/N_e$ (%)
100	1.5	120
100	15	12
500	1.5	23
500	15	2.3
1000	15	11
1000	150	1

We see from the table that a direct application of the Faraday technique is only marginally useful between 100 and 1000 km with a height resolution of 15 km. The role of the Faraday technique probably should be to calibrate the power profiles accurately by comparison over extended height intervals in order to remove systematic errors from the conversion of power to electron density. This is particularly important in the auroral ionosphere where ionosonde data may be unobtainable.

The determination of T_e and T_i from the spectra or the correlation function is an exercise in curve fitting which is virtually impossible to optimize on a rational basis. Estimates of accuracy in determinations of T_e and T_i can, therefore, best be assessed by comparison with data from other stations, notably Jicamarca which is most similar in capability. On this basis one should be able to obtain 3 - 5 % accuracy between 170 and 700 km, 10% at 1000 km and probably 3% near 120 km provided composition problems do not confuse the determination.

In the determination of "vertical" drift one is on much firmer ground in estimating the uncertainty. For the model ionosphere used, again assuming 10 minutes integration time one obtains the results shown in Table 4.5.4. It should be observed that the numbers are obtained on the basis of a non-optimum two-pulse analysis and that a better choice of parameters than assumed in the table might improve matters by a factor of two, possibly three. The results as they are shown, however, appear to be quite useful.

Of other virtues the VHF system might have, we shall only mention two more. The fact that the antenna will be designed to be tiltable in the magnetic meridian by 20° either way means that a latitude range of 370 km may be covered at 400 km height. In the auroral zone this represents a considerable variation in ionospheric conditions and might hence produce invaluable information.

Table 4.5.4 Drift velocity parallel to the magnetic field; uncertainties in a two-pulse experiment for the mean ionospheric model, 10 minutes integration time.

Height (km)	Height resolution (km)	δv (ms^{-1})
80	1.5	0.4 - 2.
100	1.5	1
500	15	10
1000	150	15

The 240 MHz frequency is also quite useful for the observation of precipitating electrons. Observation of the plasma lines can provide information on the electron precipitation in a certain narrow energy interval. With a tiltable beam it appears possible also to study particle precipitation as a function of L-shell parameter.

4.6 COMPARISON WITH EXISTING FACILITIES

Here a very simple outline will be given of how the facility will compare with what is already in existence. Considering firstly the UHV system, the transmitter area will be about 2×10^3 m^2. This is nearly an order of magnitude lower than that of the Arecibo radar. Even allowing for equal output powers, the EISCAT UHF monostatic system cannot approach the Arecibo system in directivity and therefore in sensitivity for electron density measurements.

It is a different matter when one considers multistatic observations. Comparison with the Saint Santin - Nancay system - the only operational multistatic system - shows a significant gain in sensitivity of drift determinations for the EISCAT system. In other words much shorter integration times may be necessary and this is of course very desirable in rapidly fluctuating auroral situations.

Fixing attention now on the VHF system it is appropriate to compare it with the Jicamarca installation which resembles it most closely. Here the Jicamarca system turns out to be more sensitive for electron density measurements, but the advantage is not great.

4.7 THE SYSTEM AS AN ENTITY

The complementarity of the UHF and VHF systems is visible in the analyses that have been presented in the earlier sections of this chapter: the VHF system while enabling measurements to be taken over the whole range of heights for which N_e exceeds 10^9 electrons m^{-3} is none the less at its best relative to the UHF system at the extremes of the altitude range. The UHF system will on the other hand enable precise measurements to be made in the middle altitude range at or above the F-region ionization maximum.

In Table 4.7.1 this is illustrated in another form where special conditions have been chosen so that both systems where possible can attempt to fulfil the scientific objectives given in Table 3.3.1. It is clear that these objectives can in general be achieved with the proposed system regarded as a whole.

Table 4.7.1 Tentative performance of the total system. Underlined values indicate that scientific requirements of Table 3.3.1 have been achieved. (V_1, V_2, V_3 are as defined in sect. 4.4.4).

h (km)	$\delta N_e/N_e$ (%)	$\delta T/T$ (%)	δV_3 (ms^{-1})	δV_1 (ms^{-1})	δV_2 (ms^{-1})	δh (km)	t (min)
UHF system (mean model, monostatic and/or multistatic, coded pulses).							
85	3	-	2	11	16	3-5.5	4
100	1	2	2	10	14	3-6	4
120	0.5	1	1.5	8.5	13	3-6	4
120	1	2	2.5	13	19	"	1
200	0.5	1	4	16	21	6-7	1
500	0.8	1.5	16	140	160	15-20	1
500	0.3	0.6	5	-	-	"	10
1000	0.6	1.2	15	-	-	75	10
VHF system (mean model, fixed beam, ionic spectrum and/or Faraday rotation).							
85	9	-	0.1	-	-	3	4
100	4	8	3,5	-	-	3	4
120	3	6	4	-	-	3	4
120	2.5	5	3	-	-	15	1
200	1.5	3	3.5	-	-	15	1
500	1.5	3	60	-	-	15	1
500	0.5	1	20	-	-	"	10
1000	1.5	3	10	-	-	75	10
1000	0.5	1	5	-	-	150	30
2000	2	4	80	-	-	150	30

Perhaps an even more clear example of the complementarity comes in the consideration of plasma line measurements which have been stressed, inter alia, for their importance as absolute and direct calibration of electron density determinations.

Because of Landau damping on the one hand and electron ion collisions on the other, detectable plasma lines are limited to the range of plasma frequencies given by

$$2 < f_N\lambda < 6 \quad \text{MHz m.}$$

where λ is the ISR wavelength and f_N the plasma frequency. Since f_N varies as the square root of the electron density, this implies a range of possible electron densities.

In terms of the Mean Model Ionosphere this leads to the result that the UHF system can only measure the plasma line between 200 and 400 km altitude. On the other hand the VHF system is limited to the two ranges of from 100 to 150 km and from 500 to 1500 km altitude. It is clear that the two systems together nearly encompass the whole range from 100 to 1500 km.

Detectability of the plasma line is determined also by the presence of excess electrons in the upper range of the normal Maxwellian distribution of electron velocities.

The energies of these electrons are in the range 3 to 5.5 eV for the high frequency case and 3 to 30 eV for the low frequency.

4.8 LOCATIONS OF TRANSMITTER AND RECEIVING STATIONS

4.8.1 General considerations

In the choice of locations for the various stations of the incoherent scatter facility the following factors must be considered besides the scientific ones presented in Chapter 3: ambient electrical interference, nature of the terrain, accessibility and electrical power supply.

The simplest solution to the problem of obtaining a radio quiet site is to seek some remote spot. The need for remoteness is, however, to a certain extent in conflict with the need for easy access. If the latter requirement is taken to mean that the site should not be more than an hour's drive from a larger community, selecting a remote site merely lowers the probability of experiencing unwanted interference, but does not guarantee its removal. It is therefore, necessary to test proposed sites for radio interference by a suitable survey before the final choice is made. So far such a survey has only been carried out for the Norwegian locations, discussed below. Of course there will be occupied dwellings at the sites and power lines leading to them and to the scientific equipment, but the construction and maintenance of these will to a considerable extent be within our control. In order to minimize radio interference problems power would best be brought in to the sites at voltages of about 20 kV or less.

The local terrain should afford radio screening of the site from potential sources of interference, and particularly from coherent auroral reflections and propagation between the transmittter and the receiver stations via tropospheric scatter from mountain peaks, aircraft or other objects visible from both the transmitter and receiver anntennae. A succession of gently rounded mountains between transmitter and receiver stations gives the best protection against diffracted and tropo-scatter signals. Such terrain is common in northern Scandinavia. To protect against coherent auroral reflections the northern horizon should be at an elevation of some 10 degrees at both the transmitter and the receiver sites. This requirement may be relaxed for the receiver stations if the transmitter is very well shielded towards the north (and the south) so that it cannot illuminate the aurora. For the transmitter station, finally, the distance to the furthest points on the Earth's surface that can be seen from the antenna should not exceed 70 km, in order not to have ground clutter at time delays within the measuring range. For this due allowance should be given to refraction and radio wave ducting.

The general location of the sites studied is shown in figure 4.8.1 together with quantities of geophysical interest. In figure 4.8.2 the properties of the magnetic field line originating at Tromsø are plotted. On the basis of the considerations discussed above the following locations are proposed.

4.8.2 Transmitter station

Three alternative locations in the Tromsø area are proposed, one at Ramfjordmoen (grd.ref. 772135, 43200 zone 34) and two in Breivikeidet (772720, 44550 and 772850, 44800, zone 34). The preliminary results of a radio interference survey by the official Norwegian agency indicate a very low radio noise level in this region.

The topography of the three places is shown in Figs. 4.8.3 and 4.8.4, where the sites are marked with centre darkened circles. The site at Ramfjordmoen is shielded to the north up to 15,8° elevation. This degree of shielding is preserved round to 20° E of N while it increases towards the west. There is also appreciable shielding to the south. The site consists of some 10^6 m^2 of essentially flat land in a sandy region with low agricultural potential. The distance from Tromsø is 28 km and the main road to Tromsø is about 4 km away. Electrical supply conditions are good, in that a new 22 kV power line runs along the valley. Its power handling capability far exceeds any ISR demands. The sites in the valley are near Breivikeidet. The first lies at Fjellstad near the road to Sjursnes. Due north the mountains subtend 14,5° elevation; at 20° E of N this has fallen smoothly to 11°; westward the angle increases. This site like the previous one is also rather flat; however, here the land is of good quality, and there might be some difficulty in obtaining permission to use it for non-agricultural purposes.

The next site is on the coast just below Breivika (see Fig. 4.2.2). Here again there is a level region with about the same shielding towards the north. The land here is, however, unsuitable for agriculture. The situation by the coast could present difficulties as regards corrosion from salt water. The road to Breivikeidet along the valley from Ramfjord is of reasonable quality. The total road distance from Tromsø is 45 km. Electrical supply conditions are good as the same power line as in the first site passes close to the region.

The value of some climatic parameters for Tromsø are given in Tables 4.8.1 and 4.8.2.

Table 4.8.1 Snow and wind data for Tromsø

Maximum snowdepth	155 cm
Most probable wind speed	2 beaufort
Maximum wind speed	8 beaufort
Most prevalent wind direction	South West

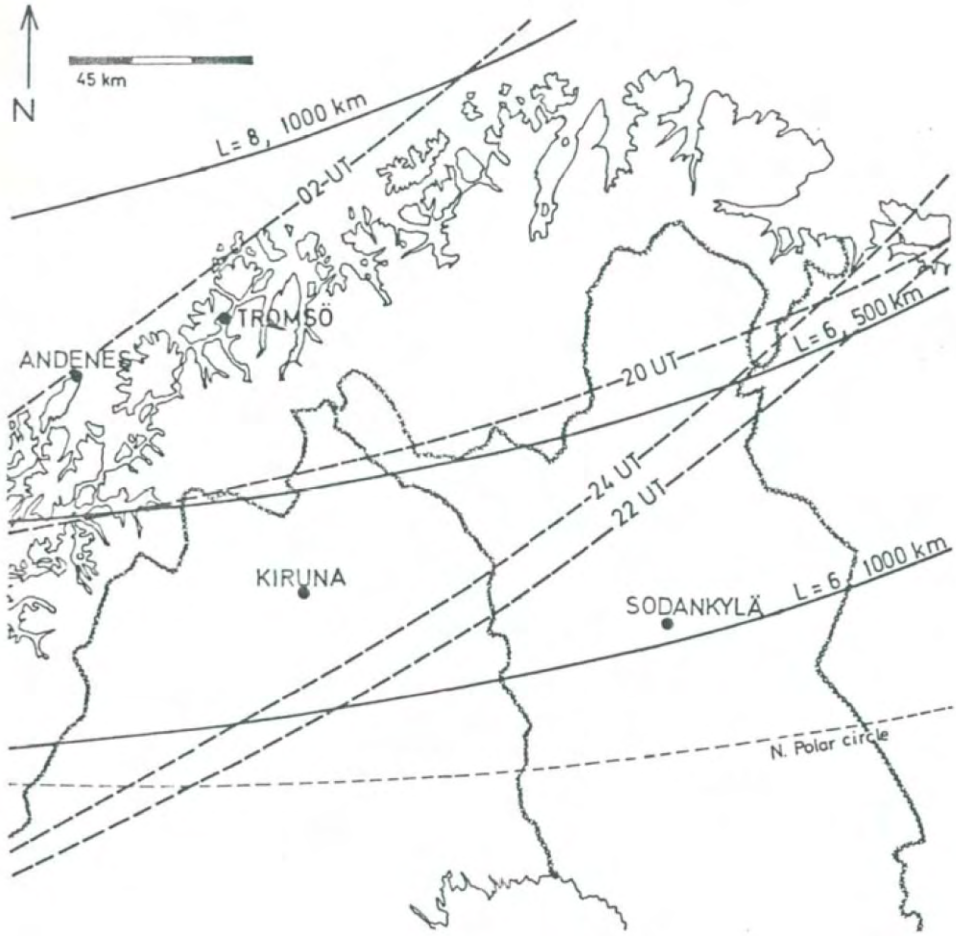


Figure 4.8.1 A map of Northern Scandinavia showing Tromsø, Kiruna, Sodankylä and Andenes, which is close to the Andøya rocket base. Also shown are L = 6 contours at 500 km and 1000 km altitude and the L = 8 contour at 1000 km. In addition the southern boundary of the auroral oval is drawn for four local times, following Akasofu, 1968.

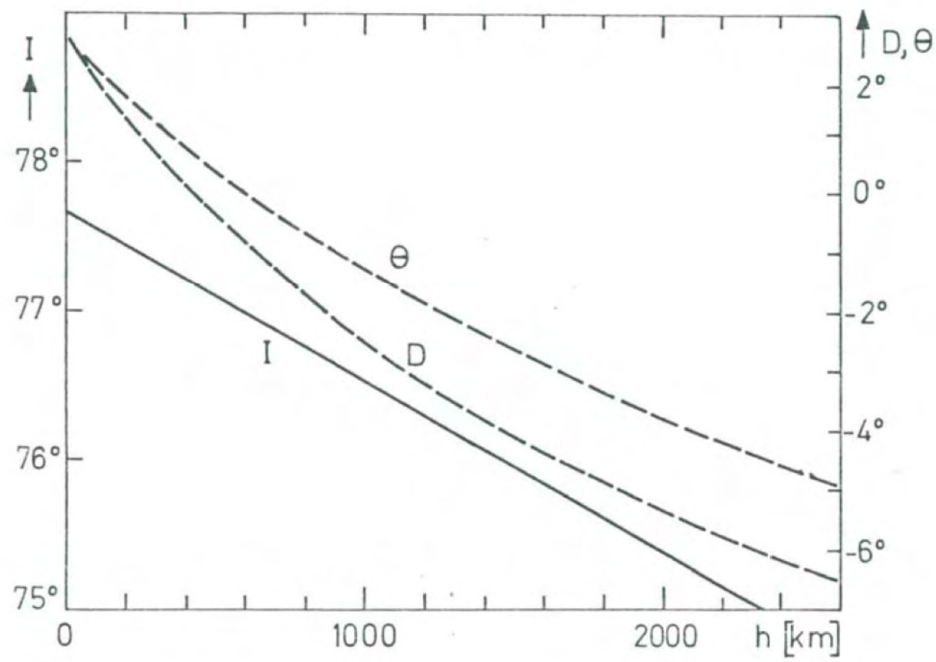


Figure 4.8.2 This figure shows the declination (D), Inclination (I) and the deviation of the field line from its direction at 600 km altitude (θ), following Haerendel, 1971. All the quantities are measured along the field line which meets the earth's surface at Tromsø.

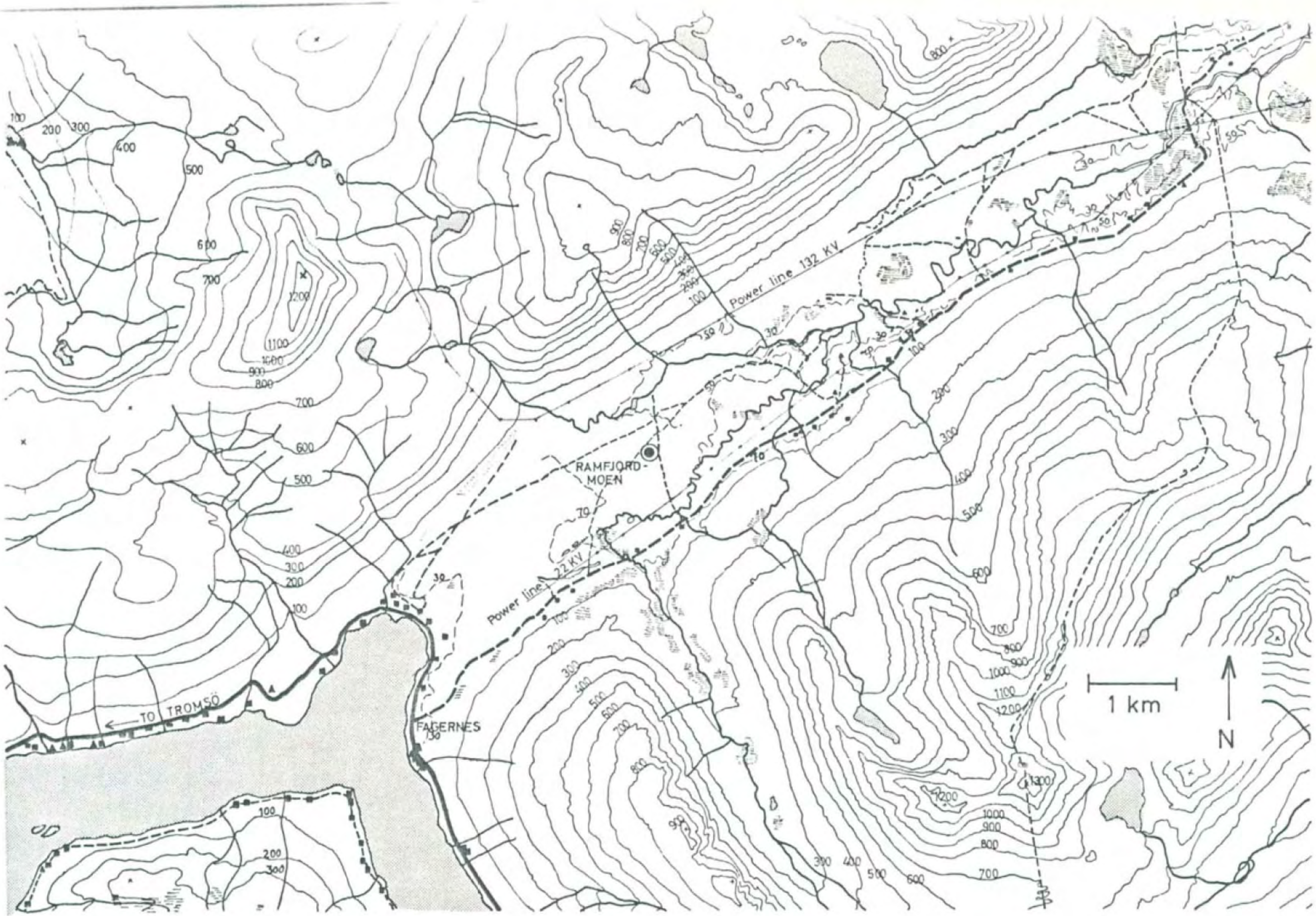


Figure 4.8.3 The site location at Ramfjordmoen. Contours are given in metres above sea-level.

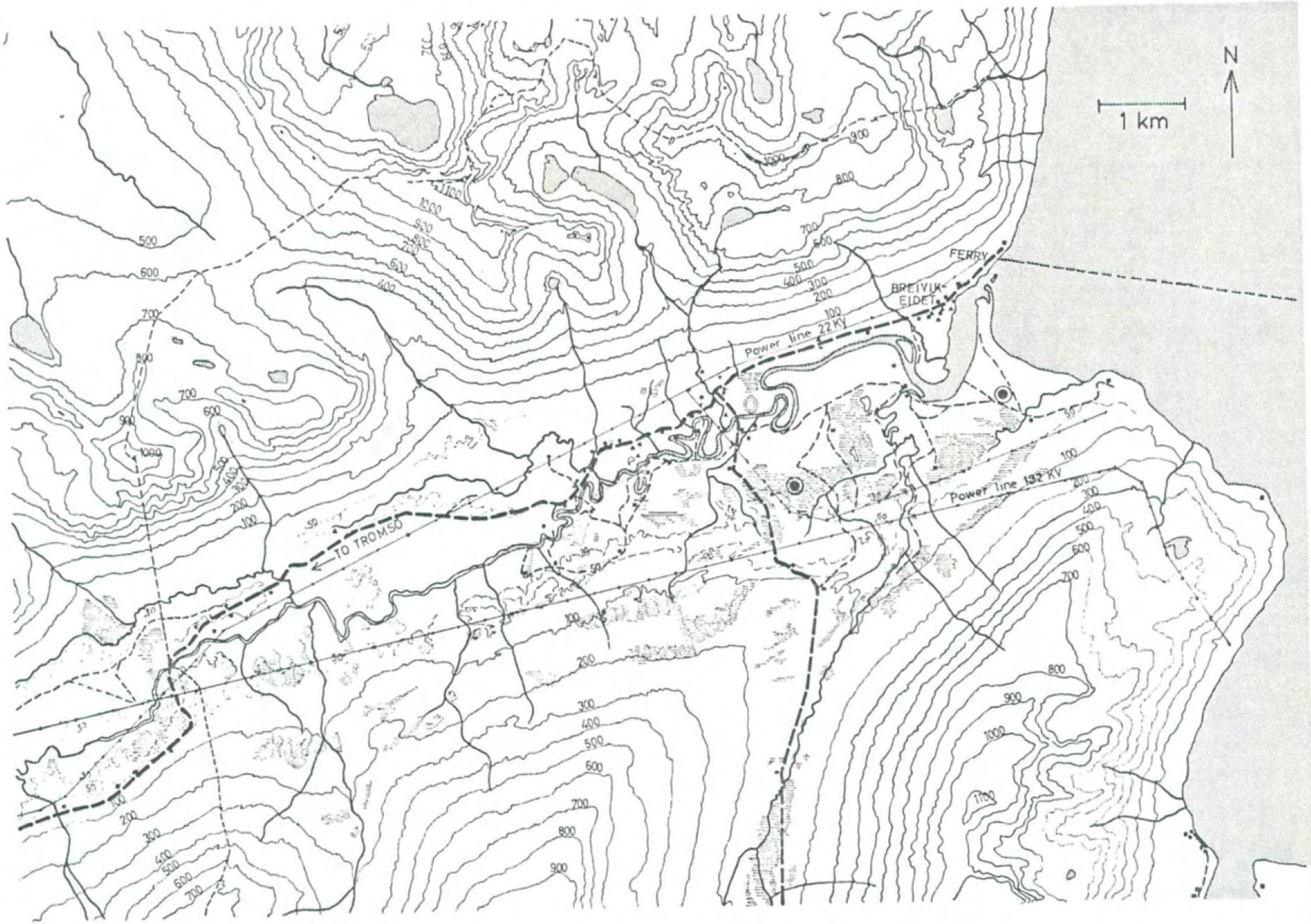


Figure 4.8.4 The site locations in Breivikeidet. Contours are given in metres above sea-level.

Table 4.8.2 Maximum and minimum temperatures in °C at Tromsø

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max. temp.	7.4	8.2	8.6	13.9	23.2	27.7	28.5	26.6	22.4	15.4	11.3	8.8
Min. temp.	-15.8	-15.4	-15.5	-14.7	-6.6	-2.5	0.7	0	-4.1	-9.0	-14.2	-15.1

The climate in Breivikeidet is rather more severe than in Tromsø. For example the minimum temperature in the winter is about -30 °C as opposed to -16 °C for Tromsø. It is probable that the maximum snow cover is less than at Tromsø.

4.8.3 Receiver station near Sodankylä

Three alternatives are considered, two of which are located at Tähtelä quite close to the observatory. They are marked on Fig. 4.8.5. The third site is in the neighbourhood of Oratuntuuri and is the more northerly centre filled circle on Fig. 4.8.6. Whereas the two first mentioned sites have a very low horizon in all directions, the third has reasonable screening towards magnetic north where the elevation angle of the horizon is 11°. The final choice should be based on a radio interference survey. From the point of view of shielding the receiver from coherent auroral scatter, the location at Oratuntuuri is to be preferred.

Distances from the three alternative sites to the centre of Sodankylä, to a road and to the nearest power line are given in Table 4.8.3.

Table 4.8.3

Site no.	Figure	Distances in km from Sodankylä	nearest road	power line
1	4.8.5	8	0.2	1.1
2	4.8.5	7	0.1	0.4
3	4.8.6	24	1.3	11

The ground on which sites Nos. 1 and 3 are located, belongs to the State whereas site No. 2 is on private ground.

The minimum winter temperatures in the Sodankylä area are appreciably lower than at Tromsø and may reach -40 °C but wind speeds and snow cover depth show lower values than at Tromsø.

4.8.4 Receiver station near Kiruna

Three alternative locations in the Kiruna area have been investigated. They all provide some shielding towards the north.

Alternative 1, Vietovaare:

This site is located on the southern slope of Vietovaare about 20 km to the west of the centre of Kiruna (see Fig. 4.8.7). A good road passes about 1.7 km from the site. A new access road of this length would have to be built. The road distance from the station to central Kiruna will be about

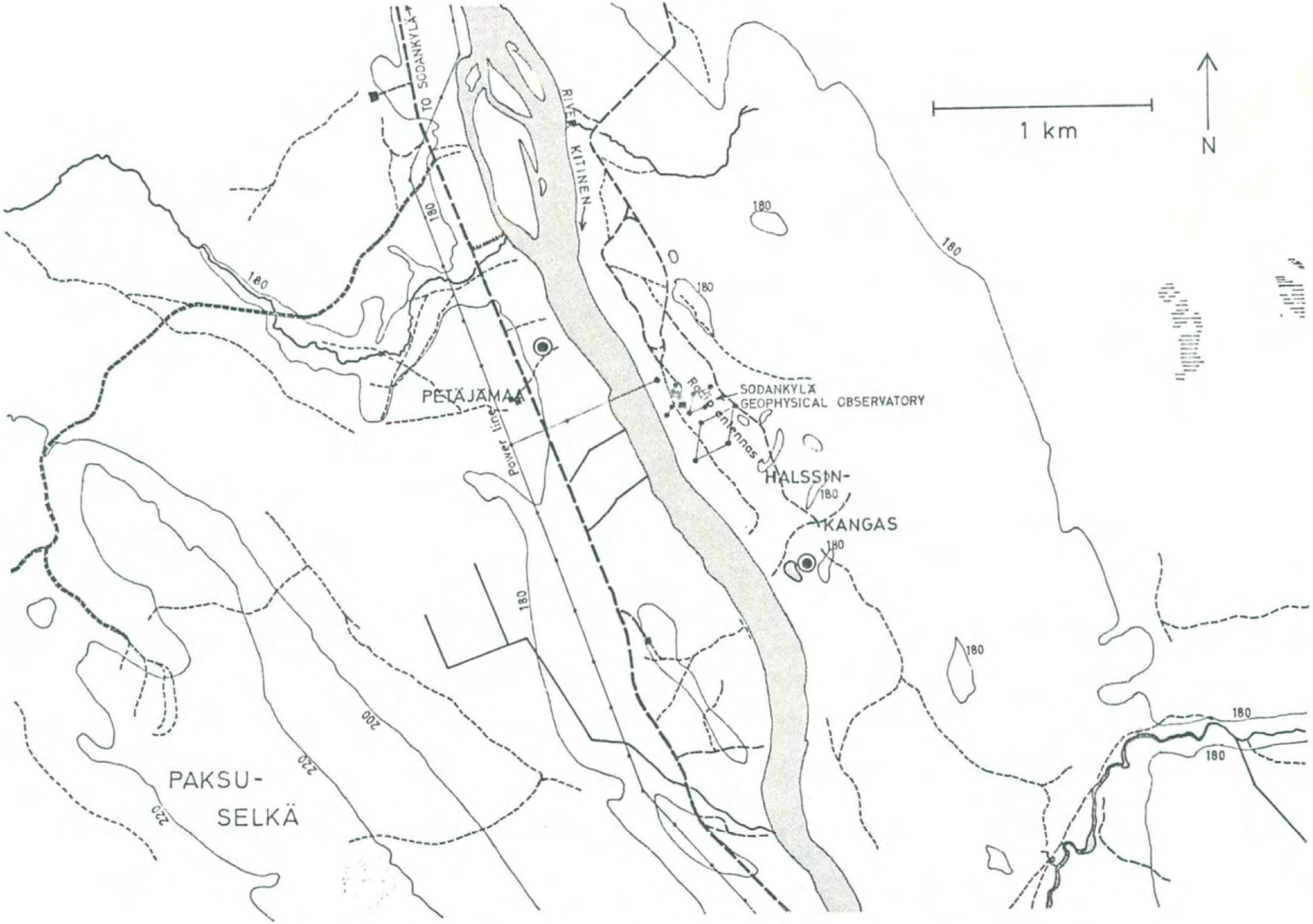


Figure 4.8.5 The site locations close to Sodankylä Geophysical Observatory. Contours are given in metres above sea-level.

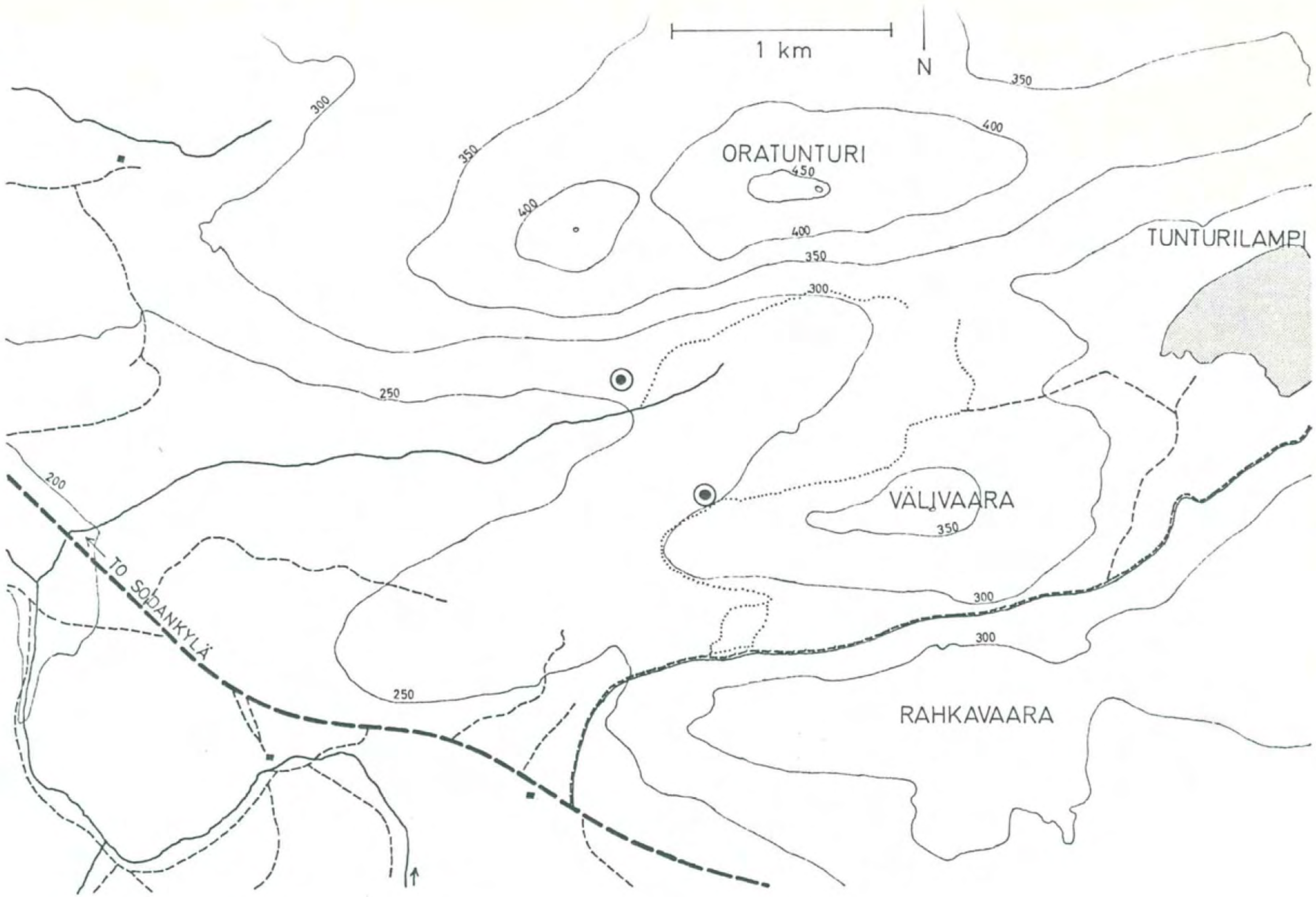


Figure 4.8.6 The site locations near Oratuntuuri. Contours are given in metres above sea-level.

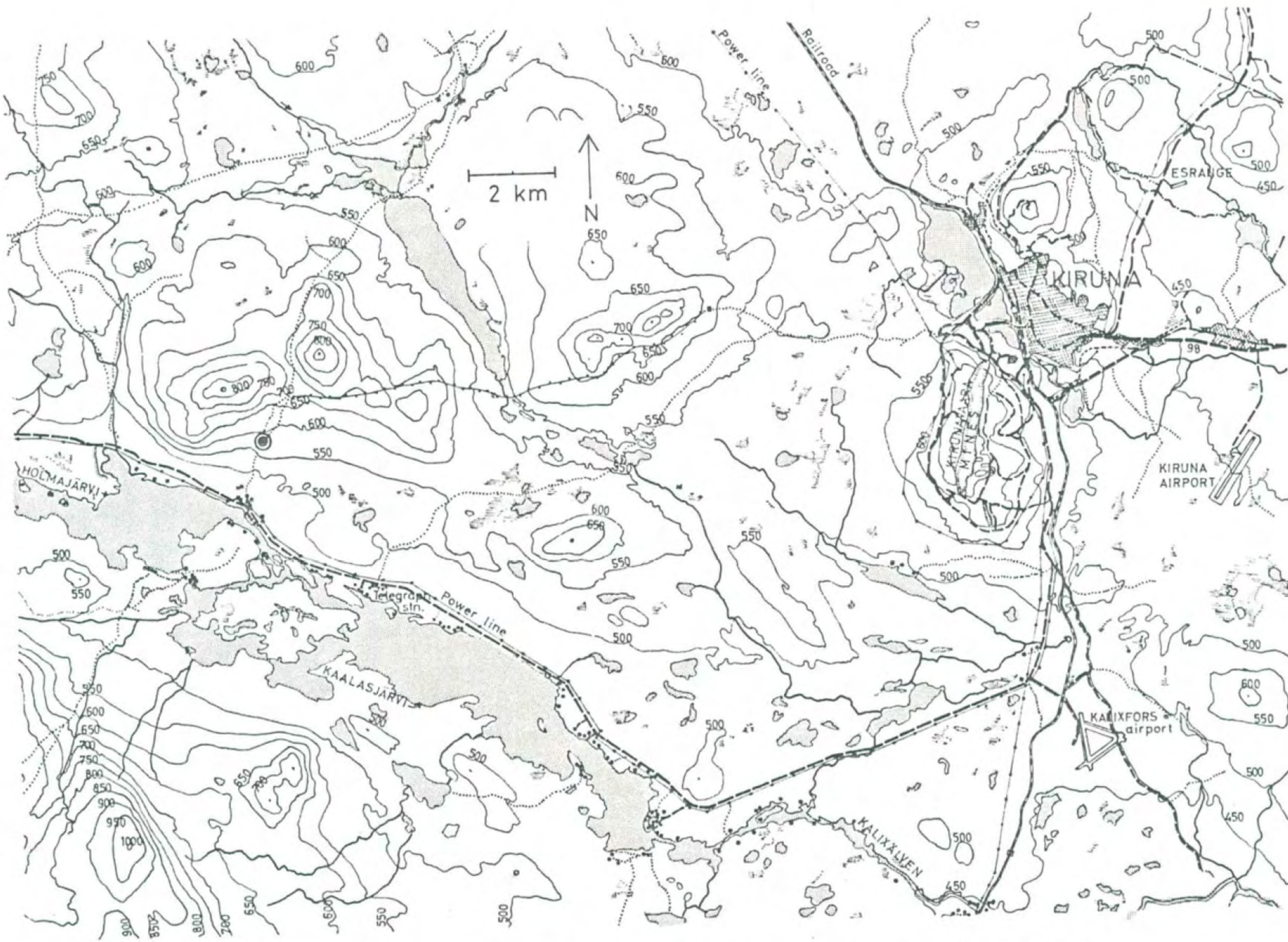


Figure 4.8.7 The site location on Vietovaare to the west of Kiruna. Contours are given in metres above sea-level.

32 km and to the Kiruna Geophysical Observatory about 41 km. The ground belongs to the State. The Lapps have some rights for reindeer herding in the area, and it may be that problems would arise in obtaining the right to use the ground.

A power line passes along the main road. The feed line to be built would then have a length of 1.7 km.

The site has a very open location on the slope of the mountain above the timber line. The climatic conditions are therefore extreme.

The elevation of the horizon is 9° to 10° in the northern direction depending on the exact location of the site. It is somewhat lower east of north and a little higher to the west.

Alternative 2, Aptasvaara:

The site is situated on the southeastern slope of the mountain Aptasvaara, located about 10 km southeast of the centre of Kiruna (see Fig. 4.8.8). The distance to the field station of Kiruna Geophysical Observatory which contains the ionosonde is 4.1 km. Over this distance a new road would have to be built. The distance by road to the centre of Kiruna will be 14 km and to the main building of the observatory 5 km.

The ground is State owned, and no particular problems are foreseen for obtaining the right to use the ground. The rights of the Lapps will, however, have to be investigated in detail before a decision on the location is taken.

The distance to Kiruna airport is only about 5 km so that the interference level may be too high. This will also have to be studied on the spot before this site is chosen.

The necessary power line will have a length of 5 km.

The elevation of the horizon is very low in all directions except for a fairly narrow sector towards north, where it is 5° to 6.5°.

Alternative 3, Saurusvaara:

This site is located on the river Kalixälven about 33 km southeast of central Kiruna (see Fig. 4.8.9). There is a private road leading from the main road (No. 98) to the area. This road is usable for a distance of about 5.3 km, but needs improvement. Over the remaining distance of 4.6 km a new road would have to be built. The road distance to the centre of Kiruna will be 45 km and to the Observatory 36 km. The road is shown on Fig. 4.2.7.

The ground at the site is State owned. The existing road is, however, private as mentioned above. There may be difficulties in obtaining the right to use it. This needs investigation before a decision is taken. A mining company (LKAB) may build a new road from Route No. 98 to Hopukka, where certain minerals exist. If this happens, that road may be used instead of the existing one. A new power line will have to be built over a distance of about 15 km.

The screening angle in the northern direction is 11.5° and it is somewhat higher towards east and somewhat lower towards west.

The final choice between the three alternative sites in the Kiruna area will be based on radio interference surveys. It seems, however, very probable that Alternative 3 is best in this respect. Since it also provides the best shielding in all directions it is certainly the best place except with regard

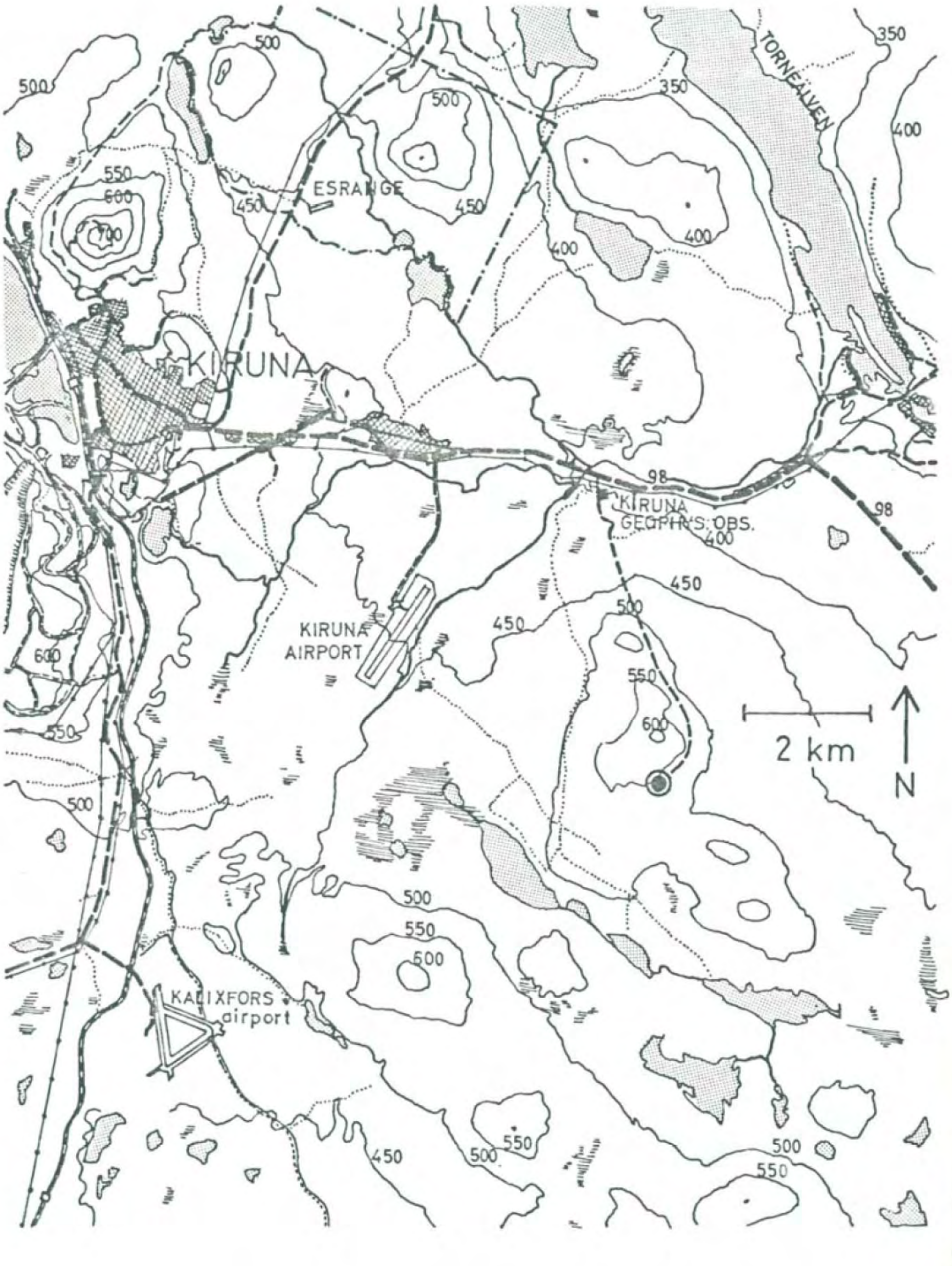


Figure 4.8.8 The site location on Aptasvaara to the east of Kiruna. Contours are given in metres above sea-level.

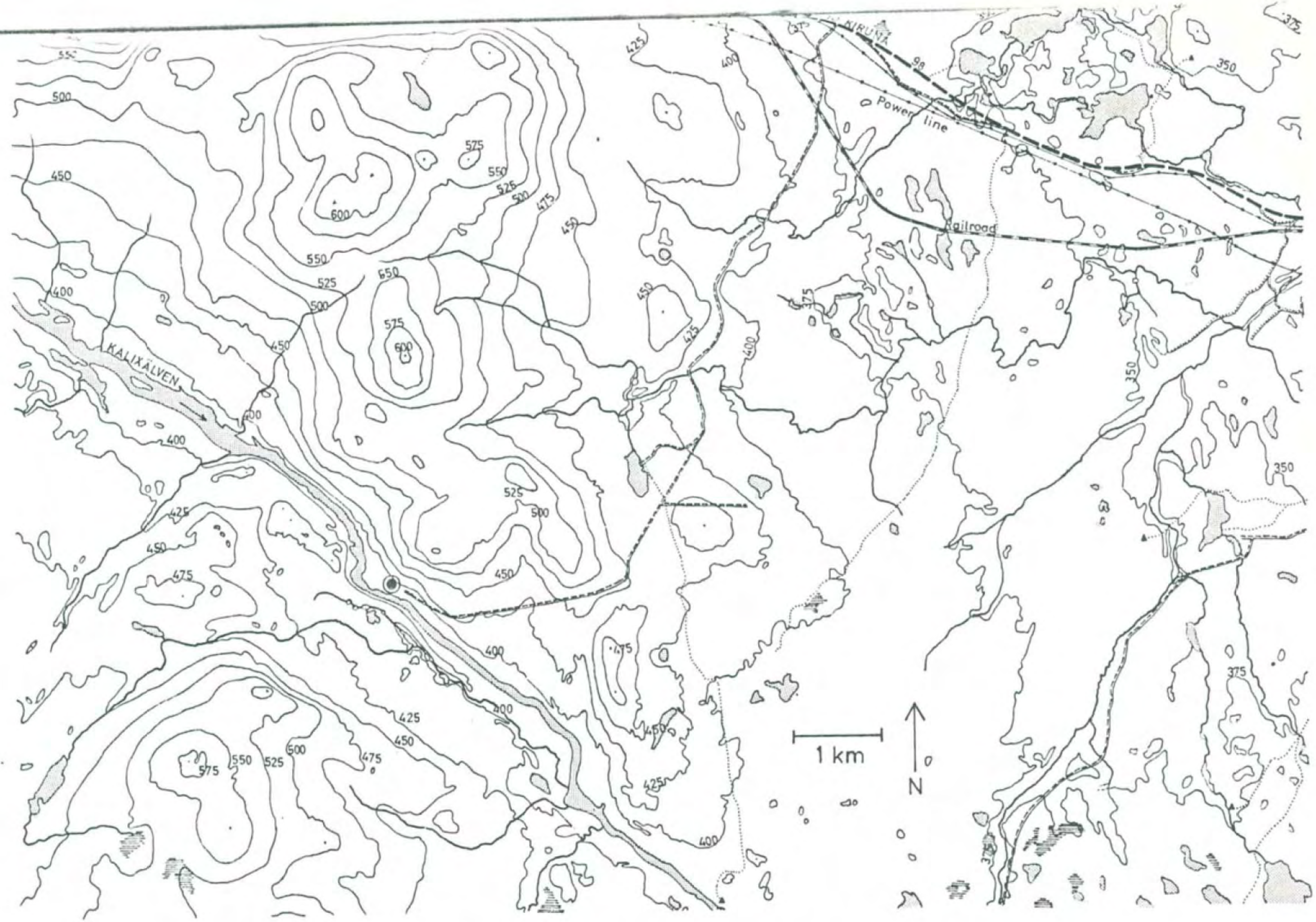


Figure 4.8.9 The site location near the river Kalix. Contours are given in metres above sea-level.

to access and cost. From the point of the view of easy access from the observatory Alternative 2 is best, but it is worst from the shielding point of view and probably also has the highest radio interference level.

The climate at the three alternative sites is certainly quite different; most severe in Alternative 1 and least severe in Alternative 3. The maximum snow depth does not often exceed 1 m in any part of the Kiruna area. The winter temperatures may occasionally reach -40 °C, particularly in the river valleys (for example Alternative 3). The average wind speed is certainly not extreme in the Kiruna area but high winds may occur at sites 1 and 2 due to their exposed situation on mountain slopes. For more details about climatic parameters for the Kiruna area, see Reference Report No. 11.

4.9 DATA HANDLING SYSTEM

Two different types of data handling systems are required in the incoherent scatter network. One type must be designed for the receiver stations in the bistatic configuration and another type for the more taxing task of the monostatic pulsed radar site.

If O^+ ions are the only ones of importance, the monostatic signal bandwidth may be somewhat less than 20 kHz. If H^+ ion spectra are to be detected these numbers must be multiplied by a factor of four. For each height one might, therefore, require to analyze the data at a rate of 100 kHz under certain situations. These rates are impossibly high for many types of data analysis one might consider. A storage of data for non-real time processing is completely unacceptable, at least on a routine basis.

A fairly large number of alternatives are discussed in Reference Report No. 10. The general data handling scheme is thought to be the most advantageous for a receiver site is one which comprises a preprocessor specially designed for fast operation in one particular mode. The preprocessor would carry out a preliminary integration and averaging of the data over a certain time interval and would then transfer the integrated data to a minicomputer. Some of the tasks of the minicomputers would be to interface with station clocks, to record the status of the antenna and the receiving equipment and to transfer the data to a digital magnetic tape for further analysis in a large digital computer. The minicomputer should also interface with a data display unit so that the operator may keep a watch on the performance of the equipment and the state of the ionosphere. It is also highly desirable to have a low data rate link to and from the transmitter station so that the parameters of the experiment may be changed in accordance with the state of the ionosphere.

The data processing at the transmitter site is considerably more complex in that a large number of heights can be observed at the same time and a considerable amount of control and book-keeping tasks related to the transmitter must be performed. Most of the considerations regarding the data handling are to be found in Reference Report No. 10 and are based on a careful study of the data handling requirements at the Jicamarca radar site. This system is made up of a small general purpose computer (Sugar et al., 1968) consisting of a central processing unit, a magnetic core storage unit and peripheral devices such as a magnetic tape unit, a high speed paper punch and reader, one or possibly two tele-typewriters and a magnetic storage drum or disk. The special purpose peripherals include an analogue multiplexer and analogue to digital converter for analogue inputs, a special high speed arithmetic unit - or a preprocessor - a magnetic core storage unit for the preprocessor, a controller for the radar transmitter and receiver and a cathode ray tube for display of the main data storage contents.

The central processing unit has two primary functions. It controls the overall operation of the system and it does a second stage of data editing and data reduction. Incoming voltages from the receiver outputs are sampled periodically and converted into digital form. These numbers (8 bits) are then stored in the data storage core. Preliminary analysis of the data - such as the computation of a number of delayed cross prducts - is then carried out for each interpulse period and the results are added into other data storage locations for the data accumulation. This process continues until the required integration time has been reached. As soon as this time has been reached the data are transferred to the core of the central processing unit for magnetic tape storage, for display and for transfer via data links to other stations. Whenever this task has been completed the central processing unit is ready to accept other information from the data core.

In addition the central processor must keep track of a large number of other tasks. First of all it must be able to set into the preprocessor a certain sequence of instructions to handle the incoming data. It must be able to set and change a number of control counters which determine pulse length and phase of the transmitter tubes, it must control the sampling rate and the height intervals to be sampled, it must control the position and temperature of a noise calibration pulse, it should keep track of the transmitter power and other essential data and it should probably, through the data link, also keep itself informed about the pointing status of the bistatic stations. A number of different observation programs should be kept in a background storage in the central processing unit so that the data taking program may be easily changed to adapt to varying ionospheric conditions. Signals must, of course, also be sent to the bistatic receivers when this happens so that their parameters may also be changed.

It may be desirable but not strictly necessary to have multiple access to the central processing unit so that one might develop and modify data taking programs during actual observation periods. The execution time per instruction in the preprocessor should be 200 - 500 ns. The preprocessor should operate on 8 bit words and accumulate in 32 bit storage locations.

4.10 COMPLEMENTARY EQUIPMENT

The upper atmosphere has been studied intensively from the Earth's surface for half a century, mainly by observing electromagnetic waves emitted from or interacting with the ionosphere. For more than a decade European scientists have also had the opportunity of sending instruments for in situ measurements up into the ionosphere.

Whereas most ground-based techniques measure in a fairly indirect way only one or two quantities, the incoherent scatter technique is unique in the amount of information on different parameters it provides and in the directness with which most of the observations can be interpreted. This does not mean that this technique is completely independent of other kinds of measurements. The very high degree of complexity that characterizes the physical phenomena in the plasma surrounding the Earth makes it most important to define the physical situation in which the incoherent scatter measurments are made, as well as possible both locally and on a global scale.

Northern Scandinavia is undoubtedly already one of the regions of the World where the facilities for ground based, rocket and satellite observations of the ionosphere are best developed. These facilities therefore, provide a most valuable complement to the proposed incoherent scatter facility. The existing, more or less continuously operating, measuring equipment of the observatories at Tromsø, Sodankylä and Kriuna is listed in Table 4.10.1. In addition to the instruments listed in the table there are magnetometers and riometers at Andenes and a riometer at Karasjok. Some of the equipment in the Tromsø area is located at the field station in Lavangsdalen. Besides the instruments listed in Table 4.10.1 there are temporary experimental programs going on at all three observatories, many of them in cooperation with other groups in many parts of the world.

Of great importance for the prospects of obtaining scientific results of maximum interest from the incoherent scatter installation is the existence in Northern Scandinavia of two sounding rocket ranges (at Andenes and Kiruna) and a satellite telemetry station (at Tromsø). Significant parts of the trajectories of rockets launched in both ranges lie within about 120 km from the proposed field line of ISR measurements.

In conclusion: the existence of the observatories in Finland, Norway and Sweden makes Northern Scandinavia a most suitable location for the incoherent scatter facility, not only from the point of view of operating the three stations but also with regard to the availability of the necessary complementary equipment.

Table 4.10.1 Ground based measurements carried out at the Tromsø, Sodankylä and Kiruna areas.

	Tromsø area	Sodankylä area	Kiruna area
Ionosonde, sweep frequency	x	x	x
" fixed frequency		x	x
" interferometric fixed frequency			x
Riometer	x	x	x
Radio-aurora		x	x
Partial reflections	x		
Pulse reflection drift	x		
Ionospheric electron content	x		x
Phase and amplitude of VLF transmissions	x	x	x
VLF emission at 8 kHz	x		
Scintillations at 136 MHz	x		
Magnetometers, standard (3 components, DC-2 minutes period)	x	x	x
Magnetometers, micropulsation	x	x	x
Allsky camera	x	x	x
Auroral spectrophotometer	x		x
" spectrograph	x		
Fabry - Perot interferometer	x		
Infrasonic waves			x

5 FINANCIAL ESTIMATES AND TIMETABLE

5.1 COST ESTIMATION

Based on the information given in the preceding sections, and in the reference reports, the capital costs may be summarized as follows. (All costs in this report are as of June 1971 and are given in terms of the accounting unit, AU, which had the value of 1 US dollar in June 1971).

	Cost MAU
UHF transmitter	3.6
VHF transmitter	1.2
UHF transmitter antenna	0.8
VHF transmitter antenna	0.6
Transmitter station incl. receiver and data handling	1.1
Receiver station near Kiruna incl. data analysis etc.	0.7
Receiver station near Sodankylä incl. data analysis etc.	0.5
UHF receiver antenna, Kiruna	0.4
UHF receiver antenna, Sodankylä	0.6
Total	9.5

The total is estimated to be accurate within ± 10 %.

It is assumed that some parts of the VHF and UHF systems will be shared, viz. the transmitter power supplies and most of the data handling system.

The cost of the stations is estimated as follows :

	KIRUNA	SODANKYLÄ	TROMSØ
Building	100	100	340
Road, power line	240	40	60
Receivers	160	160	200
Data handling equipment	120	120	350
General equipment	80	80	150
Total	700	500	1100

Unit: KAU

General equipment includes electronic test gear and those items of office equipment, furnishing etc. which cannot reasonably be included in building costs. The running cost per year includes salaries of the EISCAT staff, maintenance and spare parts, power consumption, computation etc.

The following table summarizes these expenses per year, from the time that the installations are in operation:

Salaries (20 persons)	160
Fellowships	20
Travel funds	20
Computation	50
Electronic maintenance	120
Station overhead expenses	30
Total	400

Unit: KAU

5.2 COST DISTRIBUTION

The total investment necessary to realize the proposed project assuming an operational period of 10 years amounts to about 14 MAU. Even if the two larger countries participating in the project can pay a substantial fraction of this, the remaining costs will still represent a major part of the total amounts spent on ionospheric and auroral research in the Scandinavian countries.

It seems reasonable to argue that, wherever possible, the money provided by one country should be spent on development and construction work done mainly in that country. In that way, it is felt that the building of the proposed system will not only fulfil the scientific goals outlined in the preceding chapters, but should also be of some benefit to industry in all the member countries.

Following this line of thought, we suggest that the transmitter for the UHF system be built in France, that the responsibility for the UHF antennae rest with Germany, and that Finland, Norway and Sweden each be responsible for the station on its own territory, including buildings, receivers and data handling facilities. As regards the VHF system, it is hoped that other countries will join the project. It would then be natural that they provide the VHF transmitter. The costs of the VHF antenna could then be shared between Sweden and Finland and the cost of additional buildings and data handling facilities would fall upon Norway. If no other country joins, the cost for the VHF transmitter will have to be shared among the countries already participating.

The proposed distribution of running costs between these countries, shown below, has been based on the following principles:

First, the costs should be shared between the various participants in such a way that the major contributors to the capital costs pay smaller shares of the running costs. This is reasonable because in this way the installations and staff will be located in the countries paying larger shares of the running costs, which countries will then have a return flow of money in the form of taxes and miscellaneous local purchases. Secondly, the general level of resources likely to be available for research in each country has been taken into account.

On the basis of such considerations, the following distribution of costs is suggested:

	CAPITAL COSTS MAU First stage	CAPITAL COSTS MAU Second stage	RUNNING COSTS total 10 years	TOTAL MAU
FINLAND	0.5	0.2	0.6	1.3
FRANCE	3.6		0.4	4.0
GERMANY	1.8		0.4	2.2
NORWAY	0.9	0.2	0.8	1.9
SWEDEN	0.7	0.4	1.0	2.1
OTHER SOURCES		1.2	0.8	2.0
TOTALS	7.5	2.0	4.0	13.5
	9.5			

(Accuracy of the totals ± 10 per cent).

5.3 TIME TABLE

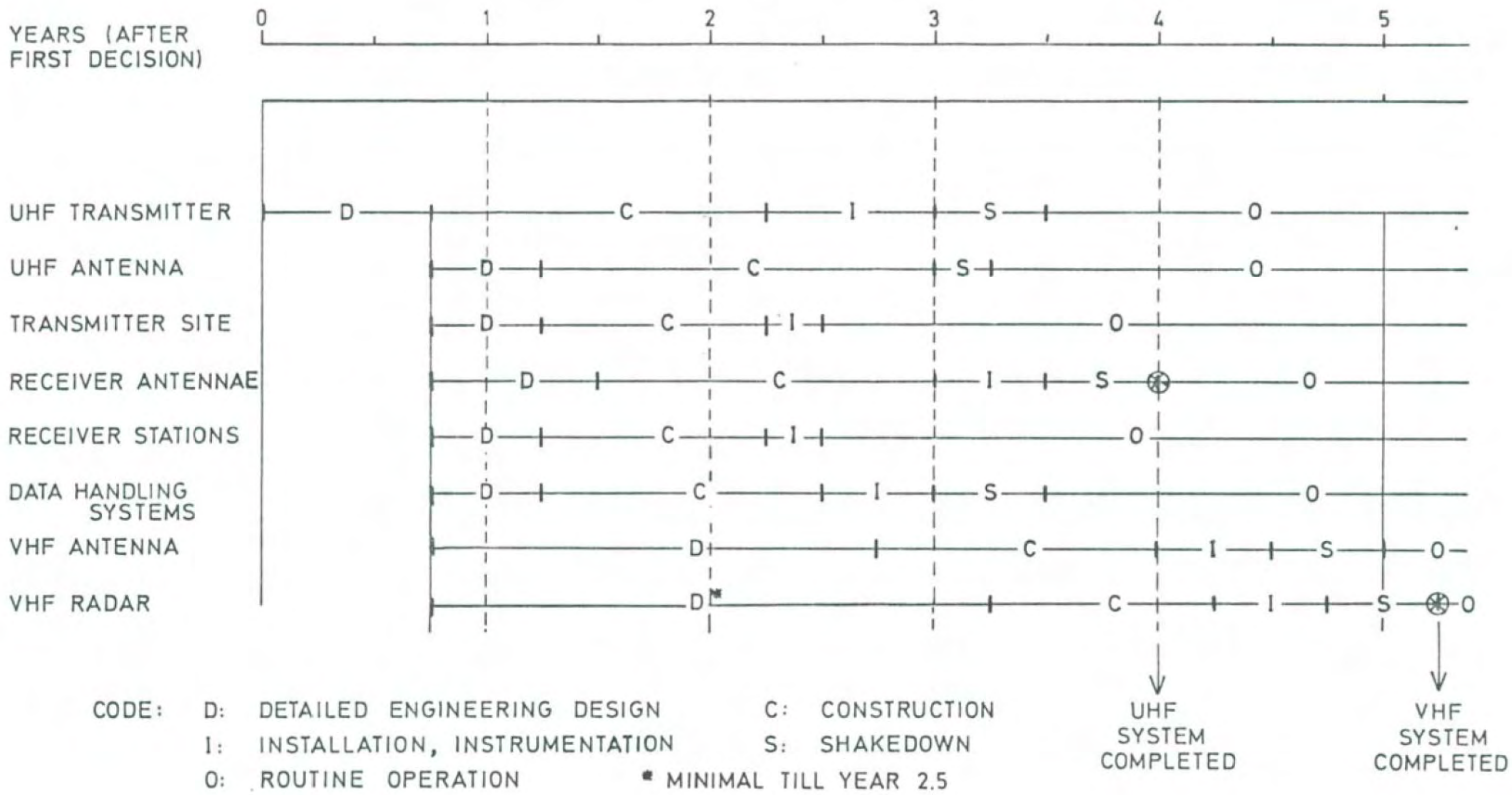
A schedule for the design, construction and commissioning of the incoherent scatter facility in Northern Scandinavia is shown in Fig. 5.1. The epoch 0 is taken to coincide with the time when a decision to go ahead is made. In the first 9 months the design of the UHF transmitter, which is the most time consuming is carried out. The transmitter is constructed in the second phase. In the later part of the first year and the first part of the second the engineering design work for the two receiver stations is done. In the second and third years design studies for the VHF radar antenna are also carried out. The three-station UHF facility will be operated, on a routine basis from the beginning of year 4.

If epoch 0 in Figure 5.1 is taken to be the beginning of 1972, the three station UHF facility will be in operation in the middle of 1975, just in time for the planned launching of the ESRO geostationary satellite. The complete facility will not be in operation until five years after a first positive decision.

If so desired the financial commitments needed for the realization of the complete facility may be made in two steps. The first commitment must cover the first two phases of Fig. 5.1. The second commitment should be made within about two years of the first one in order to have the complete facility operable before the end of the International Magnetospheric study (1975 - 1977).

A preliminary schedule for the work on each of the largest components of the facility is shown in Fig. 5.1. The financial planning must be compatible with the technical planning.

Figure 5.1 Preliminary schedule for the work on each of the largest components of the Northern Scandinavian Incoherent Scatter Facility



6 MANAGEMENT OF THE FACILITY

It is proposed that the participating governmental authorities of the countries involved form a special organization for this cooperation. It is suggested that it be called the "European Incoherent Scatter Facility" (EISCAT). Because of the length of time which will be needed to build and commission the equipment, and the long term nature of the proposed research program, it is essential that the governing body of EISCAT should be able to plan its financial commitments several years ahead. In this respect EISCAT is not different from other international research organizations. It is clear that most of the money required will have to come from the resources of National Governments. We propose that the member organizations shall be national bodies, such as National Research Councils or Institutes, through which Governments are accustomed to channel funds for fundamental research. Requests for the provision of the global sums required for capital and running expenses will be made through the appropriate official channel in each country, and arrangements for the delegation of financial control will be a matter for negotiation in each case. It is hoped in this way to provide for adequate accountability for expenditure, while at the same time giving the scientific community of each country an opportunity to influence the planning and policy of EISCAT.

The governing body of EISCAT will be a Council composed of representatives from the member organizations. On the basis of the distribution of costs proposed in Chapter 5 it is proposed here that the distribution of members of the Council from the participating countries be as follows:

FINLAND	2
FRANCE	4
GERMANY	2
NORWAY	2
SWEDEN	2

with a total membership of 12.

The Council will carry overall responsibility of EISCAT, comprising administrative and economic as well as scientific matters. It will need to meet only 2 to 4 times per year. It may delegate the scientific program decisions to a sub-committee which can meet more frequently if desired.

Day-to-day operation of the facility will be in the hands of a Director chosen by the Council. He will have two assistant scientists and a technical staff of about 18 people. The group at the transmitter station at Tromsø will be in charge of the technical operation of the facility. The scientific headquarters will be at Kiruna and will be responsible for the handling of the recorded data.

EISCAT will formally contract out the running of the facility and its program to the following research institutes:

The Auroral Observatory, Tromsø

The Geophysical Observatory, Sodankylä

Kiruna Geophysical Observatory, Kiruna

This means that EISCAT will not employ any personnel directly but they will all, including the Director, be formally employed by these institutes.

It is foreseen that it may be convenient to involve an existing international scientific organization as an intermediary in transferring national funds to EISCAT.

It is proposed that EISCAT should provide a small number of Fellowships, (1 to 3) for young scientists from member countries for one, or possibly two, years work with the facility. Besides the Director and the two assistant scientists and the Fellows mentioned above, the facility will be used by

- members of groups in member countries, who will have the right to use the existing facility without cost if their scientific program has been approved by the Council (or its program committee),

- scientists from non-member countries, who will reimburse EISCAT for running costs according to conditions agreed on the Council in each case,

- particularly competent scientists (from any country), invited by the Council to work with EISCAT for a limited period of time.

The Council will decide on the conditions for accepting prospective new member organizations of EISCAT, including their representation on the Council.

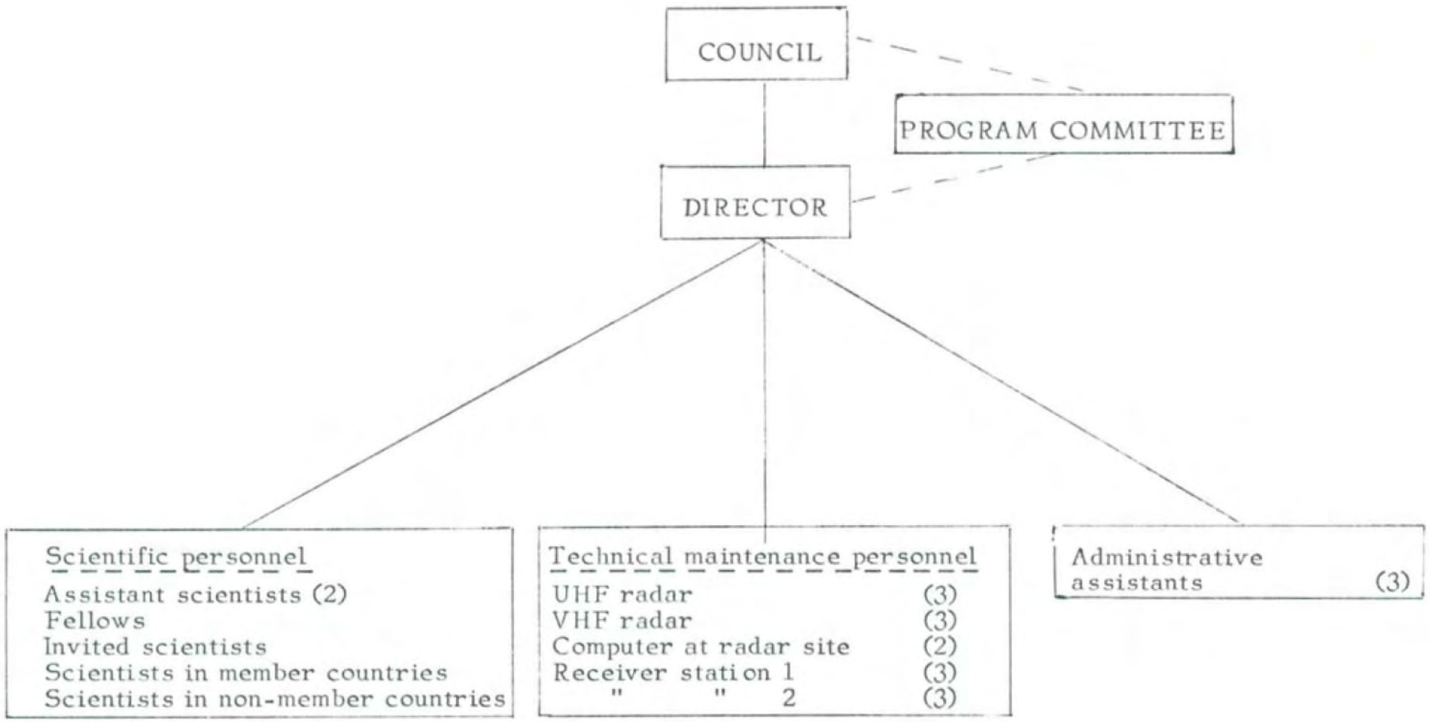


Figure 6.1 Organigram for EISCAT.
The numbers in parentheses give the number of posts.

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University of Illinois	1971	Upper Atmospheric Observatory, Preliminary Engineering Study
Waldteufel, P.	1968	Some preliniary considerations for an incoherent scatter radar embarked on a ship, CNET Technical Report

LIST OF SYMBOLS USED

a	Loss factor of system
b	Receiver bandwidth
b_i	Half power bandwidth
B	Magnetic field
c	Velocity of e.m. waves
d	Distance to scattering element
E	Energy in eV
f	Frequency
f_H	Gyro frequency
f_N	Plasma frequency
G	Antenna gain
h	Altitude
k	Boltzmann's constant
^oK	Degrees Kelvin
L	Mc Ilwain shell parameter
m_i	Ion mass
$\bar{m}_i$	Mean ion mass
n	Repetition frequency
N_e	Electron density
N	Number density
N_o, N_{N_2}, N_{o_2}	Number densities for O, N_2 and O_2
P	Power
P_n	Noise power
P_s	Signal power at the receiver
R,r	Suffix indicating receiver
R	S/N ratio
r_e	Electron radius
S	Ratio correlated to uncorrelated power
t	Time
t	Integration time

T	Suffix indicating transmitter
T_e	Electron temperature
T_i	Ion temperature
T_n	Noise temperature
V	Plasma drift velocity
V	Scattering volume
α	$2\pi \lambda_D/\Lambda$
β	Angle between incident and scattered radiation
δ	Differential
Λ	$\lambda \sec(\beta/2)/2$
λ	Radio wavelength
λ_D	Debye length
λ_{in}	Mean free path for ion neutral collisions
ν_{in}	Collision frequency for ion neutral collisions
ρ	Correlation function
σ	Total cross section
σ_0	Scattering cross section for electrons
τ	Pulse length
χ	Angle between electric field and direction of observation

APPENDIX 1

URSI Commission III
Ottawa 1969

RECOMMENDATION III. 16. - INCOHERENT SCATTER OBSERVATORIES IN THE AURORAL ZONE

considering:

(a) that the potential value of the incoherent scatter technique for studies of ionospheric electron density, temperature and composition in the auroral zone has not yet been exploited;

(b) that there is great uncertainty concerning the properties of the ionosphere in the auroral zone;

(c) that the establishment of a high-power incoherent scatter installation in this zone is one of the most desirable future extensions of the incoherent scatter program;

notes with satisfaction that it is planned to move an existing radar from Stanford to Alaska in the near future, and that this minimum installation will make possible some exploratory studies and will also provide information about possible special problems that may occur in the application of the scatter technique in these latitudes;

and considering further:

(d) that the climate and other factors in northern Europe seem to be more favourable than in other parts of the auroral zone for the operation of such an installation;

recommends that European research groups be urged to investigate the possibility of establishing an incoherent scatter observatory in the European auroral zone.

APPENDIX 2

LIST OF REFERENCE REPORTS

No.	Title	Author or editor
1	Interference of Radio-Aurora	A. Egeland, University of Oslo
2	Non-Specular Clutter	G.N. Taylor, Royal Radar Establishment, Malvern
3	Sondeur ionospherique auroral (UHF) (Premiere Partie)	B. Daveau, Thomson-CSF, Bagneux
4	Sondeur ionospherique auroral (UHF) (Deuxieme Partie)	B. Daveau, Thomson-CSF, Bagneux
5	Evaluation des performances d'un sondeur a diffusion incoherente	F. du Castel and G. Vasseur, CNET
6	The UHF Transmitter Antenna	G. Svennerus, Research Institute of National Defence, with the collaboration of Allmänna Imgenjørsbyrån AB, Stockholm
7	The VHF System	T. Hagfors, Lincoln Laboratory, M.I.T.
8	Grid antenna array for VHF incoherent scatter radar	M. Tiuri, S. Tallqvist and S. Urpo, Technical University, Helsinki
9	Reference Ionosphere	A. Haug and O. Bratteng, Auroral Observatory Tromsø
10	The Data Processing System	T. Hagfors, Lincoln Laboratory, M.I.T:
11	Locations and costs of transmitter and receiver sites for an incoherent scatter facility in northern Sweden	G. Sørensson, Allmänna Ingenjørsbyrån AB, Stockholm