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SPATIAL MONITORING OF AURORAL EMISSIONS

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Preface

This report was presented at the 10th Annual Meeting on Upper Atmosphere Studies by Optical Methods, in Grasse, France, September 1982.

The interest for auroral imaging systems has increased considerably in northern Scandinavia during the last year. The ideas presented in this report were preliminary at the time when the report was written. In December 1983 one of the systems is in operation and the second system is under development. The final performances of the systems will be reported about in later publications.

Kiruna in December 1983

Åke Steen

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Abstract

A ground based technique to monitor the three-dimensional distribution of auroral emissions is presented. The system is composed of two subsystems. A monochromatic imaging system with digitizing capability monitors the two-dimensional variation of auroral intensity with 50° field of view. A second height measuring system obtains in real time the height distribution of the auroral luminosity within the field of view of the imaging system. This paper is a report of the stepwise development of the complete system. The measurements will be carried out in the magnetic meridian plane through the EISCAT-site in Norway and the Kiruna Geophysical Institute. The operation of the optical system will as much as possible be combined with incoherent scatter radar measurements.

1. Introduction

The aurora is a three-dimensional time dependent process with an unknown spatial distribution of the cause and effect relationship. The optical emissions from atoms, molecules and ions are spread out over a large altitude interval in the ionosphere. The spatial distribution of the emissions is one of the results of all processes that are active during an auroral event. Consequently the spatial development of auroral emissions has always been a desirable object for auroral studies. The spatial development gives information about the mechanisms that are responsible for the aurora. However passive ground based measurements suffer from an unavoidable integration of light along the line of sight. But compared to space borne experiments it is easy to make the ground based experiments repeatable and unexpensive.

Two systems can be constructed, one imaging system that records the auroral intensity variations in a nearly horizontal plane and one system that measures the vertical intensity variations. Both systems are influenced by the integration of light along the line of sight, but by combining the measurements with models for the energy dissipation of the precipitating particles it will be possible to obtain a three-dimensional representation of the aurora, at least for special events. Necessary computer simulations will be carried out but are not a topic of this experimental report.

Two-dimensional imaging systems have been used both from ground (Mende and Eather, 1976; Oguti, 1976) and from space. The complexity of the imaging systems has varied from just being a TV-camera connected to a video recorder to high speed systems with digitizing capability.Auroral height measuring systems have a longer history. Most of our information about the height of auroral structures are based on the measurements made during the first half of this century (Størmer,1955), using a photographic triangulation technique. That material shows that most of the auroral luminosity is located between 90 and 150 km altitude. Mechanically scanning photometers have been used to determine the height but with low temporal resolution (Romick and Belon, 1967b). Stenbaek-Nielsen and Hallinan (1979) demonstrated, by a new stereo TV technique, that the vertical extent for certain auroral forms can be less than 2 km. Kaila (1981) has recently developed the photographic triangulation technique further by using a net of all-sky cameras in northern Scandinavia. Kaila (1981) achieves a three-dimensional representation of the aurora. So far it has not been possible to determine the height of an auroral form in real time. The height measuring system discussed in this report is designed to meet that demand. It will also give good height and temporal resolution.

There are many reasons for studies of the spatial distribution of auroral emissions. If the process of excitation is known the energy of the primary particles is directly related to the height and the intensity of the appropriate emission. This relation can be checked together with incoherent scatter radar measurements. Besides combined EISCAT-measurements, artifical optical emissions produced by the Heating radar (Stubbe and Kopka, 1979) at Ramfjordmoen will be a suitable object for application of the height measuring system. The combination of the imaging system and the height measuring system will make it possible to study the auroral intensity distribution in an arc and the temporal and spatial variation during the movement of an arc.

2. Auroral Dynamics Imaging System

2.1. Optical part.

The Auroral Dynamics Imaging System (ADIS) has been constructed to give as much flexibility as possible to various modes of operation. The construction of ADIS is now, in august 1982, to be completed. The components of the system are shown in figure 1. So far only the components have been tested not the whole system acting together. It means that the technical specification given here is only preliminary and not complete.

Figure 2 is a schematic illustration of the optical part. To allow monochromatic imaging with a wide angle front lens a telecentric lens system is used. The telecentric design ensures the same size light cone at the focal plane for each point in the field of view. At F4.0 the front end lens gives a 75 mm telecentric image with 5^{o} cone angle in the plane of the interference filter, which fully fills the F0.7 camera lens and reduces the scattered light entering the system. A light weight filter wheel has been constructed to hold 4 interference filters, 3 inch diameter each. The filter wheel axis is connected to a powerful stepping motor which is under computer control. A preliminary test indicates that 0.3 seconds is enough to change filter position. If the stepping motor should fail the absolute position of the filter wheel can be read from a 10 bit angle encoder by a computer. At present only two interference filters are used centered at λ_p4284 Å and λ_p4335 Å, both with 25 Å passband,suitable for studying the N_2^+emission of λ 4278 Å and the background continuum approximately 50 Å above.

The image in the filter plane is reimaged onto the face plate of an ISIT-camera with a 12.8 x 9.6 mm vidicon format. If for instance all-sky video recording is desired it is only necessary to change the front lens and the telecentric lens. Two Betalights, with interference filters, are mounted in holders as indicated in figure 2. The two Betalight images in the corners will allow for frame to frame calibration. The absolute calibration source will be applied from outside. The optical part shown in figure 2 will be mounted in a temperature controlled box, steerable both in azimuth and elevation. The box will be installed at the roof of the main building of the Kiruna Geophysical Institute.

2.2 Data processing

ADIS is built around a general purpose interface bus, IEEE-488, as shown in figure 1. The definition of the IEEE-488 bus permits data transfer rates up to 1.0 Mbytes/second. Most of the control and data flow are taking place on that bus.

The ISIT-camera produces an analog video signal with a frame to frame interval of 20 ms. A digital data supply unit encodes house-keeping data such as filter position, time and date on the video signal. Ten per cent of each frame is used for the encoding which is in a computer and human eye readable format. The digital data supply unit gets its information from the control unit and from a quartz clock.

After passing through the encoding unit the video signal can either be stored on a video tape or connected to a real time image processor. The image processor works with 8 bits for the A/D-conversion and uses 12 bits for storage. Each frame is digitized into 256x256 pixels. The IEEE-interface on the image processor can transfer at maximum 600 kbytes/second, which means that an integration time of at least 0.2 seconds is needed in the processor to keep up with the video rate. The image processor is capable of integrating frames, to subtract subsequent frames from each other and to convert the digitized frame back to a video signal. All of these functions can be programmed on the IEEE-bus.

A fast HP-computer with 830 kbytes of memory acts as a control unit. All activities taking place on the IEEE-bus are initiated by the HP-computer. The stepping motor drive is supplied with an IEEE-interface, which makes it possible to programme speed, acceleration and how many steps to move the filter wheel axis. The information from the angle encoder and the quartz clock are also made available to the IEEE-bus. All units mentioned so far are placed only 10 meters from the ISIT-camera. More elaborate image processing can be made on a high speed general purpose computer which also has been supplied with an IEEE-interface. The two IEEE-buses are connected by a bus extender which will permit data transfer rates close to 500 kbytes/second. The 75 Mbyte hard disc connected to the general purpose computer can store 20 seconds of video data.

The flexibility of ADIS allows for several modes of operation. The major problem today in image processing is the storage of large amount of digital data with random access. A solution to this problem can be foreseen when optical video discs become available for both read and write. The most economical way today is to store video data in an analog form on a video cassette tape recorder. That will be the technique used here. For shorter time intervals, 20-120 seconds, the data will be processed through the image processor where integration and subtraction of background can be done. After an integration of typical 10 frames the IEEE-interface can transfer data to the hard disc for later advanced processing. During auroral recording situations the data will go to the video recorder from the ISIT-camera. Afterwards playback from the video recorder is made with a decrease in the signal to noise ratio.

3. Height Measuring System

3.1 Principle of operation

The idea behind the Height Measuring System (HMS) is demonstrated in figure 3. HMS is planned to measure the height and the height distribution of auroral emissions above EISCAT's radar station at Ramfjordmoen, Norway. HMS is designed to be a low light level 1-D imaging system with capability to obtain height information in real time. The system consists of two nearly identical stations, A and B. Station A is located on the roof of the main building of the Kiruna Geophysical Institute. Station B is placed in Kurravaara at a distance of 12 km from station A, geomagnetic north of Kiruna. Each station obtains an intensity profile with high spatial resolution. The intensity profiles are the results of the integration of light along the lines of sight. For an auroral structure the same point on the two profiles can easily be identified by a correlation technique, due to the short base line. Two angles can be obtained and the latitude and altitude of the auroral form can be calculated. The formulas in figure 3 are not corrected for a spherical earth.

As was shown by Romick and Belon (1967a) the most accurate profiles are determined for auroras positioned over the most poleward station when viewed by an equatorward station at least 200 km away. This is due to the geometrical effects of perspective and path length of observations. That makes auroras located over Ramfjordmoen very favourable to study from Kiruna.

For more complicated auroral situations such as multiple arcs, it will also be necessary to obtain data from a meridian scanning photometer at Ramfjordmoen. Simultaneous measurements with EISCAT will also contribute.

3.2 1-D camera

The development of the 1-D camera is in its early stage and the camera will not exists in hardware before 1983. We hope to construct the camera with a single camera lens giving approximately 20° field of view (figure 4). The interference filter will be placed in front of the lens, and centered at λ 4278 Å. The image intensifier is planned to be a second generation inverter image tube, 25 mm diameter, selected for low dark current, and with a special red output phosphor. The coupling between the image intensifier and the linear array will be a fiber optics reducer coupling to achieve good efficiency and resolution. The linear array will be a choice between a CCD-array and a photodiode type array with at least 1024 pixels resolution. The whole assembly is going to be cooled down to approximately -50° C to reduce the integrated dark current on the linear array and the statistical and thermal noise for the image intensifier. It is estimated to get a sensitivity of approximately 20 R for an integration time of 1 second. Although each element in the linear array subtends approximately 70 m at auroral heights for a 1024 elements array and 20° field of view we will supply the local station with such an array, to be able to study very fine structures during special auroral events.

3.3 Data flow

The configuration of the Height Measuring System is shown in figure 5. Each station is operated by a μ-processor which in turn is controlled by a computer at the Kiruna Geophysical Institute. All data and control flow are taking place on the IEEE-bus. The remote station data transfer rate is limited by the telephone lines to about 1.2 kbytes/second, whereas the nearby station can transfer at maximum speed, 1.0 Mbytes/second. The difference in data transfer rates implies a longer integration time or a smaller linear array at the remote site.

The integration time is controlled by the central computer. On command the local μ-processor makes a readout from the array and transfers the intensity profile data to the central computer. The two profiles are processed by a correlation technique and the height of an auroral arc can be displayed in real time. The raw data or just the heights are to be stored.

4. Future developments

As was discussed in the introductory part of this paper a three-dimensional measurement technique of the aurora is highly desirable. By letting the field of view of the two systems intersect as shown in figure 6, a three-dimensional technique is possible. ADIS will measure the two-dimensional horizontal intensity variation while HMS measures the vertical intensity variation. To do this both stations must be moved approximately 200 km south of Kiruna along the magnetic meridian.

All of the optical measurements are taking place in the magnetic meridian plane where incoherent scatter radar measurements will be made on a routine basis. It means that information about several other ionospheric parameters also will be available.

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Figure Captions

Figure 1 Configuration of the Auroral Dynamics Imaging System (ADIS). All control and digital data flow are taking place on the IEEE-488 bus. The connections to the IEEE-488 bus are drawn without arrows, which means that the flow of information is bidirectional. The numbers given are the maximum data transfer rates in bytes/second.

Figure 2 The optical part of the Auroral Dynamics Imaging System. Only the essential details are shown.

Figure 3 The principle of measurement for the Height Measuring System (HMS). Triangulation from Kiruna is favourable when auroral structures are located over Ramfjordmoen. Formula 1 and 2 are only approximative and are not corrected for a spherical earth.

Figure 4 Optical part of the Height Measuring System (HMS). The drawing shows only the details of most importance, and is not drawn to scale.

Figure 5 Configuration of the Height Measuring System (HMS). One station is located 12 km away from the IEEE-488 bus and the other is placed within 15 meters.

Figure 6 Merging of ADIS and HMS implies that the two stations must be moved 200 km south of Kiruna. The lower figure shows the principle of data flow after merging.

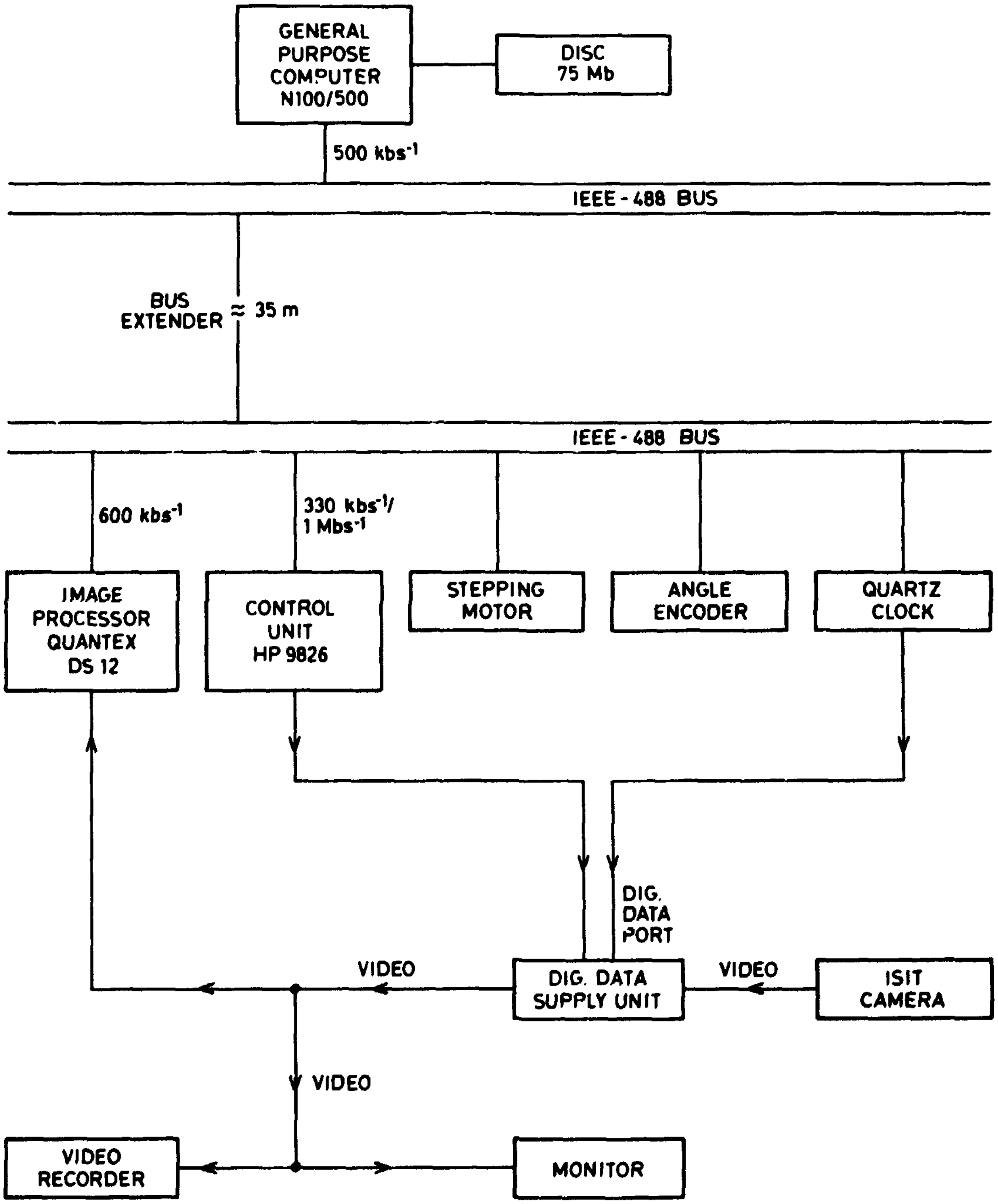

GENERAL PURPOSE COMPUTER N100/500
DISC 75 Mb
500 kbs⁻¹
IEEE-488 BUS
BUS EXTENDER
≈ 35 m
IEEE-488 BUS
600 kbs⁻¹
330 kbs⁻¹/ 1 Mbs⁻¹
IMAGE PROCESSOR QUANTEX DS 12
CONTROL UNIT HP 9826
STEPPING MOTOR
ANGLE ENCODER
QUARTZ CLOCK
DIG. DATA PORT
VIDEO
DIG. DATA SUPPLY UNIT
VIDEO
ISIT CAMERA
VIDEO
VIDEO RECORDER
MONITOR

Figure 1

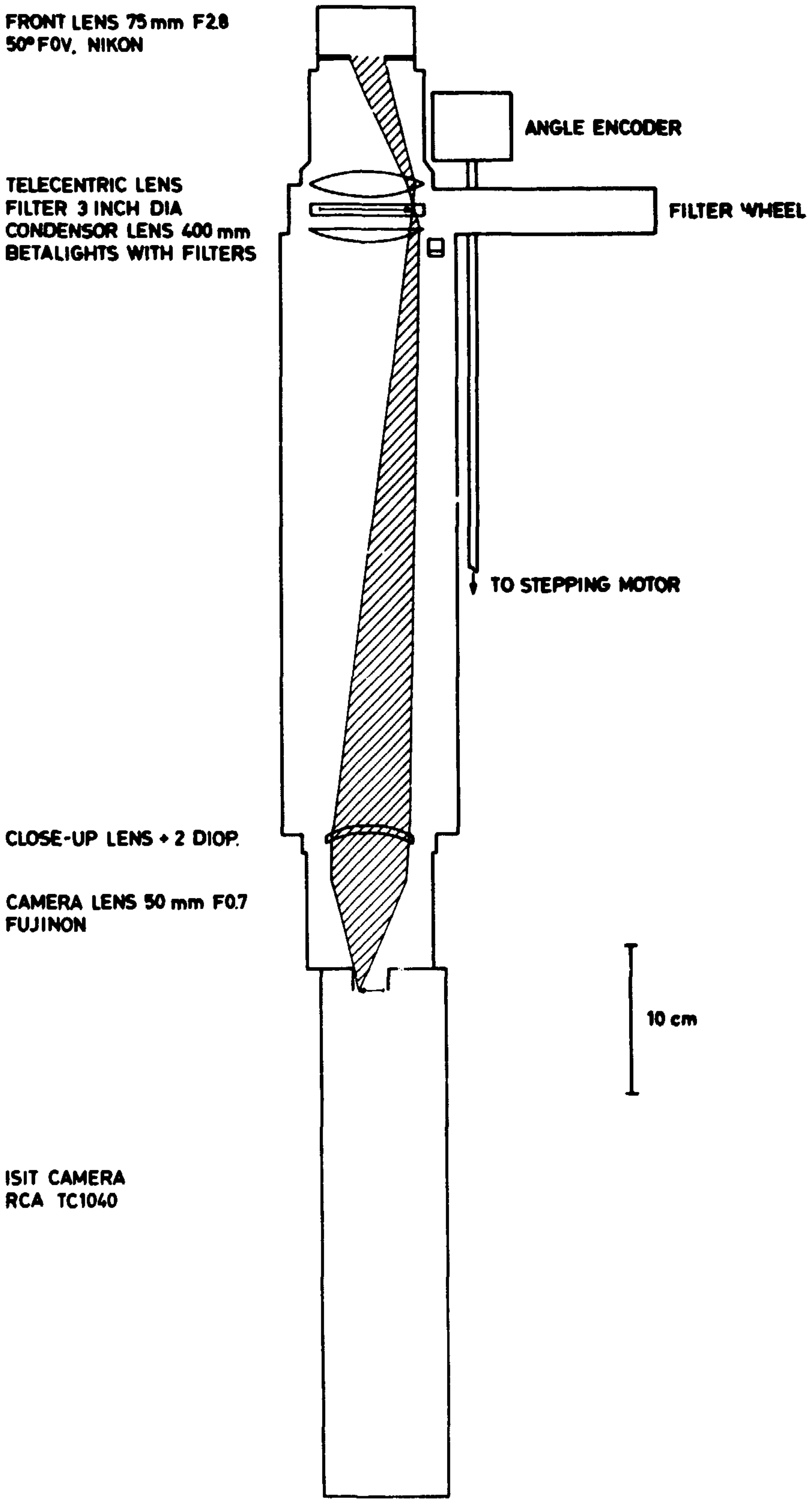
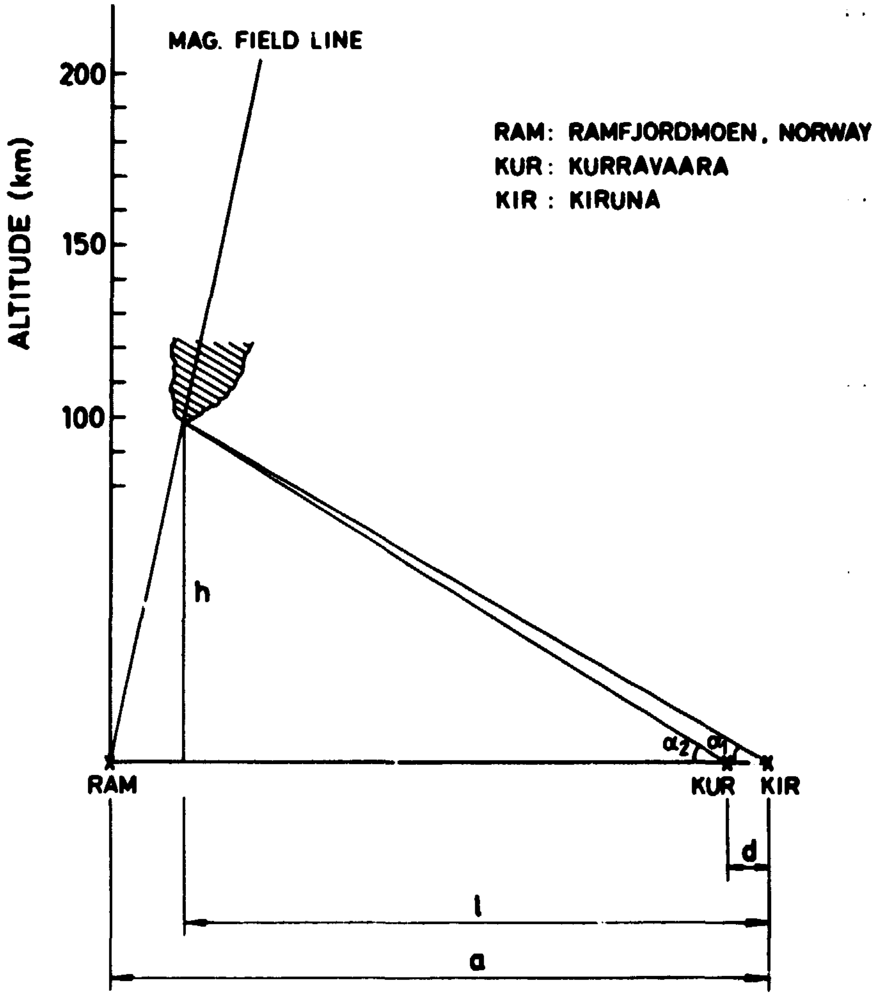

FRONT LENS 75 mm F2.8
50° FOV. NIKON
ANGLE ENCODER
TELECENTRIC LENS
FILTER 3 INCH DIA
CONDENSOR LENS 400 mm
BETALIGHTS WITH FILTERS
FILTER WHEEL
TO STEPPING MOTOR
CLOSE-UP LENS + 2 DIOP.
CAMERA LENS 50 mm F0.7
FUJINON
10 cm
ISIT CAMERA
RCA TC1040

Figure 2



$$h = d \cdot \frac{\tan \alpha_1 \cdot \tan \alpha_2}{\tan \alpha_2 - \tan \alpha_1} \quad \text{(km)} \qquad (1)$$

$$l = d \cdot \frac{\tan \alpha_2}{\tan \alpha_2 - \tan \alpha_1} \quad \text{(km)} \qquad (2)$$

$$d \approx 12 \quad \text{(km)} \qquad (3)$$

$$a = 198 \quad \text{(km)} \qquad (4)$$

Figure 3

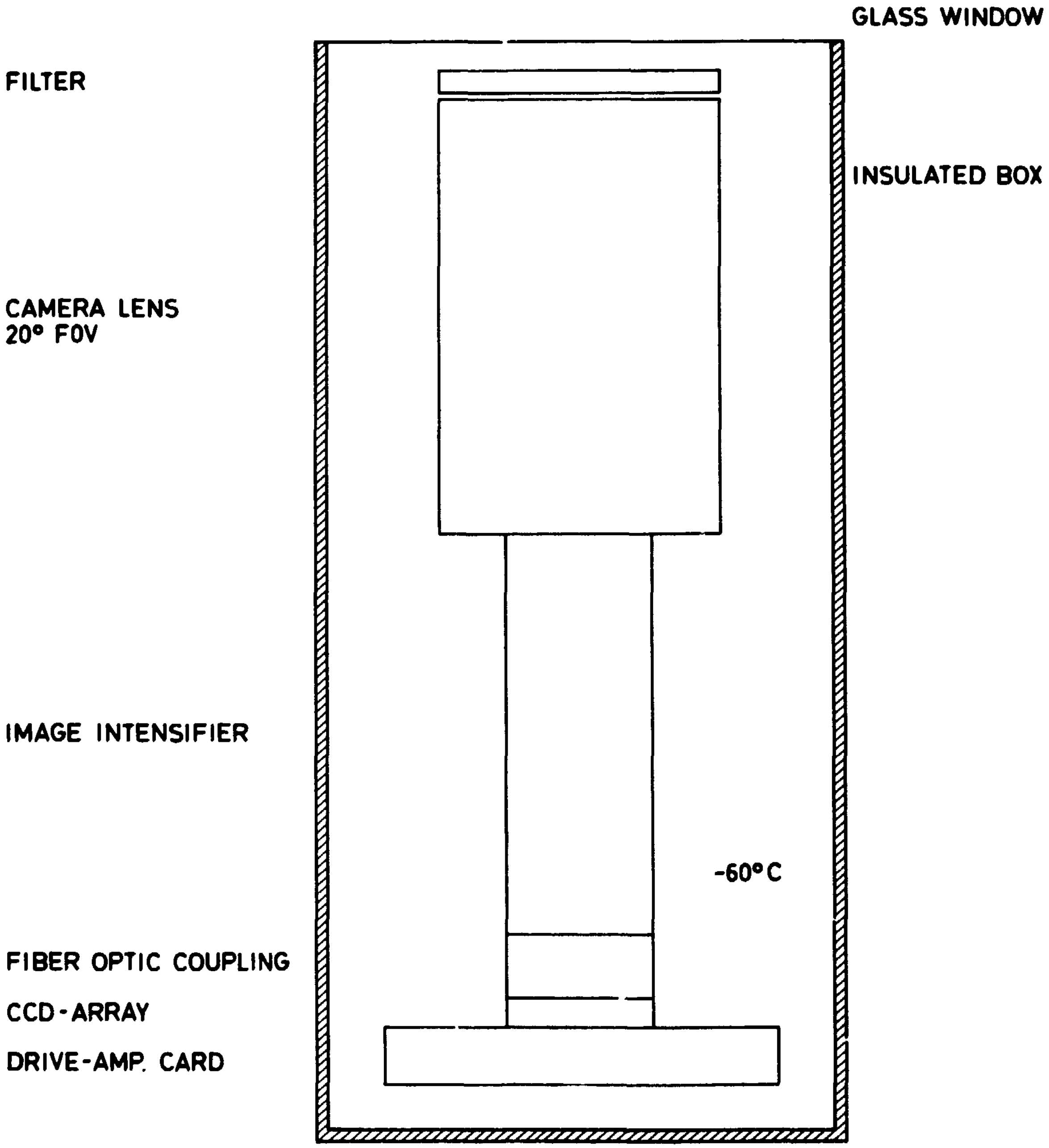

GLASS WINDOW
FILTER
INSULATED BOX
CAMERA LENS
20° FOV
IMAGE INTENSIFIER
-60°C
FIBER OPTIC COUPLING
CCD-ARRAY
DRIVE-AMP. CARD

Figure 4

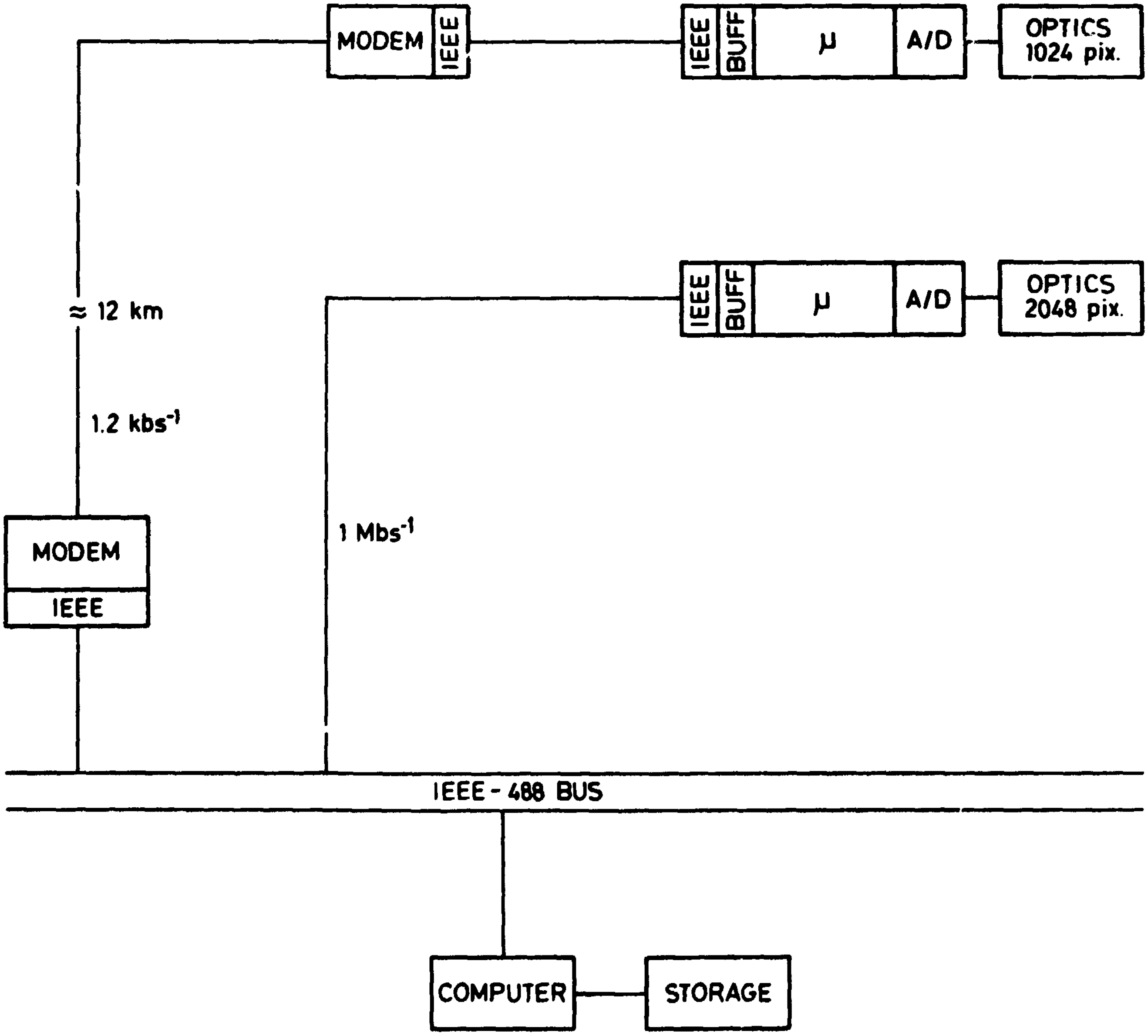

MODEM
IEEE
IEEE
BUFF
μ
A/D
OPTICS 1024 pix.
IEEE
BUFF
μ
A/D
OPTICS 2048 pix.
≈ 12 km
1.2 kbs⁻¹
1 Mbs⁻¹
MODEM
IEEE
IEEE - 488 BUS
COMPUTER
STORAGE

Figure 5

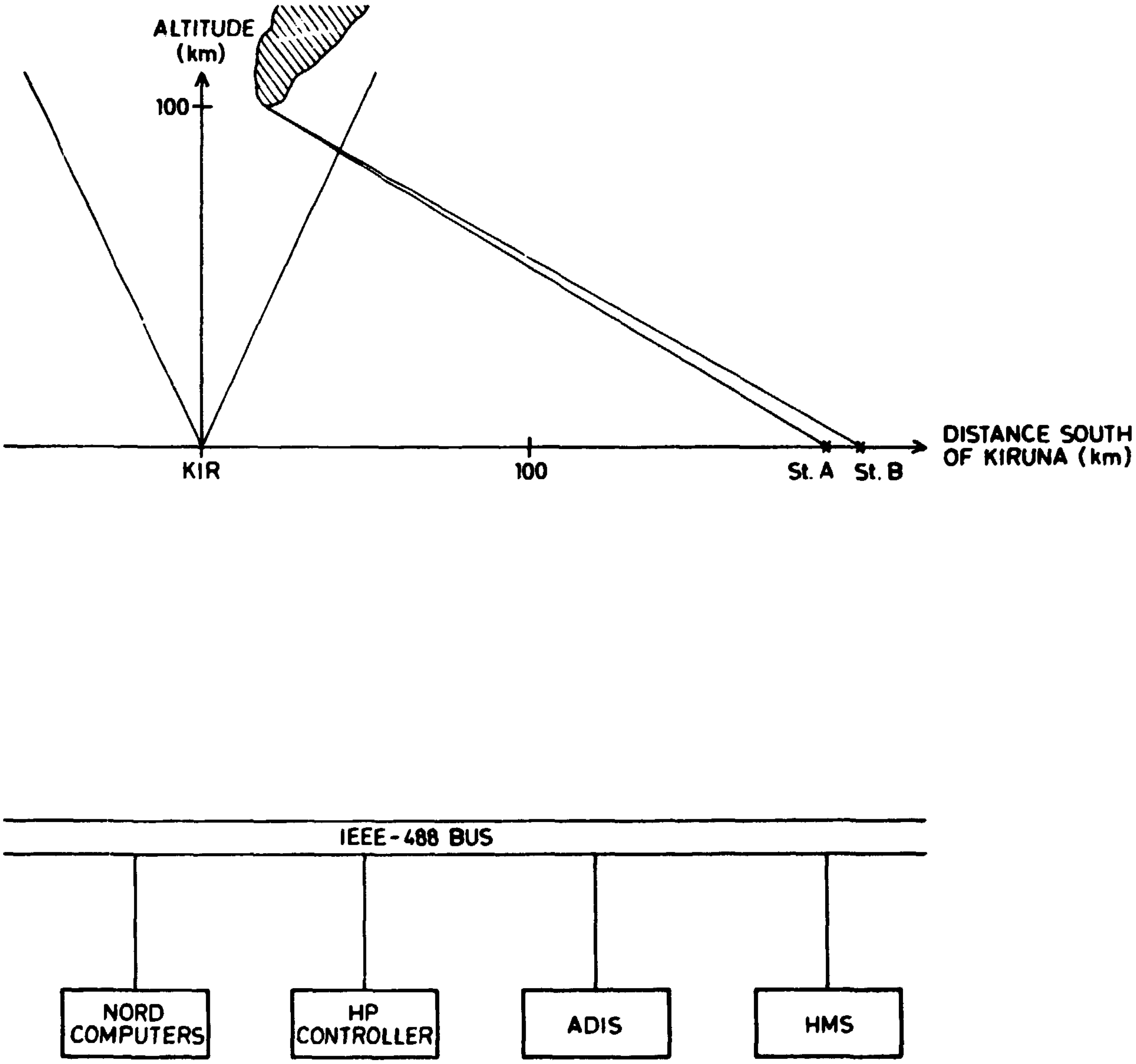

ALTITUDE (km)
100
KIR
100
St. A
St. B
DISTANCE SOUTH OF KIRUNA (km)
IEEE-488 BUS
NORD COMPUTERS
HP CONTROLLER
ADIS
HMS

Figure 6