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Multichannel Scanning Auroral Photometer

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Abstract

A new auroral photometer for low light level measurements has been designed by making use of the latest development of the technology. As a result, PC controlled scanning multichannel auroral photometer has been built at the University of Oulu, Department of Physical Sciences. The photometer consists of several photometer tubes with narrow bandpass interference filters and separate power supplies as well as the scanning module. The measured data is transferred to counter card inside the measurement PC. PC controls the measurement via I/O (in/out lines) according to prewritten file, which consists of header and measurement parameters including the starting and stopping times. Timing is based on data received with GPS receiver and the PC time is corrected accordingly. Three of these second generation photometers have been installed to measure auroral emissions in Northern Scandinavia and Antarctica. According to the measurements the quality and continuity of the data is most acceptable for scientific research of auroras.

Key words: Aurora, photometer, CCD camera, interference filter, photomultiplier tube, amplifier

1. Introduction

Bright auroral displays are the end product of the solar terrestrial interaction as a result of, for example, a sudden coronal mass ejection (CME) or unusually high speed solar wind created in the coronal hole regions. A part of the charged solar wind particles (electrons and protons) penetrate to the Earth's magnetosphere. The magnetosphere guides particles along the magnetic field lines into the Earth's ionosphere. The earthward propagating particles precipitate into the atmosphere creating various kinds of aurora, which at best can show a beautiful, bright and dynamic auroral display in the arctic ionosphere. By measuring the emissions, it is possible to derive the electron and proton flux and the characteristic energy on electrons.

The first optical instruments for measuring auroral emissions were constructed during 1950's using analog electronics. The auroral displays were photographed with a wide angle or fish eye optics to black and white films. In Finland Finnish Meteorological Institute started to record auroras routinely with all-sky cameras in 1957 during International Geophysical Year (IGY). The change to color films occurred in 1963. The first German photometer was used in Sodankylä in 1960's.

The first auroral photometer at the University of Oulu was designed and built in 1986 (*Kaila et al*., 1987). The development started two years earlier. This photometer was fully digital, PC controlled sophisticated instrument, which had interference filters with a diameter of 50 mm, 135 mm f:2.8 camera optics and 30 mm head-on EMI photomultiplier tubes 9798B and 9924B. Two of the three high voltage units and all the amplifier boards, based to LeCroy amplifier MVL-100, were self made (details in *Kaila et al*., 1987). This first photometer was based on an Intel SDK kit, which was extended e.g. by pulse counters. The card computer fully controlled the measurements and communicated them by a remote PC via RS232 serial port. The original prototype was running in five years. After that it has been revised couple of times and the card computer has been changed to PC counter card as well.

Since the first prototype photometer three revised photometers have been built at the Department of Physical Sciences. The characteristics of the most recent photometer are described in this paper.

2. Multichannel photometer

Auroral photometer has two main parts, 1) photometer tubes with power units, amplifiers and scanning module and 2) a PC with a program controlling the measurements and data collection. All these will be described separately. Block 1) is mounted in a thermally insulated wooden box (Fig. 1). The box will be installed outside in an open place and the photometer is making the measurements through an acrylic window. The data collecting unit is somewhere inside in a warm and dry place. The data transferring between photometer and PC occurs via leads and cables. The schematic pictures of the photometer are in Fig. 2 and 3.

A channel in the photometer means a single photometer tube with a filter, optics and detector. In a multichannel photometer there are several photometer tubes aligned close to each other and each of them will measure a wavelength range through its own filter. The scanning module takes care of the pointing of the direction. It is fulfilled with a mirror and mirror turning system. With the scanning module the photometer is able to measure intensities along a meridian plane in the sky.

If the photometer is a sensitive instrument it can measure also the intensities of much weaker airglow emissions. The present photometers are capable to be used for auroral as well as airglow measurements. The auroral photometry is mainly concentrated to the visual range, 350-660 nm. In airglow research one is also interested in the infrared region due to OH emission bands.

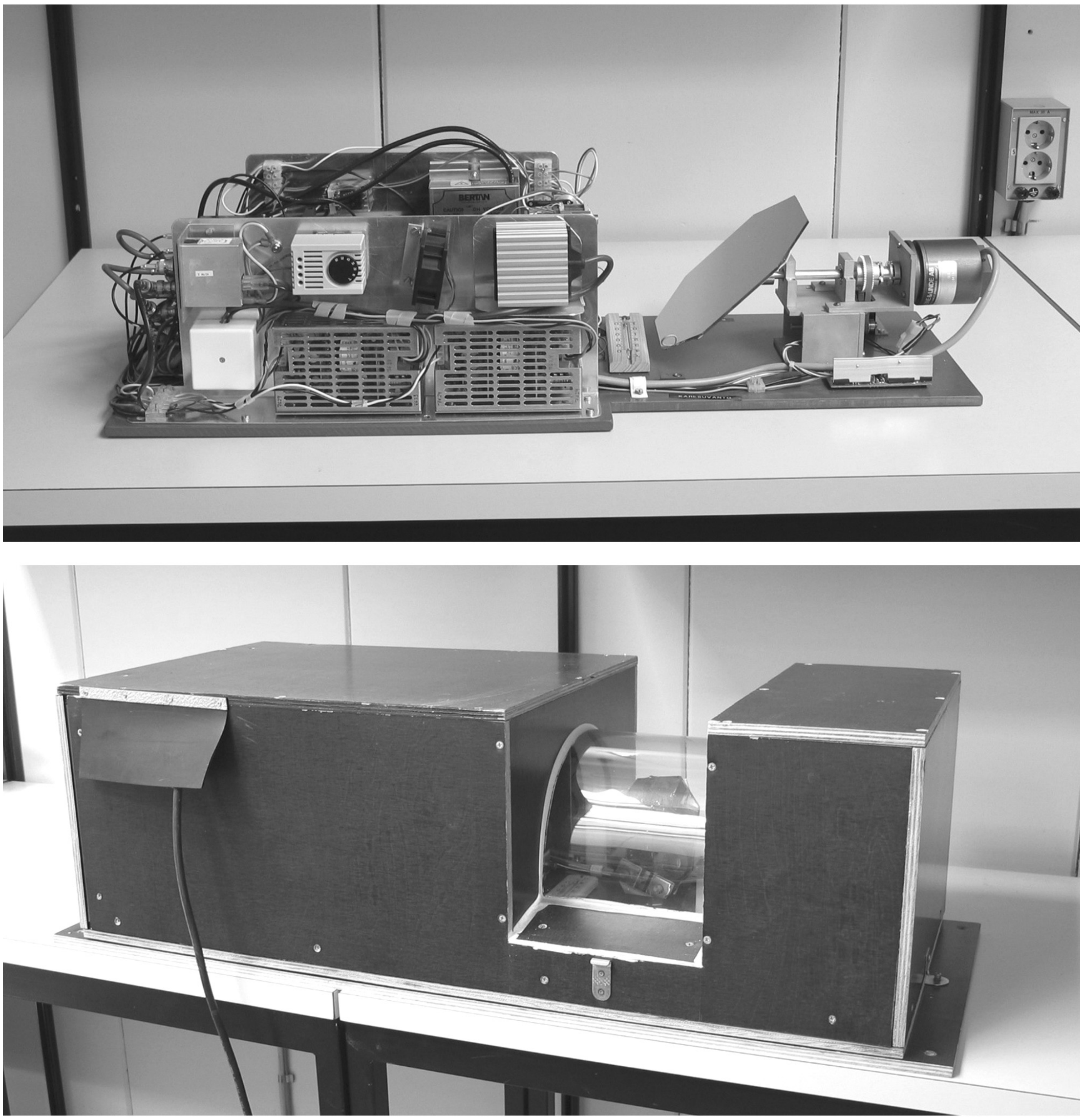

Fig. 1. On the top: The scanning auroral photometer in the laboratory. Bottom: The same photometer mounted in its wooden box ready to operate in outdoor conditions.

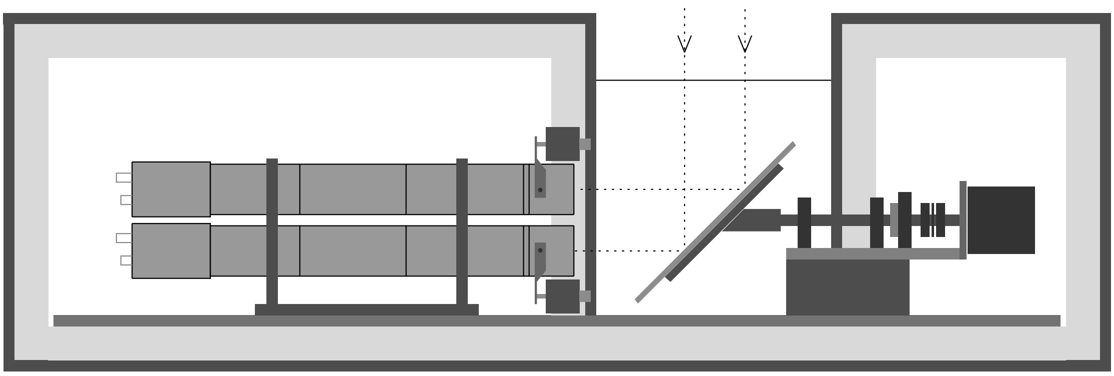

Fig. 2. A schematic side view of an auroral photometer box. On the left there is a block of photometer tubes. The scanning module is on the right. The light enters to the box via a cylindrical acrylic window and reflects from the first surface mirror to the photometer tubes. The light beams are marked with dashed lines.

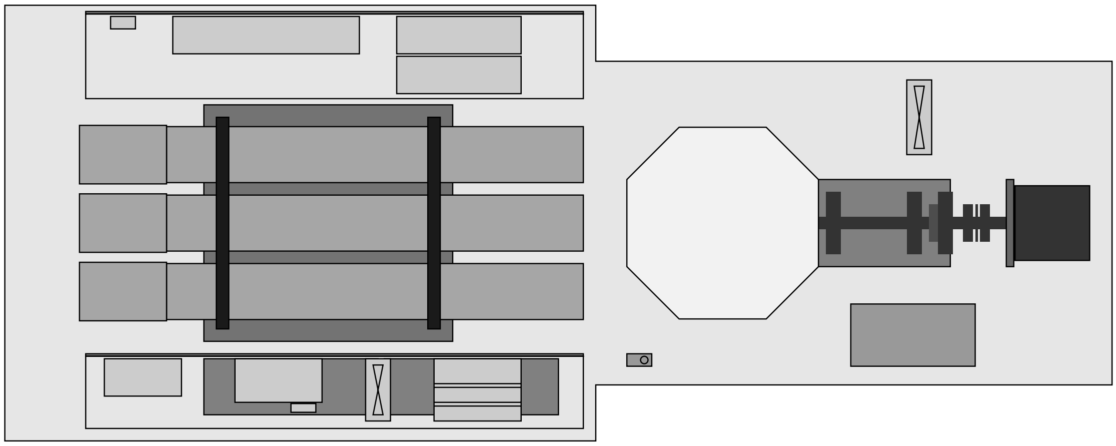

Fig. 3. A schematic top view of an auroral photometer. On the left center there is a block of photometer tubes, above it there is a high voltage block. On the lower left there are the main switch, heating and other power supplies in its own module. On the right side there is the scanning module with an octagonal mirror, stepping motor with its driver and absolute angle encoder.

2.1 *Photometer tubes*

The photometer tubes are lathered from solid aluminum bar. The interference filter in one end of the tube allows a fixed wavelength range to pass through. After this the optics focuses the light to a focal plane. There is an iris diaphragm, which limits the beam and provides the required field of view to the photometer. After iris the light will be detected by a detector. Figure 4 shows the structure of a photometer tube.

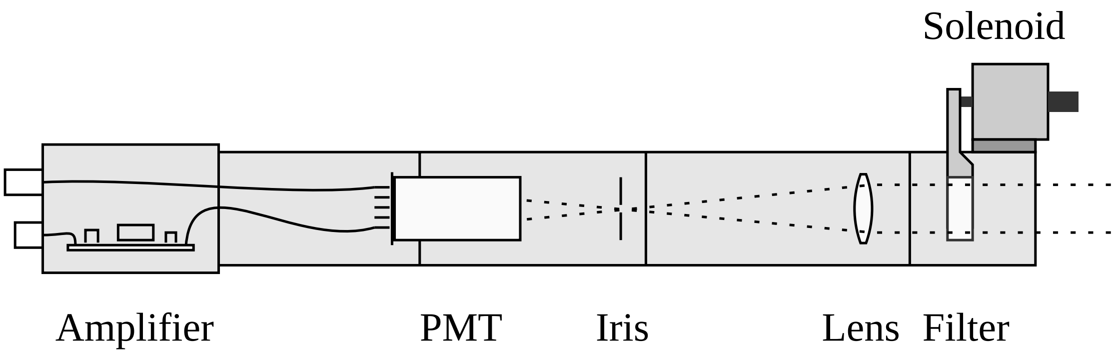

Fig. 4. A photometer tube consists from right to left: a filter and the tilting solenoid, lens, iris, photomultiplier tube (PMT) and amplifier.

The detector is a photomultiplier tube (PMT). It needs a high voltage power supply in order to operate. The light which has passed a filter, optics and iris will enter to the photocathode of a photomultiplier. Light quanta create pulses in the anode end of the photomultiplier tube. Before conducting the pulse further away it has to be amplified with an amplifier. A line driver will help to transfer the pulse to the data collecting unit.

2.2 *Photomultiplier tubes*

Photomultiplier tubes are light sensitive detectors. When a photon enters the photocathode it looses an electron. This electron will be multiplied in the dynode chain. At the anode end a pulse of about 10^6 electrons will be detected. This small pulse will be amplified. After amplification the width of the pulse will be widened to 200-400 ns. The high energy cosmic ray induced and thermal pulses will be amplified as well. Cosmic rays generate a much stronger pulse than normal pulse originating from a single photon from photocathode. Thermal electrons can be emitted from any place in the dynode chain and they generate only weak pulses. Too strong and weak pulses will be discriminated by the amplifier-discriminator and the relevant pulses will pass through for further handling.

The typical quantum efficiency of a photomultiplier tube is 25-35% (*Hamamatsu*). About every fourth photon entering to the photocathode will be detected. In the low light applications photomultiplier tubes with 10-12 stages in the dynode chain will be used.

If there is no need to measure wavelengths higher than 620 nm, the best choice is a bialkali photomultiplier tube. They are the basic tubes which have low dark pulse rate even at room temperature. If the wavelength is between 620 and 750 nm, a red sensitive tube with multialkali S20 photocathode should be chosen. Its dark counts are 5-10 times higher than those in bialkali tubes. Bialkali tubes can just be used for the red wavelength of atomic oxygen, 630.0 nm, even if its quantum efficiency is already quite low, about 2%. By cooling the tube the dark pulse rate is reduced by one decade for every 15º C.

2.3 *Optics and iris*

The optics will focus the target to focal plane, where an iris diaphragm is limiting the field of view to the predeterminated size. After the iris diaphragm the incoming light spreads to the photomultiplier photocathode. A photometer tube can also be designed with a field lens just after the iris diaphragm.

The length and width of the photometer tube is partly determined by the optics. Thus all the optics should be small enough so that the size of the whole photometer box does not grow very large. The diameter of the optics should be large enough to collect as many photons as possible. In the first prototype photometer, 50 mm diameter optics was used. In the recent photometers a smaller diameter was selected. The focal length of the focusing lenses is 90 mm and their free diameters are 25 mm.

It is also important to avoid stray light. The mounting of the lenses should be light tight and all the surfaces inside the photometer tube should be nonreflecting. The diameter of the iris diaphragm has been selected so that the field of view is 0.6º - 2.0º. A suitable baffle construction prevents effectively the disturbing stray light photons to pass the tube.

2.4 Filters

The emissions to be measured are either emission lines of atomic species or rotational bands of molecular species of atmospheric origin. In the visible wavelength range the auroral spectrum consists of hundreds of emission lines and bands. A narrow bandpass filter is required to measure particular emission. An interference filter is most suitable for an auroral photometer. Each channel has its own filter. The desired wavelength has been tuned by tilting the filter slightly. If the background emission is measured 1.0-1.5 nm shorter than the measured wavelength, the interference filter will be tilted by several degrees. Then the wavelength is shifted by

$$\Delta\lambda = \frac{\lambda_o \cdot \theta^2}{2 \cdot n^2}$$

where $\Delta\lambda$ is the wavelength shift, λ_o is the central wavelength of the filter when light passes perpendicularly through the filter, θ is the tilt angle of the filter in radians and n is the effective refractive index of the filter (typically 1.0-2.0) (*Vallance Jones*, 1974). The temperature is also shifting the wavelength because of the thermal expansion of the dielectric layers of the filter. The layer thicknesses change with time (an aging effect) and the basic wavelength is slowly shifting toward lower wavelengths. This is the reason why the filter transmission curves should be measured from time to time (*Kaila and Holma*, 2000).

Large filters with narrow bandpass widths are expensive. For the second generation photometers only filters with 25 mm in diameter were used. They are big enough for most auroral emissions. Their bandwidths are from 0.6 nm to 2.0 nm.

Intensities of following emissions are measured by the present photometers: proton H_β line at 486.1 nm, red atomic oxygen line at 630.0 nm, green atomic oxygen line at 557.7 nm and three different parts of the nitrogen N_2^+ 1NG band (band head at 427.8 nm).

2.5 Amplifiers

The photometer measurements have been made by a pulse counting method. Every pulse generated by a photon coming to the photomultiplier photocathode will generate a pulse of 10^6-10^7 electrons. This pulse is amplified by an Amptek A-101 charge sensitive preamplifier-discriminator on a PC-11 board. A low impedance high current line driver TSC427 CPA is used to drive the pulses via a coaxial cable RG174U to Computer Boards I/O and counter card CIO-CTR10 inside the PC. An opto isolator prevents the possible disturbances generated in a long wire.

Cosmic ray pulses and thermal pulses from the dynode chain have been discriminated. External capacitor of 20 *pF* coupled onto a PC-11 board increases the pulse width to 350 ns. An external resistor of 1 $k\Omega$ increases the threshold charge from

0.16 *pC* to 0.6 *pC* which is equivalent to $4 \cdot 10^6$ electrons (Amptek Inc. A-101 data sheet).

2.6 High voltage and other power supplies

Low and high voltage power supplies are installed in their own separate modules. They are seen in the Fig. 2 above and below the photometer tube block, and their details also in Figs. 5 and 6.

Photomultiplier tubes need a high voltage of about 1 kV, but their current consumption is low. All the high voltage power supplies are installed on a single block (Fig. 5). Bertan PMT-10A-P, PMT-20A-P and HV-1250P high voltage power units have output voltages of 1000 V, 2000 V and 1250 V and output currents of 4 mA, 2 mA and 2 mA, respectively. One power supply adjusted to a suitable high voltage can easily drive two or three photomultiplier tubes simultaneously. The same type of photomultiplier tubes may need different high voltages. Thus the high voltage should be selected so that it is suitable for all photometer tubes it drives. The Bertan high voltage power units require either a voltage of ± 12-18 V or 24-30 V. Also a high voltage unit with a positive output has been used. It means that the cathodes are grounded in all photomultiplier tubes. The grounding of the cathode makes the low light level measurements less noisy.

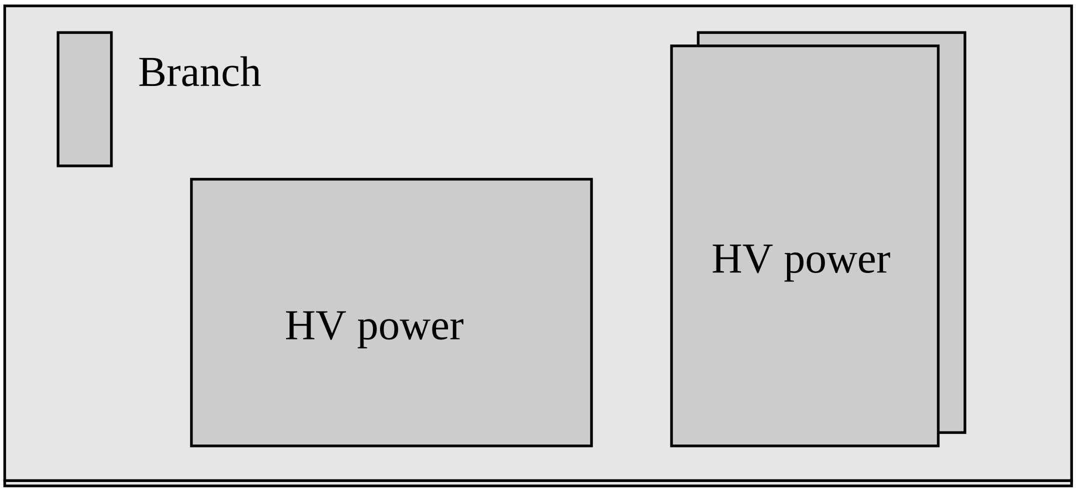

Fig. 5. The high voltage block consists of three Bertan high voltage power supplies, one in the middle and two on the right side.

The low voltage power supplies are installed in another block with mains and a heating system (Fig. 6). One low voltage power supply produces 5 V and 12 V, the other supply only 24 V for the photometer. Above them there are the heating system with a heater of 25-50 W, a thermostat and a fan, which circulate the heated air in the photometer box.

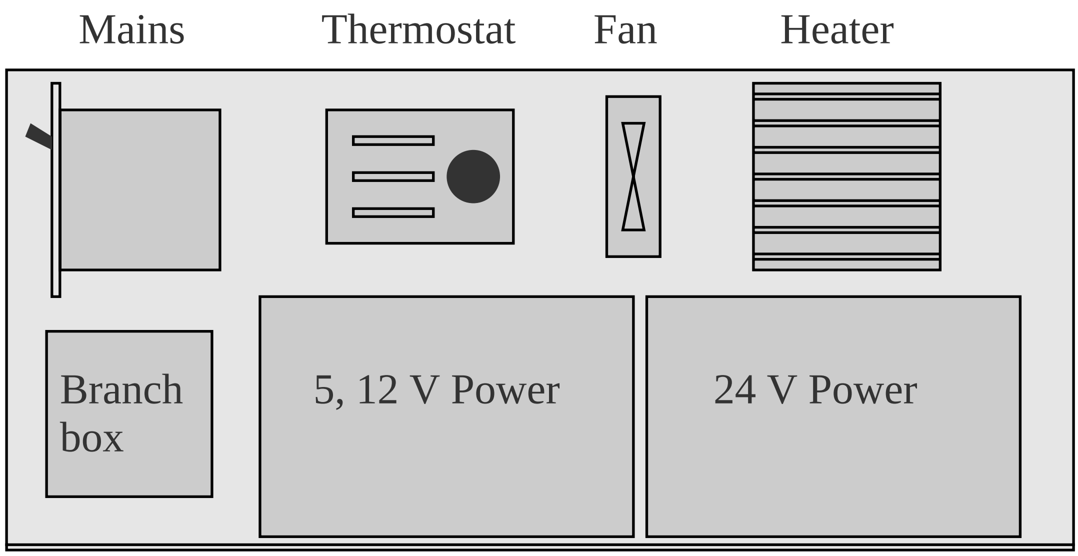

Fig. 6. The other power supply block contains the mains, heating system and the low voltage power supplies.

2.7 *Scanning system*

There are two possibilities to scan the sky with a photometer: a) to rotate the whole system with photometer tubes along the selected meridian or b) to fix the photometer tubes on the photometer box and to rotate a mirror in front of the tubes. The first possibility could be very accurate in pointing the photometer to the sky because of a flat window. But this may be a large and heavy system. The second system is lighter but it has a curved cylindrical window around the mirror. That may cause some problems in pointing all the photometer tubes to the same point in the sky.

The second method has been applied in the Oulu photometers. A compact set of photometer tubes are lying horizontally on the photometer platform. In front of them there is the scanning system. The mirror turning unit consists of an axis where a flat, aluminized and coated first surface mirror is fixed at an angle of 45°. At the other end of the axis there is a 10 bits Leine & Linde absolute angle encoder fixed with Flex-M coupler to the axis. This ensures that the direction of the measurement will be recorded with an accuracy of 360°/10 bit = 360°/1024 = 0.35°. The Vexta 5 V or 12 V stepper motor is turning the axis and the mirror. The motor turns 1.8°/step and it can run with a half step mode. The cogged belt and cogged belt pulleys change the step angle to about 0.4°. The scanning angle interval can vary from 0 to 180°. It can start from any starting angle and scan any angle interval above the horizon. The schematic picture of the scanning system is seen in Fig. 7. The photometer tubes are mounted in a tight block and a big enough mirror reflects the light from the sky to the tubes. The block of the photometer tubes can be seen in Fig. 8.

Measurement program gives the direction and enable bit to the stepper motor controller. It gives also the pulses for the stepper motor to make steps forward. Normally one step is made at the beginning of each integration time. If the integration time is long enough (more than 0.3 *s*), two or three steps can be made within an integration time in order to make the scan faster.

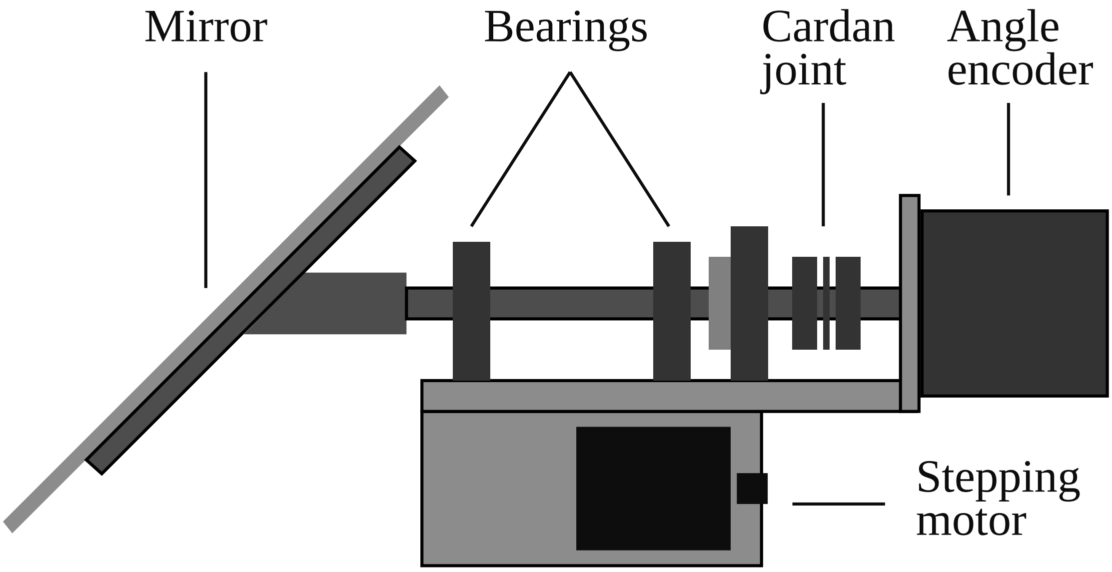

Fig. 7. In the scanning system of the photometer a first surface mirror is installed at an angle of 45° to the scaning axis. The stepper motor below is turning the axis and at the end of the axis there is an absolute angle encoder.

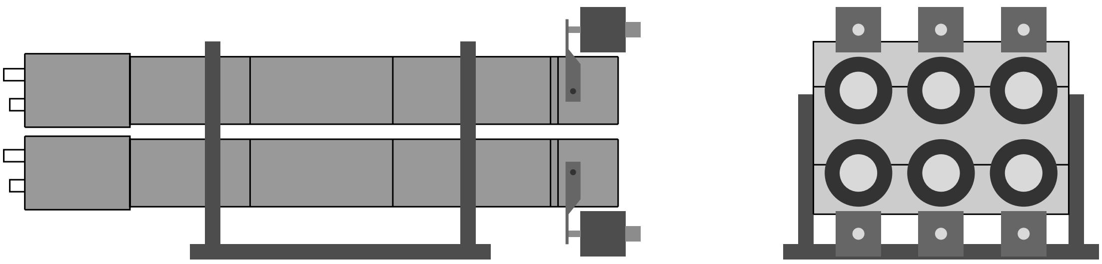

Fig. 8. All the photometer tubes are mounted in a tight block. Here the block is seen from side (left) and front (right).

The angle encoders have two different modes, normal and Gray code. In the normal mode one or more bits can change simultaneously, but in Gray code only one bit will change at a time. This ensures that by reading the angle value by the Gray coded encoder, no bigger error than 1 bit can arise. The stepper motor turns the mirror from 0.4° to 1.2° during an integration time. After every step the angle encoder value is compared with the start and stop angle values. When the limit is reached, the motor direction is changed. A big error may arise if the mirror is crossing the 0° value. Then the angle values start again from 360° and comparison fails. An offset error of more than 10° has been applied to fully prevent the 0° crossing of the angle encoder.

It is difficult to install the absolute encoder correctly. The platform where the photometer is installed is only about horizontal. The real offset angle has been determined by the known star positions after the photometer has been installed on its place at the measurement station. Azimuth and elevation angles of a few bright stars have been detected from the measured files afterwards and the offset angle has been derived accordingly.

2.8 Counter card and light protection

The Computer Boards I/O and counter card CIO-CTR10 has 10 counters, 16 bits each. They can count with a pulse rate of up to several MHz. In addition there are 32 in/out (I/O) lines, with which a PC can give or receive information from or to the photometer. Two counters have been used for timing of measurements. One counter is counting the integration time value downwards from a certain given value to zero. When the counter is reaching 0, it will give a pulse to the card output. The measurement program itself is polling the high bit of that output. It may happen that writing the data buffer to the hard disk takes so long time that polling of one (or more) pulse does not succeed. Then a multiple integration can occur. During the measurement cycle another counter is started and stopped at the same moments as all the measurement channels. From these timing counters the multiple integration times can be derived and the measurement data are corrected accordingly. There are eight counters left for the measurement channels. Only six photometer channels have been used until 2002.

The photomultipliers can be destroyed when they are illuminated with a bright light under high voltages on. Thus there is a light diode sensing the light level of the surrounding sky. The photometer does not start the measurement until the starting time has been reached and there has been ten dark values from the light diode. The surrounding light level is checked always when the photometer is operating. So bright but short living meteors do not stop the measurement. The light diode detection level has been adjusted so that even bright auroras or moon light do not stop the operation.

2.9 The data collecting and controlling unit

The measurements are made automatically. The timing of the measurements is based on GPS (Global Positioning System). It gives the position and the accurate time for the measurements. To read the GPS data via serial port takes at least seconds, so that in this system it is difficult to read the time information during the measurements. The check of the PC clock and its correction will be made before and after each measurement period (which typically lasts some hours) and the timing errors are written to a log file. During the measurements the timing is based only to the PC clock. It has been proven to be reliable. The error in PC clocks is of the order of couple of seconds within a day or some tenths of seconds within a measurement period.

2.10 Photometer box

The photometer box is made of 12 mm water proof plywood. Inside the box there is 30 mm thick polyurethane thermal insulation everywhere except at the photometer window. The outside size of the box is about 440 mm (w) × 320 mm (h) × 990 mm (l). The corresponding inside measures are 360 mm × 235 mm × 910 mm. The 3 mm acrylic window is cylindrical and its length is 210 mm and radius 135 mm. A heater of 25-50 W heats the box inside according to the thermostat. The photometer needs a voltage of 230 V, which is taken through switch, fuses and filter. All the low voltage inlets outside the photometer box are made with Lemo couplers, a multipin military quality coupler.

3. *Operation*

The operation of the photometer is fully controlled by a PC. It is reading the starting and stopping times and the parameters for the next measurement. One minute before the measurement period starts the program checks the PC time and corrects it with the GPS time. Then it checks the light level of the background sky, switches the high voltages on if it is dark enough and starts finally the measurements. At the end of the measurement period it again corrects the PC time with GPS time. If the next measurement period does not start immediately, the program switches the high voltages off and waits the moment of the next starting time. The data as well as log information will be stored only to the PC hard disk. With this arrangement the system can be run through the whole winter period. Every now and then the photometer data will be downloaded to a safer place.

3.1 *Measurement modes and limits*

The measurement program is written in Borland C language. The measurement times and all the required parameters are written into a measurement file of type .tim (Table 1).

Table 1. Short example of the .tim file information. Every measurement has the starting time, stopping time and all measurement parameters in one line.

start time						stop time						mode	int.	start	step	tilt	tilt	fix
yyyy	mm	dd	hh	mm	ss	yyyy	mm	dd	hh	mm	ss		time	angles		int.	time	time
2003	2	22	17	25	0	2003	2	22	20	30	0	1	10	10	160	880	20	0
2003	2	22	20	30	0	2003	2	23	02	00	0	3	20	77.5	160	880	20	800
2003	2	23	02	00	0	2003	2	23	04	19	0	1	5	77.5	0	880	20	0

Its header has common information for the photometer e.g. station, offset angle, channel numbers, their wavelengths, background wavelengths and fields of view. After the header each measurement is described within a line. Each line consists of the starting and stopping times, mode, integration time, measurement angles, tilting interval and tilt time. The photometer is operating according to this tim-file.

The program has three basic measurement modes:

1) **normal mode**, where all integration times are the same. The photometer can be measuring toward fixed direction (stepping angle = 0) or it can scan back and forth with a selected angle interval. Background measurements are made at

predeterminated time intervals. Then the interference filters are tilted to their background position for the predeterminated period of time.

2) **fast mode**, where three different integration times in different channels can be selected. The shortest integration time in the present photometer is 10 ms (it is by no means a limit) and the photometer is measuring toward a fixed direction (stepping angle = 0). The PC is collecting the data to a buffer, which will be stored after being full. The interference filters are tilted for background measurements. Only one channel can have the shortest integration time. The other channels have n times or m times the shortest integration time, where n and m are positive integers.

3) **mixed mode**, where all integration times are the same. The photometer makes a full back and forth scan over the selected angle interval after which it is measuring toward a predeterminated fixed direction in the sky for a predeterminated period of time. Background measurements are made just after the scan for a selected period of time.

The typical measurement parameters for different modes are given in Table 2.

Table 2. Typical measurement parameter values for each mode.

Parameter	Mode 1	Mode 2	Mode 3
Intergration time	0.1-0.6 s	0.01 s	0.1-0.3
Fixed angle	77.5° or	77.5° only	77.5° and
Scanning angle	10°-170°	-	160°
Tilting interval	880 s	880 s	880 s
Tilting period	20 s	20 s	20 s

4. Results

The photometers have been working well and the data quality has been high. Some problems have been in the scanning system and with the counter cards. The filter tiltings do not recover always although in every photometer tube there is a spring pulling the filter back to its measurement position. Fig. 9 shows an example of the photometer recordings.

4.1 Measurement stations

In the winter 2002-2003 there were three multichannel photometers in use. One has been in Kilpisjärvi during every winter since 1986, one has been in Karesuvanto since 1998.

One five channel photometer was brought to CRIRP (Chinese Research Institute of Radiowave Propagation) Xinxiang, China in 1995. The local scientists were trained to use it and the photometer was brought to Zhong Shan, Chinese Antarctic station.

Recordings were made there during 1997-1999. In 2000 the photometer was sent back to Oulu for service and revise. Then a sixth channel was added to it. Since 2001 it has been measuring Southern auroras from March until October. The station is located in a suitable position in order to measure the daytime auroras during the darkest time in the Antarctic winter (from May to July).

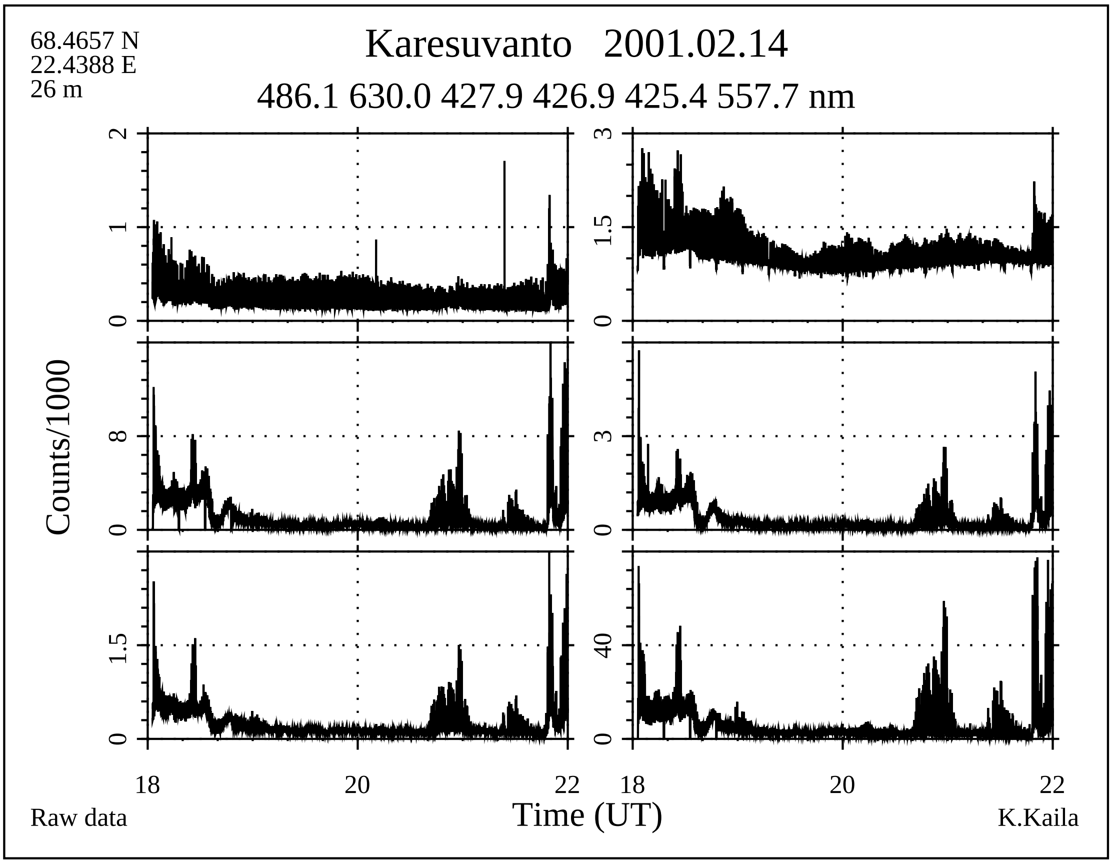

Fig. 9. An example of the photometer recording from Karesuvanto on 14.02.2001 at 18:00-22:00 UT. The station name, date and wavelengths of following panels are shown at the top. The position obtained from GPS is seen in the upper left corner.

The Table 3 shows the location of the photometer stations during 2002-2003. The revised prototype photometer has been in Tromsø during EISCAT and optical campaigns, but more permanently in Pittiövaara, Sodankylä since 2001.

Table 3. Geographic location, geomagnetic latitude and L-value of photometer stations during 2002-2003.

Station	Geographic latitude	Geographic longitude	Geomagnetic latitude (CMG)	L-value
Kilpisjärvi	69.0198° N	20.8592° E	65.87°	5.98
Karesuvanto	68.4656° N	22.4431° E	65.22°	5.69
Zhong Shan	69.3711° S	76.3694° E	-74.54°	14.08

5. *Discussion*

The intensities of different auroral emissions can be measured by photometers. The photometer measurements do not solely tell much about the target and conditions. A photometer and a sensitive camera (*Kaila and Tanskanen*, 1988) is a powerful combination in optical auroral research. The shape and motion of auroral forms can be photographed by different types of cameras. The weather conditions can also be detected from night time auroral images.

Are the photometers still important? Would a modern and sensitive wide field CCD camera be enough? It is obvious that photometers have still several advantages over CCD cameras. They can measure absolute intensities of auroral emissions through narrow bandpass interference filters. Each photometer tube has its own filter. Several photometer tubes can be combined to operate simultaneously. A multichannel photometer can measure absolute intensities with many channels simultaneously and with a high temporal resolution.

Whatever instrument is built, it is always a compromise. If you gain in temporal resolution, you loose in spatial resolution. You cannot get many different types of data simultaneously. If you get six simultaneous channels, you are able to measure only one point in the sky at a time. If you use only one filter, you can get information from a wider area of the sky with a CCD camera. If you want to record 25 frames per second with an auroral camera, your dynamic range is limited to 8 bits, but if you want a resolution of 16 bits, you can get only one image in every few seconds.

In 1980's and 1990's personal computers and especially their mass storage systems were rather small. It would have been impossible to store more than 100 pieces of 512 $\times$ 512 bit images to a hard disk in 1980's or some thousands of images in 1990's. Photometer data from one night has been of the order of two megabytes (MB). Earlier the space on a hard disks was very limited. At present this is no more a problem. The size of an auroral image is easily half an MB. The images can be compressed to smaller size. The compressions loose information of the image and thus the images will be stored in the unpacked format.

In the following advantages and disadvantages between a photometer and a CCD camera has been compared.

Advantages of photometer over CCD camera:

- photometer: intensity measurement with an integration time from 1 ms upwards
  CCD: possible with a digital CCD camera as well
- photometer: next measurement can be made immediately after the previous one
  CCD: impossible with a digital camera because of downloading of the image takes seconds
- photometer: possibility to use narrow bandpass interference filters
  CCD: possible as well with a digital CCD camera but not with wider field. The light cone increases quickly to 10° and the filter does not work as wanted. Cameras need wider filters.

- photometer: several simultaneous monochromatic measurements with multichannel photometer
  CCD: possible but it needs a set of cameras (practically impossible)
- photometer: large dynamical range, over 16 bits
  CCD: real speed cameras have typically 8 bits resolution, digital CCD's typically 16 bits resolution
- photometer: easy absolute calibration
  CCD: difficult to make an absolute calibration of auroral cameras. The light should pass the interference filter perpendicular to the filter, but it will pass within a cone of several degrees.
- photometer: two byte data per measurement
  CCD: uncompressed 256-512 kB of data per image
- photometer: large but not huge data set within a year
  CCD: huge data set even during one night

Disadvantages of photometer over CCD camera:

- photometer: measurement towards one direction at a time
  CCD: intensified or pure CCD-cameras have wide field, in practice thousands of photometers (pixels) over the field, but impossible to use narrow bandpass interference filters
- photometer: spatial resolution is the same as the field of view of the photometer tube
  CCD: high resolution, depends on the amount of pixels
- photometer: does not show the features of auroras
  CCD: shows clearly auroral features and events in the sky

5. Summary

A second generation multichannel auroral photometer has been introduced in this paper. It is the latest one in the series of photometers built at the University of Oulu, Department of Physical Sciences. The first prototype photometer was built in 1986 and several improvements have been made to the second generation instrument. It is sensitive enough to measure auroral as well as airglow emissions. In the photometer there are six channels, each of which measure simultaneously emission of its characteristic wavelength range. Their fields of view are 0.6° - 2.0°. The photometers use photomultiplier tubes as detectors. The diameter of the optical parts is 25 mm.

Narrow bandpass interference filters are used in each photometer tube. Commercially available amplifiers as well as low and high voltage power supplies have been used. In the scanning system a flat mirror is fixed at an angle of 45° to an axis. The axis is turned by a stepper motor and the angle is read from an angle encoder. By turning the axis the photometers measure emissions along a meridian plane. The data from different photometer channels is collected by an I/O and counter card inside PC, which takes care of the measurements. The photometers have three operation modes for different uses. Two photometers are measuring in the Finnish Lapland during Northern winter periods and one in the Chinese Antarctic station during Southern dark periods. The quality and continuity of the data after the first experiments have been most acceptable for scientific research of auroras.

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