



Symmetric Inclined Grid Mobility Analyzer

# SIGMA

MANUAL for the Instrument No. 2

*version 20110214*

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## FOREWORD

The Symmetric Inclined Grid Mobility Analyzer SIGMA (Tammet, 2011) is an instrument for atmospheric aerosol nucleation research with special attention to long-term routine measurements in natural atmospheric conditions. It was elaborated using the experience of the preceding scanning mobility analyzers IGMA and BSMA (Tammet, 2006). The range of electric mobility is  $0.032\text{--}3.2\text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  and the range of particle diameter is  $0.4\text{--}7.5\text{ nm}$  when using the high air flow rate. An alternative regime of the low air flow rate extends the diameter range up to  $18\text{ nm}$ . The particle diameters are calculated considering the size-mobility correlation at air temperature and pressure measured with built-in sensors. The positive and negative particles are sampled from the same inlet air flow and measured exactly simultaneously. The sensitivity of the instrument allows measuring the mobility fraction concentrations of charged fine nanometer particles in atmospheric air at a standard 5-minute time resolution with random errors of about  $1\text{ cm}^{-3}$ .

The present manual is long and requires a lot of time to learn everything. However, different users of the instrument may learn only limited information:

- People who are responsible for the installing and maintenance of the instrument need information from Chapters 2–4 and Appendices 4, 6–9.
- People attending to routine measurements should read Section 2.3, be well familiar with Chapter 3, Sections 4.1–4.2, and read the first three sections of Appendix 4.
- People processing the recorded data can acquire main information from Chapters 5 and 6, and additional information from Appendices.
- People supervising the measurements and interpreting the recorded data can skip only Appendices 7 and 8 and should pay special attention to the first chapters.

The present manual is compiled considering the Instrument No. 2 used in the regime of the high air flow rate. The regime of the low air flow rate is briefly explained only in Appendix 9. The principles of SIGMA are universal but some technical issues and calibration information will be specific for different instruments. Fresh information about SIGMA and recent revisions of documents and software are available in SIGMA website

<http://ael.physic.ut.ee/tammet/sigma/>.

## 1. INTRODUCTION

### 1.1. *Air ions and nanometer aerosol particles*

Charged molecular clusters and nanometer particles act as carriers of the electric current in the air. Therefore, they are called *air ions* in many documents including the present manual. Hörrak et al. (2000) carried out long-term measurements of natural air ion mobility distribution in the rural air. The dataset was analyzed using the method of principal components, producing a classification of atmospheric ions according to their mobility and size in such a way that the variation of the values of the size distribution function is well correlated inside the classes and ill correlated between the classes. The principal component classification is in good accordance with the earlier intuitive classification of air ions (Israël, 1970) and the classes are called the cluster ions or the small ions (diameters 0.4–1.6 nm), intermediate ions (charged fine nanometer particles of the diameter of 1.6–7.4 nm) and large ions (charged aerosol particles of the diameter above 7.4 nm). The physical background of the 1.6 nm threshold is the transition from elastic collisions with gas molecules characteristic to the electron structure of a molecular ion to the inelastic collisions characteristic to the condensed matter electron structure of aerosol particles (Tammet, 1995). The physical background of the empiric 7.4 nm correlation threshold has no definite theoretical explanation.

The size range of an instrument for applications in atmospheric aerosol nucleation studies must include cluster ions and intermediate ions up to the diameter of at least 7.4 nm. The nonlinear character of the size-mobility relation makes the relative range of ion mobility wider than the size range. As a minimum, it should cover two magnitudes of mobility. The standard size range of the SIGMA 0.4–7.5 nm and the mobility range of  $0.032\text{--}3.2\text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  cover the region of cluster ions and charged small nanometer particles. The mobility and size range can be modified changing the air flow rate and the control program.

### 1.2. *Measuring methods and special requirements*

Traditional methods of measuring ions in atmospheric air were reviewed from the viewpoint of atmospheric electricity by Israël (1970) and Tammet (1970), and from the viewpoint of aerosol science by Flagan (1998). Three methods of mobility spectrometry are dominating in atmospheric aerosol nucleation studies: single-channel method with a CPC-detector (traditional DMAS, see Flagan 1998), multichannel method (Tammet et al., 1973; Mirme et al., 2007), and single channel method with an internal electrometric detector e.g. the BSMA (Tammet, 2006).

Traditional DMA systems equipped with CPC-detectors are not appropriate for the measuring of cluster ions. The calibration of CPC-s below 3 nm is complicated and can include large systematic errors. Thus, the electrometric detectors of ions are preferred when the clusters should be included into the size range.

Multichannel instruments have some known advantages. The measuring information is collected simultaneously with many electrometers and the full distribution is measured as fast as the signal from a single channel. A weak point is that in this case it is difficult to identify the events where signals of one or a few channels include a moderate systematic error. However, the main factor limiting the usage of multichannel instruments is their complicated construction and calibration, bringing about a high price and complex maintenance. Thus the single-channel scanning may appear to be a good alternative method in many situations.

Measurement of intermediate ions in the natural atmospheric air is a hard challenge for any instrument. The charging probability of a neutral-born nanometer particle is very low and the concentration of fine intermediate ions is often less than ten particles per  $\text{cm}^3$ . If the particles

are divided into narrow mobility or size fractions, then the concentration of charged particles may appear less than  $1 \text{ cm}^{-3}$  in some fractions. The electric current carried by the collected charged particles may come out very low. An example: if a size fraction contains 10 charged particles per  $\text{cm}^3$  and the sample air flow rate is 1 liter per minute, then the collected current of about  $3 \times 10^{-17}$  amperes is much less than the noise level of the best electrometric instruments when applied in atmospheric conditions. Hence, to collect more particles and make the measurement possible, the sample air flow rate should be much larger.

The clusters and the smallest nanoparticles are subjects to rapid transformations and their composition can be changed when the air is heated during passage through the instrument. If the subject of the measurement is the size distribution of particles in natural conditions then the residence time of the air in the instrument should be short and the temperature and humidity of the sheath air should be preserved as in the atmosphere. This is a high-priority requirement at many applications.

The necessity of sampling the finest particles from the open atmospheric air generates some extra difficulties. The high diffusivity causes a loss of ions in the inlet tract. The numerical correction of the diffusion loss may include considerable uncertainty and complicate the calibration of the instruments. The higher the loss, the greater is the uncertainty. Minimizing of the inlet loss of highly diffusive clusters and nanoparticles is an essential requirement for the instrument.

Some hardly controlled distortions can appear due to the effect of the external electric field on the sampling of ions. A typical fine-weather atmospheric electric field over the flat ground is  $100\text{--}200 \text{ V m}^{-1}$  and it can be largely increased during the presence of convective clouds in the neighborhood. The electric field-driven speed of a cluster ion near the instrument inlet may exceed tens of  $\text{cm s}^{-1}$ , which can modify the amount of sampled ions. The effect is asymmetric: the amount of ions forced by the electric field opposite the intake air flow is decreased but the sampled amount of ions attracted to the inlet remains unchanged (Tammet, 1970).

The control voltage required for the classification of intermediate ions at a high flow rate is thousands of volts. Keeping the electrometric collector on high potential is technically inconvenient and can lead to troubles in exploitation. On the other hand, the inlet of the instrument must be grounded to avoid the effect of the electric field on the sampling of ions. The distortion caused by the electric field in the inlet channel is known as the edge effect in atmospheric electric instruments (Israël, 1970; Tammet, 1970). Labowsky and Fernández de la Mora (2006) introduced the term *isopotential* to mark the DMAs where both the inlet and outlet are on the same potential and can be connected to the ground. Instruments for the research of intermediate ions in natural atmospheric air must be isopotential. This requirement is satisfied in modern air ion analyzers designed for atmospheric research (e.g. Tammet, 2006; Mirme et al., 2007).

### 1.3. Predecessors of the SIGMA

The uniform increase in the DMA characteristic mobility during a scan requires exponential decay of the control voltage. In the SIGMA and its predecessors, the exponential decay of the voltage is produced by the discharge of a RC-circuit, which is called the RC-technique. This technique was introduced in an early instrument UT-7509 (Tammet et al., 1977), which is still used for the measuring of artificially generated high concentration cluster ions (Parts and Luts, 2004). Immediate predecessors of the SIGMA (Symmetric Inclined Grid Mobility Analyzer) are the RC-scanning mobility analyzers of natural atmospheric ions IGMA (Inclined Grid Mobility Analyzer, Tammet, 2003) and BSMA (Balanced Scanning Mobility Analyzer, Tammet, 2006).

The IGMA was the first application of the method of inclined grids, which carries out the idea by Loscertales (1998) to design a DMA with the electric field inclined relative to the air flow. Loscertales proposed the inclined field with the aim to improve the diffusion-limited mobility

resolution. However, the IGMA is a low-resolution instrument, where the diffusion of ions is of secondary importance. The configuration with inclined grids was chosen in consideration of some engineering aims and for testing the new principle in the air ion mobility analysis. The IGMA was used in a few research projects studying the atmospheric aerosol nucleation (Iida et al., 2006).

An alternative instrument intended for the same applications is the Balanced Scanning Mobility Analyzer BSMA (Tammet, 2006). Different of the IGMA, the aspiration condensers of the BSMA have a classic configuration, which is familiar in atmospheric electric research. One instrument contains two identical aspiration condensers connected as the Komarov bridge. The BSMA was applied in studies of atmospheric aerosol nucleation (Kulmala, Tammet, 2007).

Exploitation experience of the instruments showed that easier maintenance is the strength of the BSMA, but its drawback is a higher noise level when compared with the IGMA. There are two reasons: two collectors are connected to the same electrometer and the fluctuations of the bridge balance are generating an extra noise component, especially at high humidity that deteriorates the insulation of the analyzer electrodes.

#### 1.4. Distinctive properties of the SIGMA

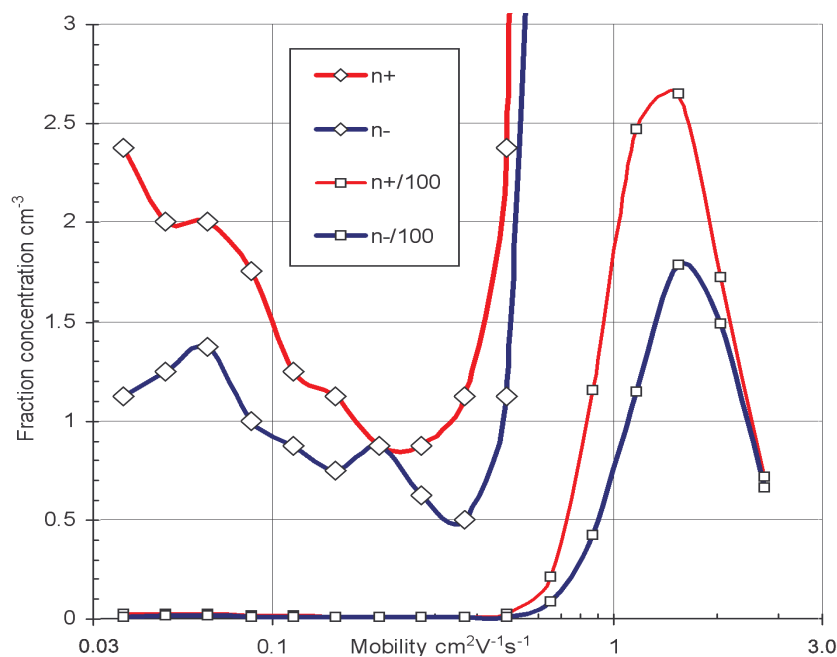


Figure 1.1. Mobility distribution presented by fraction concentrations measured in rural air 20090920 from 16:00 until 24:00, a period without nucleation events. The BSMA was not able to detect the nanometer particles on the occasion of extra low concentrations like that.

Some distinctive properties of the instrument are:

- The positive and negative air ions are sampled from the same inlet air flow and measured exactly simultaneously.
- A high standard rate of air flow more than 30 dm<sup>3</sup>/s and the isopotential principle suppress the disturbing effect of the external electric field and assure the representative sampling of air ions.
- The sheath air is sucked into the instrument directly from the atmosphere together with the analyzed air and ions pass only the unaffected atmospheric air during the analysis.
- The loss of ions in the inlet tract is only 5% at the mobility of 1 cm<sup>2</sup>V<sup>-1</sup>s<sup>-1</sup>.
- The residence time less than 0.2 s and low heating of air less than 0.5 K suppress the risk of the changing of the ions during the measurement.

- High sensitivity allows measuring of 8 fractions of intermediate ions on a mobility decade in atmospheric air at a standard 5-minute time resolution with random errors of about  $1 \text{ cm}^{-3}$ . The sensitivity is demonstrated by an example in Figure 1.1.
- Time resolution up to 20 s is available at random errors in the mobility fraction concentrations between 4 and  $10 \text{ cm}^{-3}$ , see example in Figure 1.2.
- The ions are independently distributed into the mobility fractions and the size fractions while the mobility borders of the size fractions are determined considering the simultaneously measured air temperature and pressure.
- The scanning technique assures that possible peculiarities in the recorded distributions are not generated by the technical troubles of individual mobility channels.
- The mobility and size range can be modified changing the air flow rate and the control program.
- The methods of measurement and instrument calibration are explicitly described in the attached documentation and the source code of the internal data processing is open and available for the user.

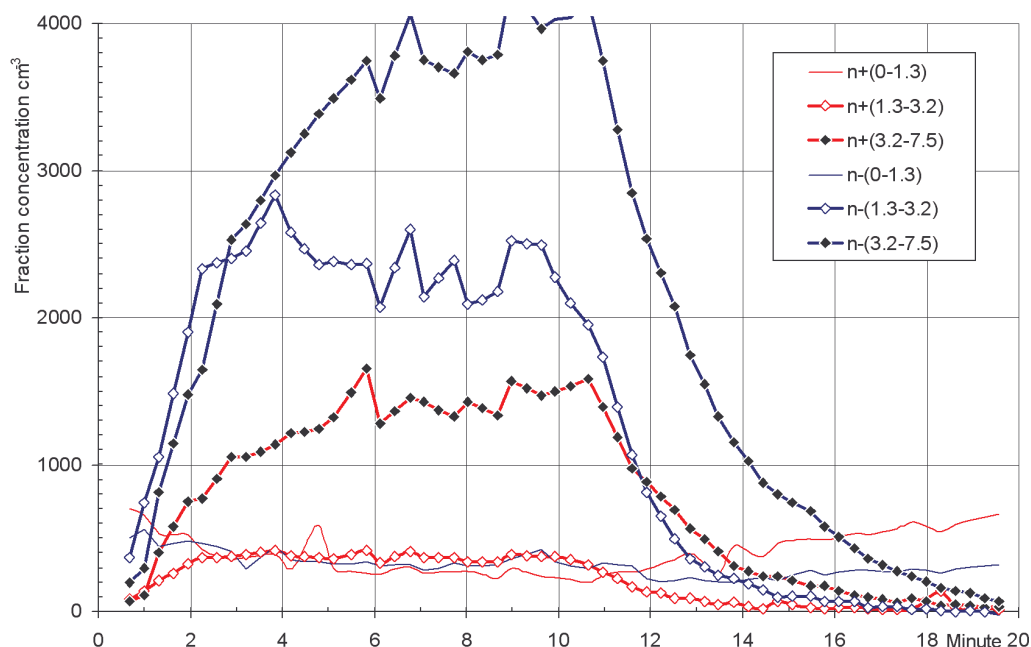


Figure 1.2. Concentrations of three size groups of ions during a water jet experiment. Blue lines show negative and red lines positive ions. The numbers in the legend show the diameter limits of the groups expressed in nanometers. The water jet was opened at 0 and closed at 10 minutes from the beginning of the experiment. During the first half-period (minutes 0–10), the concentrations are fluctuating due to the turbulent transfer of ions from the splashing point to the instrument. In the previous experiments (Tammet, Hõrrak, Kulmala, 2009) the dynamics of the processes remained unknown due to the limitations of the BSMA.

## 2. DESCRIPTION OF THE INSTRUMENT

### 2.1. Aspiration condenser

The analyzer includes a plain aspiration condenser equipped with an inlet electrostatic filter for preparing the deionized sheath air. The SIGMA analyzes simultaneously both the positive and negative ions that enter the instrument through the common inlet slit and are separated according to the polarity into two symmetric sections of the instrument. The ions are collected in two electrostatic filters shielded from the variable electric field of the mobility analyzer. A section of a SIGMA plain aspiration condenser is illustrated in Figure 2.1.

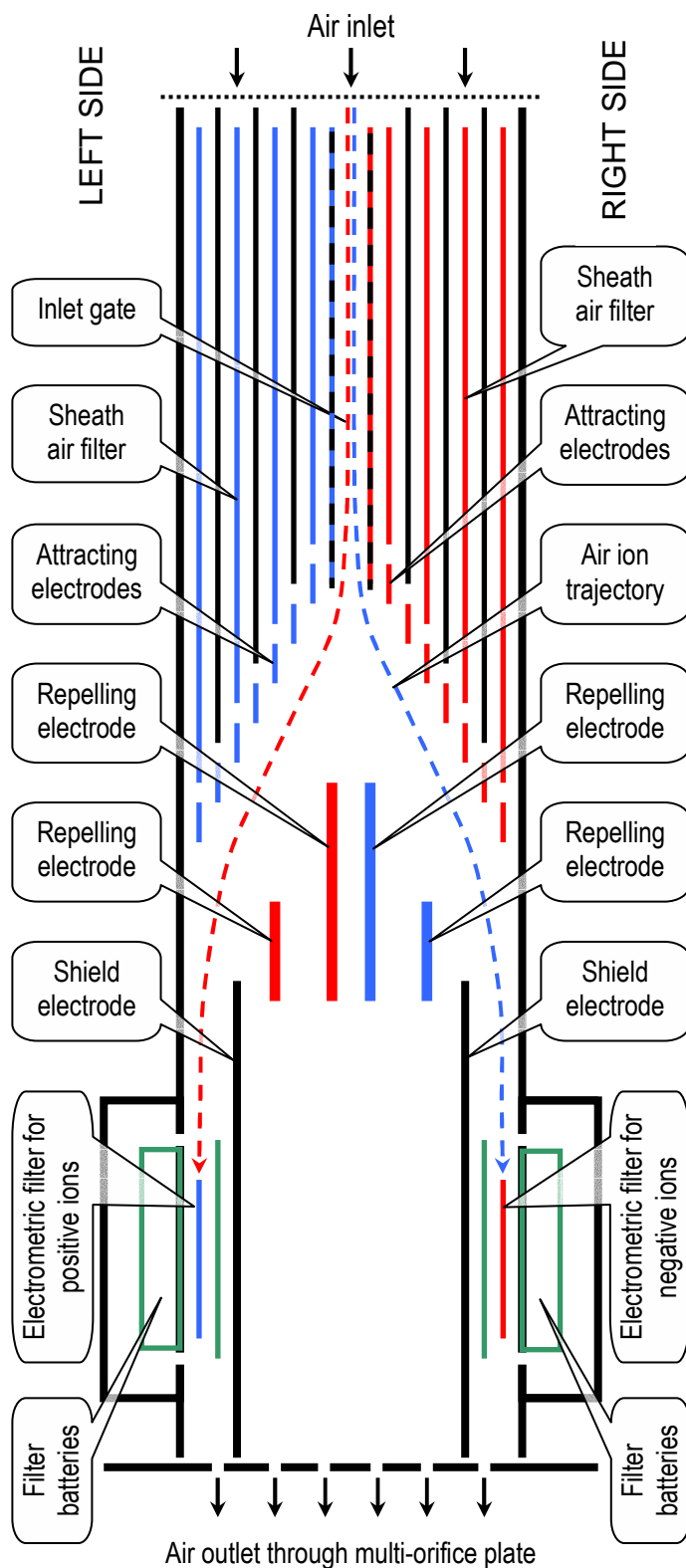


Figure 2.1. A simplified diagram of the SIGMA analyzer (M1:2). Air flow is controlled by exchangeable multi-orifice plate and can be up to  $40 \text{ dm}^3/\text{s}$ . Positive electrodes are marked with red, negative blue, neutral black, and commutable with two colors. Electrodes connected to the inlets of the electrometers are marked with green. Dotted lines show two air ion trajectories. Positive ions are deflected to the left and negative to the right. The sheath air filter voltage is 520 V. Voltages of the attracting and repelling deflection electrodes are relaxing from 3000 to 20 V during each 20-second scan. Collectors of electrometric filters are supplied from 240 V internal batteries. A detailed drawing is presented in Appendix 7.



The atmospheric air enters the instrument through the inlet grid. The disturbing effect of external electric fields near the inlet is inversely proportional to the total air-flow rate and the extra high air-flow of about  $30 \text{ dm}^3 \text{ s}^{-1}$  is helpful in suppressing the distortions. The grid is made of a perforated metal sheet with the perforation diameter of 1 mm and the transparency of 46%. The inlet grid is necessary to prevent the entering of spiders, insects, fuzz, and hairs.

Next, the air will pass the inlet gate and the sheath air filter. The flat filter plates are 1 mm thick and the distance between the neighbor plates is 4 mm. The mean air flow speed in the filter is about  $1.8 \text{ m s}^{-1}$  and the Reynolds number between the plates of about 500 ensures the damping of the carried-on turbulence. The potential of the sheath air filter odd plates is  $-520 \text{ V}$  (left side) or  $+520 \text{ V}$  (right side), while all the even plates are on the zero potential. The low mobility ions passing the middle sections will not reach the collectors even if they are not precipitated in the filter. The crucial elements are the outermost sections, whose critical mobility is tenfold less than the lowest mobility of ions to be measured using the SIGMA. However, the concentration of low mobility ions can largely exceed the concentration of intermediate ions and still cause systematic errors in the collector signal. For correcting this systematic error, the zero level of the signal is to be determined and subtracted from the general measurement signal.

The inlet gate is composed of the two central plates of the filter and the space between these plates (see Figure 2.1). The voltages of the inlet gate plates are computer-controlled. The distance between the gate plates is 10 mm and the mean air speed is about 1.9 m/s. The gate is open when the plates are on the zero potential and closed when the plates are switched to potentials  $-260 \text{ V}$  and  $+260 \text{ V}$ . The critical mobility of the closed gate of about  $0.03 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$  is a little less than the mobility of the largest particles to be measured. A closed gate scan yields a zero level record, which includes the effect of large ions passed through the sheath air filter, as well as the effect of the residual electrostatic displacement current. The air flow between the gate plates at the Reynolds number of about 1260 does not suppress the incoming turbulence. However, the main part of an ion trajectory from the gate to the collector passes the sheath air, where large-scale turbulence is damped in the filter. The Reynolds number is high in the classification zone and turbulence is one of the main factors limiting the mobility resolution discussed in the Appendix 6.7. However, a high Reynolds number in the short zone cannot lead to large distortions because there is not enough time for developing the turbulent pulsations as shown by Tammet (1970) and comprehensively verified by Rosell-Llompart et al. (1996).

The ions, which have passed the inlet gate, are deflected in the electric field between the attracting and repelling electrodes depending on their polarity and mobility. In the IGMA both the attracting and repelling electrodes were made of a perforated sheet, which caused strong distortions in the air flow in the mobility classification zone. In the SIGMA, the attracting grid is a slat grid of the same step as the sheath air filter and the distorting effect is reduced. The repelling grid is replaced by particular repelling electrodes.

The geometry of the analyzer was optimized using a numerical model, which solves the Laplace equation according to the Jacobi-Seidel method on the uniform rectangular grid with a step of 0.1 mm. The ion trajectories were calculated integrating the displacements of ions when passing in an electric field and air flow from one grid cell into the next one. The diffusionless geometric transfer function was found out by repeating the calculation of trajectories at different control voltages. The calculations were carried out on the assumption of plug air flow. However, the diffusionless transfer function depends only on the fluxes of air flow and electric field and is not sensitive to the air flow profile while it remains laminar (Tammet, 1970). The model was the crucial tool that allowed discovering the possibility to separate the positive and negative ions from the common inlet flow with a minor internal edge effect. The internal edge effect, which means the loss of ions on the rear edges of the plates of the inlet gate, is considered in the numerical model when estimating the effective width of the gate.

Nearly all ions of the central critical mobility will travel to the electrometric collector filters. The electrometric filters are shielded from the variable electric field issued from the classifier electrodes with long zero-potential shield plates. A minor part of the electric field still penetrates the channel to the collector. The penetration capacitance of 45 aF is estimated using the numerical model. The small signal of the residual displacement current is effectively removed by the procedure of subtracting the records of the closed-gate scans.

An electrometric filter consists of one attracting plate between the two zero-potential plates. The distance between the plates is 4.5 mm, the effective electrostatic length about 50 mm, the voltage 240 V, and the air flow velocity  $190 \text{ cm s}^{-1}$ . This ensures the critical mobility of about  $0.03 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ , which is just low enough to collect the ions in the instrument mobility range and high enough to minimize the collecting of the large ions penetrating the inlet sheath air filter.

The time of passage of the ions through the classification zone is about 0.07 s. The passage of the air of the total distance of about 27 cm from the inlet grid to the collector entrance requires about 0.15 s. The walls of the analyzer are thermally insulated by foam polystyrene. In an extreme situation of 20 K temperature difference, the heat flux causes the mean temperature change of the air flow still less than 0.5 K.

A detailed drawing of the aspiration condenser is presented in Appendix 7.

## 2.2. Principles of operation

Performance of the SIGMA substantially depends on manipulating the instrument by a computer and internal processing of the recorded signals under the supervision of the control program. The computer is connected to the electronic circuits inside the instrument via the USB port. The data acquisition unit USB-1608FS, manufactured by the Measurement Computing Corporation, is built into the SIGMA. The control program, which was used during the test measurements, had been written for a PC-compatible computer running under Windows.

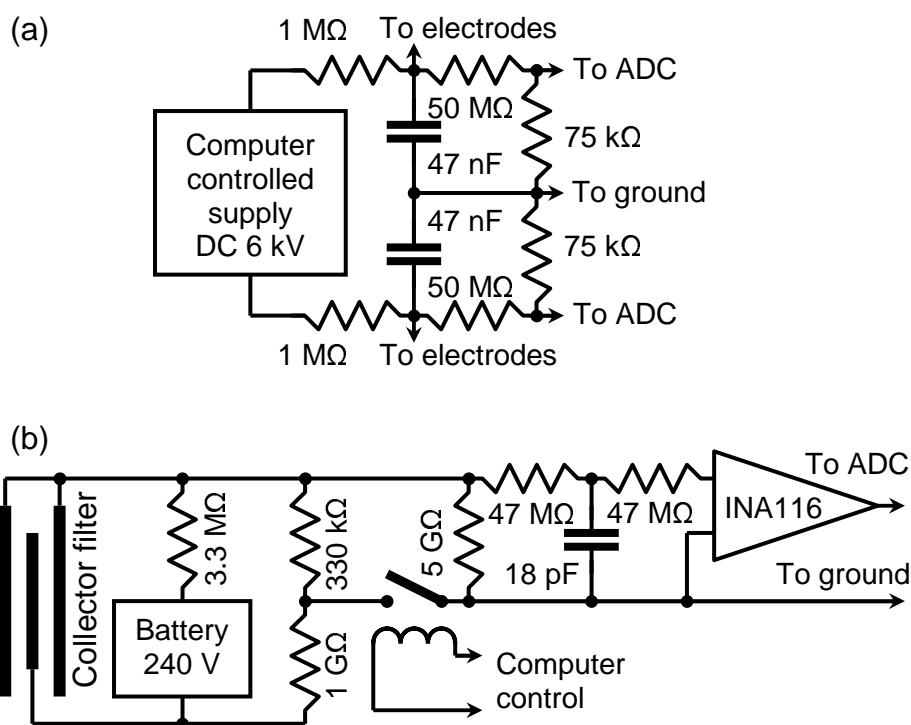


Figure 2.2. Simplified electric diagrams of the SIGMA. (a) High voltage relaxation RC-circuit, (b) electrometric collector and amplifier.

The circuit for the control of the voltage between the attracting and repelling electrodes of the mobility classifier is illustrated in Figure 2.2a. The high voltage up to 6 kV is generated by a

well-insulated voltage converter U3-6PN manufactured by the Matsusada Precision Inc. The output internal capacitance of the converter is about 15 nF and the time constant of the RC-circuit is about 4 s. The positive output is connected to the attracting grid for the negative ions and to the repelling electrodes for the positive ions. The negative output is connected to the attracting grid for the positive ions and to the repelling electrodes for the negative ions. The control computer can switch the inlet power of the converter on and off. About one second of power on is enough to charge the capacitors. After charging, the power is switched off and the classifier voltage will exponentially decay, which follows in an approximately logarithmically uniform increase in the critical mobility. The actual values of the decaying voltages are monitored using two ADC inputs of the data acquisition unit. The full mobility range with some reserve is passed during 18 seconds. The period composed of charging and discharging of the RC circuit is called a scan. Typically, three scans are performed during one minute. This provides the time resolution of about 20 seconds.

The circuit for collecting and recording the ion current is illustrated in Figure 2.2b. An electrometric collector filter is powered by twenty 12 V miniature batteries type GP27A. The batteries have the capacity to serve for at least one year without changing. They are enclosed into a metal box connected to the electrometric collector and well insulated from the other details. The computer-controlled electrometric relay shown in Figure 2.2b is open during the measuring of the ion current. The ion current is converted to the voltage on a precision 5 G $\Omega$  resistor and amplified with the electrometric instrumental amplifier INA116. The 1 G $\Omega$  load of the battery is required to make possible a regular check of the voltage using the computer-controlled electrometric relay. The checking procedure includes two measurements of the electrometer outlet voltage in the closed inlet gate regime. One measurement is made with the open relay and the second with the closed relay. The difference between these measurements corresponds to the voltage drop on the 330 k $\Omega$  resistor and allows estimating the actual voltage of the battery.

Detailed electric diagrams of the SIGMA are presented in Appendix 8.

During the routine measurement, the scans are performed alternately with the open inlet gate and the closed inlet gate. The schedule usually contains the groups of three scans where two scans are made with the open inlet gate and one scan with the closed inlet gate. The zero level is estimated according to the closed gate measurements. The zero level can drift due to the technical drift of the electrometric amplifier and the variation of the residual signal of large ions. The drift is usually slow, which allows integrating the zero signals over a considerably longer time interval than the open gate signals. An additional benefit of repeated closed-gate-measurements is providing data for the estimate of the instrumental noise.

During a scan the classifier voltages and the electrometric signals are recorded with the time step of few milliseconds. After the required lower border of the voltage has been reached, the collected data are processed. Initially, the full mobility range is logarithmically uniformly divided into 16 narrow fractions per decade, altogether 35 fractions. The voltage range is split into subintervals corresponding to these mobility fractions and the fraction averages of the electrometric signals are calculated. Afterwards, the data are processed as explained in Appendix 4. The 16 wide fractions (see Table 5.2) are calculated on the basis of the initial narrow fractions. The parameters of the air are measured using built-in sensors during every scan and the size distribution of air ions is determined considering the air temperature and pressure according to the algorithm by Tammet (1995). The results are displayed as shown in Figure 3.2 and issued as output files described in Chapter 5.

The measuring algorithm and internal data processing are independent of the hardware. In the present manual, the measuring process is described as specified by the control program SIGMA1A. A user of the instrument is free to modify the control program or write a new control program, which may specify completely different methodology of the measuring process and a new structure of the output data.

### 2.3. Installing of the instrument

The SIGMA package consists of

1. Main unit of the SIGMA.
2. 24 V power supply Mascot 2020 and the power cord.
3. USB-A to USB-B cable.
4. Documentation and software for SIGMA
5. Documentation and software for MCC DAQ CD.
6. Prepared control computer (optional).

The air flow in SIGMA is controlled by a multi-orifice plate located between the analyzer section and the fan section. Replacing of the plate is described in Section 4.2. Present manual is concerned about an instrument, which is equipped with the standard 4.0 mm orifice plate.

A computer should be prepared for controlling the SIGMA. It should run under MS Windows (version XP with SP2 or SP3 or version 7) and have a free USB connector. The SIGMA includes a built-in data acquisition unit USB-1608FS and the MCC DAQ software for USB-1608FS should be installed first. The SIGMA software included into the folder "SIGMA" should be copied from the included SIGMA CD into the computer. The programs are ready to launch and do not require installation. The location of the SIGMA folder on the computer disk is arbitrary, most convenient location is the root folder of the main disk.

Be aware that hidden system programs have a higher priority than the SIGMA control program. Aggressive background programs, like many of Antivirus programs, may take over the processor and cause failures during measurements. Thus the processes of automatic scanning and software updates, as well as all unneeded simultaneous applications, should be turned off for the period of routine measurements. If necessary, the base priority of the control program should be increased using Windows task manager.

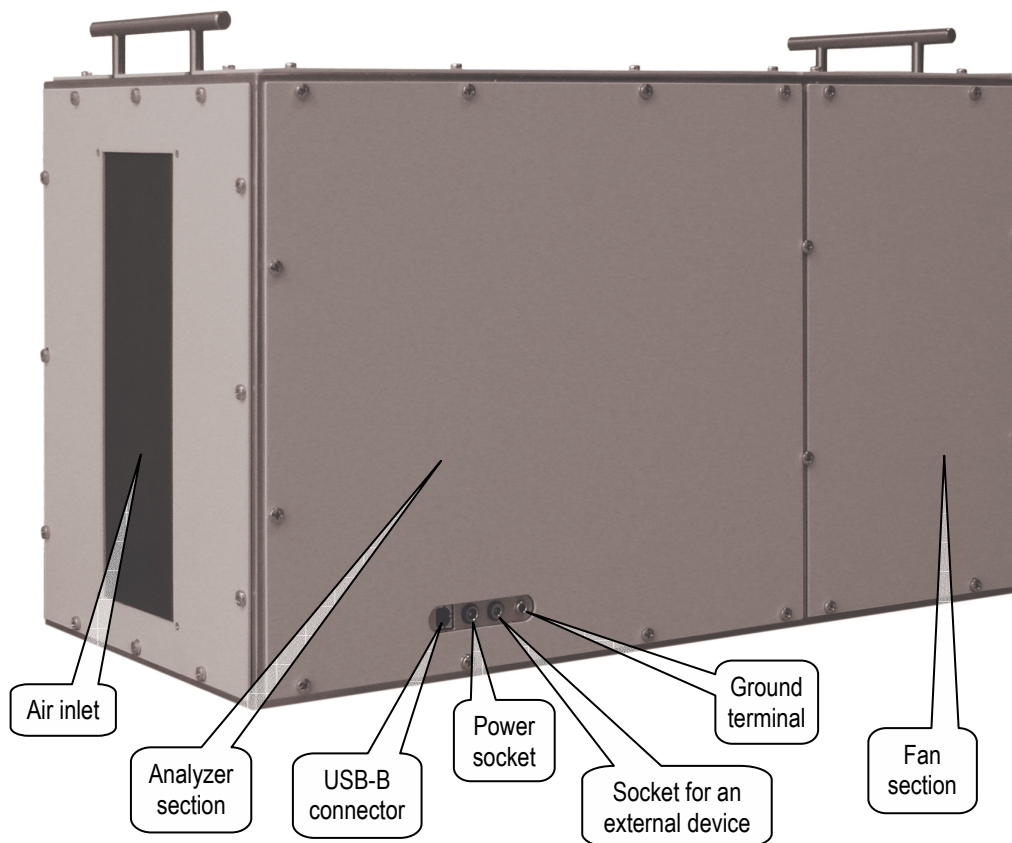


Figure 2.3. Main unit of the SIGMA.

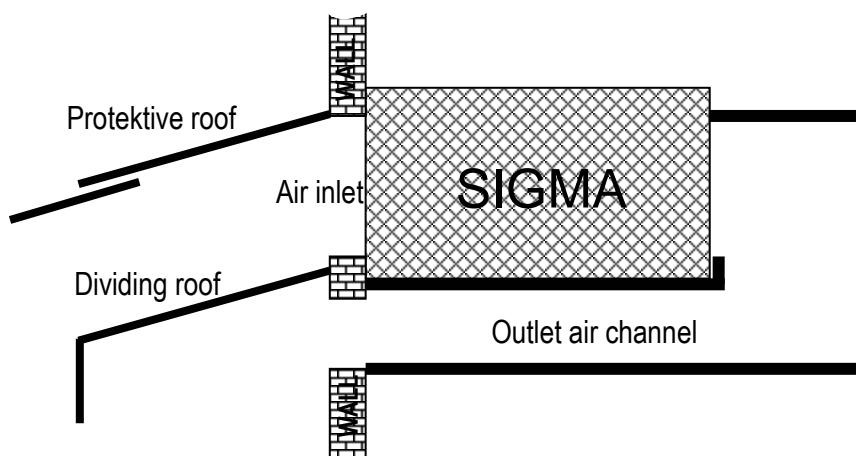


Figure 2.4. Installation of the SIGMA insensitive to wind.

The main unit of the SIGMA is shown in Figure 2.3. The normal position of the instrument is with the horizontal airflow. On this occasion, the height of the instrument with handles is 350 mm, the width is 280 mm and the length along the airflow is 550 mm. The air is sucked in through a vertical opening of 240 (height)  $\times$  90 (width) mm in the front end of the instrument (see Figure 2.3). The air flows out from a similar opening in the rear end. The pressure drop generated by the internal air blower is about 200 Pa. This is not a high value and the instrument is slightly sensitive to wind. The external wind velocity difference of 5 m/s between the inlet and the outlet of the instrument will generate an extra pressure of about 15 Pa that results in a 4% change of the internal air flow velocity. It is recommended to install the instrument for stationary measurements in such a way that the air will flow out from the same side of the building as the inlet (see draft in Figure 2.4). The cross section of the external air channel should be at least 4 dm<sup>2</sup>.

The independence of the measurement of wind is conventional. Installation according Figure 2.4 avoids a systematic shift of mobility and concentration. However, if the instrument is not protected of wind, then the concentration of large dust particles near the inlet can be high during windy weather and these particles would generate a strong noise signal in the measurements.

It is not recommended to install the instrument inlet through a wall that is exposed to the direct sunlight. The convection of heated air and temperature fluctuations near the wall can disturb the measurement, resulting in increased fluctuation noise in the measurements.

The most frequent service operation is the cleaning of the electrometric collectors, which requires opening of the short upper panel of the fan section, as well as the long left or right side panel. Thus it is strongly recommended to keep the access to these panels free and leave at least 300 mm free space above the fan section of the instrument.

After the instrument has been positioned, the electrical connections have to be made:

- A ground wire must be connected to the ground terminal or to a cover screw of the SIGMA.
- After the ground wire is connected, the computer should be connected with the SIGMA by means of an USB cable.
- A 24 V DC power supply (Mascot-2020 or accumulator battery) should be connected to the SIGMA via the power inlet. Make sure that the center electrode of the power plug is positive (warning: the polarity of the Mascot-2020 output plug is convertible).
- NB: when using the mains, the ground wire must be connected with the Protective Earth of the mains (green-yellow cable wire, abbreviation PE) and a mains surge voltage protector is recommended especially during the thunderstorm period.

The ground connection is obligatory because the electric field around the case of the instrument can disturb the admission of ions and charged particles into the inlet of the instrument. However, the SIGMA is relatively insensitive to weak external electric fields due to its high ventilation rates.

**WARNING:** some computers do not recognize ready-connected USB1608 after start-up or restart. Please detach the USB connector when the computer is turned off and connect again when the computer is running.

A desktop computer should be powered via UPS during routine measurements. A laptop computer with a good internal battery can be used without UPS. The control program SIGMA1A will restart the measurements after a power blackout when the computer is still running.

The SIGMA has an additional socket, which enables the switching of an external device (see Table 4.2 and Appendix 8). The standard control program SIGMA1A.EXE supports only the manual control of the external device. Automatic control can be included when modifying the program code; see Appendix A4.4 of the manual.

It is strongly recommended to learn the instructions in the next chapter before starting the measurements.

## 3. OPERATION OF THE INSTRUMENT

### 3.1. Launching the measurements

We expect that the SIGMA and the control computer are installed as explained above in the present manual and SIGMA is equipped with the standard 4 mm multi-orifice plate. At first the SIGMA folder should be opened. This folder must contain as a minimum the program file SIGMA1A.EXE, calibration file SIGMA1A.CAL, control file SIGMA1A.INI, subfolder DAYS, and subfolder MONTHS. These two subfolders can be empty before the first run. The calibration file and the control file are explained in Appendix 4, see Section A4.2.

The program SIGMA1A.EXE could be launched by double-clicking the icon. After a while a window with the message "please turn SIGMA power on" will appear. When the power is on, the welcome window with the start menu will be displayed as shown in example Fig. 3.1.

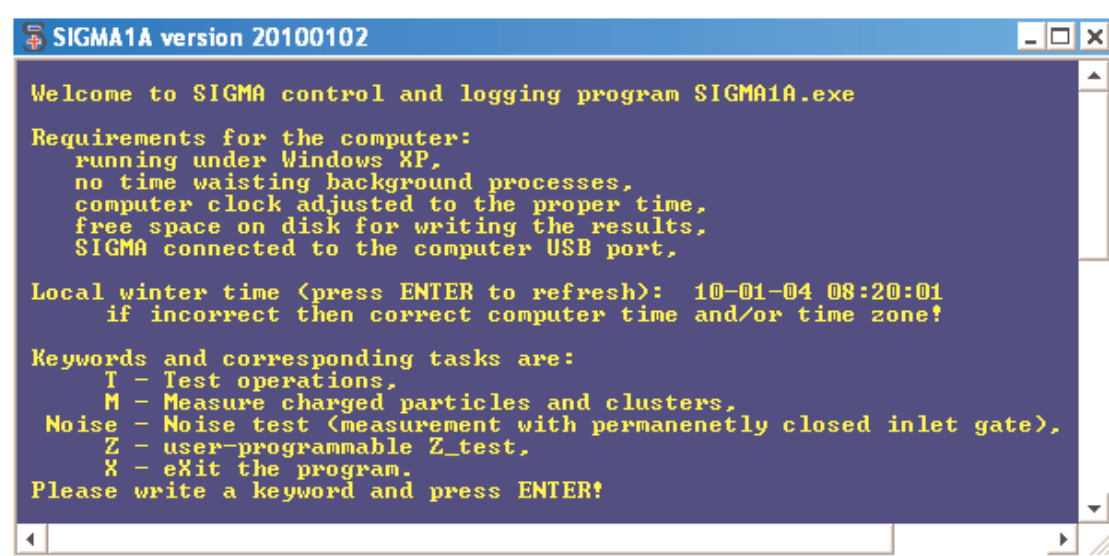


Figure 3.1. Start menu of SIGMA1A.

When the SIGMA is powered before running the control program, then the electric control lines of the SIGMA may appear in a random status. It is recommended to run the control program SIGMA1A.exe first and, after that, turn on the power of the SIGMA.

The local winter time used in the program may differ from the local civil time during summer. Test operations and noise test explained in Chapter 4 may appear useful for technical diagnostics. Normal measuring process should be launched pressing the key M.

The SIGMA folder can contain some optional files. If an optional file SIGMA1A\_exmeteo.txt is presented then the computer will read some data from this file and ignore the readings of meteosensors for the quantities presented in the file. A quantity can be presented with a text line, which begins from P=, T=, or RH=. The value of the corresponding quantity should be written immediately after the mark =. An example: a file including just two lines

```
RH=48  
T=24.3
```

leads to the replacement of the readings of the humidity and temperature sensors with the presented values. This option is used in occasion of the sensor failures.

### **3.2. Control of the SIGMA during measurements**

The measuring and data processing is controlled via the calibration file SIGMA1A.CAL and the control file SIGMA1A.INI, see Appendix 4. These files are read once when the control program is launched. It is strongly recommended to learn all parameters of the control file SIGMA1A.INI before launching the measurements, see Section A4.2.

During the measurement, the computer screen gradually fills with information as shown in Figure 3.2. In this example, the fraction concentrations of ions are displayed. The control file allows the user to choose the display of the fraction concentrations or the values of logarithmic distribution functions. The last values are usually 8 times larger than the fraction concentrations and equal to the values saved in the standard output files, see explanations in Appendix 2 and A4.2. The diagnostic parameters in the right side of the screen are explained in Section 4.1. An important parameter is the noise index displayed in the upper part of the screen. The index does not depend on the chosen presentation of the distributions and it is always calculated as a coarse estimate of the standard deviation of the random errors in the values of the logarithmic distribution function.

The raw scan details are saved after every scan. The processed results are displayed and saved for reference cycles. The schedule is arranged so that a cycle begins just at the full hour and the duration of every cycle is equal to the parameter *cycleminutes* assigned to it in the control file. During long term routine measurements, the typical value is *cycleminutes* = 5. The zero level is additionally considered during 2 cycles before and 2 cycles after the reference cycle. This is followed by a delayed display and recording the results. In case of 5-minute cycles, the results for the first reference cycle will appear 25-30 minutes after the launching of the measurements and the following results will appear with the delay of 12.5 minutes from the central moment of the reference cycle.

Possibilities for interaction with the control program during the routine measuring process are limited. All control keys are explained on the screen. NB!: the keys will act only when the program window is active (click the SIGMA1A title bar after working in another window). During a scan, which lasts about 20 s, the computer is busy and does not show any reaction on the pressing of a control key M, E, D, S, or mark key 0...9. The reaction appears at the end of the scan. Only the last key pressed during a scan is considered. An exception is the key combination XZ, these two keys should be both pressed in the indicated order during one scan.



SIGMA1A version 20101201									
Date 20110204					scanning mob&dia distributions				
HH:MM	14:47	14:52	14:57	15:02	15:16				
T:C	3.53	3.52	3.53	3.56	3.62				
RH:z	64.59	64.56	64.47	64.38	64.69				
p:mb	990.84	990.75	990.57	990.27	989.62				
noise	6+	6-	5+	7-	6+	7-	Scan	2	reg 0
MOB	Mobility fraction concentrations : cm-3								ADC counts
0.037	6	6	3	8	6	6	11	5	-14 -610
0.049	5	7	3	7	4	6	7	8	-15 -595
0.065	4	8	6	5	4	8	7	6	-7 -588
0.087	6	8	7	4	3	5	6	8	-5 -577
0.115	4	7	4	5	4	5	4	5	-1 -573
0.154	4	3	4	2	6	4	6	1	0 -566
0.205	3	2	4	5	3	5	4	7	4 -562
0.274	3	3	1	4	1	6	3	11	4 -558
0.365	2	6	3	6	4	1	3	8	-1 -555
0.487	3	6	6	13	5	9	6	10	1 -555
0.649	24	27	30	28	23	27	24	24	1 -552
0.866	115	92	113	90	113	86	108	75	4 -554
1.155	270	160	239	146	238	141	234	122	3 -537
1.540	220	154	194	137	187	143	182	136	0 -553
2.054	97	91	81	66	90	77	88	71	3 -554
2.738	34	37	29	30	34	34	31	33	4 -555
DIA	Diameter fraction concentrations : cm-3								DIAGNOSTICS
0.487	84	85	74	69	81	73	81	71	Cycle 181
0.649	179	137	149	114	149	123	149	117	Scans 15
0.866	312	195	277	175	277	173	268	155	Supply 23.3
1.155	177	131	171	128	167	122	163	105	Filter+ 524
1.540	21	27	28	34	22	30	24	30	Filter- 520
2.054	4	8	3	9	5	6	5	17	Battery+ 230
2.738	6	4	7	6	7	8	8	9	Battery- 228
3.652	7	10	7	7	7	8	8	8	E-bias+ -0.01
4.870	8	15	12	8	6	12	12	12	E-bias- 1.68
6.494	10	12	5	14	9	10	16	12	Pretime% 163
N-prt	38	51	38	51	38	48	52	63	Tau 3631
n-cls	769	581	698	524	698	522	683	479	Asymmetry 13
Z-cls	1.39	1.45	1.37	1.41	1.39	1.42	1.39	1.45	HU0+/- 9/-7
Save current data into MONTHS&DAYS: ON <Key M turns off>      Set mark = Key 0...9 Save diurnal data into Extrafolder: OFF <no access>      Effect of a key appears Save diagram tables into DIATABLES: ON <Key D turns off>      at the end of the scan Save scan details into SCANDETAILS: ON <Key S turns off>      SAVE & EXIT = XZ									

Figure 3.2. Computer screen during measurements.

The value set by a manual mark key 0...9 will be recorded in the last columns of the standard data and of the table of scan details. Marks 1...9 are displayed just after the date in the first line of computer display. Default mark is 0 and the key 0 is used to clear the mark. Marks 1...8 do not have any effect on the measuring process. Mark 9 is exceptional: it turns on the external device connected to the socket shown in Figure 2.3. The external device is physically turned on just at the beginning of the next cycle and will be turned off after the mark is changed to a regular value of 0...8.

Additionally, two Windows standard operations can be used. Alt+PrtScr saves the screen as a picture into the clipboard ready to paste into MS Word document. Right click on the window title bar opens a menu, where the choice "Edit" and "Mark" allow marking a part or full window as a text. Following "Enter" will copy the marked text into the clipboard.

Any of the four saving options can be in one of three states: accessible and on, accessible and off, not accessible and off. No access means that the destination folder of the data is not available. The availability of the folders is rechecked during every cycle. The destination folders and saving schedule (midnight is defined according to the local winter time) is explained in Table 3.1.



Table 3.1. Location of SIGMA1A output files (see descriptions in Chapter 5).

Files	Location	When saved
Monthly standard data	...SIGMA\MONTHS and extrafolder	midnight & XZ-exit
Diurnal standard data	...SIGMA\DAYS	end of every cycle
Diagram tables	...SIGMA\DIATABLES and extrafolder	midnight & XZ-exit
Scan data	...SIGMA\SCANDetails	end of every scan

The initial positions of the control keys are set by the control file SIGMA1A.INI and can be changed when editing this file. The possibility to switch the data storage temporarily off using the key M is necessary on the occasion of service operations that could distort the recorded data.

Path of the extrafolder is to be indicated in SIGMA1A.INI, see Appendix 4. It could be a folder on removable media, a shared folder or a remote folder.

The measurements can be disturbed due to different reasons. Typical disturbances are: the pollution of collector and deflection electrodes with fibers, pollution of the insulators, condensing of water inside the instrument, dust or tiny ice crystals in the air, etc. If a diagnostic parameter is out of the critical range, then a message is displayed and the measuring process may be temporary stopped. The critical ranges are:

- power voltage 21.6...26.5 V,
- filter voltage 450...550 V,
- polarity asymmetry of deflecting voltages up to 5 %
- collector battery voltage 200...300 V,
- electrometer bias -5...+5 mV,
- zero shift of HV ADC readings 100 ADC counts
- number of electrometer overload events during one scan up to 3.

The time and explanation of the failure are recorded in the logfile *SIGMA1A\_failure.txt* that will be automatically written into the SIGMA folder. The control program will continue to check the parameters and make attempts to restart the measuring process after some pause (usually 10 minutes). In a specific situation of electrometer overload, the program will repeatedly turn the fan off and on during the failure pause, attempting to suck away the fibers from the air ion collector.

More information about the diagnostics of the instrument is presented in the next chapter of the manual.

### 3.3. Terminating of the measurements and the data capture

The measuring procedure is normally terminated after pressing the keys X and Z in the given sequence. In this case, the program will complete the monthly output file and the diagram table file before stopping. Another way is the standard Windows method to click the upper right corner of the window. However, this is not recommended because the instrument hardware control lines will not be safely turned off and the program will not complete the monthly file, which remains as it had been written at the previous midnight.

The data files can be copied onto the removable media every time when the control program is not accessing the disk. It is best to wait until the number of the scan in a running cycle (see display) is 1 or 2, and there is free time until the end of the running cycle for copying the diurnal data file. The safest time to copy all the data to the external media is when data saving has stopped. It does not need terminating the measurements and can be performed using the keys M and S.

If an output file will appear to be opened by the user (e.g. inspecting a file using Excel) during the time of regular saving operation, then the control program will skip the current operation and a part of the data will be lost. However, if the user is not touching the files at midnight,

then the loss of data in a diurnal file is not followed by the loss in the monthly file, where all standard data will still be presented.

The manufacturer of the included data acquisition unit does not assure undisturbed functioning of USB1608 during the connection and disconnection of additional USB devices. However, no disturbances have been observed when connecting and disconnecting USB memory sticks during the test exploitation of the SIGMA.

A comfortable tool for quick copying of all new (that means not present on the removable media) data onto a removable media is a self-explaining program *data\_transfer.exe* that should be located in the SIGMA folder. Simply connect a removable media e.g. a memory stick, and double-click the program icon.

## 4. MAINTENANCE OF THE INSTRUMENT

### 4.1. Simple diagnostics of the hardware problems

Some diagnostic information is displayed in the lower right-hand table in the SIGMA1A window. The most essential diagnostic parameters are explained in Table 4.1

The parameter *Pertime%* shows the reserve of the HV when beginning a scan expressed as the ratio to the time of passage one 1/16 decade fraction. This value should be at least 50. A lower value does not cause a formal failure but indicates the need for checking the condition of the HV source.

*Asymmetry index* is defined as the relative deviation of the positive deflection voltage from the average of positive and negative deflection voltages at half-time of the scan. The ions are deflected between the positive and negative voltage electrodes and a moderate asymmetry has no considerable effect on the measurements. Increased asymmetry is a symptom of HV leakage, caused usually by pollution of the insulators. The asymmetry index more than 50 promille (5%) is not tolerated and it is identified as a serious failure. Specific diagnostics is possible in the test regime, see Section 4.6.

Table 4.1. Diagnostic parameters in the SIGMA1A window

Name	min	typ	max	Explanation
Supply	21.6	23.2	26.5	Voltage of power supply, V. Mascot 2020 provides 23...24 V
Filter+ Filter-	450	520	550	Voltages of inlet filters, V. Low value can be a result of insulator pollution.
Battery+ Battery-	200	240	300	Voltages of filter batteries, V. A gradual decrease indicates the discharge of batteries. Rapid decrease and fluctuations indicate pollution of the collector insulators, electrometer relay or battery contacts. In this case the indicated values may largely differ from the true voltages.
E-bias+ E-bias-	-5	0	+5	Bias of the electrometer amplifier INA116. High value usually indicates leakage from the collector electrode via a stuck hair or web, or damage of the amplifier.
Pertime%		100		$100 \frac{\text{fractiontime [1]}}{\text{fractiontime [2]} - \text{fractiontime [1]}}$
Tau	3600	3900	4100	Time constant of HV relaxation, ms. Low value may indicate pollution of the condenser insulation or deterioration of the HV capacitor of the RC circuit.
Asym	-50	0	+50	Asymmetry index of +/- HV, promille. High absolute value indicates asymmetric pollution of the condenser insulation.
HV0+/-	-100	0	+100	Bias of HV zero readings expressed in ADC counts
Ovrl+/-	0	0	3	+ and - electrometer overloads during a cycle

An additional diagnostic parameter is the noise index recorded in the standard data and displayed in the measurement screen for every cycle, see Figure 3.2. The index is a coarse estimate of the standard deviation of the noise in the values of the logarithmic distribution function; its typical values during calm weather and a low concentration of coarse aerosol are 5–10. Presence of coarse aerosol particles can essentially increase the noise. A value over 100 is an attribute of a highly enhanced dust concentration or the malfunctioning of the instrument. The air ion distribution can be displayed on the screen by values of the logarithmic distribution function or by values of the fraction concentrations depending on the choice made in SIGMA1A.INI. However, the noise index is always displayed for the logarithmic distribution function and it should be considered that the values of the distribution function are about 8 times larger than the fraction concentrations.

Some disturbances cannot be identified according to the displayed values. Thus a regular visual inspection of the instrument is required.

Most frequent disturbance is the pollution of the inlet grid with fibers and fuzz. The fibers and flakes adsorb ions and decrease the recorded values of the ion concentration especially in the region of small ions; adsorption is proportional to the mobility in the power of 2/3. Slight pollution cannot be identified according to the displayed fraction concentrations because there is no information about adsorption-free measurements. The inlet grid should be periodically cleaned according to the results of visual inspection. This can be made by sucking the fiber and fuzz away outside with a vacuum cleaner (use the end of the tube without any additional nozzle). The procedure can be carried out without stopping the measurements and disassembling the instrument. Operations of a more thorough cleaning are described in the following sections of the manual.

In summer time, the inlet electrostatic filter can be polluted by the smallest insects that have passed through the grid and have been trapped in the strong electric field of the filter. The electric resistance of dry insects is high and usually they do not overload the filter voltage supply. The filter voltages are continuously monitored and recorded together with the measurements. The absolute values of these voltages should both be about 520V. If a filter voltage is less than 450 V, then a failure message is recorded and displayed, and the measuring process is interrupted for 15 minutes. The filters require cleaning when any of the filter voltages drops below of 500 V. The experience of routine measurements has proved that usually it is enough to clean the filters during the regular cleaning of aspiration condensers.

Pollution of the condenser insulation has usually no effect in case of low relative humidity and the measurements are not disturbed. Troubles emerge during the periods of high humidity.

Fluctuations in the electrometer signal, which appear as the measurement noise, have several simultaneous origins. The main contributors of high noise are charged dust or a coarse aerosol, whose concentration in atmospheric air usually increases with wind speed, especially in the conditions of low humidity. Charged low-mobility particles can pass through the inlet filter and induce electrical pulses in the electrometric collector even if they do not deposit. The neutral particles can generate noise pulses when they collide with the collector electrodes and get charged due to electrostatic induction. The dust noise in the SIGMA is about the same or even higher than in the BSMA. Fortunately, the dust noise is strongly suppressed during such atmospheric situation that supports nucleation events. The dust noise in the output standard tables can partially be suppressed in the range of low values of the distribution function, when assigning the value of 1 or 3 to the parameter *extracorrect* in the control file SIGMA1A.INI. This parameter does not affect the output of scan details.

Another important component of noise in air ion analyzers is produced by the alpha rays emitted by the daughter elements of radon. The most essential among them are  $^{218}\text{Po}$  ( $t_{1/2} = 182\text{ s}$ ),  $^{214}\text{Pb}$  ( $t_{1/2} = 1620\text{ s}$ ), and  $^{214}\text{Bi}$  ( $t_{1/2} = 1190\text{ s}$ ), all having about equal activities in the

air. They are carried by air ions and aerosol particles and deposited onto the electrodes of the aspiration condenser. One alpha particle generates about 100000 ion pairs. These ions, when attracted to the collector, produce a noise pulse. This component of noise cannot be eliminated by cleaning the instrument, because the electric field in the condensers continuously collects radioactive ions and aerosol particles. The radioactive pollution on the electrodes will decay by itself in a few hours after the radon concentration in the air has been returned to a low level. The design of the SIGMA pretty effectively suppresses the alpha-noise, which is much less than that in the BSMA.

Considerable component of noise may appear as a result of the fluctuations of temperature and pressure of the inlet air. Thus the air should be sucked into the instrument from a place where the air temperature is uniform.

A specific for the SIGMA very harmful disturbance can be caused by long fibers and spider webs attached onto the plates of the electrometric collectors or the contacts of the electrometer relays. The instrument cover should always be properly closed to avoid the getting of insects and small spiders into the case and polluting the electrometer relay and input details. The leakage of a very weak electric current from the collector or the electrometer input causes a slow drift of the zero level. The drift is not fully filtered out by the zero control algorithm of the control program SIGMA1A and the data may contain large systematic errors, which are about equal in all components of the distribution function. Additionally, the leakage current shifts the electrometer bias and disturbs the measuring of the battery voltages, which can be identified in the display and records of diagnostic parameters.

Weak disturbances caused by the attached fibers usually result in enhanced values of the noise index. If the attached fibers are identified as the probable reason of the noise, then it is, first, recommended to try and clean the internal air stream of the electrostatic filters as described in the next section. This procedure does not require essential disassembling of the instrument – it is enough to take off one panel of the cover. If this procedure does not help, the next step is the minimum disassembling and cleaning of the corresponding electrometric filter as described in the following sections.

NB: disturbances caused by fibers in electrometric collectors induce large errors of measuring the battery voltages. Thus abnormal values of displayed voltages along with noise and shifted values of E-bias should not be considered as identification of real impairment of the batteries.

## ***4.2. Internal air stream cleaning of the electrostatic filters***

The simplest way to remove the fibers from the filter electrodes is to use a strong air stream. The speed of the normal air flow in the filters is a little less than 2 m/s. According to the experience, this air flow can carry away many of attached fibers itself, which typically happens during a few hours after the fiber has attached. If the control program detects a strong disturbance, then the measurement is interrupted for about 10 minutes and during this time, the air flow is several times switched off and on to help the detaching. However, often, this is not sufficient.

The next step is to enhance the air stream driven by the SIGMA's own internal fan. This can be done by removing the multi-orifice plate (see Figures 2.1 and 4.1) used for the calibration of the air flow and replacing it with a special plate that channels the full air flow through one electrometric filter. The recommended procedure is:

- stop the measurement with keys XZ,
- enter T for the test regime and press 0 to switch on the fan (the fan will start slowly with a delay of several seconds),
- take off all the screws fastening the upper cover plate of the fan section,
- remove the cover plate and the multi-orifice plate (see Figure 4.1),
- put the cover plate back and remove it again several times – the air stream will be moderately enhanced in all filters,

- install the special asymmetrical plate as a replacement of the multi-orifice plate (see Figure 4.1),
- put the cover plate back and remove it again several times – the air stream will be strongly enhanced in one electrometric filter,
- turn the special asymmetrical plate so that the air flow will be open for the other electrometric filter,
- put the cover plate back and remove it again several times – the air stream will be strongly enhanced in the second electrometric filter,
- press X to exit the test regime,
- reinstall the multi-orifice plate and the cover plate as they were before the cleaning procedure,
- enter M to continue the measurement.

If the described procedure does not help, then the instrument should be disassembled and cleaned as described below.

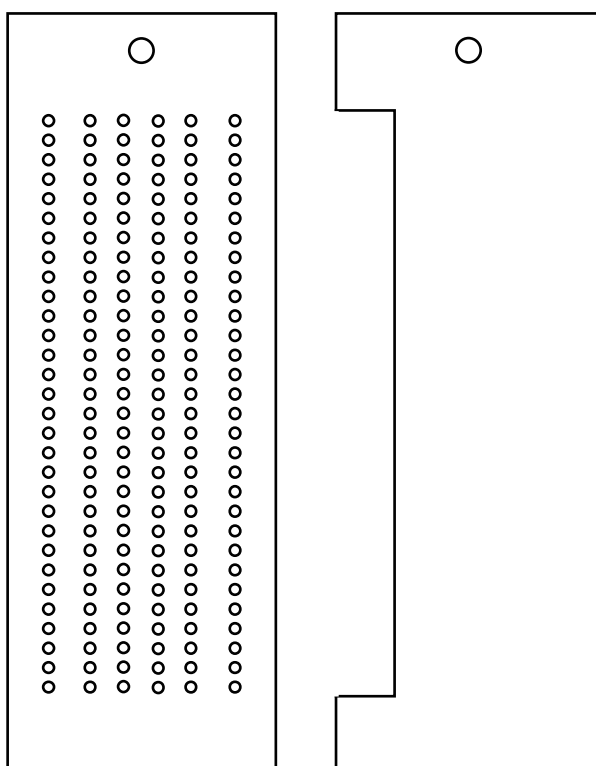


Figure 4.1. The multi-orifice plate and the asymmetric plate for internal air stream-cleaning of the electrometric filters.

### 4.3. Disassembling and assembling of the instrument

#### Warnings:

- *The instrument contains high voltage circuits. The case of the instrument can be opened (except of the upper panel of the fan section) only after the power cord has been detached from the instrument for at least 30 s.*
- *The transparent details in the instrument are made of polycarbonate, which is soluble in acetone. Keep acetone and acetone-containing solvents carefully away of the instrument as the insulators can be damaged when contacted with acetone.*

- *The screws should be fixed in polycarbonate with a low moment, the torque should not exceed 0.1 N/m. It is recommended to use a thin-handle screwdriver (diameter up to 10 mm).*

Cleaning and service of the collector filters requires *minimum disassembling*, which can be done independently for one or the other side of the instrument. If there is enough space near the SIGMA, the servicing can be carried out at the measuring location. However, the minimum disassembling is more convenient when the instrument is removed from the measuring location and placed on one side so that the collector to be removed is above.

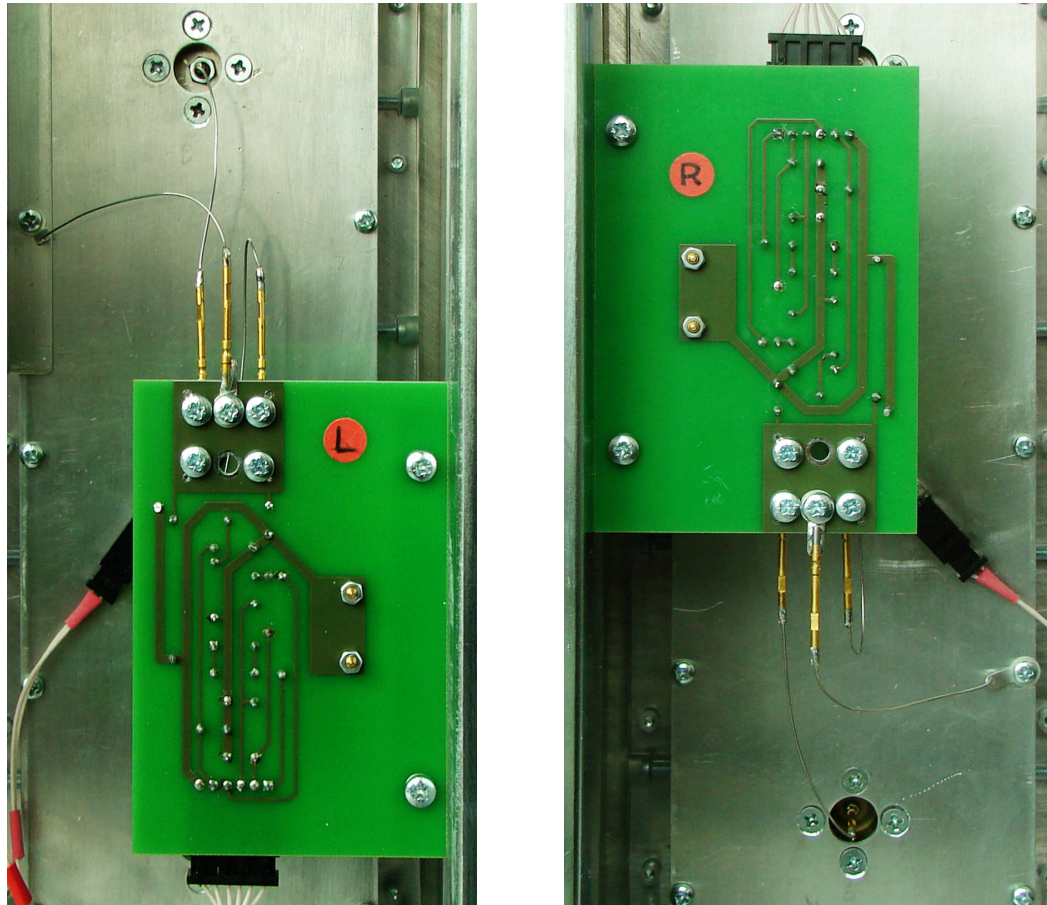


Figure 4.2. Connections of the left and right electrometers. Upper contact of the collector is connected to the electrometer input and lower contact to the electrometric relay.

The required tools are a magnetized PH1 screwdriver and good tweezers. The sequence of operations is:

- remove a side panel of the instrument case, opening a view of the electrometers and collectors as shown in Figure 4.2,
- Detach the cable from the electrometric amplifier,
- disconnect the three electrometer connection wires from the electrometer (warning: *keep one hand in the electric contact with the instrument frame when touching these wires*),
- screw away the two screws fastening the electrometric amplifier and remove carefully the amplifier (be careful and do not damage the relay and inlet details),
- detach the cable from the heating resistor located in the middle of the collector unit,
- screw away 12 screws holding the collector and remove carefully the collector unit.

When removing the left side collector, the shielding plate (upper left corner of Figure 4.2) is to be removed first. Store the collector and electrometric amplifier carefully, avoid damaging

the fragile details and polluting the insulators. Especially vulnerable details are the electrometric relays.

The two collector units are not interchangeable because the batteries are installed in the opposite way: the left collector is collecting positive ions and the internal plate is negative, the right collector is collecting negative ions and the internal plate is positive. In case of the opposite installation, some amount of cluster ions would be lost as deposited on the shielding electrodes near the collectors due to the edge effect. The internal plate of a collector receives the voltage of about 240 V via the protective resistor of 3.3 M $\Omega$ . It follows a short-circuit current of about 72  $\mu$ A, which is not dangerous for people, but can discharge the GP27A batteries fully during about a week.

When reinstalling the collector unit, the connector of the heating resistor must be directed down. After reinstalling the electrometric amplifier, the electrometric wires should be connected following Figure 4.2.

The large number of fastening screws makes a more radical disassembling and assembling of the instrument troublesome. The large number is necessary to keep the instrument in working order even after losing or impairing some odd screws.

*Medium disassembling* allows the fundamental cleaning of the aspiration condenser. The sequence of operations:

- remove the front panel with the inlet grid and three more panels (two sides and upper panel) of the wide section of the instrument case (the bottom panel and the fan section panels can be left as they are),
- take away the electrometer connection wires from both sides (the electrometric amplifiers may stay fastened as they are), the cables from the heating resistors, the connector of the inlet filter cable, and the HV cables (see Figures 4.2 and 4.3),
- use a long screwdriver and screw away four screws fastening the condenser to the instrument frame,
- remove very carefully the aspiration condenser through the front opening of the frame.

After removing the condenser, the electrometric collectors should be removed just as in case of minimum disassembling. Remember well all the connections to be able to assemble the instrument again. Be careful not to interchange the collectors when reassembling the condenser.

In an extreme situation the two side panels of the analyzer can be removed that opens better access for cleaning to the main insulators. Fortunately, such a fundamental disassembling was never needed during the 1.5 year operation of SIGMA No. 1.

*Warning: the wider border of a front panel must be directed upwards when reassembling the case of the instrument.*

#### **4.4. Cleaning the aspiration condenser**

The main components of the aspiration condenser are shown in Figure 2.1. When the top panel of the instrument case is removed, the internal details are visible through the upper transparent insulator of the condenser, see Figure 4.3.

The main tools for cleaning are a strong air blower, a fine brush, brushing wires (see Figure 4.4, these wires are available in "Tiimari" shops) and bidistilled or deionized water. Some details can be cleaned using cellulose hankies. The brush wires tend to leave fibers on the cleaned details. A finest painting brush and a lens-cleaning brush, available in shops of photographic equipment, are fiber-safe tools for wiping the collector and the electrometer details.



When the front panel is detached from the instrument then the inlet grid can be washed with a detergent and water using a fine brush. The grid is made of zinc-coated steel and should not be processed using acids.

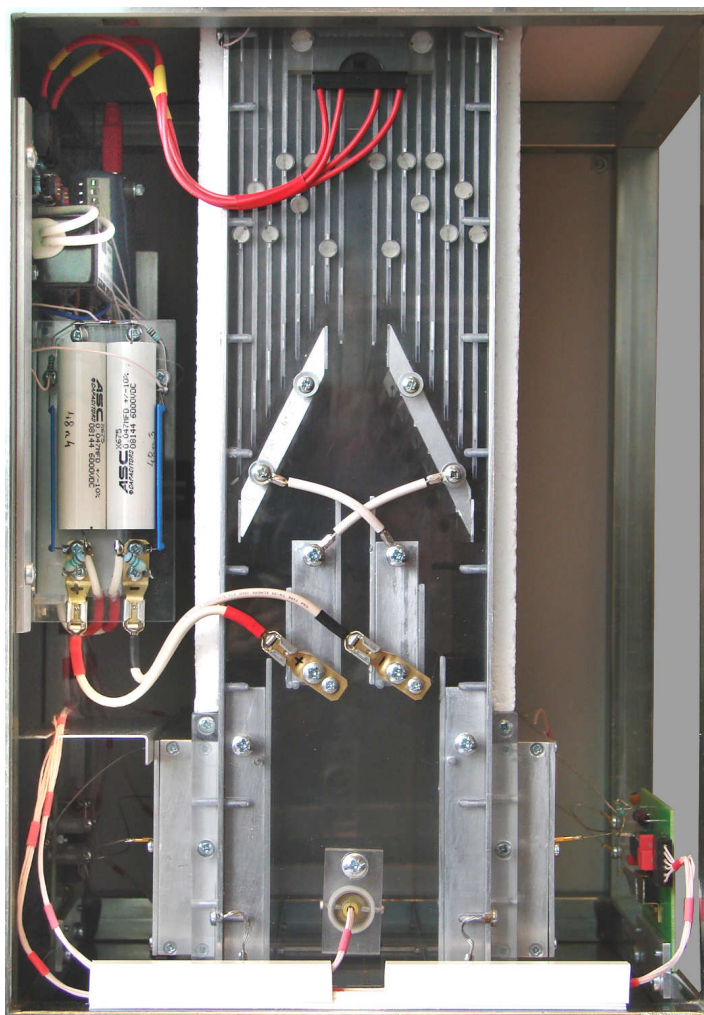


Figure 4.3. The SIGMA with a removed upper panel.



Figure 4.4. Bent brushing wire.

The frequent service operation is the *cleaning of the collector filters*. The plates of the filters collect dust, which seems to be harmless itself. However, the hairs and fibers tend to stick to the dusty plates and cause fluctuating leakage current, which heavily corrupts the measurements. The minimum disassembling is sufficient to make possible the cleaning of the filters.

At first, the filters should be visually inspected in strong sidelight and visible fibers removed using tweezers. Overall cleaning of electrodes and insulators can be made using a fine painting brush or a bent thin brush wire. Usually, it is enough to use a dry brush, but in case of heavy pollution, the brush or brush wire can be wetted with bidistilled or deionized water. Alcohol could be used only as an exception and after using alcohol, the insulators should be additionally cleaned using water.

The insects trapped in the inlet sheath air filter can be removed from the filter by using the fine brush or brushing wire. For a slight cleaning of the filter it is enough to perform minimum disassembling and additionally remove the front panel of the SIGMA. The upper panel of the instrument case could be removed to make the brush between the filter plates



visible. Brushing loosens the insects from the filter electrodes and they can finally be sucked away from the front side of the condenser by a vacuum cleaner or blown away by an air jet directed into the condenser from an opening for the removed electrometric collector. For the fundamental cleaning of electrodes, the wire brush can be rotated using a small cordless drill or electric screwdriver. Another tool for the fundamental cleaning of the electrodes and insulators is a thin jet of pressurized water, but this requires the medium disassembling of the instrument.

NB: the brush wire can leave fibers in the filters. Thus an additional cleaning by means of a strong blower is a must after using the brush wire.

During long-term measuring, dust and soot are accumulated on the insulators of the aspiration condenser. At first, the lower insulator will be polluted. This may cause the leakage of the high voltage. The symptoms are the reduction of the HV relaxation time constant  $\tau$  and fluctuating values of the asymmetry index  $asym$ , which are shown in the lower right area of the program window. Critical value of  $\tau$  is about 3600 ms and  $asym$  30 promille. However, the value of  $\tau$  for a clean condenser can be reduced during years of exploitation because of the deterioration of the HV relaxation capacitors. In this case the capacitors should be replaced.

The best cleaning liquid is deionized water. For a preliminary cleaning of very dirty surfaces, use clean ethyl alcohol. *Warning:* keep acetone and acetone-containing solvents always away from the instrument. After using cleaning liquids other than clean water, the insulators must be properly rinsed, first with tap water and then, at least twice, with deionized water. After every rinsing, blow water droplets off from the insulators using a strong blower. Use the spray of deionized water for the final rinse and dry the details properly before assembling the instrument.

After cleaning and reassembling the insulators may appear to be charged. Thus a waiting period of about 15...30 minutes is recommended before starting the measurements.

#### 4.5. Changing the collector batteries

Batteries should be replaced when the voltage drops below 220 V. Both of the collector units contain 20 miniature twelve-volt batteries GP27A and altogether 40 new batteries are required. The structure of the left side battery box is shown in Figure 4.5. The right size battery box has opposite polarities of the batteries, see Figure 2.1. The large cover of the battery case should not be opened without a specific need. It is necessary to unscrew two screws and detach a small cover plate (see Figure 4.6) from the upper end of the battery box together with spring-equipped contacts.

Be careful to unscrew only the two side screws. The other three screws fix the spring contacts and should not be unscrewed. First, check and remember the polarities of old batteries and remove them by slightly shaking the collector unit. When installing new batteries, follow Figure 4.5 and the polarities engraved on the side cover of the battery box.

Different techniques are used in different instruments for insulating the batteries. In the SIGMA No. 1 the long insulating tubes were used. In the SIGMA No. 2 the batteries are individually wrapped into the insulating tape so that the external diameter will be 8.0–8.1

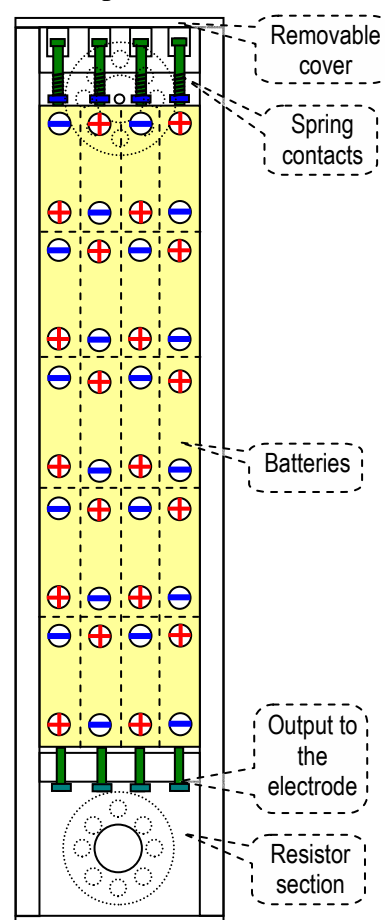


Figure 4.5. The battery box of the left electrometric collector unit. Only difference of the right side box is the opposite polarities of batteries

mm. Proper pieces of 0.13 mm tape is of size 50×20 mm. Prepare and install new batteries according to the pattern of the formerly installed batteries.

The contact ends of every battery should be lubricated with conductive grease immediately before installing. Recommended grease 7100 is available in ELFA, item no. 80-801-29. Otherwise, there will be a high probability of losing the contact between the batteries during the exploitation of the instrument in variable temperature conditions. *Warning:* use a very small point of grease about  $0.2 \text{ mm}^3$  and carefully avoid getting the grease off of the contact surfaces, where it can cause leakage and quick exhausting of batteries.

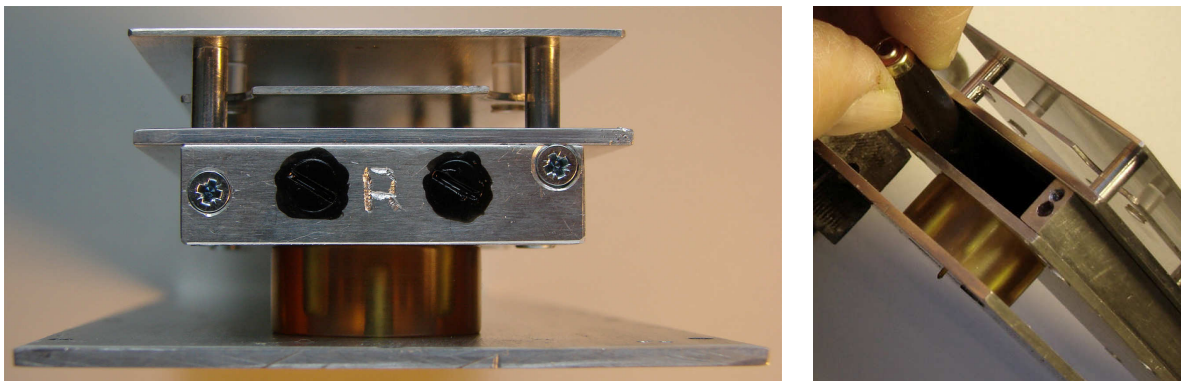


Figure 4.6. Left: the cover of batteries. Right: inserting of a wrapped battery

#### 4.6. Advanced diagnostics of the hardware problems

The program SIGMA1A contains a special test block which can be launched from the start menu shown in Figure 3.1. The test regime allows individual switching of each channel of the data acquisition unit and reading raw signals from all the ADC channels. Advanced diagnostics expects a detailed knowledge of the hardware of the SIGMA. The test block displays the menu shown in Figure 4.8.

Numerical commands allow switching single bits of the control port, and space bar displays the ADC readings from all signal channels. The control bits and signal channels of the data acquisition unit USB1608 are explained in Tables 4.2 and 4.3. USB1608 pins 22, 24,...,34 are digital ground and the pins 2, 4,...,18, 19, 20 are analog ground.

The USB1608 ADC count range is -32768...32767 and the corresponding voltage range is -5...+5 V. One count corresponds to 0.1526 mV.

Electrometer output is of the same polarity as ions. If the ion concentration is  $1 \text{ e/cm}^3$  and air flow 1 l/s, then the current in the collector is  $1.602 \times 10^{-16} \text{ A}$ . This generates  $8 \times 10^{-7} \text{ V}$  in the electrometer input and  $4 \times 10^{-5} \text{ V}$  or 0.2625 ADC counts in the electrometer output.

The control voltage of the collector battery is the opposite of the voltage of the central plate and of the same sign as the measured ions. The transfer to the electrometer input is 1:3030 and to the electrometer output 1:61. Thus the battery voltage is  $0.093 \times \text{ADC counts}$ .

Signal of the HV is taken from the repelling deflection electrode and is of the same polarity as ions. The transfer coefficient is  $75 \text{ k}\Omega / 50 \text{ M}\Omega = 1:666$  and the ADC reading at the fully charged capacitor is about 32200.

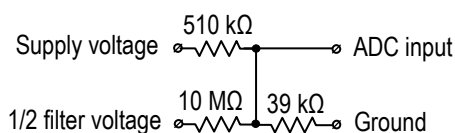


Figure 4.7. Transfer of supply and filter voltages to the ADC.

```

SIGMA1A version 20100102

SIGMA test

Controls:          0 / 1      ADC counts:
C_0 = fan          off/on    ADC0 = + ion electrometer
C_1 = HV 6 kV      off/on    ADC1 = - ion electrometer
C_2 = ext_dev_A    off/on    ADC2 = + ion voltage (HV)
C_3 = ext_dev_B    off/on    ADC3 = - ion voltage (HV)
C_4 = + gate       open/closed ADC4 = fan&filter voltage
C_5 = - gate       open/closed ADC5 = pressure sensor
C_6 = + relay      off/on    ADC6 = temperature sensor
C_7 = - relay      off/on    ADC7 = humidity sensor

Remember test commands:
0...7 : toggle control line C_# between 0 and 1
space bar: display milliseconds, readings of ADC, and control settings
R      : repeat the space bar action 20 times during 2 s
N      : statistics of 100 measurements of all channels
S      : show voltages, temperature, pressure, and RH
I      : test scan with saving of the record
U      : test scan relative to saved record
E      : display explanation of controls and channels
A      : developer programmable extra operation A
B      : developer programmable extra operation B
X      : exit the test
another: display again the instruction above
Channel signals are displayed in ADC counts (-32768...+32767)
1 count is 0.1526 mV <6.1 fA for Ch 0&1 and 0.1 V for 2&3

Please enter command: _

```

Figure 4.8. Menu of the diagnostic tests.

The signals of the supply voltage and filter voltages are transferred to the ADC input as shown in Figure 4.7. One ADC count corresponds to the supply voltage of 0.002167 V. The signal from the filter is the opposite of ion polarity. 1 ADC count corresponds to the filter voltage of -0.089 V.

The operation T displays the deflection voltages and electrometer output readings during a test scan. This may help to understand the problems with anomalous values of the diagnostic parameters *wait\_mob*, *wait\_dia*, *tau*, and *asym*.

The noise of the ADC input channels can be checked using the operation N. When the air flow is off, then normal level of noise standard deviation of the electrometric channels 0 and 1 and the humidity channel 7 is about 4...8. The standard deviation of other channels is typically 1..2 ADC counts.

Table 4.2. Controls in the SIGMA

USB1608 channel	USB1608 pin	Function	Variable in SIGMA1A
<b>0</b>	21	Fan: 0 = off, 1 = on	fan
<b>1</b>	23	6 kV: 0 = off (scan), 1 = on (charging)	HV
<b>2</b>	25	External device A (0/+11 V via internal 1.5 k $\Omega$ )	extern1
<b>3</b>	27	External device B (initially unused)	extern2
<b>4</b>	29	+ Ion gate: 0 = open, 1 = closed (0V / -260V)	gate_pos
<b>5</b>	31	- Ion gate: 0 = open, 1 = closed (0V / +260V)	gate_neg
<b>6</b>	33	Electrometer relay + ions: 0 = ions, 1 = check	relay_pos
<b>7</b>	35	Electrometer relay - ions: 0 = ions, 1 = check	relay_neg

Table 4.3. Signals in the SIGMA

USB1608 channel	USB1608 pin	Function	Approximate transfer coefficient
<b>0</b>	01	Electrometer for + ions	1 pA => 250 mV
<b>1</b>	03	Electrometer for - ions	1 pA => 250 mV
<b>2</b>	05	Analyzer voltage for + ions	1 : 666, 3 kV => 4.5V
<b>3</b>	07	Analyzer voltage for - ions	1 : 666, 3 kV => 4.5V
<b>4</b>	09	Power&gate voltage	1 : 14 & 1 : 556, 1.7V + -0.9V
<b>5</b>	11	Atmospheric pressure	1000 mb => 4.5 V
<b>6</b>	13	Temperature	15 mV/K, 0 C => 4.1 V
<b>7</b>	15	Humidity	0% => 0.7 V, 100% => 3.8V

Possible messages in the file SIGMA1A\_failure.txt with comments (in parentheses) are:

- POWER BLACKOUT.
- List of irregular values of diagnostic parameters.
- TIMEOUT (HV does not approach zero, the responsible components are USB1608, UDN2981, and STP70, see Appendix 8).
- LARGE ASYMMETRY (the responsible components are analyzer insulators, U3-6PN, 50M resistors and 47nF capacitors on the HV board).
- ELECTROMETER OVERLOAD (too high concentration of ions in a laboratory experiment, extreme concentration of charged dust or snow crystals, leakage from the central electrode of the electrometric collector).
- SHORT FRACTION (possible reasons: a high priority side process in the computer is still not blocked, low initial HV or quick relaxation. Check processes using the Windows task manager, check *tau* in the recorded data, check voltages in the test regime (initial ADC readings should exceed 30000), check relaxation using the operation T, the ADC readings should drop below 1000 after 11-12 s).

## 5. OUTPUT FILES

### 5.1. Nomenclature of data files

Output of the SIGMA is compiled by the control program and may be different when using different control programs. The nomenclature and structures explained below correspond to the software, which is distributed together with the instrument.

The name of a data file is composed of the prefix, date and extension. The date is written with 6 digits, which are replaced by letters YYMMDD (year, month, day) in the examples below. If a file corresponds to several days then the combination DD is replaced by 00. If a file contains data for several months, then MM is replaced by 00. Example: filename S1A090700.XL contains the prefix S1A and extension XL, and the file contains data for several days in September of 2009.

The extension of the filenames in the examples is XL, but it can be changed by the user when editing the control file SIGMA1A.INI.

All files contain tab-delimited text tables and can be read using MS Notepad or Excel.

The output data files are:

- The *scan data* \_S1AYYMMDD.XL is saved online by the control program into the subfolder SCANDETAILS of the SIGMA folder. It contains full information, which can later be converted offline into the basic data or standard data using the converter SIGMA1C. The conversion allows flexible setting of structure parameters independent of the cycle length in the display and in the immediately saved standard data. Typical size of a diurnal file of scan data is about 1.7 MB.
- The *basic data* ~S1AYYMMDD.XL can be created only offline, converting the scan data by means of the program SIGMA1C.EXE. The basic data contains less information than the scan data but more than the standard data. It is suitable for a user, who is processing the data using self-written programs.
- The diurnal *standard data* S1AYYMMDD.XL is saved online by the control program into the subfolder DAYS and the monthly standard data S1AYYMM00.XL is saved online into the subfolder MONTHS. The diurnal and monthly files contain the same data and can be considered as a backup for each other. The standard data contain significantly processed information, which is easy to use by means of universal data analysis programs, e.g. MS Excel and modify by means of the preprocessor SIGMA1P.EXE. The size of a standard data file is inversely proportional to the duration of the measuring cycle. Typical size of a standard data file is about 80 kB per day in case of 5 minute cycles. Different versions of standard data corresponding to different structure parameters can be created later offline when converting the scan data with the converter SIGMA1C.EXE.
- The diurnal *diagram table* dYYMMDD.XL is saved online by the control program into the subfolder DIATABLES. It is prepared for the MATLAB program SIGMA1D, see Section 6.4 and Appendix 5. Typical size of a diurnal diagram table file is about 25 kB in case of 5 minute cycles. The diagram tables corresponding to different processing parameters can be created later offline when converting standard data by means of the preprocessor SIGMA1P.EXE.

In case of a serious technical failure, SIGMA1A will save into the SIGMA folder a log file named SIGMA1A\_failure.txt, which includes the values of the diagnostic parameters in the moment of detecting the failure.

Additionally, the *normal tables* and *fraction tables* can be compiled afterwards by means of the postprocessor programs. Postprocessing of data and the structures of the resulting files are explained in Chapters 6 and 5.

**Warning:** Usage of MS Excel for file inspection requires special care. If an output file is opened and afterwards saved by MS Excel as a workbook, then the structure of the file is changed and may be unacceptable for the postprocessing program SIGMA1P and the diagram function SIGMA1D.

## 5.2. Standard headers

A file of the scan data, basic data, or standard data begins with three header lines. The following lines of the file present the rows of the data table. The header lines are:

- 1) calibration header, consisting of tab-delimited words explaining the calibration constants presented in the next line (see Table 5.1),
- 2) calibration line composed of tab-delimited numerical values: program date, calibration date, and calibration constants acquired from the current calibration file (see Table 5.1. and Appendix 4),
- 3) data header, consisting of tab-delimited words explaining the contents of the data columns depending on the specific data (see Sections 5.3–4 and Tables 5.2–3).

Table 5.1. Columns of the calibration header and the calibration line  
(explanations of the parameters see Appendix 4)

No	Header	Corresponding parameters in the calibration line and SIGMA1A
1	SIGMA1A	date of the control program
2	CALIBR	date of the calibration file
3	V-fctr	voltagefactor for voltage-mobility conversion
4	C-fctr+	concentrationfactor for +ADC to dn/dlogZ conversion
5	C-fctr–	concentrationfactor for –ADC to dn/dlogZ conversion
6	st-ads	standardadsorption
7	filter-Z	filtermobility
8	c-sup-V	c_supplyvolt
9	c-filt-V	c_filtervolt
10	c-bat-V	c_batteryvolt
11	c_bias	c_bias
12	c-pres-a	cpressurea
13	c-pres-b	cpressureb
14	c-temp-a	ctemperaturea
15	c-temp-b	ctemperatureb
16	c-hum-a	chumiditya
17	c-hum-b	chumidityb
18	delay	delaytime
19	charging-t	chargingtime
20	timeout	timeout
21	c-inv-n2	c_inv_n2, parameter of inversion matrix
22	c-inv-n1	c_inv_n1, parameter of inversion matrix
23	c-inv-p1	c_inv_p1, parameter of inversion matrix
24	c-inv-p2	c_inv_p2, parameter of inversion matrix
25	z-limit	z_limit, threshold mobility of inversion matrix

The five last words of the calibration header may consist of default values when the procedure of the numerical improvement of the mobility resolution is not applied.

### 5.3. Scan data

A table of scan data begins with three standard header lines where the third line consists of 87 words corresponding to the columns of the data table. Every data line corresponds to one 20-second scan. The 87 tab-delimited columns contain integer numbers:

- 1) time HHMMSS (midpoint between the start and finish of the scan),
- 2) regime: 0 = inlet gate closed, 1 = inlet gate open,
- 3) temperature, 0.01 C,
- 4) RH, 0.1%,
- 5) atmospheric pressure, 0.1 mb,
- 6–40) ADC counts for positive ion extended mobility distribution, 0.1 counts,
- 41–75) ADC counts for negative ion extended mobility distribution, 0.1 counts,
- 76) supply voltage, 0.1 V,
- 77) filter voltage +, V,
- 78) filter voltage –, V,
- 79) battery voltage +, V,
- 80) battery voltage –, V,
- 81) electrometer bias +, 0.01 mV,
- 82) electrometer bias –, 0.01 mV,
- 83) pretime, % (see Section 4.1),
- 84) analyzer voltage RC relaxation time constant, ms,
- 85) analyzer deflection voltage polarity asymmetry, promille,
- 86) number of electrometer overloads in the scan, 100×positive ions + negative ions,
- 87) regime, a complex index equal to the variable 78 of the standard data (see Section 5.5).

The values of ADC counts are averages over the extended mobility distribution fractions, whose center mobilities are shown in the header.

**Extended mobility distribution** contains the concentrations of 35 narrow mobility fractions of positive ions and 35 narrow mobility fractions of negative ions. It is available only in the scan data and the basic data. A decade of mobility is logarithmically uniformly divided into 16 fractions in the extended distribution.

If the fractions are numbered with index  $i = 1, 2, \dots, 35$  then the

- lower borders are  $Z = 10^{(i-26)/16} \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  (0.0274–3.65),
- fraction centers are  $Z = 10^{(i-25.5)/16} \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  (0.0249–3.92),
- upper borders are  $Z = 10^{(i-25)/16} \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  (0.0316–4.22).

Prefix of a scan data filename is \_S1A.

### 5.4. Basic data

Prefix of a basic data filename is ~S1A. The structure is the same as of the scan data; only the content of columns 1, 2, 6–75, and 86 is different. The rows can be written for every open-gate scan or as averages for uniformly distributed time intervals up to 60 minutes. One file can include data for several days and the date is indicated in the first column of every row. The ADC readings of electrometers, which were presented in the scan data, are replaced by the values of the mobility distributions.

The 87 tab-delimited columns of the table contain integer values:

- 1) date YYMMDD,
- 2) time HHMMSS (if the time interval is one minute or more, then the midpoint between the start and finish of the interval),
- 3) temperature, 0.01 C,
- 4) relative humidity, 0.1%,
- 5) atmospheric pressure, 0.1 mb,
- 6–40) positive ion extended mobility distribution  $dn / d \log Z$ ,  $\text{cm}^{-3}$ ,

- 41–75) negative ion extended mobility distribution  $dn / d \log Z$ ,  $\text{cm}^{-3}$ ,
- 76) supply voltage, 0.1 V,
- 77) filter voltage +, V,
- 78) filter voltage –, V,
- 79) battery voltage +, V,
- 80) battery voltage –, V,
- 81) electrometer bias +, 0.01 mV,
- 82) electrometer bias –, 0.01 mV,
- 83) pretime, % (see Section 4.1),
- 84) analyzer voltage RC relaxation time constant, ms,
- 85) analyzer deflection voltage polarity asymmetry, promille,
- 86) *ovl&sc*, a complex index described below,
- 87) regime, a complex index described below.

The index *ovl&sc* is composed as

$$10000 \times (\text{number of positive electrometer overloads in the cycle}) + \\ 100 \times (\text{number of negative electrometer overloads in the cycle}) + \\ 1 \times (\text{number of scans in the cycle}).$$

The index regime is composed as:

$$100000 \times (\text{structure, 0, 1 or 2}) + \\ 10000 \times (\text{simulated measurement, 0 or 1}) + \\ 1000 \times (\text{noise regime, 0 or 1}) + \\ 100 \times (\text{extracorreption 0 = no, 1 = dust pulses, 2 = transfer, 3 = both}) + \\ 10 \times (\text{external meteodata used, 0 or 1}) + \\ 1 \times (\text{mark, which was manually set using keys 0...9 during measurements})$$

The subindex *structure* of the regime is defined as:

- 0 = 16-fraction full range mobility distribution,
- 1 = 16-fraction cluster range mobility distribution,
- 2 = 35-fraction extended mobility distribution

Thus the value of *subindex structure* is always 2 in the basic data; the alternative values of 0 and 1 are reserved for the standard data.



## 5.5. Standard data

Prefix of a standard data filename is S1A. The file is composed of three standard header lines and following data lines. The structure of the third header line is explained in Tables 5.2 and 5.3. The data line consists of 78 numeric values. Most of these are presented as whole numbers and a few contain a point-separated decimal part. The data columns are explained in Tables 5.2 and 5.3. The content of the columns 29...60 depends on the parameter *clusterregime* of the control file SIGMA1A.INI. *Clusterregime* = 0 initiates the full mobility range and *clusterregime* = 1 initiates the cluster ion regime. Columns 1...28 and 61-78 are universal and do not depend on the parameter *clusterregime*. A decade of mobility is logarithmically uniformly divided into 8 standard fractions in the regime of the full mobility range and into 16 narrow fractions in the cluster ion regime.

Table 5.2. Columns of the standard data table in case of the full mobility range

No	Excel	Header	Value	Sign	Range, nm or $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$
1	A	YYMMDD	Date YYMMDD		
2	B	HHMM	Time HHMM (center of the interval)		
3	C	DAY	Day of year (4 decimal places)		
4	D	T:C	Temperature, °C (1 decimal place)		
5	E	RH:%	Rel. humidity, % (1 decimal place)		
6	F	p:mb	Air pressure, mb (2 decimal places)		
7	G	noise+	Index of zero level noise, $\text{cm}^{-3}$		
8	H	noise-	Index of zero level noise, $\text{cm}^{-3}$		
9	I	D+0.487	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	+	0.42–0.56
10	J	D+0.649	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	+	0.56–0.75
11	K	D+0.866	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	+	0.75–1.00
12	L	D+1.155	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	+	1.00–1.33
13	M	D+1.540	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	+	1.33–1.78
14	N	D+2.054	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	+	1.78–2.37
15	O	D+2.738	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	+	2.37–3.16
16	P	D+3.652	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	+	3.16–4.22
17	Q	D+4.870	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	+	4.22–5.62
18	R	D+6.494	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	+	5.62–7.50
19	S	D–0.487	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	–	0.42–0.56
20	T	D–0.649	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	–	0.56–0.75
21	U	D–0.866	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	–	0.75–1.00
22	V	D–1.155	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	–	1.00–1.33
23	W	D–1.540	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	–	1.33–1.78
24	X	D–2.054	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	–	1.78–2.37
25	Y	D–2.738	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	–	2.37–3.16
26	Z	D–3.652	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	–	3.16–4.22
27	AA	D–4.870	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	–	4.22–5.62
28	AB	D–6.494	$f_{\log d} = dn / d \log d, \text{cm}^{-3}$	–	5.62–7.50
29	AC	Z+0.037	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.032–0.042
30	AD	Z+0.049	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.042–0.056
31	AE	Z+0.065	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.056–0.075
32	AF	Z+0.087	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.075–0.100
33	AG	Z+0.115	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.100–0.133
34	AH	Z+0.154	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.133–0.178
35	AI	Z+0.205	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.178–0.237
36	AJ	Z+0.274	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.237–0.316

No	Excel	Header	Value	Sign	Range, nm or $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$
37	AK	Z+0.365	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.316–0.422
38	AL	Z+0.487	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.422–0.562
39	AM	Z+0.649	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.562–0.750
40	AN	Z+0.866	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.75–1.00
41	AO	Z+1.155	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	1.00–1.33
42	AP	Z+1.540	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	1.33–1.78
43	AQ	Z+2.054	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	1.78–2.37
44	AR	Z+2.738	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	2.37–3.16
45	AS	Z–0.037	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.032–0.042
46	AT	Z–0.049	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.042–0.056
47	AU	Z–0.065	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.056–0.075
48	AV	Z–0.087	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.075–0.100
49	AW	Z–0.115	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.100–0.133
50	AX	Z–0.154	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.133–0.178
51	AY	Z–0.205	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.178–0.237
52	AZ	Z–0.274	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.237–0.316
53	BA	Z–0.365	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.316–0.422
54	BB	Z–0.487	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.422–0.562
55	BC	Z–0.649	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.562–0.750
56	BD	Z–0.866	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.75–1.00
57	BE	Z–1.155	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	1.00–1.33
58	BF	Z–1.540	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	1.33–1.78
59	BG	Z–2.054	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	1.78–2.37
60	BH	Z–2.738	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	2.37–3.16
61	BI	supply	Supply voltage, V		
62	BJ	filt+	Filter voltage +, V	+	
63	BK	filt–	Filter voltage –, V	–	
64	BL	batt+	Battery voltage +, V	+	
65	BM	batt–	Battery voltage –, V	–	
66	BN	bias+	Electrometer bias +, mV	+	
67	BO	bias–	Electrometer bias –, mV	–	
68	BP	pre%	$100 \times \text{frt} [1] / (\text{frt} [2] - \text{frt} [1])$		
69	BQ	tau	HV relaxation time constant, ms		
70	BR	asym	HV asymmetry, promille		
71	BS	N+	Concentration of aerosol ions +, $\text{cm}^{-3}$	+	0.032–0.49
72	BT	N–	Concentration of aerosol ions –, $\text{cm}^{-3}$	–	0.032–0.49
73	BU	n+	Concentration of cluster ions +, $\text{cm}^{-3}$	+	0.49–3.16
74	BV	n–	Concentration of cluster ions –, $\text{cm}^{-3}$	–	0.49–3.16
75	BW	Z+	$Z_{\text{average}}$ of cluster ions +, $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$	+	0.49–3.16
76	BX	Z–	$Z_{\text{average}}$ of cluster ions –, $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$	–	0.49–3.16
77	BY	ovl&sc	Complex index (explanation see 5.4 )		
78	BZ	regime	Complex index (explanation see 5.4 )		

Table 5.3. Columns 29...60 of the standard data table in case of *clusterregime* = 1.

No	Excel	Header	Value	Sign	Range, $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$
29	AC	Z+0.45	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.42–0.49
30	AD	Z+0.52	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.49–0.56
31	AE	Z+0.60	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.56–0.65
32	AF	Z+0.70	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.65–0.75
33	AG	Z+0.81	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.75–0.87
34	AH	Z+0.93	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	0.87–1.00
35	AI	Z+1.07	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	1.00–1.15
36	AJ	Z+1.24	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	1.15–1.33
37	AK	Z+1.43	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	1.33–1.54
38	AL	Z+1.65	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	1.54–1.78
39	AM	Z+1.91	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	1.78–2.05
40	AN	Z+2.21	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	2.05–2.37
41	AO	Z+2.55	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	2.37–2.74
42	AP	Z+2.94	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	2.74–3.16
43	AQ	Z+3.40	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	3.16–3.65
44	AR	Z+3.92	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	+	3.65–4.22
45	AS	Z–0.45	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.42–0.49
46	AT	Z–0.52	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.49–0.56
47	AU	Z–0.60	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.56–0.65
48	AV	Z–0.70	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.65–0.75
49	AW	Z–0.81	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.75–0.87
50	AX	Z–0.93	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	0.87–1.00
51	AY	Z–1.07	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	1.00–1.15
52	AZ	Z–1.24	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	1.15–1.33
53	BA	Z–1.43	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	1.33–1.54
54	BB	Z–1.65	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	1.54–1.78
55	BC	Z–1.91	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	1.78–2.05
56	BD	Z–2.21	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	2.05–2.37
57	BE	Z–2.55	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	2.37–2.74
58	BF	Z–2.94	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	2.74–3.16
59	BG	Z–3.40	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	3.16–3.65
60	BH	Z–3.92	$f_{\log Z} = dn / d \log Z, \text{cm}^{-3}$	–	3.65–4.22

The concentrations of aerosol ions (variables 71 and 72) and cluster ions (variables 73 and 74) are calculated according to the measured mobility distribution, where ions of the mobility of less than  $0.5 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  are considered as aerosol ions and ions of the mobility of above this threshold are considered as cluster ions. Explanations of the complex index variables 77 and 78 are presented at the end of Section 5.4.

## 5.6. Diagram table

A diagram table dYYMMDD.XL saved by SIGMA1A corresponds to one day. The table has no header and contains 21 columns of tab-delimited numerical values. The number of rows is  $1 + 1440 / \text{cycleminutes}$  (289 rows in case of standard value *cycleminutes* = 5) and they correspond to the values of minute in the day 0...1440. The first column contains the minute in the day and the columns 2...21 the same data as in the columns 9...28 of the standard table (values of  $dn / d(\log d)$  for positive and negative particles). The missing values and the negative values are replaced by zeroes. The tables, which are saved immediately by the control program, are couple smoothed. The smoothing methods are explained in Section 5.7.4.

If the control program SIGMA1A was temporarily closed for some time during the day, then only the data collected after the restart are available and presented in the immediately saved diagram table.

The online saved diagram tables are intended for a preliminary inspection of the data. The diagram tables of the same structure can be generated afterwards using the postprocessor program SIGMA1P, which acquires information from the scan details or standard data and makes the flexible control of data conditioning available. See Chapter 6.

## 5.7. Comments about the output data

### 5.7.1. Recurrent files

A diagram table dYYMMDD.XL is created and saved once at midnight and will never be changed afterwards. This is the only non-recurrent output file of the control program.

Other online output files of the control program are recurrent. The diurnal file of scan data \_S1AYYMMDD.XL is completed after every scan and the diurnal file of standard data S1AYYMMDD.XL is completed after every cycle. If the data saving is temporarily interrupted by a control key or a pause in measurements then the completing process will be restarted after restoration of the data saving regime and the beginnings of the files are preserved.

The monthly file of standard data S1AYYMM00.XL is completed every midnight and the saving regime set by the controls M and D is checked just before saving. If the control program SIGMA1A was temporarily closed for some time during the day then only the data collected after the restart are available in the computer memory. Thus the completeness of S1AYYMM00.XL depends on the way the program SIGMA1A was closed before the interruption. In case of a normal XZ procedure the computer saves the data of the unfinished day into the monthly file and no data are lost. In case of an irregular closing of the program, the beginning of the day may be absent in the monthly file. However, the lost data can be found and restored using the parallel diurnal file S1AYYMMDD.XL.

The log of failures SIGMA1A\_failure.txt is always appended and contains data since it was first created.

**Warning:** The headers of the files contain information read from the calibration file and the control file. The headers of a recurrent file are written once when the file is first created. If the measurements are interrupted and restarted with new settings, then the header lines are not changed and will not correspond to the new settings. This may be followed by misinterpretation of the saved data in the future. Thus an **urgent recommendation:**

*rename data files S1AYYMMDD.XL and \_S1AYYMMDD.XL if the measurements will be restarted during the day of changes and rename S1AYYMM00.XL if the measurements will be restarted during the month of changes in the calibration file. Do not change the date included into the filename and use only an additional letter after the date.*

Example: S1A091218.XL can be renamed as S1A091218a.XL.

Another way is to move the existing recurrent files away from the standard folders. In both cases the control program will create new data files including up-to-date header lines.

### 5.7.2. Treating of negative values

The true values of concentrations and distribution functions cannot be negative. However, the recorded values are sometimes negative due to the random noise. When the real concentration of intermediate ions is much less than the instrumental noise, then about half of the measured values of distribution functions can be negative in the intermediate ion range. The negative values may be treated in different ways.

The control program SIGMA1A always records the scan data without any corrections. The standard tables can be recorded without corrections or corrected with the aim of dust pulse

suppression. A cloud of charged dust generates a negative pulse in one polarity channel and a positive pulse in the other polarity channel. If a measurement of fraction concentration comes out negative, then a compensating positive value can be added to this fraction concentration and simultaneously subtracted from the fraction concentration of the opposite polarity. The probability of such an event is nearly equal for both polarities and the correction does not produce a systematic shift in the results. The dust pulse correction can be switched on or off by editing the control file SIGMA1A.INI.

All negative values are replaced with zeroes only in the diagram tables. Replacement of negative values with zeroes produces a shift in the averages calculated for longer time intervals or wider mobility ranges. Thus the diagram tables should not be used as a source for further calculations.

A recommended method for suppressing the negative values is the smoothing of the data in time during the offline postprocessing, see the next section and Chapter 6.

### 5.7.3. Extra corrections

Extra corrections are options in the SIGMA standard software. They can be applied or not according to the choice by the user. In SIGMA1A.INI the choice is expressed by the value of the parameter *extracorrect*.

Pulses induced by clouds of charged dust passing the analyzer are the essential elements of noise in the electrometric signal. These pulses have different polarity in records of positive and negative air ions and can be identified when the real value of the distribution function is near to zero. Then a negative value in the distribution function for one polarity and a positive value in the opposite polarity is an indication of the dust pulse. In this case the disturbance can be compensated by a transfer of some part of the negative signal from one polarity to another. The dust pulse correction algorithm in the SIGMA standard software is applied to the array of 35 narrow fraction signals, which are denoted below  $pos_i$  and  $neg_i$ :

```
for i := 1 to 35 do begin
  p := posi; q := negi;
  if (p < 0) and ((p + q) ≥ 0) then begin posi := 0; negi := p + q; end;
  if (q < 0) and ((p + q) ≥ 0) then begin negi := 0; posi := p + q; end;
end;
```

Another extra correction available in SIGMA1A is numerical improving the mobility resolution preferably in the small ion subrange. The correction algorithm is applied to the array of 35 narrow fraction signals. Let  $x_i$  be the true distribution and  $y_j$  be the broadened record of the spectrometer. Then  $y_j = \sum_i G_{ji} \times x_i$ , where  $G$  is the transfer matrix, and

$$x_i = \sum_j H_{ij} \times y_j,$$

where  $H = G^{-1}$  is the inverter matrix. Unfortunately, the inversion can intolerably increase the signal noise. As a rule, the exact inversion appears inappropriate and the matrix for partial inversion is to be chosen as a compromise between mobility resolution and signal noise. The SIGMA standard software allows using only pseudo-five-diagonal inverter matrices, whose elements are calculated according to the five user prescribed parameters  $c\_inv\_n2$ ,  $c\_inv\_n1$ ,  $c\_inv\_p1$ ,  $c\_inv\_p2$ , and  $limit$ . Values of the parameters should be presented in the optional configuration file SIGMA1A\_inverter.txt. Structure of this file is explained and illustrated in Appendix 4, Section A4.2.

Conservation of the air ion concentration requires  $\sum_j H_{ij} = 1$ . In SIGMA1A and SIGMA1C the inverter matrix is assembled according to following algorithm:

```
for i := 1 to 35 do begin
  if Zi < z_limit then c := Zi / z_limit else c := 1;
  sum := 0;
  for j := 1 to 35 do begin
    Hij := 0
    if j = i - 2 then Hij := c × c_inv_n2;
    if j = i - 1 then Hij := c × c_inv_n1;
```

```

      if j = i then Hij := 1;
      if j = i + 1 then Hij := c × cinv_p1;
      if j = i + 2 then Hij := c × cinv_p2;
      sum := sum + Hij;
    end;
    for j := 1 to 35 do Hij := Hij / sum;
  end;

```

Some considerations about the choosing of the inverter parameters are presented in Appendix 6, Section A6.8

#### 5.7.4. Smoothing of data in time

Smoothing of time series can be used to suppress the occasional negative values of the distribution functions and to reduce the random noise. The control program SIGMA1A applies smoothing only in diagram tables. Deeper smoothing is available in the postprocessor SIGMA1P. Two methods are used:

- couple smoothing replaces each member of time series  $x_i$  with  $(x_{i-1} + x_i) / 2$ ,
- triplet smoothing replaces each member of time series  $x_i$  with  $(x_{i-1} + 2x_i + x_{i+1}) / 4$ .

The couple smoothing involves a half-step time shift. This is just welcome when compiling the diagram tables because the standard data in case of *cycleminutes* = 5 correspond to the minutes 2.5, 7.5, etc but the values in a diagram table should correspond to the minutes 0, 5, 10, etc. Thus the couple smoothed diagram tables saved by the control program are free of the time shift.

The postprocessor can apply triplet smoothing when compiling normal tables and both triplet and couple smoothing when compiling the diagram tables. The triplet smoothing can be applied repeatedly and the number of reiterations is called the *smoothing level*. The smoothing level can be set independently for smoothing only around negative values and for total smoothing.

The standard tables saved online by SIGMA1A are not smoothed, which means the smoothing level is zero.

#### 5.7.5. Mobility distribution or size distribution?

The control program SIGMA1A records simultaneously the distribution of ions according to the particle diameter and the distribution according to electric mobility. The two distributions are compiled using different partitions of the series of electrometer signals according to the voltage of the aspiration condenser recorded during a scan. However, the distribution according to mobility is a more fundamental result, because it presents a better size/mobility resolution and does not depend on:

- the specific mobility-size conversion algorithm,
- the assumptions about the particle density and charge,
- the measurements of atmospheric pressure and air temperature,

The control program SIGMA1A uses the algorithm by Tammet (1995) assuming the particle density of  $2.08 \text{ g cm}^{-3}$  and the particle charge of 1 elementary charge. The results do not fit well the assumptions because particle density affects the conversion only for the finest particles of the diameter of below 2 nm and the probability of double charges on particles below 7.5 nm is usually negligible (warning: an exception may occur when measuring electrospray ions).

The most fundamental result is the extended mobility distribution saved in scan data as a raw table of the ADC counts and in the basic data as a table of  $dn / d \log Z$ . These tables are accompanied by the values of air temperature and pressure and allow a later compilation of size distributions on the arbitrary diameter grids as specified by the user.

## 6. DATA PROCESSING

### 6.1. Patterns of data processing

As a rule, the control computer is not used for data processing. Thus the data are to be transferred into another computer at first. Three typical methods of data processing are:

#### *Introductory level*

- use online-saved standard data and diagram tables,
- process the diagram tables with SIGMA1D and inspect the results,
- analyze the standard data by means of MS Excel or similar programs.

#### *Medium level*

- use online-saved scan data and diagram tables,
- process the diagram tables with SIGMA1D for a preliminary inspection of the results,
- convert the scan data into the standard data using the converter SIGMA1C,
- if necessary, then convert the data into an appropriate structure using the postprocessor SIGMA1P,
- visualize the data (use SIGMA1D) and analyze it by means of MS Excel or packages for statistical analysis,
- repeat the last operations until obtaining required results.

#### *Advanced level*

- use online-saved scan data,
- convert the scan data into the basic data using the converter SIGMA1C,
- analyze the data by means of advanced statistical packages and user-written programs.

### 6.2. Converter SIGMA1C

SIGMA1C.EXE converts the raw scan data into the standard data or the basic data. It makes possible repeating the low level data processing using different values of the parameters. The user is free to choose the duration of the cycle and the period of the checking of the zero level independent of the parameters of the online-saved standard data.

The program is to be launched dragging a file or a folder onto the converter icon. The dragged item should be:

- a file of scan data, whose name begins with \_S1A or
- a folder containing files of scan data (maximum 1000000 scans  $\approx$  7.5 months).

The dragged folder or the folder, where the dragged file is located, is called the *working folder*. All files in the dragged folder are expected to be recorded with the same version of SIGMA1A.EXE and the same version of SIGMA1A.CAL in the regular situation. Otherwise, the file headers can be imported only from the last file. The output file will be saved into the working folder. If all records belong to the same day, the name of the standard data will be S1AYYMMDD, otherwise S1AYYMM00, S1AYY0000, or S1A000000. Corresponding names of the basic data have additional prefix ~. The extension will be set according to the demand.

The converter asks for five control parameters, whose values can be entered from the keyboard or written as a plain text into the control file SIGMA1C.INI. This file is compiled according to the same rules as SIGMA1A.INI and should be saved into the *working folder*. If the control file is found, then the parameters will be imported from this file. If a line of the control file is absent or marked as a comment (the first symbol is space), then the converter asks for the missing value from the keyboard. An example of the content of the control file is:

```

SIGMA1C.INI 20101027
outputstyle=0      0 = full range (8 fr/dec) standard data,
                   1 = clusterregime (16 fr/dec) standard data,
                   2 = basic data
extracorrect=1     0 = no, 1 = dust pulses, 2 = resolution, 3 = both
cycleminutes=3     0..60, 0 means one cycle per scan, otherwise
                   60/cycleminutes must be a whole number
zerominutes=20     3..600 but not less than cycleminutes
extension=xl       extension of the output file name

```

If the parameter *cycleminutes* is indicated as 0, then the output will be compiled for all individual open-gate scans that have an interval of about 20 s or 40 s.

*Extracorrect* has the same function as in the control program SIGMA1A. If the header of the file of scan details contains the inverter parameters then their values can be imported from the header. However, there is a possibility to use different parameter values, which should be appended to the control file SIGMA1C.INI as optional lines, e.g.:

```

c_inv_n2=-0.16     inverter parameter
c_inv_n1=-0.22     inverter parameter
c_inv_p1=-0.10     inverter parameter
c_inv_p2=-0        inverter parameter
z_limit=1          inverter parameter

```

In this case, the second header of the output files includes the new values of the parameters.

The control program SIGMA1A begins to issue the standard data only when the full symmetric zero period, containing  $(\text{zerominutes} - \text{cycleminutes}) / 2$  minutes before as well as after the cycle, is available. Different from of this, the converter begins to issue the results straightaway when a reference cycle comes available, at first using only one wing of the full zero period.

### 6.3. Postprocessor SIGMA1P

The postprocessor allows modifying the structure of the standard data, which was saved by the control program SIGMA1A or the converter SIGMA1C. It is used for merging the files, extracting the excerpts with limited time range and/or limited set of variables, calculating the size distribution on an user-defined diameter grid, calculating the averages for hours or different special time periods, smoothing the time series, correcting the outliers, and compiling the diagram tables according to the standard data. *Technical restriction*: the number of lines in the input tables as well as in the output table should not exceed the number of minutes in one year ( $366 \times 24 \times 60$ ).

The program is to be launched by dragging a file or a folder onto the postprocessor icon. The dragged item should be a standard file, whose name begins with S1A, or a folder containing standard files. The dragged folder or the folder, where the dragged file is located, is called the *working folder*.

If the user is going to calculate values of the size distribution at extra diameters, then a special file *diameters.txt* must be prepared and saved into the working folder beforehand.

If the dragged item is a folder, then a situation when some files are saved in the cluster regime and some in the normal regime is possible. In this case the postprocessor identifies the regime according to the first file and skips all the data recorded in the conflicting regime.

The data in the input folder can be duplicated e.g. when a monthly file and some diurnal files are simultaneously included into the working folder. If two input rows appear equal, then only one of them is accepted as the actual input data.

After the program is launched, the user is asked several questions. The sequence of questions can be interrupted any time pressing immediate ENTER without entering any answer. An exception is stating the name of the output subfolder for diagram tables: here the immediate



ENTER means that the tables should be written directly into the working folder. When all questions are answered, the postprocessor analyzes the dragged files, compiles an output file or files, and saves them into the working folder. The questions are:

- if the input data is presented for several days, then the first day and the last day to be processed (6-digit format yymmdd),
- correction method (0...3),
- multiplier of standard deviation (3...9)  
is asked only when the correction method is 1 or 3,
- smoothing level for negatives  $n$  (0...9),
- total smoothing level  $k$  (−1...9),
- time step in the output tables expressed in full minutes (1...1440).

The ratio (1440 / time step) should be a whole number. Time step in the output table should be equal or larger than the time step in the input tables. If the time step is larger, then a row of the output table will present an average of several rows of the input standard table. If the time step is 3 minutes or more then the next question is:

- trimming degree  $g$ .

The following question will be:

- compile Normal table, Fraction table, or Diagram tables (N, F, or D).

If the required output is diagram tables then the program will ask for the

- name of the output subfolder.

If the folder with the chosen name does not exist, it will be automatically created as a subfolder of the working folder.

If the required output is a normal table or a fraction table, then three questions follow:

- format of the time presentation,
- list of variables,
- name of the output file.

## 6.4. Explanations of the parameters of the postprocessor

Three cycles are called *close neighbor cycles* if both the time steps before and after the central cycle do not exceed 10 minutes and the ratio of these time steps does not exceed 1.5.

► **Corrections** will be made *only in the range of the intermediate ions* of  $d = 2.05\text{--}4.87\text{ nm}$  and  $Z = 0.049\text{--}0.365\text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ . **Method 0** marks no data correction. **Method 1** is a formal outlier analysis and replacement. At first the close neighbors (neighbor size or mobility and close neighbor cycle) of the value of the distribution function are collected. A correction can be made when at least 6 close neighbors of possible 8 are present. The minimum and the maximum values are trimmed away from the sample of neighbors. A value is qualified as outlier when the deviation from the average of neighbors exceeds at least *multiplier* times the standard deviation inside the sample of neighbors. An outlier is replaced by the trimmed mean of the neighbors. **Correction method 2** is based on the strong negative correlation of errors created by charged dust clouds in the positive and negative ion channels. When a result of measuring the concentration of a distribution fraction is negative in one polarity and positive in the opposite polarity, then the event is identified as the dust cloud effect and the negative value is fully or partially moved into the opposite polarity. **Correction method 3** includes both the methods 1 and 2. NB: the integral values  $Z$ ,  $n$  and  $N$  are not subjects of correction and could be extra recalculated according to the corrected distributions when needed.

Correction and smoothing operations will be carried out when analyzing the input data before converting the time series to the output time step.

► Triplet **smoothing** (see Section 5.7.4) of close neighbors in time is performed at first  $n$  times for negative values and, after that,  $k$  times for all values.

An exceptional value  $k = -1$  means no smoothing, as does  $k = 0$ . The difference appears only when the output is diagram tables. Normally, the diagram tables are additionally once *couple*

*smoothed* after  $k$  repeated procedures of triplet smoothing are finished. The couple smoothing is performed as well at  $k = 0$ . The exceptional value  $k = -1$  prevents the couple smoothing. This ensures the best time resolution but produces a half-cycle time shift. E.g. at the 5-minute cycles the diagram table lines marked with 0, 5,... minutes will correspond to the time of 2.5, 7.5,... minutes etc. Such a time shift is peculiar only to the SIGMA1P-produced diagram tables in case of  $k = -1$ . Otherwise, the couple smoothing ensures exact synchronization of time in diagrams.

The smoothing is performed on the time grid of input files. If the output time step largely exceeds the input time step, then the calculating of averages may outperform the smoothing, which will have only a minor effect in this case.

Variables 1–4, 66, 67, 77 and 78 of Table 5.2 are excluded from processing during the smoothing of negatives and variables 1–3, 77, and 78 are excluded during total smoothing.

► If the *time step* in the output table equals the time step of the input table, then every row of the input standard table produces one row in the output normal table of the fraction table. A larger number requires averaging of the data in time. The maximum allowed output time step of 1440 minutes leads to a table of diurnal averages as the output. The averages are calculated as  $g$ -trimmed means in the output time intervals. As an exception, the columns 1, 77, and 78 (YYMMDD, ovl&sc and regime) of the standard table are processed in a different way and presented by the input values in the center of the output time intervals independent of the trimming degree. Variable 2 (HHMM) is exceptionally presented independent of the input data by the calculated central time of the interval.

*Warnings:*

- the output time step must be chosen so that a full day will consist of a whole number of the steps,
- the output time step must be equal to or larger than the time step in the input tables.

► *Trimming degree  $g$*  shows how many of the smallest and the largest entries are excluded while calculating the arithmetic average of  $n - 2g$  middle entries of the  $n$  input values ( $n$  is the number of input time steps in an output time interval). Trimming can be prevented by choosing  $g = 0$ .

The computer has no information about the actual time steps in the input tables when asking for the trimming degree. Thus the answer to the question about the trimming degree is limited to assuming that an input table can contain measurements with one minute time step. Too high trimming degree will be automatically reduced. The maximum trimming will result in the median mean.

► A *Normal table* includes three header lines and the following data lines like a standard data table (see section 5.5). The differences are:

- the first line is the header explaining the process parameters asked by SIGMA1P,
- the second line contains the values of the process parameters,
- the third line contains column headers for the output variables, specified by the entered list of variables,
- the data lines contain the values of variables selected according to the entered list,
- time can be presented in a flexible format explained below.

► *Fraction tables* differ from normal tables only in the presentation of the distributions. In a fraction table, the values of  $dn / d \log d$  or  $dn / d \log Z$  are replaced by the fraction concentrations, which are, in the decade-to-eight structure, just 8 times less than the values of the distribution functions :  $dn / d \log d = 8 n (d_1, d_2)$  and  $dn / d \log Z = 8 n (Z_1, Z_2)$ .

► *Diagram tables* have the same structure as produced online by SIGMA1A, see Section 5.6. The smoothing level is flexible (level 0...3 is recommended), the gaps up to one hour are filled with interpolated data and tables with less than one hour of measurements are skipped in the output. For comparison: SIGMA1A always applies couple smoothing (like in case of

smoothing level 0), does not fill the gaps and delivers a table independent of the number of actually recorded cycles.

► The *filename* should not coincide with a name of any pre-existing file in the working folder.

► If the *format of time presentation* differs from "x", then a row of the output table will proceed from the time presented according to the chosen format. The time compiled according to the specified format corresponds to the center of the time interval in the normal table. The format of time presentation can be:

- x – no extra time column in the output,
- j – day of year (integer 1...366),
- j.f – day of year with the 4-digit decimal fraction,
- t.f – MS Windows DateTime with the 4-digit time fraction,
- custom format.

Table 6.1. Examples of time presentation

Format	Example
yyyy-mm-dd hh:nn	2009-08-09 15:52
dd.mm.yyyy @ hh	09.08.2009 @ 15
j	221
j.f	221.661

A *custom format* of time presentation can be compiled using following notation:

- yyyy – year, yy – two last digits of the year,
- mm – month, dd – day, hh – hour,
- nn – minute (NB: mm would be month),
- any separator different of the following letters: y m d h n j f t x .

Some examples are given in Table 6.1.

If the user is satisfied with the time presentation style of the input standard table then the description of the time format can be written with one letter x (no extra time column). The time columns (1, 2 and/or 3, see Table 5.2) of the standard table will be carried forward into the output table when the corresponding column numbers are included into the list of variables.

► *Extra diameters* (an option) should be specified in a special file *diameters.txt* saved into the working folder. This file should contain just as many lines as the number of extra diameters. Each line should contain one diameter expressed in nanometers. The number of diameters should not exceed 20 and the diameters must lie in the range of 0.5–7 nm. Calculation of the distribution function on an extra diameter begins with a search for three logarithmically closest diameters in the standard table diameter set, which contains 10 diameters from 0.49 to 6.5 nm. Next, the value of the distribution function is calculated using the method of square interpolation on the logarithmic scale of the diameters.

► *List of variables* for the output table is to be compiled from the numbers of the variables shown in the first column of Table 5.2 or 5.3 using delimiters "," and "-". Spaces in the list are ignored. An example: the variable list 6,4,29-60 requires the including of 34 variables – the atmospheric pressure, temperature, and mobility distributions for positive and negative air ions. The legal entries of the list of variables are limited with intervals 1...78, 81...80 + *n*, and 101...100 + *n*, where *n* is the number of extra diameters specified in the file *diameters.txt*.

Values of  $dn/d\log(d)$  for *extra diameters* can be indicated in the list by numbers exceeding 80. The value of  $dn/d\log(d)$  should be indicated in the list as the variable number 80 + *k* for positive and 100 + *k* for negative ions, where *k* is the number of the line in the file *diameters.txt*.

```

Postprocessor SIGMA1P version 20100601
Date 2010-06-01, time 18:50:52
dragged item is folder C:\test
found 3 $1A-files:
C:\test\S1A100419.xl
C:\test\S1A100420.xl
C:\test\S1A100421.xl
found a file of 7 extra diameters:
1.00 2.00 3.00 4.00 5.00 6.00 7.00

Please answer some questions below. Asked parameters are explained
in the manual of SIGMA. NB: the input procedure can be interrupted
pressing ENTER without entering any answer.

Choose the days to be processed:
first day (use 6-digit format YYMMDD) = 100419
last day (use 6-digit format YYMMDD) = 100420

Correction methods (see SIGMA manual for detailed explanations):
0 = no correction,
1 = elimination of outliers
2 = suppression of dust-induced errors,
3 = combination of the methods 2 and 3.
Please choose the method (0...3) = 3
A value is qualified as outlier when the deviation from the average
of neighbors at least multiplier times exceeds the standard deviation.
Choose multiplier of std (3...9) = 5

Some random errors can be suppressed repeating n times the smoothing,
which replaces only negative values of distribution functions with
(1+2+1)/4-triplet averages over the neighborhoods of these values,
please choose smoothing level for negatives n (0...9) = 5

The data can be totally smoothed repeating k times the replacing
of values with (1+2+1)/4-triplet averages over the neighbors.
Diagram tables will be additionally couple-smoothed by default.
Extra choice k = -1 is equivalent of k = 0 for triplet smoothing,
but cancels default couple smoothing of diagram tables.
Please choose total smoothing level k (-1...9) = 0

Write time step for output table in minutes (1...1440) = 60

g lowest and g highest entries can be trimmed away
when calculating averages in the enhanced time intervals.
Please choose trimming degree g (0...20) = 3

Compile Normal table, Fraction table, or Diagram tables (N, F, or D) = n

See rules for time formatting in the manual
(examples: x = no extra column, yyyy-mm-dd hh:nn = ISO standard)
and choose format for time presentation = x

Example of a list: 6,4,29-60 (see rules in the manual)
Write list of variable numbers = 1-28,81-87,101-107

Please choose name for the output file = example.xl
Method 1: outliers are corrected in 1.240 % of available cells
Method 2: dust pulses are corrected in 0.548 % of available cells
Done

Finished 18:52:59, press ENTER!

```

Figure 6.1. Window of the postprocessor after answering all questions.

An example of the computer display during data postprocessing is presented in Figure 6.1.

The DataDiurna data manager (Tammet, 2009) makes available different possibilities for data reorganization and, especially, for compiling of a data archive.

## 6.5. Diagram function SIGMA1D

Two kinds of time-size distribution diagrams that can easily be created by means of MATLAB are surface plots and contour plots. A good MATLAB function written by Kaupo Komsaare allows creating surface plots using the monthly standard files. This function is available in the SIGMA website <http://ael.physic.ut.ee/tammet/sigma/>. Contour plots can be created by means of a MATLAB function SIGMA1D.m, which is presented in Appendix 5. The function processes automatically all diagram table files from the folder indicated by the *filepath*, which correspond to the indicated year *yy*. The results are saved in the same folder as the diagram tables and named *prefixYYMMDD.PNG*, where *prefix* is an arbitrary text defined in SIGMA1D. One image contains diagrams for both polarities. The size of an image file is usually in the range of 60–100 kilobytes in case of standard 5-minute cycles.

It is recommended to use a special working folder, which contains only the file SIGMA1D.m and the necessary diagram table files. After processing, the diagram table files and the resulting png-files can be moved away from the working folder.

Before launching the function, SIGMA1D.m should be edited because the information about the data location and process control parameters are written immediately into the function code. The full text of the function is presented in Appendix 5. The text can be copied into the clipboard and then pasted into the Notepad, M-editor, or immediately into the MATLAB command window.

Control lines are explained by comments in the program code:

```
% The control lines to be modified by the user (the permanent sample is preserved above):
prefix = 'SIGMA'; % for output file name
filepath = 'C:\_A\Aparaat\SIGMA\SIGMA1D\test\'; % where the files are located
yy = '09'; % year
months = 6:10; % interval of months, can be restricted
days = 1:31; % interval of days, can be restricted
first_hour = 0; % integer 0...23
hours_in_plot = 24; % integer 1...24
plots_in_day = 1; % (first_hour + plots_in_day * hours_in_plot) should not exceed 24!
first_mark = 0; % number of extra letter: 0 = nothing, 1 = a, 2 = b, ...
levels = [100 200 300 500 700 1000 2000 3000]; % for dn/dlogd
% The controls, which could be modified only in special situations:
pos_axes = [50 320 700 200]; % left, bottom, width, height
neg_axes = [50 60 700 200]; % width (standard is 700) may be sometimes modified
y_tickpositions = [1 2.18 3.43 4.85 6.65 8.3 10]; % vertical positions
y_ticklabels = {'0.5';'0.7';'1.0';'1.5';'2.5';'4.0';'6.5'}; % nanometers
```

The typical settings of the time parameters are written in the example above. It follows one full day diagram per day like presented in Figures 6.2 and 6.3. The name of the output file in Figure 6.2 is SIGMA090806.png and the file occupies 56 kB on the computer disk. Figure 6.3 is compiled for the same day and thus it is recommended to set a different value of *first\_mark*. If *first\_mark* = 1 then the diagram file is named SIGMA090806a.png.

Figures 6.4 and 6.5 are generated using different settings of parameters *first\_hour*, *hours\_in\_plot*, and *plots\_in\_day*, see explanations at the end of Appendix 5.



## 6.6. Examples of processed measurements

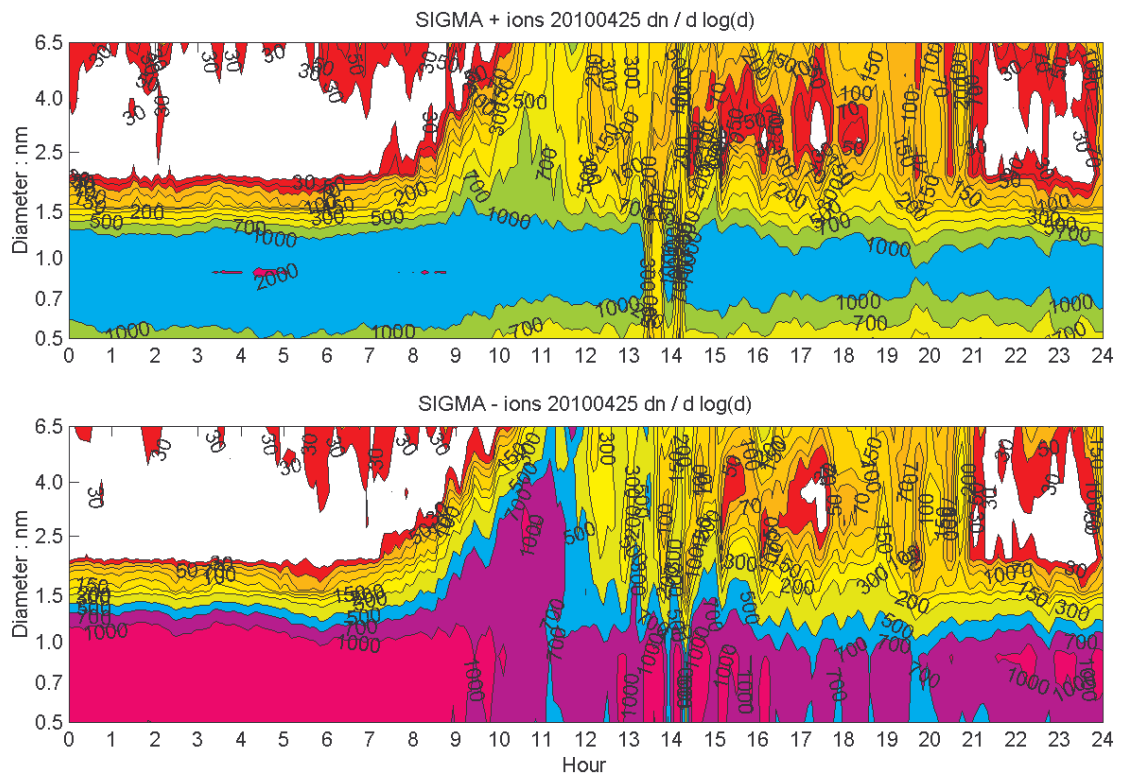


Figure 6.2. Diagram, created using the original diagram table file d100425.xl saved by SIGMA1A. Routine measurements over the roof of the Physics Building of the University of Tartu. Time resolution 5 min.

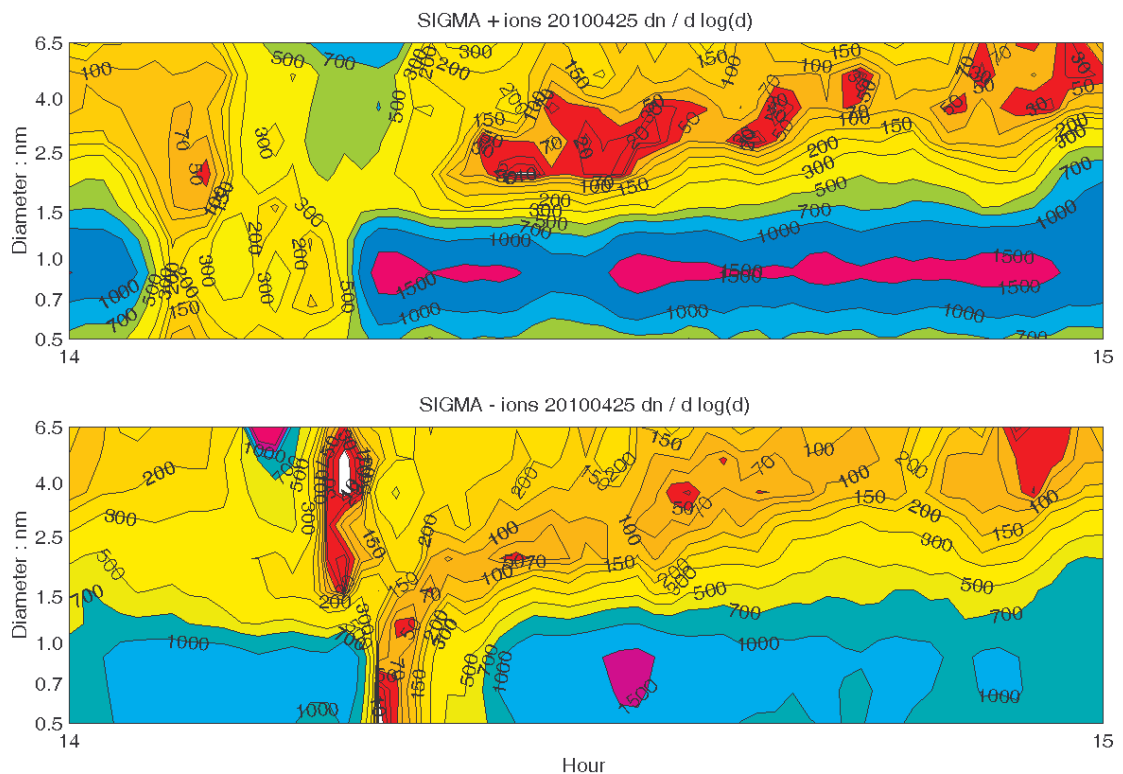


Figure 6.3. Diagram, created for the same measurements as in Figure 6.1 using the file of scan details \_S1A100425.xl processed by means of converter SIGMA1C. Time resolution 1 min.

# APPENDICES

## Appendix 1. Mobility versus size, temperature and pressure

Mobilities of 2 g/cm <sup>3</sup> particles at 950 mb							
d:nm	t=-20	t=-10	t=0	t=+10	t=+20	t=+30	t=+40
0.398	2.7573	2.8464	2.9357	3.0235	3.1098	3.1946	3.2781
0.501	2.2232	2.2878	2.3511	2.4132	2.4742	2.5342	2.5931
0.631	1.7725	1.8188	1.8643	1.9089	1.9527	1.9957	2.0379
0.794	1.3841	1.4177	1.4506	1.4829	1.5146	1.5457	1.5763
1.000	1.0545	1.0787	1.1025	1.1258	1.1487	1.1711	1.1932
1.259	0.7768	0.7925	0.8076	0.8222	0.8362	0.8497	0.8627
1.585	0.5176	0.5249	0.5320	0.5390	0.5457	0.5524	0.5589
1.995	0.3282	0.3336	0.3389	0.3442	0.3495	0.3547	0.3598
2.512	0.2174	0.2215	0.2256	0.2297	0.2336	0.2376	0.2414
3.162	0.1468	0.1497	0.1526	0.1554	0.1582	0.1609	0.1636
3.981	0.0989	0.1009	0.1028	0.1047	0.1065	0.1084	0.1102
5.012	0.0660	0.0673	0.0686	0.0699	0.0711	0.0723	0.0735
6.310	0.0437	0.0446	0.0454	0.0462	0.0470	0.0478	0.0486
7.943	0.0287	0.0293	0.0298	0.0303	0.0309	0.0314	0.0319
10.000	0.0188	0.0191	0.0195	0.0198	0.0201	0.0205	0.0208

Mobilities of 1 g/cm <sup>3</sup> particles at 1000 mb							
d:nm	t=-20	t=-10	t=0	t=+10	t=+20	t=+30	t=+40
0.398	3.1232	3.2241	3.3252	3.4246	3.5224	3.6185	3.7130
0.501	2.3779	2.4470	2.5147	2.5811	2.6464	2.7105	2.7735
0.631	1.8096	1.8569	1.9033	1.9488	1.9935	2.0374	2.0805
0.794	1.3692	1.4024	1.4350	1.4669	1.4982	1.5290	1.5593
1.000	1.0237	1.0473	1.0703	1.0929	1.1151	1.1369	1.1583
1.259	0.7464	0.7614	0.7760	0.7900	0.8034	0.8164	0.8289
1.585	0.4946	0.5016	0.5084	0.5151	0.5215	0.5279	0.5341
1.995	0.3128	0.3179	0.3230	0.3281	0.3331	0.3380	0.3429
2.512	0.2069	0.2108	0.2147	0.2186	0.2224	0.2261	0.2298
3.162	0.1396	0.1424	0.1451	0.1478	0.1504	0.1530	0.1556
3.981	0.0940	0.0959	0.0977	0.0995	0.1013	0.1030	0.1048
5.012	0.0628	0.0640	0.0652	0.0664	0.0676	0.0687	0.0699
6.310	0.0416	0.0424	0.0432	0.0439	0.0447	0.0455	0.0462
7.943	0.0273	0.0279	0.0284	0.0289	0.0293	0.0298	0.0303
10.000	0.0179	0.0182	0.0185	0.0188	0.0192	0.0195	0.0198

Mobilities of 2 g/cm <sup>3</sup> particles at 1000 mb							
d:nm	t=-20	t=-10	t=0	t=+10	t=+20	t=+30	t=+40
0.398	2.6198	2.7044	2.7892	2.8726	2.9546	3.0352	3.1145
0.501	2.1123	2.1737	2.2338	2.2928	2.3508	2.4078	2.4637
0.631	1.6841	1.7282	1.7713	1.8137	1.8553	1.8961	1.9363
0.794	1.3152	1.3470	1.3783	1.4089	1.4391	1.4686	1.4977
1.000	1.0020	1.0250	1.0476	1.0697	1.0914	1.1128	1.1337
1.259	0.7381	0.7530	0.7674	0.7812	0.7945	0.8074	0.8197
1.585	0.4918	0.4988	0.5056	0.5122	0.5186	0.5249	0.5310
1.995	0.3119	0.3170	0.3221	0.3271	0.3321	0.3371	0.3419
2.512	0.2066	0.2105	0.2144	0.2183	0.2220	0.2258	0.2294
3.162	0.1395	0.1423	0.1450	0.1477	0.1503	0.1529	0.1555
3.981	0.0940	0.0959	0.0977	0.0995	0.1013	0.1030	0.1047
5.012	0.0628	0.0640	0.0652	0.0664	0.0676	0.0687	0.0699
6.310	0.0416	0.0424	0.0432	0.0439	0.0447	0.0454	0.0462
7.943	0.0273	0.0278	0.0284	0.0289	0.0293	0.0298	0.0303
10.000	0.0179	0.0182	0.0185	0.0188	0.0192	0.0195	0.0198

Mobilities of 2 g/cm <sup>3</sup> particles at 1050 mb							
d:nm	t=-20	t=-10	t=0	t=+10	t=+20	t=+30	t=+40
0.398	2.4954	2.5759	2.6567	2.7361	2.8142	2.8910	2.9665
0.501	2.0121	2.0704	2.1277	2.1839	2.2391	2.2934	2.3467
0.631	1.6042	1.6461	1.6872	1.7276	1.7672	1.8061	1.8443
0.794	1.2528	1.2831	1.3129	1.3421	1.3707	1.3989	1.4266
1.000	0.9545	0.9764	0.9979	1.0190	1.0396	1.0599	1.0799
1.259	0.7032	0.7173	0.7310	0.7442	0.7569	0.7691	0.7808
1.585	0.4685	0.4752	0.4816	0.4879	0.4940	0.5000	0.5059
1.995	0.2971	0.3020	0.3069	0.3117	0.3164	0.3211	0.3257
2.512	0.1968	0.2006	0.2043	0.2079	0.2115	0.2151	0.2186
3.162	0.1330	0.1356	0.1382	0.1407	0.1432	0.1457	0.1481
3.981	0.0896	0.0914	0.0931	0.0948	0.0965	0.0981	0.0998
5.012	0.0598	0.0610	0.0622	0.0633	0.0644	0.0655	0.0666
6.310	0.0396	0.0404	0.0411	0.0419	0.0426	0.0433	0.0440
7.943	0.0261	0.0266	0.0270	0.0275	0.0280	0.0284	0.0289
10.000	0.0170	0.0174	0.0177	0.0180	0.0183	0.0186	0.0189

## Appendix 2. Presentation of the mobility and size distributions

The concentration of ions in a narrow interval of the ion electric mobility  $dZ$  around the mobility  $Z$  is  $dn = f_Z(Z) dZ$ , where  $f_Z(Z)$  is the distribution function of ions according to the mobility. The geometric size of an ion can be described by the ion mass diameter  $d$  (Tammet, 1995). The electric mobility depends on the mass diameter as  $Z = \text{mob}_{\text{air}}(d, T, p)$ , where  $\text{mob}_{\text{air}}$  is a specific function,  $T$  is the air temperature and  $p$  is the pressure. An approximation of the function  $\text{mob}_{\text{air}}$  proposed by Tammet (1995) is used in the SIGMA software. The size distribution of ions is described by the function  $f_d(d) = dn / dd$ , where  $dn$  is the concentration of ions in a narrow interval of the ion size  $dd$ .  $dZ = (d \text{mob}_{\text{air}}(d) / dd) dd$  and

$$f_d(d) = \frac{dn}{dd} = \frac{d \text{mob}_{\text{air}}(d)}{dd} f_Z(Z). \quad (\text{A2.1})$$

An alternative is the presenting of distributions according to the decimal logarithms of the size and mobility. In this case  $dn = f_{\log Z}(Z) d(\log Z) = f_{\log d}(d) d(\log d)$  and

$$f_{\log d}(d) = \frac{dn}{d(\log d)} = \frac{d \log(\text{mob}_{\text{air}}(d))}{d(\log d)} f_{\log z}(Z) = \frac{d}{Z} \frac{d \text{mob}_{\text{air}}(d)}{dd} f_{\log z}(Z). \quad (\text{A2.2})$$

All equations containing  $\log d$  or  $\log Z$  are conventional abbreviations, because a logarithm can be calculated only from dimensionless quantities. The strict way is to write  $\log(d / d_a)$  instead of  $\log d$ , where  $d_a$  is an arbitrary fixed size. However, the differentials are independent of the choice of  $d_a$ , and an inconvenient full expression  $d(\log(d / d_a))$  is abbreviated as  $d(\log d)$ .

Table A2.1. Units and conversion coefficients

Quantity	SI unit	Practical unit	Convert to SI
ion concentration $n$	$\text{m}^{-3}$	$\text{cm}^{-3}$	$\times 10^{-6}$
ion diameter $d$	$\text{m}$	$\text{nm}$	$\times 10^{-9}$
ion mobility $Z$	$\text{m}^2 \text{V}^{-1} \text{s}^{-1}$	$\text{cm}^2 \text{V}^{-1} \text{s}^{-1}$	$\times 10^{-4}$
$f_d(d)$	$\text{m}^{-4}$	$\text{cm}^{-3} \text{nm}^{-1}$	$\times 10^{-15}$
$f_{\log d}(d)$	$\text{m}^{-3}$	$\text{cm}^{-3}$	$\times 10^{-6}$
$f_Z(Z)$	$\text{m}^{-1} \text{Vs}$	$\text{cm}^{-1} \text{Vs}$	$\times 10^{-1}$
$f_{\log Z}(Z)$	$\text{m}^{-3}$	$\text{cm}^{-3}$	$\times 10^{-6}$

Units of the considered quantities and the conversion coefficients are shown in Table A2.1.

The control program SIGMA1A records the electrometric current as an average through the mobility and size fractions, see Figure A2.1. The geometric centers are the reference values of mobility or size when presenting a distribution function. The "decade to 16" and "decade to 8" logarithmic fraction schemes are used where the fraction borders are set according to a geometric sequence with the factor of  $10^{1/16} \approx 1.15478$  or  $10^{1/8} \approx 1.33352$ .

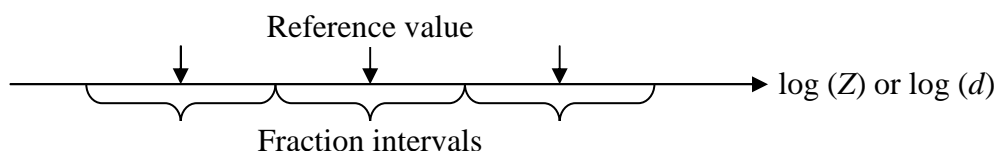


Figure A2.1. Fraction intervals and reference values of mobility or size.

The SIGMA output files include the distributions that are always presented with the values of the logarithmic distribution. The display in the computer screen is flexible as the control file SIGMA1A.INI allows to choose the display of the values of the distribution functions or the display of fraction concentrations. A mobility fraction concentration in an interval  $(Z_1, Z_2)$  is



$$n(Z_1, Z_2) = \int_{Z_1}^{Z_2} f_z(Z) dZ = \int_{\log Z_1}^{\log Z_2} f_{\log z}(Z) d(\log Z) \quad (\text{A2.3})$$

The size fraction concentrations can be expressed in similar way via the functions of the size distribution. A fraction concentration is estimated as the product of the logarithmic distribution function in the center of the fraction and the logarithmic width of the fraction, which is usually 1/8. In this case the conversion from the fraction presentation to the distribution function presentation is made according to the approximate equation

$$f_{\log Z}(\sqrt{Z_1 Z_2}) \approx 8 n(Z_1, Z_2) \quad \text{and} \quad f_{\log d}(\sqrt{d_1 d_2}) \approx 8 n(d_1, d_2) \quad (\text{A2.4})$$

An exception is the mobility distribution in the cluster ion regime where the logarithmic width of the fraction is 1/16.

Table A2.2. Size fractions and the corresponding electric mobilities in typical and extreme conditions

$d : \text{nm}$		$Z : \text{cm}^2 \text{V}^{-1} \text{s}^{-1}$	$Z : \text{cm}^2 \text{V}^{-1} \text{s}^{-1}$	$Z : \text{cm}^2 \text{V}^{-1} \text{s}^{-1}$
border	center	–20 C & 1050 mb	10 C & 1000 mb	40 C & 950 mb
0.422		2.3646	2.7158	3.0916
	0.487	2.0676	2.3590	2.6706
0.562		1.8005	2.0429	2.3022
	0.649	1.5573	1.7593	1.9756
0.750		1.3356	1.5038	1.6840
	0.866	1.1347	1.2743	1.4239
1.000		0.9545	1.0697	1.1932
	1.155	0.7937	0.8865	0.9847
1.334		0.6432	0.7110	0.7814
	1.540	0.4960	0.5426	0.5920
1.778		0.3717	0.4071	0.4456
	2.054	0.2816	0.3104	0.3418
2.371		0.2175	0.2409	0.2662
	2.738	0.1698	0.1885	0.2087
3.162		0.1330	0.1477	0.1636
	3.652	0.1040	0.1155	0.1279
4.217		0.0811	0.0900	0.0997
	4.870	0.0630	0.0699	0.0773
5.623		0.0488	0.0541	0.0598
	6.494	0.0376	0.0417	0.0461
7.499		0.0290	0.0321	0.0354

The control program SIGMA1A is designed with the aim of measuring concentrations of 10 size fractions, the borders and centers of which are shown in Table A2.2. The boundaries of the mobility fractions are arranged according to the "decade to 8" or "decade to 16" scheme shown in Tables 5.2 and 5.3. The boundary electric mobilities in Table A2.2 are not arranged according to the "decade to 8" scheme and depend on the air temperature and atmospheric pressure.

### Appendix 3. Inlet loss of ions

#### A3.1. General considerations

Some amount of ions is lost in the inlet tract before entering the mobility classifying zone (von der Weiden et al., 2009). The effect of electrostatic image forces on the deposition of ions is negligible when compared with the diffusion (Tammiet, 1970), and the inertial deposition is not important because the size range of the SIGMA is limited to fine nanometer particles. The ion concentration is limited by technical constraints of the instrument in the range, where the space charge effects can be neglected. Simple geometry of the inlet enables estimating the diffusion losses directly using the well-proven semiempirical methods of the heat transfer theory. In case of the ion and nanometer aerosol particles the preconditions required for the full analogy of heat and mass transfer (Kays et al., 2005, see Chapter 18) are satisfied and the equations of the heat transfer to the surface of constant temperature can be used when replacing the Nusselt number  $Nu$  with the Sherwood number  $Sh$  and the Prandtl number  $Pr$  with the Schmidt number  $Sc$  (Incropera and Dewitt, 2002).

The diffusion deposition flux of ions onto a flat surface is  $q_{dep} = WLn u_{dep}$ , where  $W$  is the width,  $L$  is the length of the surface along the air flow,  $n$  is the undisturbed concentration of ions and  $u_{dep}$  is the mean deposition velocity along the length  $L$ . The mean deposition velocity is

$$u_{dep} = (D/L)Sh_{mL}, \quad (A3.1)$$

where  $Sh_{mL}$  is the mean Sherwood number related to the length  $L$ , and  $D$  is the ion diffusion coefficient. The air enters as a plug flow and the boundary layer over the surface will develop along the channel. The displacement thickness of the boundary layer is estimated as

$$\delta_{disp} = 1.72 \sqrt{\frac{\nu L}{u_{flow}}}, \quad (A3.2)$$

where  $\nu$  is the kinematic viscosity of the air and  $u_{flow}$  is the free flow velocity (Incropera and Dewitt, 2002). A numeric calculation shows that the displacement thickness in the SIGMA inlet grid and filter is much less than the distance between the surfaces. Thus a semiempirical equation obtained for the boundary layer over a flat plate (Incropera and Dewitt, 2002) can be adopted in our problem:

$$Sh_{mL} = 0.664 Re_L^{1/2} Sc^{1/3}. \quad (A3.3)$$

The equation above takes into account the entrance profiles for both the ion concentration and for the air flow velocity. The Reynolds number related to the same length  $L$  and the velocity  $u_{flow}$  as the Sherwood number is

$$Re = \frac{u_{flow} L}{\nu}. \quad (A3.4)$$

Equation (A3.3) is valid when  $Sc > 0.6$  (Incropera and Dewitt, 2002). The Schmidt number  $Sc = \nu / D$  has the lowest value of about 3 in the case of cluster ions. Thus the concentration boundary layer is always thinner than the velocity boundary layer and Equation (A3.3) can be used for the evaluation of the ion deposition without restrictions so far as the boundary layer remains thin enough. The diffusion coefficient of single charged ions of the electric mobility  $Z$  is

$$D = \frac{kTZ}{e}, \quad (A3.5)$$

where  $k$  is the Boltzmann constant,  $T$  is the absolute temperature, and  $e$  is the elementary charge. The composite equation is

$$u_{dep} = \frac{kTZ}{Le} 0.664 \left( \frac{u_{flow} L}{\nu} \right)^{1/2} \left( \frac{\nu e}{kTZ} \right)^{1/3} = 0.664 (k/e)^{2/3} L^{-1/2} u_{flow}^{1/2} \nu^{-1/6} T^{2/3} Z^{2/3}. \quad (A3.6)$$

### A3.2. Deposition of ions onto the inlet grid and the parallel plate filter

The inlet grid is made of a perforated sheet and the air enters through cylindrical channels. The inlet flux of the air is  $\pi R^2 u_{flow}$  and the loss flux is  $2\pi R L u_{griddep}$ . Thus the relative loss is

$$A_{grid} = \frac{L_{grid} u_{griddep}}{2 R u_{gridflow}} = 0.332 (k/e)^{2/3} L_{grid}^{1/2} R^{-1} u_{gridflow}^{-1/2} v^{-1/6} T^{2/3} Z^{2/3}. \quad (A3.7)$$

The gate filter is a flat channel between two parallel plates separated with a distance  $h$ . The inlet flux of the air is  $W h u_{flow}$  and the flux of the loss onto both surfaces is  $2 W L u_{gatedep}$ . The relative loss is

$$A_{gate} = \frac{2 W L_{gate} u_{gatedep}}{W h u_{gateflow}} = 1.33 (k/e)^{2/3} L_{gate}^{1/2} h^{-1} u_{gateflow}^{-1/2} v^{-1/6} T^{2/3} Z^{2/3}. \quad (A3.8)$$

### A3.3. Correction of concentration according to the inlet loss

In the control program of the BSMA, the values of the distribution function or the fraction concentration  $f$  were corrected assuming a very low adsorption (Tammet, 2006):

$$f_{corrected} = \frac{f_{uncorrected}}{(1 - A_{grid})(1 - A_{gate})}, \quad (A3.9)$$

In the control program of the SIGMA the next approximation is used, where  $1 - A$  is replaced by  $\exp(-A)$ . The result is

$$f_{corrected} = f_{uncorrected} \exp(A_{grid} + A_{gate}) \quad (A3.10)$$

Let the index 0 mark the standard values of the parameters  $T_0 = 273$  K,  $p_0 = 1013$  mb,  $Z_0 = 1$  cm<sup>2</sup>V<sup>-1</sup>s<sup>-1</sup>, and  $v_0 = 1.33 \times 10^{-5}$  m<sup>2</sup>/s. The dependence of the deposition velocity on the air viscosity is weak and a rough approximation is sufficient:

$$v = v_0 \left( \frac{T}{T_0} \right)^{5/3} \left( \frac{p}{p_0} \right)^{-1}, \quad (A3.11)$$

If the deposition velocity at standard conditions is  $u_{dep0}$ , then

$$u_{dep} = u_{dep0} (T/T_0)^{7/18} (p/p_0)^{1/6} (Z/Z_0)^{2/3}. \quad (A3.12)$$

The estimate of the total relative adsorption  $A = A_{grid} + A_{gate}$  is now calculated as:

$$A = A_0 (T/T_0)^{7/18} (p/p_0)^{1/6} (Z/Z_0)^{2/3}, \quad (A3.13)$$

where

$$A_0 = c(0.332 L_{grid}^{1/2} R^{-1} u_{gridflow}^{-1/2} + 1.33 L_{gate}^{1/2} h^{-1} u_{gateflow}^{-1/2}), \quad (A3.14)$$

and

$$c = (k/e)^{2/3} v_0^{-1/6} T_0^{2/3} Z_0^{2/3} = 0.00114. \quad (A3.15)$$

The standard air flow rate in SIGMA No. 2 is about 32000 cm<sup>3</sup>/s. The parameters of the grid are  $L = 0.7$  mm,  $R = 0.5$  mm, full area 216 cm<sup>2</sup>, and the area of holes 99 cm<sup>2</sup>. It follows the air speed about 3.2 m/s. The parameters of the gate are  $L = 123$  mm,  $h = 10$  mm. The area of the free section between the inlet filter plates is 177 cm<sup>2</sup> and the corresponding average linear velocity is 1.81 m/s. The distance between the plates of the gate exceeds the distance between filter plates (which is 4 mm) and the air speed is increased in the gate up to the estimated value of 2 m/s. Calculation yields the estimates for SIGMA at standard air flow:

$$A_{0grid} = 0.0112, \quad A_{0gate} = 0.0375, \quad A_0 = 0.049. \quad (A3.16)$$

The relative uncertainty of the fraction concentrations induced by the uncertainty of the 5% correction is about 20 times less than the uncertainty of the estimate of the relative adsorption.

The specific regime of the low air flow rate of 6400 cm<sup>3</sup>/s brings about increased adsorption:

$$A_{0grid} = 0.0250, \quad A_{0gate} = 0.0839, \quad A_0 = 0.109. \quad (A3.17)$$

## Appendix 4. Control program SIGMA1A

### A4.1. Outline of the program

The control program SIGMA1A.EXE is compiled from the PASCAL-source SIGMA1A.DPR using DELPHI6 and it works under MS Windows (USB1608 requires version at least XP SP2) in the console regime. The instruction of the practical usage of the control program during routine measurements is presented in Chapter 3 and the test operations are described in Section 4.6 of the manual. The present appendix consists of the explanation of the principles of the measuring algorithm. The details of the algorithm are available in the source code of the control program that is enclosed in the software package as a separate file.

The folder, where the file SIGMA1A.EXE is located, is called below the SIGMA folder. When SIGMA1A is launched, it looks in the SIGMA folder for four configuration files: SIGMA1.CAL, SIGMA1A.INI, SIGMA1A\_inverter.txt, and SIGMA1A\_simulator.txt. The calibration file SIGMA1.CAL and the control file SIGMA1A.INI are obligatory. If any of these two files is not available, the program delivers a corresponding message and stops. SIGMA1A\_inverter.txt is necessary only when the parameter of *extracorrect* of the control file is 2 or 3, see next section. The file SIGMA1A\_simulator.txt is optional and should not be present during real measurements, see Section A4.4. After successful reading of the configuration files the program displays the start menu, shown in Figure 3.1.

Additionally, the SIGMA folder can contain an optional file SIGMA1A\_exmeteo.txt used for forced entering of meteorological data as explained in Section 3.1.

When SIGMA1A encounters a failure, it creates an additional file SIGMA1A\_failure.txt in the SIGMA folder, recording the time and a brief explanation of the failure. As a rule, the program will be stopped for 10 minutes after a failure and it will try to continue afterwards. If the file SIGMA1A\_failure.txt already exists, then a new failure message will be appended to the existing file.

### A4.2. Configuration files

The configuration files are located in the SIGMA folder and contain plain text. The header of a configuration file contains the date of the last revision. When making any changes in the file, the *date in the heading must be corrected*. Otherwise the control program interprets the change as a corruption of the configuration file. All parameters of the obligatory configuration files must be assigned. If a parameter is missing, then SIGMA1A issues a failure message and stops.

The calibration constants are presented in the file SIGMA1A.CAL. The content of the calibration file version 20110214 is:

```
SIGMA1A.CAL 20110214
Includes calibration coefficients for SIGMA No. 2 with orifice 4
Any line beginning with a space is a comment.
An assignment should be written without spaces.
A space after the assignment starts a comment until the end of the line.
Initial text of SIGMA1A.CAL is attached to the end of SIGMA1A.DPR
volt_factor=900          for voltage-mobility conversion
conc_factor_pos=6.1      for ADC-dn/dlogZ conversion
conc_factor_neg=6.3      for ADC-dn/dlogZ conversion
standardadsorption=0.049 for Z = 1 cm2V-1cm-1, 0 C, 1013 mb
filtermobility=0.03      cm2V-1cm-1, effective value for corrections
c_supplyvolt=0.002185    supplyvoltage / ADC_counts
c_filtervolt=-0.089      filter voltage / ADC_counts
c_batteryvolt=0.0093     electrometer battery voltage / ADC_counts
c_bias=0.003052          electrometer inlet mV at 1 ADC, 0.1526 / 50
c_pressurea=0.03368      pressure (mb) = c_pressurea * ADCcounts + c_pressureb
c_pressureb=120
c_temperaturea=0.0108    Celsius = c_temperaturea * ADCcounts + c_temperatureb
c_temperatureb=-291      factory value is -273
c_humiditya=0.007        humidity (%) = c_humiditya * ADCcounts + c_humidityb
c_humidityb=-48          required correction RH = RH (1.0546 - 0.0216 T:C)
```

```

delaytime=380          ms, incl. airflow + electrometer - HV signal
chargingtime=1500      ms
timeout=30000          ms

```

The user-editable control parameters are presented in the control file SIGMA1A.INI. The version 201110208 of SIGMA1A.INI is as follows:

```

SIGMA1A.INI 20110208
Includes custom controls.
Any line beginning with a space is a comment.
An assignment should be written without spaces.
A space after the assignment starts a comment until the end of the line.
Initial text of SIGMA1A.INI is attached into the end of SIGMA1A.DPR
cboard=0              defined during the USB1608 initialization
clusterregime=0        0 = dn/dlogZ full range 8 fr/dec
                      1 = dn/dlogZ only clusters 16 fr/dec
extracorrect=1         0 = no, 1 = dust pulses, 2 = transfer, 3 = both
cycleminutes=5         1, 2, 3, 4, 5, 6, or 10, standard value is 5
timezone=2             for time presentation
showfractions=1       0 = show dn/dlog, 1 - show fraction n (save still dn/dlog)
extension=xl           extension of the output file name, usually txt or xl
extrapath=***          for extracopy of midnight tables, *** means no extracopy
controls=1001          four symbols 0 or 1 setting initial values of saving
                      controls: internal, external, diatable, scandetails
extrapath can be written with or without final \
a sample: extrapath=J:\SIGMA

```

The parameter *clusterregime* is explained in Section 5.5.

*Extrapath* is essential when the *extrafolder* regime is turned on. The regime can be turned on and off during the measuring process by means of control keys, indicated on the computer screen, see Section 3.2. *Extrapath* can be directed to a shared folder or a removable media.

The optional file SIGMA1A\_inverter.txt contains parameters used for numerical improving of mobility resolution preferably in the small air ion range as explained in Section 5.7.3. It contains 5 numerical values, which should be presented according to the pattern that was used in experiments with the SIGMA No. 1:

```

SIGMA1A_inverter.txt 20110208
Warning: the present version is compiled for experiments only
Includes coefficients for optional data inverter
Any line beginning with a space is a comment.
An assignment should be written without spaces.
A space after the assignment starts a comment until the end of the line.
c_inv_n2=-0.16        inverter coefficient for i-2, default value = 0
c_inv_n1=-0.22        inverter coefficient for i-1, default value = 0
c_inv_p1=-0.10        inverter coefficient for i+1, default value = 0
c_inv_p2=-0           inverter coefficient for i+2, default value = 0
z_limit=1             inversion only if Z > limit, default value = 1

```

This file is necessary only when *extracorrect* > 1 in the control file. If a parameter is not shown in the inverter file then the default value will be used: *c\_inv\_n2* = 0, *c\_inv\_n1* = 0, *c\_inv\_p1* = 0, *c\_inv\_p2* = 0, *z\_limit* = 1. Some considerations about the choosing of the inverter parameters are presented in Appendix 6, Section A6.8.

The simulator file SIGMA1A\_simulator.txt is necessary only for the program developer and it is explained in Section A4.4.

**WARNING:** The current values of the calibration constants will be saved in the headers of the output files of the SIGMA. If the measurements are restarted after making changes in the calibration file or the control file, the headers of the recurrent output files remain unchanged in the computer. Follow recommendations presented in Section 5.7.1.

### A4.3. Structure of the measuring process

During the measuring process, the time is organized as cycles of equal duration. One of the cycles begins at the full hour and the period of cycles can be 1, 2, 3, 4, 5, 6, or 10 minutes. A cycle contains several scans of the mobility distribution and can be interrupted only pressing the key combination XZ. Simplified structure of the measurements is:

```
repeat scan and save scan details
  if voltageperiod full then measure voltages
  if cycleperiod full then process and save cycle
  if new day then append monthly file and save diagram table
until XZ pressed;
```

In the beginning of every scan the HV capacitors are charged and the voltage is increased up to about 3000 V for each polarity during about 1.5 s. Next, the voltage will exponentially decline in the relaxation process of a RC circuit with a time constant of about 4 s down to about 20 V, which covers the full size and mobility range of ions. Measurements are made during the period of the voltage decrease. Usually, three scans are made during every minute. Some of these scans are performed with an open air ion inlet gate and some with a closed air ion inlet gate. The gate (see Figure 2.1 and Appendix 7) is controlled by switching the voltage between the gate plates between zero and 520 V. The period of switching depends on the parameter *zeroperiod*, which is initiated as an internal constant in the program. In case of the standard value *zeroperiod* = 3, the sequence of closed gate (0) and open gate (1) scans is 011011011...

The full mobility range of  $0.0274...4.217 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  is divided into 35 fine mobility fractions. Before every scan, the air temperature and pressure are measured and the voltages corresponding to the boundaries between fine mobility fractions are calculated. During a scan, the voltages of electrodes and electrometer outputs are measured every few milliseconds until the voltage reaches the value corresponding to the highest mobility of  $4.22 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ . Next, the collected data is distributed into 35 fine mobility fractions and the averages are calculated for every fraction. When calculating the averages, the weak trimming is applied discarding the smallest and the largest readings of every sample. The results of a scan are collected into an array called *scanline*. Composition of this array corresponds to the composition of a line of the scan data file explained in Section 5.3. Additionally, the zero element is included: *scanline* [0] equals to the wintertime in MS Windows format referring to the midpoint between the start and finish of the scan. The following elements are the same as listed in Section 5.3.

At the end of a scan, the *scanline* is written into a circular buffer *scanbuffer* and saved on demand into the file of scan details as a string of integer numbers. The pointer of *scanbuffer* is denoted as *scanpoint* and it is incremented up and down as *scanpoint* := (*scanpoint* + 1) mod *scanmax* and *scanpoint* := (*scanpoint* + *scanmax* - 1) mod *scanmax*.

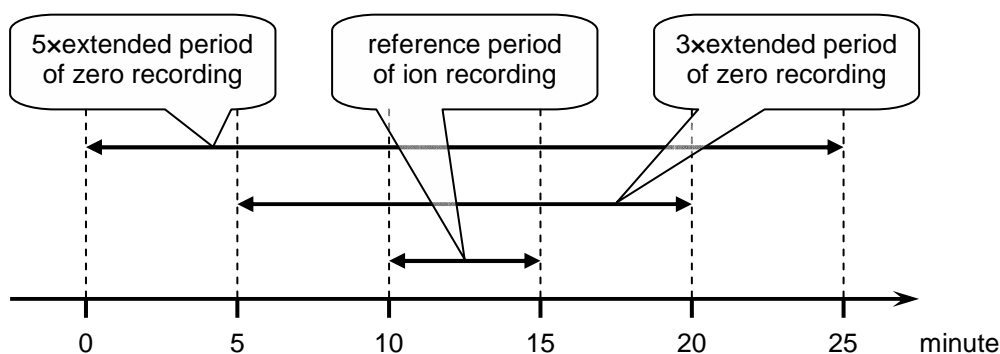


Figure A4.1. The periods of estimating the signal and zero in case of 5-minute cycles. The recorded ion measuring interval is marked with minute = 12 in the output files.

When the cycle is full, the buffered data are processed. The signal of an electrometer is composed of the signal of ions to be measured, the zero level of the electrometer, and the signal of the large ions passed through the sheath air filter (see Figure 2.1). Switching off the inlet gate affects only the signal of ions to be measured. When processing the cycle data, the average closed gate signal is subtracted from the open-gate signal. The drift of the closed-gate signal is usually slow compared with the variation of the open-gate signal. Thus the period of averaging the closed-gate signal is elongated with aim of suppressing the random noise as explained in Figure A4.1.

The statistical distribution of the noise of the electrometric signal is not Gaussian. The heavy-tailed shape of the distribution is caused by several factors, especially by the outliers generated by coarse aerosol particles. Thus the method of interquartile trimmed mean is applied when processing the buffered data. When calculating the trimmed mean of  $n$  repeated scans, the  $g$  smallest and  $g$  largest entries are discarded and the mean is estimated as the arithmetic average of  $n - 2g$  middle entries of the sample. SIGMA1A applies the trimming degree  $g = (n + 1) \text{ div } 4$ .

The noise level is estimated simultaneously for two ion polarities when analyzing the results of zero scans. The method is based on calculating the deviations from the cubic interpolation of the zero signals of the 16 mobility fractions. The deviations are calculated as

$$\Delta x_i = x_i - (x_{i-2} - 4x_{i-1} - 4x_{i+1} + x_{i+2}) / 6, \quad i = 3 \dots 14. \quad (\text{A4.1})$$

#### A4.4. Comments for the software developer

The program SIGMA1A is written as a console application, which helps to keep the well-accustomed BSMA-style user interface. The console output is localized into particular procedures, whose names begin from the word "show". This makes a future reorganization of the program into a GUI application relatively easy.

The program includes a simple mechanism to help development and testing. The user interface, internal data processing and data output can be quickly tested without a connection to a real instrument. This requires including an extra file SIGMA1A\_simulator.txt into the SIGMA folder. An example of the content of this file is:

```
100    simufactor, how many times the clock is accelerated
2220   start of the simulated clock, hhmm
1      spectrumstyle, 0 = flat dn/dlogZ, 1 = like natural
30     simunoisesigma, noise sigma expressed in ADC counts
0.01   simuoutlierprobability
300    simuoutliersigma in ADC counts
```

The six lines of this file must be written strictly in the same order as in the example; the explanations after the spaces are for humans and will not be analyzed by the computer.

If the extra file SIGMA1A\_simulator is found, then a logical variable *simulator* is assigned *true* and the real measurements are replaced by the output of the function *ADCsimulator*. Search the program code for the phrase "if simulator" to see the differences compared with the normal regime.

*Warning:* too high value of *simufactor* may lead to a situation, when the computer is not able to complete some procedures in time an "short fraction" failures will appear. In case of a 2 GHz processor the troubles are probable when *simufactor* > 100. It is recommended to close resource-consuming side processes and/or enhance the program priority when working with high value of *simufactor*.

The logical constant *developer* defined in line 9 of the program code is an additional tool. If this constant is assigned *true*, then three additional commands will be available. In the main menu, an additional command *Z* appears, which launches a user-written procedure *Z\_test*. Two additional commands *A* and *B* appear in the test menu, which allow launching the user-written procedures. In the present version of SIGMA1A, two developer procedures *electrometertransition1* and *electrometertransition3* are retained as examples.

## Appendix 5. MATLAB function SIGMA1D.m

The text of the function can be copied into the clipboard and pasted into the Notepad, M-editor, or immediately into the MATLAB command window. The user should arrange the files and edit the control lines before launching the function as explained in Section 6.5.

```
% SIGMA1D - creates contour plots using SIGMA diatable files - HT20091217
%=====
% Permanent sample of control lines, please keep unmodified:
% prefix = 'SIGMA'; % for output file name
% filepath = 'C:\SIGMA\diatables\'; % where the files are located
% yy = '09'; % year
% months = 1:12; % interval of months, can be restricted
% days = 1:31; % interval of days, can be restricted
% first_hour = 0; % integer 0...23
% hours_in_plot = 8; % integer 1...24
% plots_in_day = 3; % (first_hour + plots_in_day * hours_in_plot) should not exceed 24!
% first_mark = 1; % number of letter in the filename, 0 = nothing, 1 = a, 2 = b, ...
% levels = [50 100 200 300 500 700 1000 1500 2000 2500 3000 4000 5000]; % for dn/dlogd
% pos_axes = [50 320 700 200]; % left, bottom, width, height
% neg_axes = [50 60 700 200];
% y_ticknumbers = [1 2.18 3.43 4.85 6.65 8.3 10];
% y_ticklabels = {'0.5';'0.7';'1.0';'1.5';'2.5';'4.0';'6.5'};
%=====
% Examples of controls for covering full day with diagrams:
% first_hour = 0; % in all three examples
% hours_in_plot = 24; % one plot per day
% plots_in_day = 1;
% hours_in_plot = 8; % three plots per day
% plots_in_day = 3;
% hours_in_plot = 3; % eight plots per day
% plots_in_day = 8;
%=====
% The control lines to be modified by the user (the permanent sample is preserved above):
% prefix = 'SIGMA'; % for output file name
% filepath = 'C:\SIGMA\diatables\'; % where the files are located
% yy = '10'; % year
% months = 03:04; % interval of months, can be restricted
% days = 1:31; % interval of days, can be restricted
% first_hour = 0; % integer 0...23
% hours_in_plot = 24; % integer 1...24
% plots_in_day = 1; % (first_hour + plots_in_day * hours_in_plot) should not exceed 24!
% first_mark = 0; % number of extra letter, 0 = nothing, 1 = a, 2 = b, ...
% levels = [30 50 70 100 200 300 500 700 1000 2000 3000]; % for dn/dlogd
% The controls, which could be modified only in special situations:
% pos_axes = [50 320 700 200]; % left, bottom, width, height
% neg_axes = [50 60 700 200]; % width (standard is 700) may be sometimes modified
% y_tickpositions = [1 2.18 3.43 4.85 6.65 8.3 10]; % vertical positions
% y_ticklabels = {'0.5';'0.7';'1.0';'1.5';'2.5';'4.0';'6.5'}; % nanometers
%=====
% Modification of the text below of this line is not recommended
for month = months;
    mm = num2str(month);
    if month < 10
        mm = ['0' mm];
    end;
    for day = days;
        dd = num2str(day);
        if day < 10
            dd = ['0' dd];
        end;
        if exist([filepath 'd' yy mm dd '.xl'], 'file')
            xx = load([filepath 'd' yy mm dd '.xl']);
            [rows, nd] = size(xx);
            cycles = (rows - 1) / 24;
            for turn = 0:(plots_in_day - 1); % day sectors a, b, c, ...
```



```

a = 1 + cycles * (first_hour + turn * hours_in_plot); % first row in data table
b = first_hour + turn * hours_in_plot; % first hour of the plot
mark = char(96 + first_mark + turn); % extra letter to distinguish the files
if mark == char(96)
    mark = ""; % filename will be without an extra letter
end;
x = xx(a : a + cycles * hours_in_plot, 2:11); % sector of positive ions
if sum(sum(x)) > 9999 % empty diagram is skipped
    colormap(hsv);
    axes('units', 'pixels', 'position', pos_axes);
    [c,h] = contourf(x', levels);
    brighten(0.6);
    clabel(c, h);
    set(gca, 'xtick', [1:cycles:rows], 'xticklabel', [b:1:b+hours_in_plot]);
    set(gca, 'ytick', y_tickpositions);
    set(gca, 'yticklabel', y_ticklabels);
    ylabel('Diameter : nm');
    title(['SIGMA + ions 20' yy mm dd ' dn / d log(d)']);
    print('-dpng', [filepath prefix yy mm dd mark '.png']);
end; % if sum > 9999
x = xx(a : a + cycles * hours_in_plot, 12:21); % sector of negative ions
if sum(sum(x)) > 9999 % empty diagram is skipped
    axes('units', 'pixels', 'position', neg_axes);
    [c,h] = contourf(x', levels);
    brighten(0.6);
    clabel(c, h);
    set(gca, 'xtick', [1:cycles:rows], 'xticklabel', [b:1:b+hours_in_plot]);
    set(gca, 'ytick', y_tickpositions);
    set(gca, 'yticklabel', y_ticklabels);
    xlabel('Hour');
    ylabel('Diameter : nm');
    title(['SIGMA - ions 20' yy mm dd ' dn / d log(d)']);
    print('-dpng', [filepath prefix yy mm dd mark '.png']);
end; % if sum > 9999
close all;
end; % of turn
end; % of if exist
end; % of days
end; % of months and finish of processing

```

### *Some explanations:*

The typical settings of the time parameters are written above. It follows one full day diagram per day like presented in Figure 6.2. The name of the output file in Figure 6.2 is SIGMA100425.png and the file occupies 95 kB on the computer disk. Figure 6.3 is compiled for the same day and thus it is recommended to set a different value of *first\_mark*. If *first\_mark* = 1 then the diagram file is named SIGMA100425a.png.

The settings:

```

first_hour = 13; % integer 0...23
hours_in_plot = 1; % integer 1...24
plots_in_day = 3; % (first_hour + plots_in_day * hours_in_plot) should not exceed 24!
first_mark = 1; % number of extra letter, 0 = nothing, 1 = a, 2 = b, ...

```

generate five one-hour diagrams per day for the periods 13–14, 14–15, and 15–16. The files are named SIGMA100425a.png, SIGMA100425b.png, and SIGMA100425c.png. Figure 6.3 is compiled according to file SIGMA100425b.png.

## Appendix 6. Calibration and testing the instrument

### A6.1. Air flow and the delay time in the analyzer

The air flow rate through the instrument equipped with 4 mm standard orifice plate was measured using the rotary gas flow meter PC-400, which air flow range is  $111 \text{ dm}^3 \text{ s}^{-1}$ . A compensation method was used: the air was blown into a large box through the flow meter by means of an extra fan and sucked out from the box by the SIGMA. One side of the box is made of thin plastic film, which helps precisely to balance the pressure in the box by adjusting the slide controlling the blown-in air flow. The result was

$$Q_0 = 32000 \text{ cm}^3/\text{s}.$$

The air flow rate for the special 1.5 mm orifice plate was measured using gas flow meter BK-G16, the result was  $6400 \text{ cm}^3/\text{s}$ . In the present manual is expected use of the standard orifice plate and  $Q_0 = 32000 \text{ cm}^3/\text{s}$  is considered as the standard value.

The distribution of the standard air flow along the analyzer is characterized in Table A6.1, where the values of Reynolds number are given for kinematic viscosity of  $0.15 \text{ cm}^2 \text{ s}^{-1}$ .

Table A6.1. Air flow in different zones of the analyzer, see Appendix 7.

Zone	Length, cm	Air speed, cm/s	Re	Passage time, ms	Voltage, V	Critical mobility, $\text{cm}^2 \text{ V}^{-1} \text{ s}^{-1}$
Gate	12.5	190	1260	65	520	0.029
Inlet filter edge slit	16.5	178	470	93	520	0.0033
Classification zone	10.5	160	4000	64	variable	variable
Shielded zone	4	160	1500	25	0	–
Electrometric filter	5.5	190	570	29	240	0.029

The values of the critical mobility of the gate, the inlet filter and the electrometric filter are sufficient for operating of the analyzer according to the theoretical model. Voltage of the electrometric filter is estimated above 240 V. If the voltage drops during exploitation then some penetration of  $0.0312 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$  ions through the electrometric filter is possible. Thus the control program SIGMA1A includes monitoring of the battery voltage and carries out a correction when necessary.

The air flow in the mobility classification zone at  $Q = 32000 \text{ cm}^3/\text{s}$  appears slightly turbulent. The turbulence in the analyzer of SIGMA No. 1 was visualized using a thin soft thread vibrating in the air flow in the classification zone. The position of the free tip of the thread was measured from 130 photos and the standard deviation proved to be 1.2 mm. The vibration of the thread is damped by inertia and the standard deviation of air parcels exceeds this value. Thus the value of 1.2 mm is considered only as a lower margin of the turbulent pulsations. This result is considered in Section A6.7 when discussing the mobility resolution.

The passage time of the air from the inlet of the gate until the inlet of electrometric filter is 154 ms according the Table A6.1. Small ions are controlled in the first few mm of the gate and the time between opening the gate and collecting the ions is about 150 ms. The signal of the electrometer appears with an additional delay due to the electrometric RC-process. This delay is measured to be of 240 ms. The sum of two delay times is 390 ms. The corresponding value of the classifier high voltage is recorded with a small time delay of 10 ms. Thus the time delay between the recorded HV signal and the electrometric signal is estimated 380 ms and included into the calibration file as the parameter *delaytime*. This parameter is considered in the control program SIGMA1A where the HV signal is opposed with the electrometric signal that is recorded of *delaytime* later.

The delay time is much longer when using the 1.5 mm multi-orifice plate and the parameter *delaytime* is estimated of 980 ms in this case.

## A6.2. Reference mobility and analyzer voltage

The concepts of fraction concentration and distribution function are introduced in Appendix 2. The distribution function and the concentrations of ions between the fraction borders  $Z_1$  and  $Z_2$  are related as

$$f_{\log Z}(Z_o) = \frac{dn}{d \log(Z)} \approx \frac{n(Z_1, Z_2)}{\log(Z_2) - \log(Z_1)} \quad (\text{A6.1})$$

where  $Z_o$  is located somewhere between the fraction borders and called the reference mobility. We follow Equation A2.4 and accept the agreement

$$Z_o = \sqrt{Z_1 Z_2}. \quad (\text{A6.2})$$

In the "decade to eight" system, the argument  $\log(Z)$  is uniformly split into 8 fractions in a decade and  $\log(Z_2) - \log(Z_1) = 1/8$ . Thus in case of the SIGMA standard data

$$f_{\log Z}(Z_o) \approx 8 n(Z_1, Z_2). \quad (\text{A6.3})$$

The reference mobility of a DMA is determined as the mobility of monomobile ions, which produce maximum signal in the collector.  $Z_o$  depends on the air flow rate  $Q$  and the voltage between the attracting and repelling electrodes of the analyzer  $V$ :

$$Z = \text{const} \times Q / V. \quad (\text{A6.4})$$

The voltage  $V$  is proportional to the high voltage signal  $\text{ADC}_{\text{HV}}$ , measured in ADC counts. The flow rate in the SIGMA is proportional to the power supply voltage  $U$ . Thus

$$Z_o = \text{VC} \times (U/U_0) \times Q_0 / \text{ADC}_{\text{HV}}, \quad (\text{A6.5})$$

where  $Q_0$  is the standard flow rate at the standard power supply voltage  $U_0$  and VC is the voltage calibration constant. The calibration of the instrument requires determining of the calibration constant VC and the standard air flow rate, which value is measured  $Q_0 = 32000 \text{ cm}^3/\text{s}$  as explained in the previous section.

The calibration constant VC is calculated solving the Laplace equation for the electric field in the condenser and computing the ion trajectories when passing the condenser (see Figure 2.1 and Appendix 7). The result is

$$\text{VC} = 0.0285.$$

The calibration constant VC and the standard flow rate  $Q_0$  are never independently used in the control program, where only the product

$$\text{VF} = \text{VC} \times Q_0 = 912$$

is necessary. This product is called the voltage factor and included into the calibration file. During the scanning the voltage  $\text{ADC}_{\text{HV}}$  is continuously measured and the reference mobility is calculated as

$$Z_o = \text{VF} \times (U/U_0) / \text{ADC}_{\text{HV}}. \quad (\text{A6.6})$$

The calibration constant VF was verified by means of the iodine test. The admixture of iodine vapor in the clean air forms negative ions with the peak about the mobility of  $1.85 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$  (Tammet, 1975). The control experiments in iodine containing laboratory air were in good accordance with a little decreased value

$$\text{VF} = 900,$$

which is used later as a standard value of the calibration constant. The 1.3% difference between the estimates is explained probably by small deviations of the real instrument from the numerical model, used when calculating the value of VC:

### A6.3. Air ion concentration

The collector current  $I$  of monomobile ions of mobility  $Z$  and concentration  $n$  is  $I(Z_0) = eQ_c g(Z_0, Z)n$ , where  $Z_0$  is the reference mobility of the analyzer,  $e$  is the elementary charge,  $Q_c$  is the air flow rate through the collector and  $g(Z_0, Z)$  is the normalized transfer function, which values are in the range of (0...1). If the ions are distributed according to the mobility as  $f(Z) = dn/dZ$  then  $I(Z_0) = eQ_c \int g(Z_0, Z) f(Z) dZ$ . Let us consider the ions be distributed according to a fictive flat distribution and  $f(Z) = c$ . In this case the collector current is  $I(Z_0) = ceQ_c \int g(Z_0, Z) dZ$ . In a special situation of rectangular transfer function when  $g = 1$  in a range ( $Z_a...Z_b$ ) of mobility and  $g = 0$  elsewhere, the integral  $\int g(Z_0, Z) dZ = Z_b - Z_a$ . In the general situation, the integral  $\int g(Z_0, Z) dZ$  is called the effective width of the transfer function and denoted  $\Delta Z_G$ . In a special case of case of a triangular transfer function the effective width equals to the half-height width of the triangle. As a conclusion we get in case of the flat distribution  $f(Z) = c$  the flat value of the collector current  $I = ceQ_c \Delta Z_G$  and the value of the distribution function can be calculated according to the measured current as  $c = I/eQ_c \Delta Z_G$ . A fraction concentration of ions in a range of ( $Z_1...Z_2$ ) is  $n(Z_1, Z_2) = c \Delta Z_{fr}$ , where  $\Delta Z_{fr} = Z_2 - Z_1$ . Thus the fraction concentrations can be calculated according to the equation

$$n(Z_1, Z_2) = \frac{I \Delta Z_{fr}}{eQ_c \Delta Z_G}, \quad (A6.7)$$

where the reference mobility  $Z_0$  is expected to be in middle of the interval ( $Z_1...Z_2$ ) and the distribution function is expected to be nearly flat around the reference mobility. In sake of brevity a complex instrument calibration coefficient is introduced

$$\gamma = \left( \frac{Q \Delta Z_{fr}}{Q_c \Delta Z_G} \right), \quad (A6.8)$$

where  $Q$  is full air flow rate through the instrument. In an ideal situation  $\Delta Z_{fr} = \Delta Z_G$ ,  $Q_c/Q \approx 1/8$ , and the value of  $\gamma$  should be about 8.

Now the fraction concentrations are calculated as

$$n(Z_1, Z_2) = \frac{\gamma}{eQ} I. \quad (A6.9)$$

The control program SIGMA1A additionally considers the penetration of the inlet grid and inlet gate  $P$  (see Appendix 3) and the working formula is

$$n(Z_1, Z_2) = (\gamma \times CC_n / Q) \times (U_0 / U) \times ADC_E / P, \quad (A6.10)$$

where  $ADC_E$  is the output of the electrometric channel and  $CC_n$  is an additional calibration constant, which includes the transformations of measuring units from ADC counts to the units of ion concentration. This calibration constant can be roughly estimated according to the following considerations. Let  $n(Z_1, Z_2) = 1 \text{ e/cm}^3$ ,  $Q/\gamma = 1 \text{ cm}^3/\text{s}$ ,  $U = U_0$ , and  $P = 1$ . In this case the current of the collector is  $1 \text{ e/s} = 1.602 \times 10^{-19} \text{ A}$ . The voltage in the electrometer  $5 \text{ G}\Omega$  input resistor is  $8.01 \times 10^{-10} \text{ V}$  and the  $50\times$  amplified signal is  $4.005 \times 10^{-8} \text{ V}$ . The corresponding count rate of  $ADC_E$  is  $2.625 \times 10^{-4}$ . When all these numbers are entered into the working formula above, we get  $CC_n = 3810$ .

The values of the distribution function can be calculated by means of Equation (A6.10) when including an additional multiplicand 8 according to transformation (A6.3). This multiplicand can be written inside the first factor in the formula (A6.10). The updated factor is interpreted as a complex calibration coefficient

$$CF = 8CC_n \gamma / Q = 30480 \gamma / Q \quad (A6.11)$$

and the working formula is written immediately for the distribution function

$$f_{\log Z} = CF \times (U_0 / U) \times ADC_E / P. \quad (A6.12)$$

If  $\gamma = 8$  as expected above for an ideal situation, then CF of SIGMA should be 7.6. This is a very rough estimate. There are no known methods for exact estimation of the air flow coefficient  $\gamma$ , which is necessary for the application of the theoretical model. Thus the value of this coefficient is a subject of experimental calibration, where the SIGMA is compared with a precise integral air ion counter and the value of CF is adjusted so that small ion integral concentrations measured using the two instruments are equal.

Calibration was performed in the conditions of a relatively high concentration of cluster ions of about  $26000 \text{ cm}^{-3}$ . The concentration of small air ions was measured simultaneously with the SIGMA and an integral air ion counter of absolute calibration. The air was prepared with a special air ion generator, providing stable uniform ionization in the air flow. The measurements were made individually for positive and negative air ions and the concentration factors included into the calibration file SIGMA1A.CAL are slightly different:

$$\text{CF}^+ = 6.1,$$

$$\text{CF}^- = 6.3.$$

The results can be explained with different values of the coefficient  $\gamma$  for positive and negative ions. The declination of the factors from the theoretical estimate is probably a result of errors in estimating the air flow distribution and the mechanical imprecision of manufacturing the analyzer.

#### A6.4. Calibration of the meteosensors

Atmospheric pressure, air temperature and relative humidity are calculated according to linear transformations of the ADC counts:  $\text{result} = a \times \text{ADC} + b$ . The calibration coefficients  $a$  and  $b$  can be calculated according to two simultaneous measurements of the ADC signal and the true value of the quantity. Additionally, humidity is corrected according to temperature using the factory-recommended transformation  $\text{RH} = \text{RH}_0 / (1.0546 - 0.0215 \text{ T:C})$ .

Atmospheric pressure is measured by the sensor MPX5100 designed in Motorola and manufactured by Freescale. According to the company information, the coefficient  $b$  should be negative. The same sensor was used in the BSMA and calibration according to a mercury barometer results in rather positive values of  $b$ . According to the preliminary experimental calibration in case of the SIGMA the coefficients are  $a = 0.03368$  and  $b = 120$ .

Temperature and humidity sensors are calibrated in comparison with an Assmann psychrometer. Temperature is measured by the sensor AD590 manufactured by Analog Devices. The experimental calibration  $a = 0.0108$  and  $b = -293$  differs a little from the factory data. Relative humidity is measured by Honeywell sensor HIH-4000. The empiric coefficients  $a = 0.007$  and  $b = -50$  differ from the factory data.

The long-term stability of meteosensors is not good and the readings of sensors should be compared with readings of exact instruments every few months. The calibration constants should typically be corrected about twice a year. Two independent and possibly different measurements of correct values of a quantity  $y_1$  and  $y_2$  and simultaneous SIGMA-recorded values  $x_1$  and  $x_2$  are required to adjust the calibration coefficients. In case of the humidity, the measurements should be at first multiplied with  $(1.0546 - 0.0216 \text{ T:C})$  using the values of temperature, which were recorded respectively by SIGMA and by the correct thermometer. Then the ADC readings can be restored:

$$q_1 = (x_1 - b_o) / a_o \text{ and } q_2 = (x_2 - b_o) / a_o, \quad (\text{A6.13})$$

where  $a_o$  and  $b_o$  are the old calibration coefficients written in SIGMA1A.CAL. Next the corrected values of the calibration coefficients can be calculated:

$$a = (y_2 - y_1) / (q_2 - q_1) \text{ and } b = y_1 - a q_1. \quad (\text{A6.14})$$

#### A6.5. Test measurements

The first field test of the instrument No 1 was carried out at a rural site in Abissaare village (cottage Tammemäe,  $58^\circ 05' 39'' \text{ N}$  &  $26^\circ 43' 09'' \text{ E}$ ), located about 30 km south of Tartu,

Estonia. The instrument was installed the attic of the cottage June 2009 following the Figure 2.4, see Figure A6.1. Air is sampled through an opening in the gable facing the east. The gable is open to direct sunlight, which results in the enhanced noise in the measurements until the midday.



Figure A6.1. The installation of the SIGMA in the attic.

The main purpose of the test measurements was the identification of instrument response to different meteorological conditions, which enabled to elaborate the control program and include proper reactions to extraordinary situations, e.g. distortions emerging in case of contamination of the aspiration condenser and electrometric filters. About 10000 five-minute cycles were recorded during 2009 July-October. The acquired experience is basis for many improvements of the software and minor changes in the design of the instrument no. 2.

Afterwards the instrument served more than a year for continuous measurements of the urban air in Tartu. During the 1.5 years of exploitation the analyzer was thoroughly cleaned about three times and the collector batteries were not changed. The instrument temporarily stopped normal work mostly during snowstorms and rarely during rainstorms. After these events the it has always recovered itself without special help of the laboratory staff.

#### A6.6. Sensitivity

Sensitivity of the instrument is limited with the level of background noise in the measurements. Some series of measurements were performed especially for estimating the level of noise in measured fraction concentrations. The regime of permanently closed gates was used as explained in Chapter 4.

The background noise in 16+16 mobility fractions was measured with SIGMA No. 2 in a laboratory room where the concentration of radon is relatively high. The results are illustrated in Figure A6.2. If the classifying voltage is high then the clouds of ions generated by alpha pulses are deposited before they reach the collectors. In this case the standard deviation of noise in fraction concentrations is less than  $1 \text{ cm}^{-3}$ . If the voltage decreases then part of alpha-particle generated ions will reach the collectors and induce there noise pulses. Thus the fraction concentration noise increases until  $3 \text{ cm}^{-3}$  in the mobility range of small ions. This result is characteristic of a radon-rich room. The effect of radon in the outdoor air is usually weak and the noise of small ions is low, but the noise is often enhanced in the range of low

mobilities due to the pulses generated by dust particles. About 500 cycles of noise were recorded with SIGMA No. 1 September 26–28, 2009, during strong wind, RH between 80 and 100% and drizzling rain from time to time. The results are shown in Figures A6.3–4.

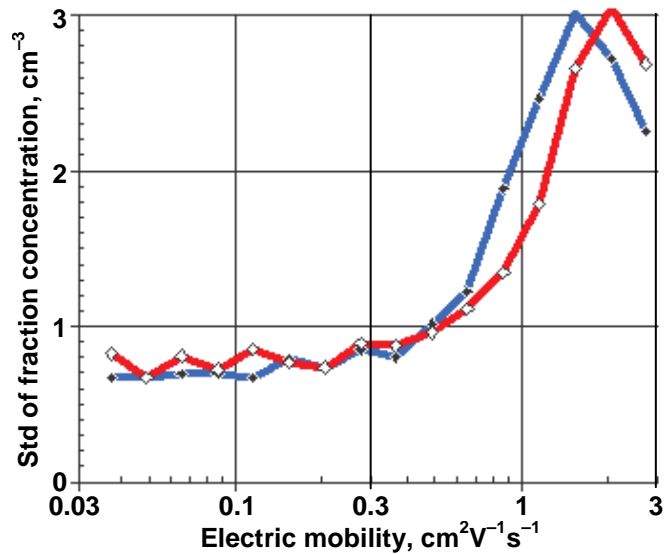


Figure A6.2. Standard deviations of noise signal in 10-minute averages. Red line marks positive and blue line negative ions. Experiment with SIGMA No. 2 in a laboratory room.

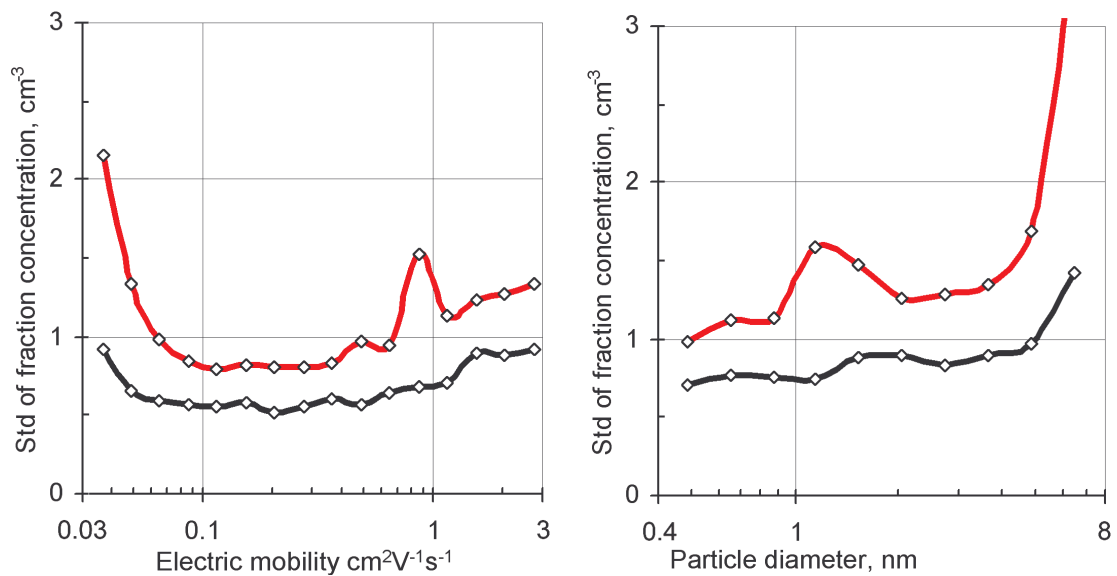


Figure A6.3. Standard deviations of noise signal in 10-minute averages. Green line for below-median and red line for above-median noise.

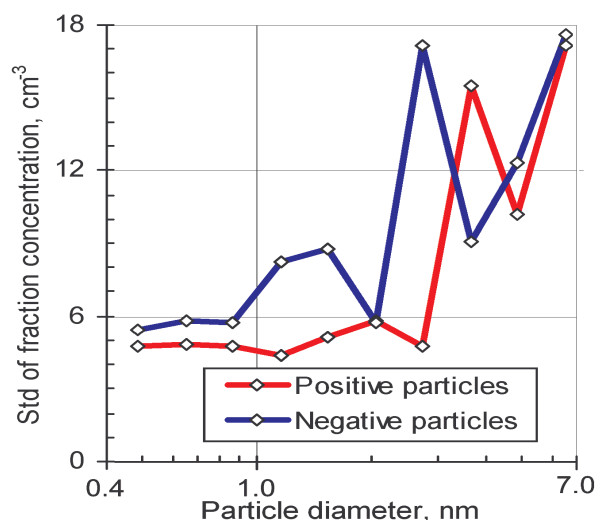


Figure A6.4. Standard deviation of noise signal in size fraction concentrations in case of 20 s time resolution (4470 scans during field measurements Sept 27, 2009).

### A6.7. Mobility resolution

Research of nucleating nanoparticles in atmospheric air brings up specific requirements, which radically differ from the requirements for a laboratory mobility analyzer. The signal to noise ratio turns up to be critical due to the extremely low concentration of nanometer ions in atmospheric air. Theoretical models of atmospheric aerosol nucleation include continuous growth of nanometer particles and the mobility distribution is expected to be relatively smooth. Thus the factors of sensitivity will have priority before the factors of resolution. Request of high sensitivity requires increasing the collected ion current. The inlet slit and the collector of the analyzer cannot be narrow and the geometric resolving power is limited. The air is sucked into the instrument immediately from the turbulent atmosphere and the flow rate should be large. Some turbulence inside the analyzer is inevitable in these conditions. As a result, the mobility resolution of instruments for atmospheric measurements cannot be high.

Traditional parameters of the DMA resolution are the relative standard deviation of measured mobilities in case of actually monomobile ions of mobility  $Z$ , and the ratio of this mobility to the width of the transfer function at the half height  $\Delta Z_{1/2}$ . These parameters are denoted below  $RSTD = \sigma / Z$  and  $RES = Z / \Delta Z_{1/2}$ . In case of a Gaussian transfer function  $RES = 0.425 / RSTD$ .

The resolution depends on several factors:

- width of the inlet slit and width of the electrometric collector,
- representing the distribution with averages over mobility fractions of definite width,
- smoothing due to the response time of the electrometer,
- thermal diffusion,
- turbulent diffusion.

The resulting composite transfer function is approximated by a Gaussian curve and the relative standard deviation of this curve is considered as the measure of the resolution. The geometric transfer function is determined by the widths of the inlet slit and the electrometric collector. According to the numerical model, the geometric transfer function of the SIGMA is very similar to the earlier discussed triangular transfer function of the BSMA (Tammet, 2006). The RSTD of this component of the transfer function proved to be 0.115. Presenting the spectra by fraction averages is necessary for increasing the signal to noise ratio. This procedure generates a rectangular smoothing function with the relative width of 1.33 and the corresponding component  $RSTD = 0.081$ . The time constant of the electrometric amplifier is about 0.24 s and the smoothed response creates the component RSTD of about 0.022. The effect of thermal diffusion in the SIGMA is low and noteworthy only in case of the smallest



ions. The estimate for the ions of the mobility of  $1.7 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  is a component  $\text{RSTD} = 0.026$ .

Exact estimating of the mobility resolution of the SIGMA was embarrassed by lack of tools for correct measurement of the turbulence inside the analyzer and lack of the sources of monomobile ions with a large air flow rate. Thus the following estimates are rough. The lower margin of the turbulent pulsations in the ion separation zone was estimated 1.2 mm, see Section A6.1. The lower margin of the corresponding turbulent dispersion of the mobility was estimated by a component  $\text{RSTD} = 0.04$  when considering the dimensions of the classification zone. The composite RSTD is a square root of the squares of the five components (0.115, 0.081, 0.022, 0.028, and 0.04), the result is the  $\text{RSTD} = 0.15$ . This value corresponds to  $\text{RES} = 2.8$ , which is considered as the upper margin when estimating the resolution of the SIGMA.

An estimate of the lower margin of the resolution can be found analyzing the measured spectra of small ions. A spectrum of small ions contains several components and it is always wider than the transfer function. The spectrum of laboratory generated small air ions of age about 1 second is approximated by a Gaussian line using values of the measured distribution function only near the spectrum peak. The shape of the spectrum varies from experiment to experiment depending of the uncontrolled trace gases in the air. The sharpest peak was found in a measurement of negative small ions, where the concentration of ions was about  $20000 \text{ cm}^{-3}$ . The empiric value  $\text{RSTD} = 0.24$  of this peak corresponds to  $\text{RES} = 1.8$ , which is considered as the lower margin when estimating the resolution of the SIGMA. The two margins approve estimating the mobility resolution parameter RES between 1.8 and 2.8. It follows that SIGMA is able to resolve as maximum 4–6 peaks of mobility distribution per decade and the 8-fractions-per-decade structure presents the details of distribution without substantial loss.

#### A6.8. Numerical improvement of mobility resolution

The mobility distribution of atmospheric intermediate ions is pretty smooth as a rule. The low mobility resolution of the SIGMA may appear unwelcome mainly in the mobility subrange of small air ions. An instrument transforms the physical high-resolution distribution into the broadened record of the spectrometer. The resolution can be improved when inverting this transformation. In a simplest linear mathematical model the instrument noise is neglected, the physical mobility distribution is described by a 35-dimensional discrete vector  $x$ , and the broadened measurement is described by the equation

$$y_j = \sum_i G_{ji} x_i, \quad (\text{A6.15})$$

where  $G$  is the transfer matrix including  $35 \times 35$  elements. A formal solution of the transfer equation is

$$x_i = \sum_j H_{ij} y_j, \quad (\text{A6.16})$$

where  $H = G^{-1}$  is the inverse matrix of the transfer matrix.

Two facts raise overwhelming difficulties in the application of the simplest model:

- the transfer matrix is not exactly know and minor errors in the matrix elements may cause huge errors in the inverted distribution  $x$ ,
- the measured record  $y$  contains random errors and minor errors in the elements of  $y$  can cause huge errors in the inverted distribution  $x$ .

A known technique to outperform the intolerable error amplification is called the regularization. In this case the inverter matrix  $H \neq G^{-1}$ , but it is compiled so that the product  $GH$  is close to the unit matrix, but the transformation A6.14 does not cause too large amplification or measurement errors.

In case of the SIGMA both vectors  $y$  and  $x$  are composed of fraction concentrations, whose sum should be invariant of the transformation procedure. Thus

$$\sum_j H_{ij} = 1. \quad (\text{A6.17})$$

The coefficient of amplification the measurement errors in distribution fractions is

$$K_i = \sqrt{\sum_j H_{ij}^2}. \quad (\text{A6.18})$$

The practical problem is to compile  $H$  in this way that the vector  $x$  can be considered a better representation of the mobility distribution when compared with  $y$ , and the elements of  $K$  will be close to unit in the range of low-concentration intermediate ions and may be slightly larger in the range of high-concentration cluster ions. An additional test requirement is that the application of inverter to the exactly measured narrow mobility distributions of high-concentration cluster ions should not generate negative elements in the vector  $x$ . A practical solution is always a compromise between different requirements and there is no universal solution best in all diverse measuring situations.

During the calibration experiments of the SIGMA No. 1, the distribution of artificially generated cluster ions was used as a test subject when compiling the inverter for the mobility distribution. The possible inverters were discriminated with pseudo-five-diagonal matrices compiled according to the rule described in Section 5.7.3. A pretty favorable choice of generating elements for a sample inverter is:

$$c\_inv\_n2 = -0.16, c\_inv\_n1 = -0.22, c\_inv\_p1 = -0.10, c\_inv\_p2 = 0, z\_limit = 1.$$

This choice is followed by an error amplification  $K_i = 2$  in range of  $Z > 1 \text{ cm}^{-2}\text{V}^{-1}\text{s}^{-1}$  and a quick decrease in error amplification when the mobility is decreasing. The near-diagonal elements of a row of the matrix  $H$  after normalizing according to (A6.16) are

$$\dots -0.31 \quad -0.42 \quad 1.92 \quad -0.19 \quad 0 \dots$$

and the near-diagonal elements of a correspondingly regularized transfer matrix  $H^{-1}$  are:

$$\dots 0.05 \quad 0.12 \quad 0.14 \quad 0.55 \quad 0.06 \quad 0.01 \quad 0 \dots$$

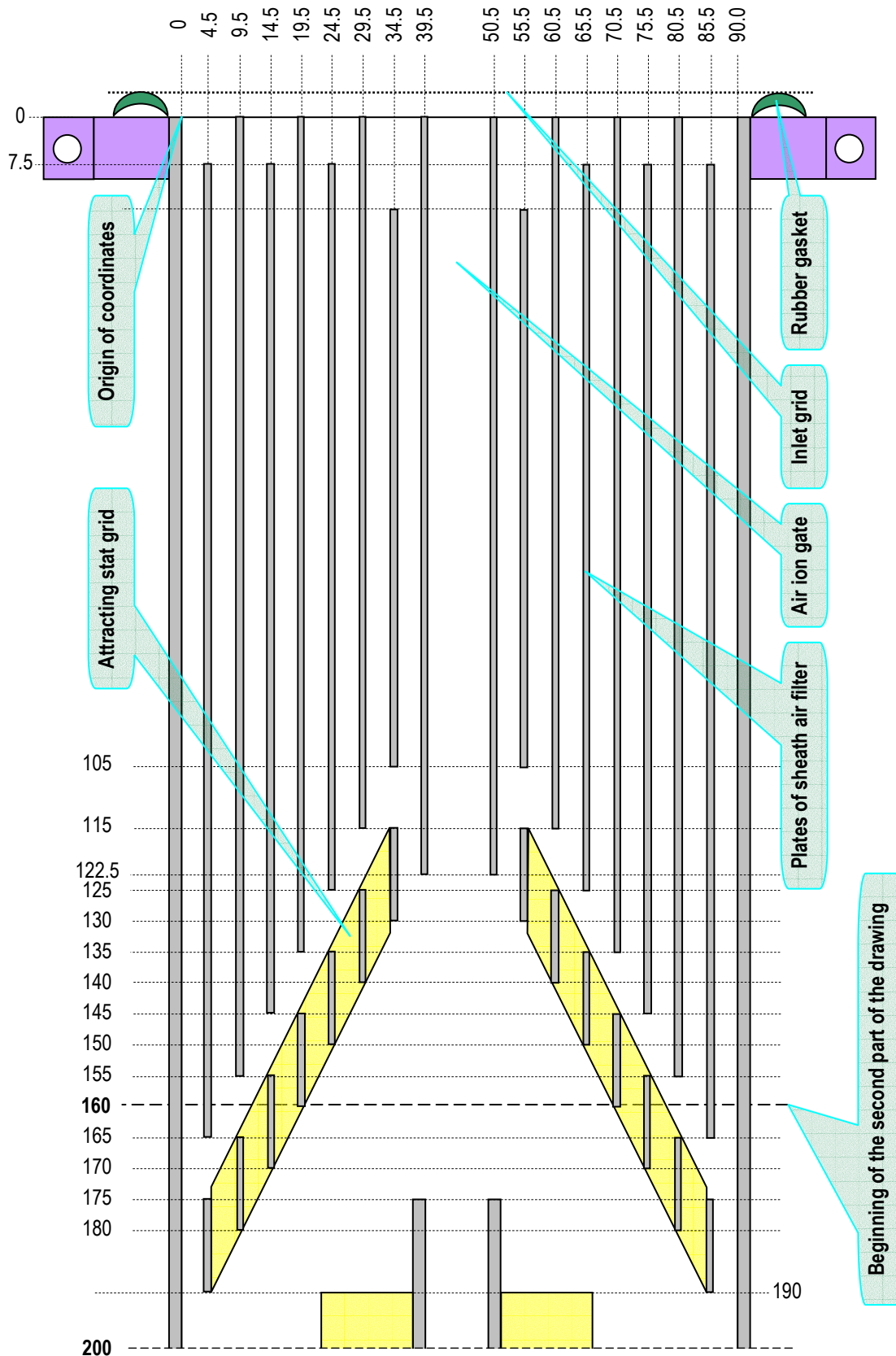
The matrix  $H$  and the corresponding regularized transfer matrix appear essentially asymmetric in this example. The explanation is the distortion of air flow in the analyzer: the air is slightly slowed down near the side insulators and in the wakes of sleeves, which are fastening the slats in the center of the attracting grids. The ions passing these regions are recorded with enhanced mobility, which is to be compensated by the stretched left wing of the rows of the inverter matrix.

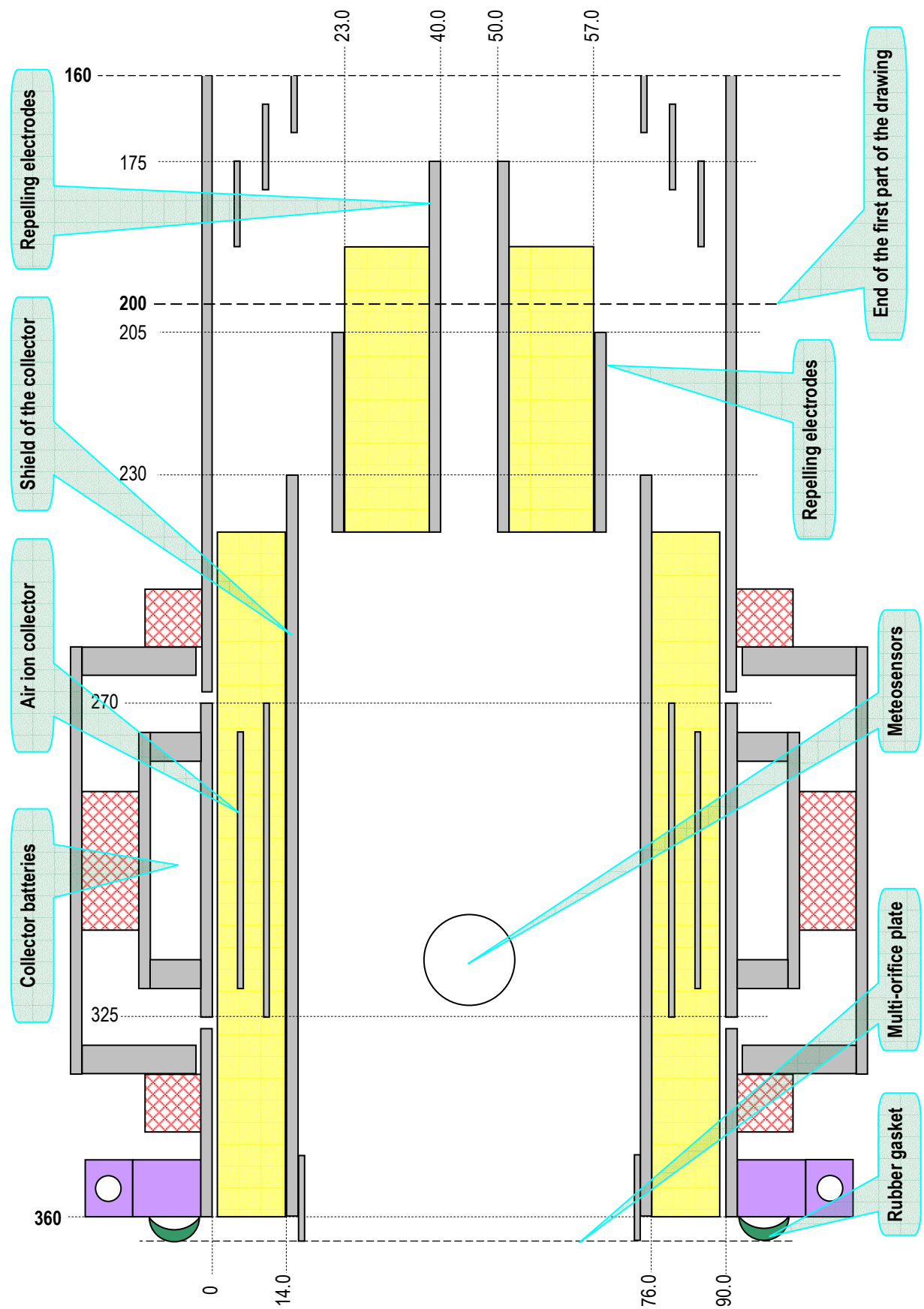
The sample matrix above is not fitted for SIGMA No. 2.

The standard software of the SIGMA enables to apply or not apply the inversion and to change the values of generating elements of the inverter when the improved calibration data will be available.

## Appendix 7. Aspiration condenser

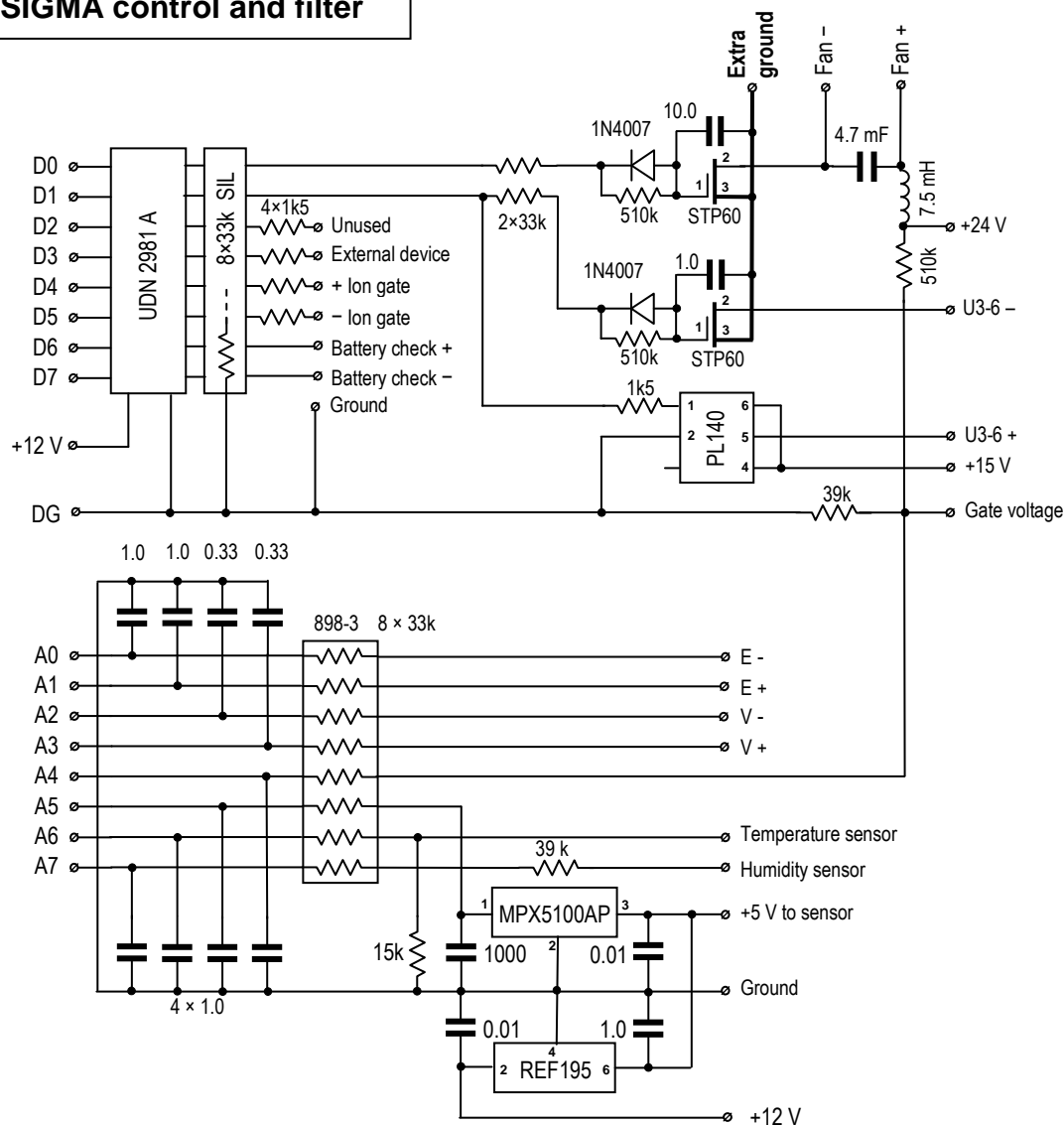
A drawing of the cross-section of the aspiration condenser is presented below in its original size on two pages, at first the outlet part and next, the inlet part. The internal height of the condenser is 240 mm and the height of the ion collector is 190 mm. All plates are made of aluminum sheets of the thickness of 1.0 and 2.0 mm.



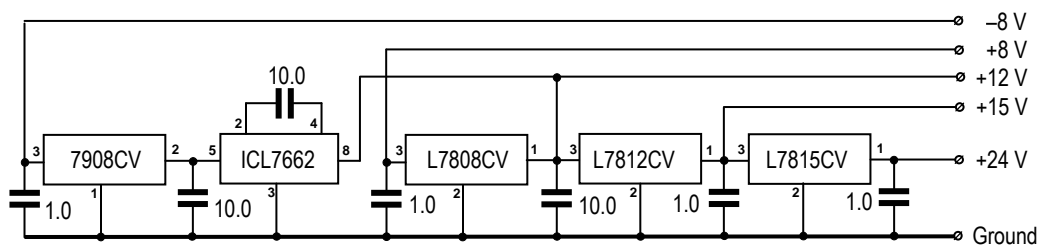


## Appendix 8. Electric diagrams and PC boards

## SIGMA control and filter

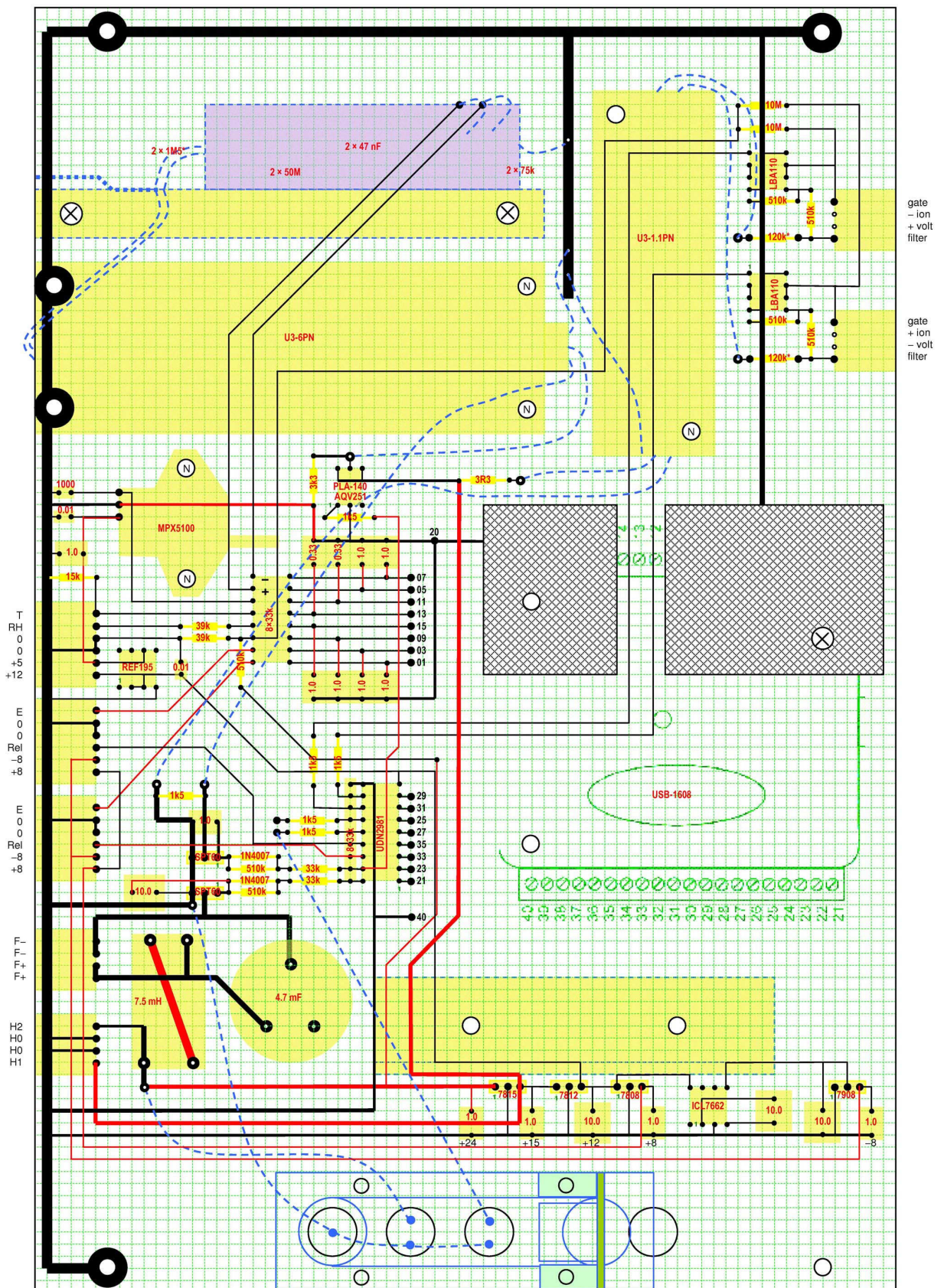


## SIGMA voltage regulator

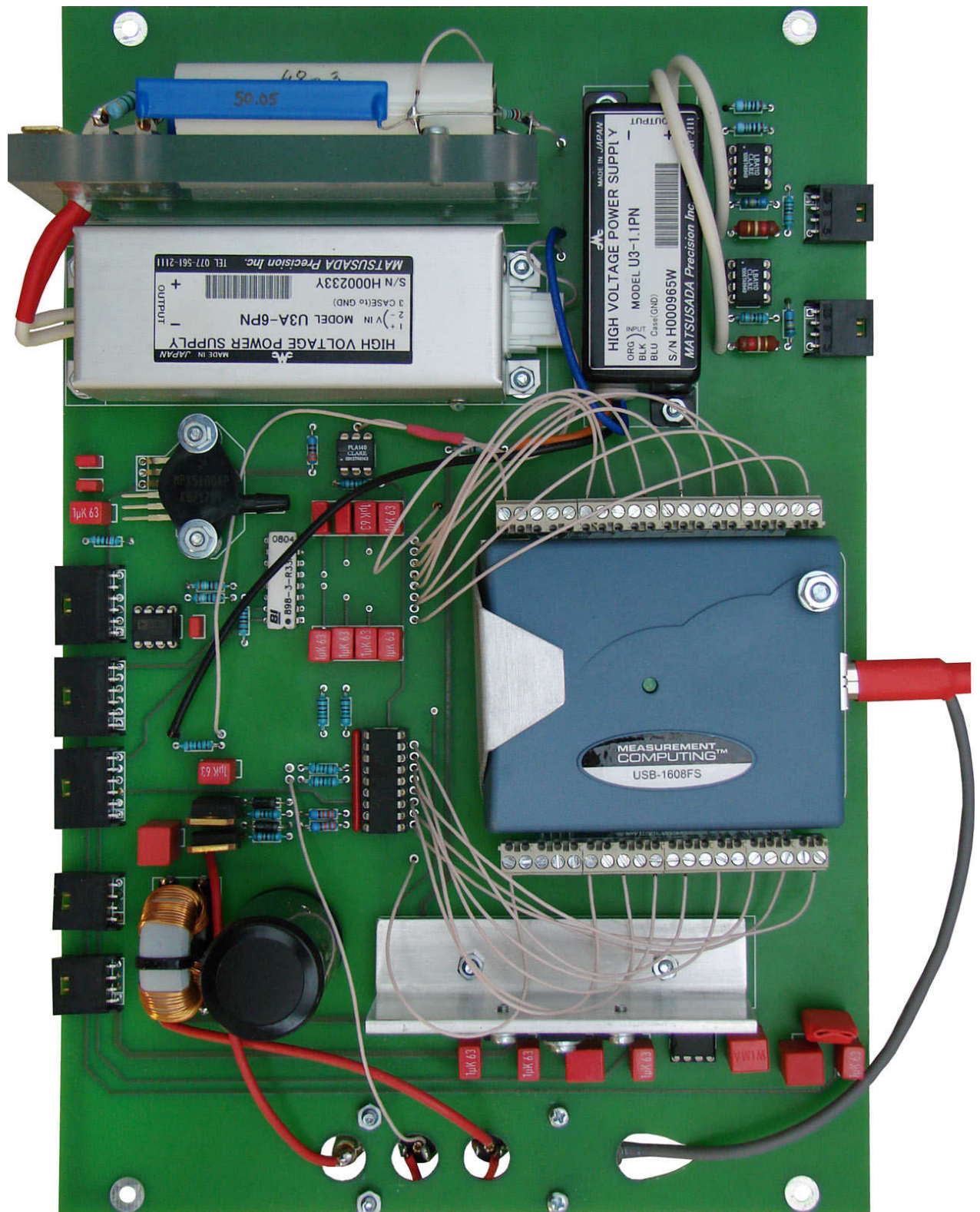




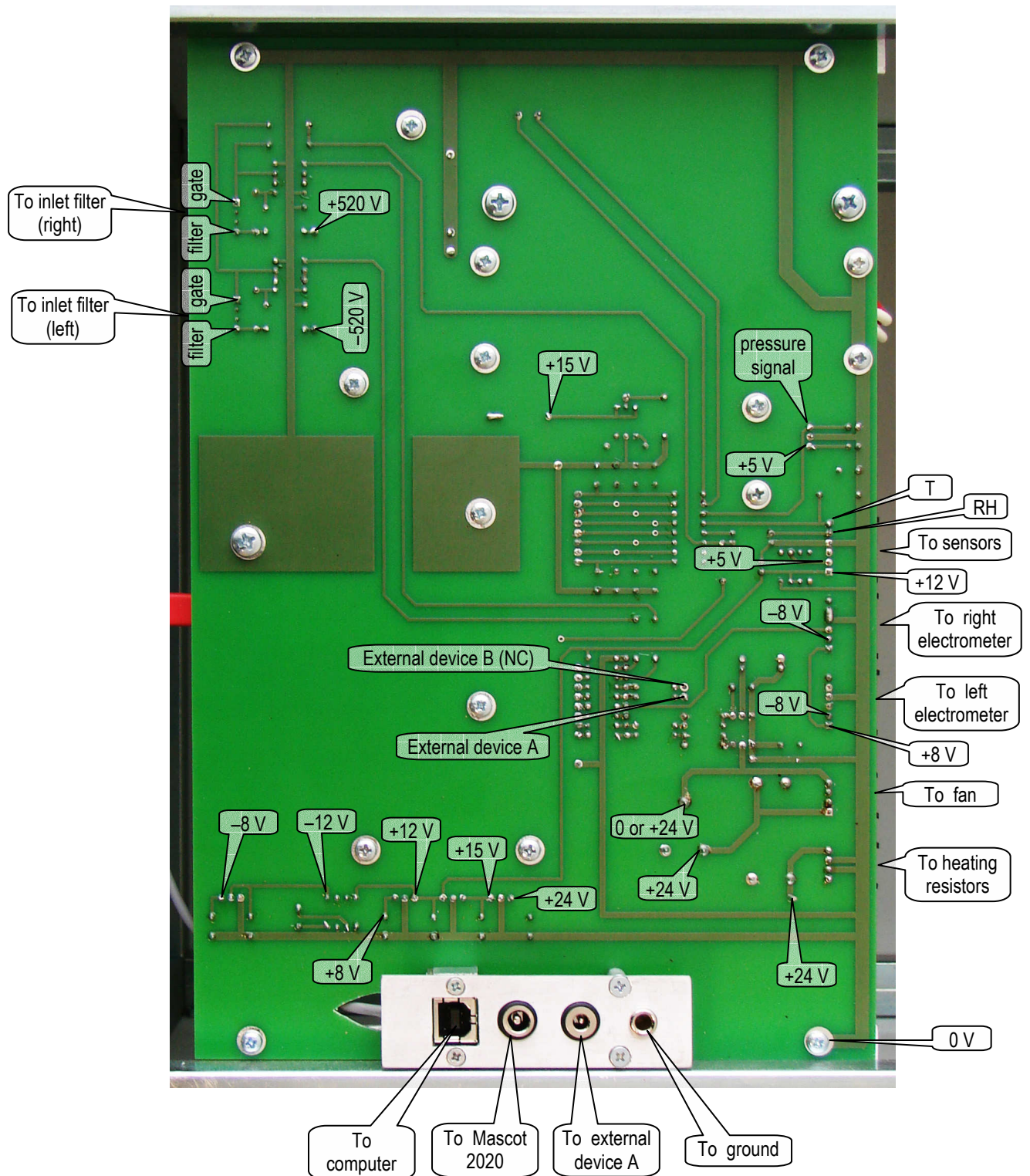
### SIGMA control PCB, view from inside the instrument



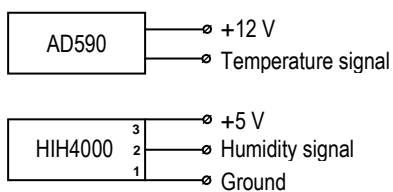
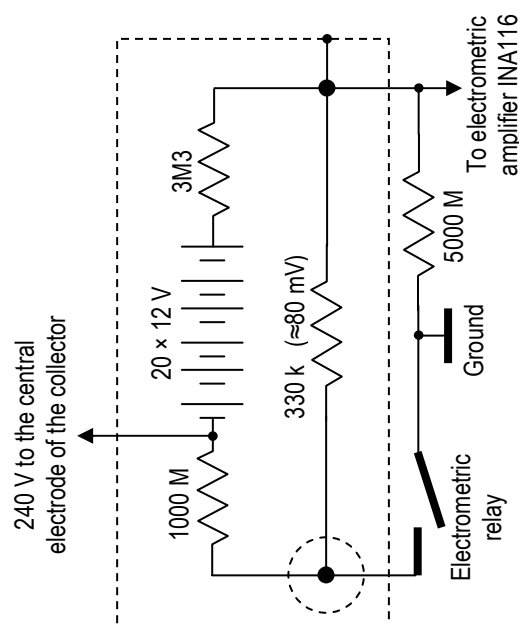
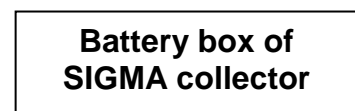
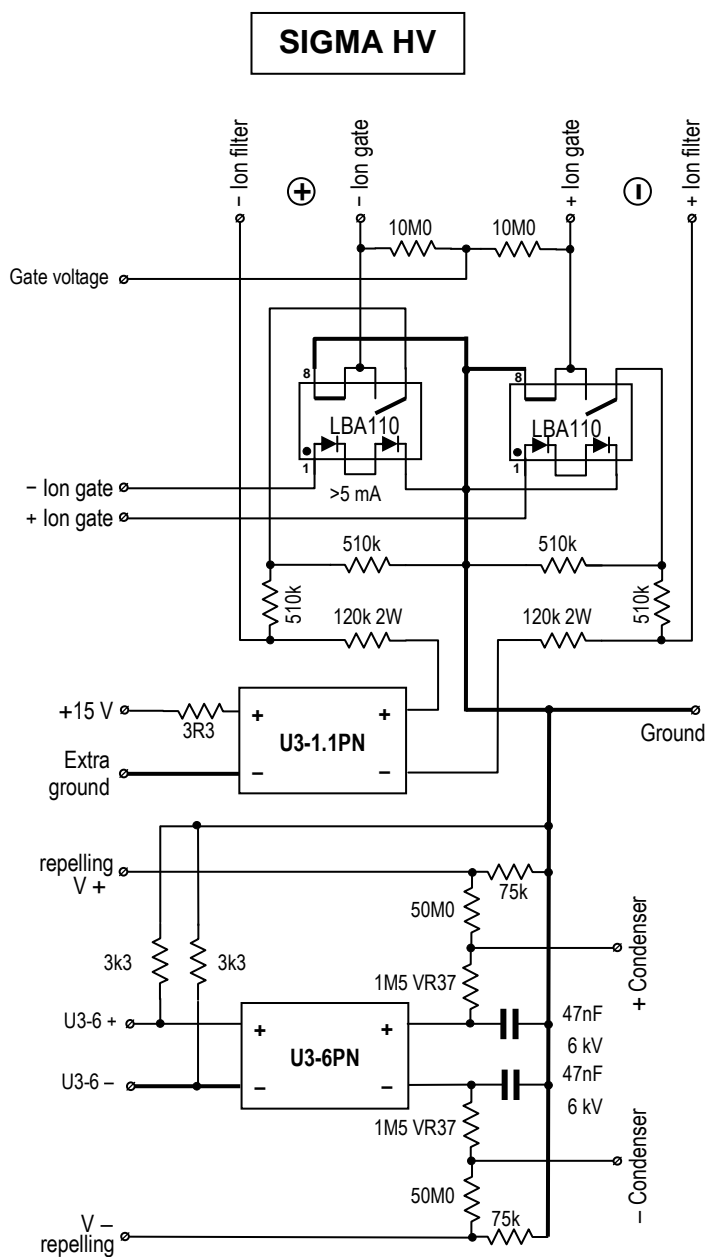


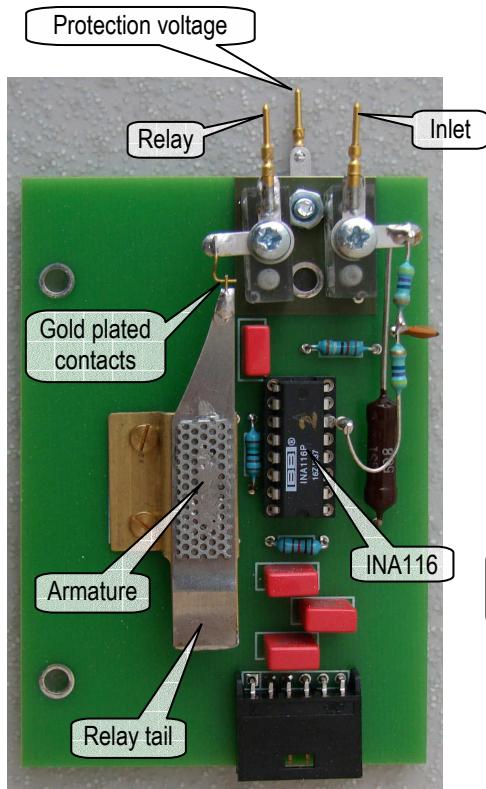
**SIGMA control PCB, view from inside the instrument**

### SIGMA control PCB and control voltages, view from outside

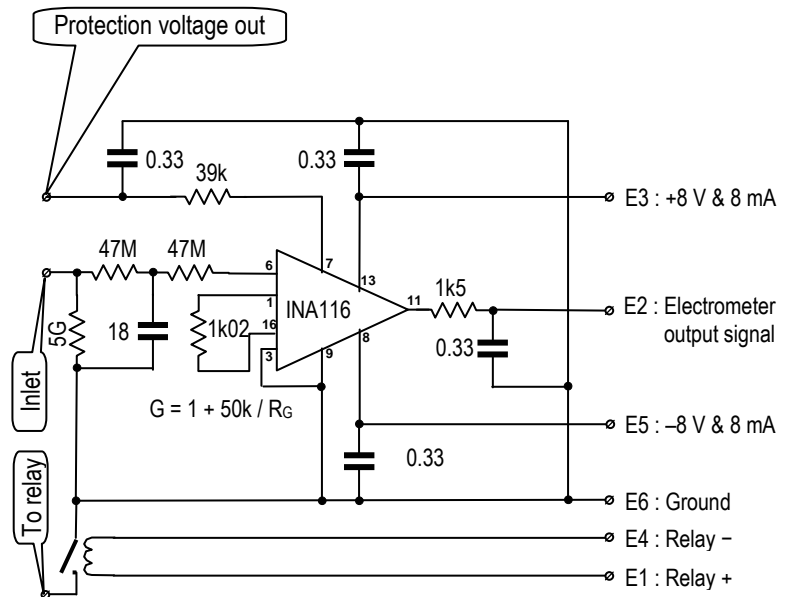








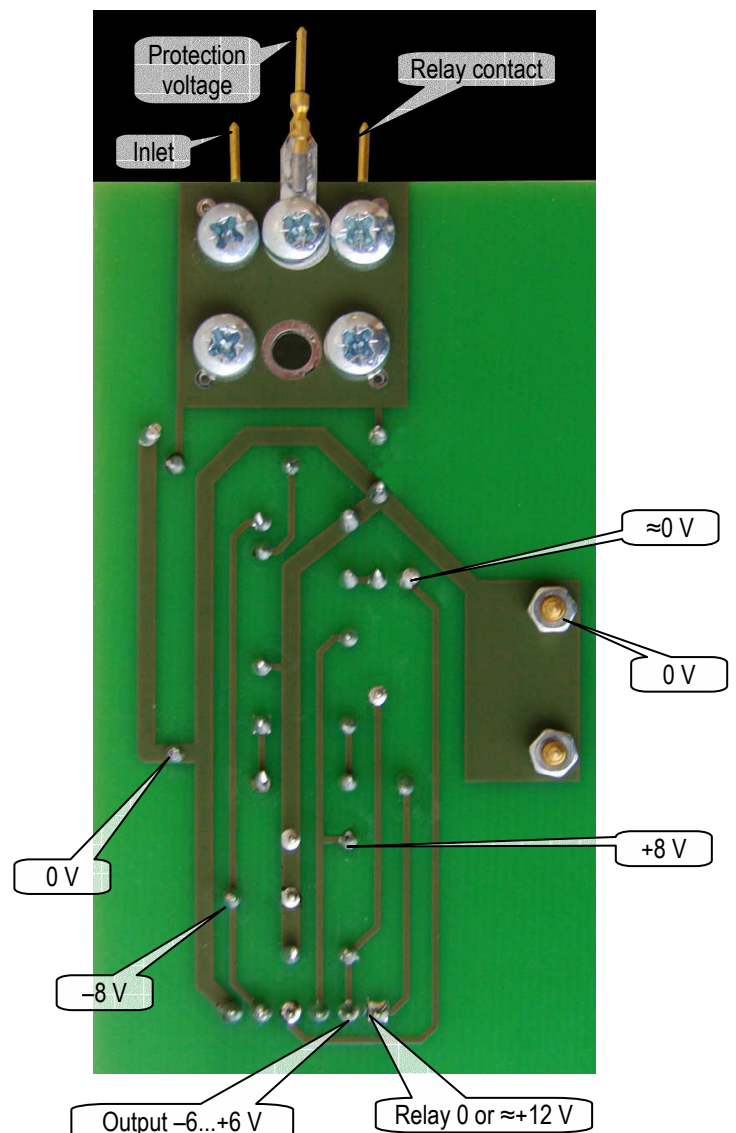
## SIGMA electrometer



Most vulnerable components of the electrometer are the instrumentation amplifier INA116, which can be damaged by electrostatic discharges, and a special electrometric relay, which has exposed contacts and can be damaged mechanically.

The pin no 6 should be bended up when installing a new amplifier INA116. Follow the original as an example.

A mechanically damaged relay can be usually repaired when bending the spring of the armature. The gap between the armature and the coil of the closed relay should be of 0.2...0.5 mm. The relay has no hysteresis and the release voltage equals the operate voltage that should be of 6...9 V. The operate voltage is controlled by the contact gap 0.6...1.0 mm, which can be adjusted when bending the brass tail of the relay.



## Appendix 9. Regime of the low flow rate

The air flow rate is controlled by the easily replaceable multi-orifice plate installed between the analyzer section and the fan section of the instrument. Replacing the plates is described in Section 4.2. The standard plate has orifices of diameter 4 mm. An additional plate with orifices of diameter 1.5 mm allows applying the regime of the low flow rate. Simultaneously must be replaced the calibration file. The new file consists of seven changed lines marked with italic font below. The full content of the calibration file can be copied from here:

```
SIGMA1A.CAL 20110206
Includes calibration coefficients for SIGMA No. 2 with orifice 1.5
Any line beginning with a space is a comment.
An assignment should be written without spaces.
A space after the assignment starts a comment until the end of the line.
volt_factor=170          HV ADC counts * mobility
conc_factor_pos=38       (dn/dlogZ) / electrometer ADC counts
conc_factor_neg=36       (dn/dlogZ) / electrometer ADC counts
standardadsorption=0.109 for Z = 1 cm2V-1cm-1, 0 C, 1013 mb
filtermobility=0.0064    cm2V-1cm-1, effective value for corrections
c_supplyvolt=0.002185    supplyvoltage / ADC_counts
c_filtervolt=-0.089      filter voltage / ADC_counts
c_batteryvolt=0.0093     electrometer battery voltage / ADC_counts
c_bias=0.003052          electrometer inlet mV at 1 ADC, 0.1526 / 50
c_pressarea=0.03368      pressure (mb) = c_pressarea * ADCcounts + c_pressureb
c_pressureb=120
c_temperaturea=0.0108    Celsius = c_temperaturea * ADCcounts + c_temperatureb
c_temperatureb=-291      factory value is -273
c_humiditya=0.007        humidity (%) = c_humiditya * ADCcounts + c_humidityb
c_humidityb=-48          required correction RH = RH (1.0546 - 0.0216 T:C)
delaytime=980            ms, incl. airflow + electrometer - HV signal
chargingtime=1500        ms
timeout=36000            ms
```

Low value of the voltage factor allows reaching the mobility of  $0.00562 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  that corresponds to the particle diameter about 18 nm. The table of decade-to-eight mobility fractions can be expanded with 6 new fractions.

However, the user should pay for the new opportunities with decrease in sensitivity of the instrument. The level of noise in measurements of fraction concentrations will increase up to 5 times when compared with the standard regime of the high flow rate.

The regime of the low flow rate provides a little better mobility resolution when compared with the standard regime. The reason is that the turbulent diffusion that limits the mobility resolution at the high flow rate is essentially suppressed when decreasing the air flow.

Unfortunately, the included standard software cannot make use of the advantages of the low flow rate because of rigidity of the standard data structure. An enhanced data structure and necessary software could be developed according to an extra agreement.

## Appendix 10. List of file types

**Data files** (YYMMDD denotes year, month and day):

S1AYYMMDD.xl – diurnal file of the standard data, see Sections 5.2 and 5.5.

S1AYYMM00.xl – monthly file of the standard data, see Sections 5.2 and 5.5.

\_S1AYYMMDD.xl – file of the raw scan data, see Section 5.3.

~S1AYYMMDD.xl – file of the basic data (if several days then DD = 00), see Section 5.4.

dYYMMDD.xl – file of the diagram table, see Section 5.6.

### Program files:

SIGMA1A.exe – control program, supervises the instrument and saves the standard data, the raw scan data and the diagram tables. See Chapter 3 and Appendix 4

SIGMA1C.exe – converts the raw scan data to the basic data and the standard data, enables flexible control of the conversion parameters. See Section 6.2.

SIGMA1P.exe – allows modifying the structure of the standard data, see Section 6.3.

SIGMA1D.m – transforms the diagram table to the contour plots, requires MATLAB, see Section 4.5.

### Configuration files:

SIGMA1A.cal – SIGMA calibration data, see Appendix 4.

SIGMA1A.ini – control parameters for SIGMA1A, see Appendix 4.

SIGMA1A\_inverter.txt – control parameters for SIGMA1A, see Appendix 4 and A6.8.

SIGMA1A\_simulator.txt – parameters for hardwareless testing the program, see Appendix A4.4, necessary only for the program developer.

SIGMA1A\_exmeteo.txt – forced assignment of meteorological quantities, see Section 3.1.

SIGMA1C.ini – control parameters for SIGMA1C.exe, see Section 6.2.

diameters.txt – control data for SIGMA1P.exe required in special situations, see Section 6.3.

## Appendix 11. Specifications of SIGMA No. 2

Size: length 505 mm, width 280 mm, height 350 mm.

Mass: 18 kg.

Power: AC 47–63 Hz, 90–260 V, 70 W,  
or DC 23–25 V (e.g. two car batteries), 60 W.

Suitable AC power units: Mascot 2020 or ZVC65SG24.

Air temperature: the instrument case 0...40°C, the air to be measured –40...+40°C.

Relative humidity: around the instrument 10...90%, the air to be measured 10...98%.

Collector batteries: 40 batteries GP27A (expected life time at least one year)

Air flow rate with standard 4 mm multi-orifice plate: 32 dm<sup>3</sup> s<sup>-1</sup>.

Passage time of air from the inlet grid to the ion collector: 0.15 s.

Heat emission of the electronics inside of the analyzer section: 20 W.

Increase in the air temperature during measurement due to the heat emission: < 0.5 K.

Electrometric amplifiers: INA116.

Mobility range at the standard flow rate: 0.032–3.2 cm<sup>2</sup> V<sup>-1</sup> s<sup>-1</sup> or 0.42–4.2 cm<sup>2</sup> V<sup>-1</sup> s<sup>-1</sup>.

Resolution: about 10 resolved peaks in the two decades of mobility.

Standard presentation of distributions:

16 logarithmically distributed mobility fractions in two decades of mobility and

10 logarithmically distributed size fractions in the diameter range of 0.42–7.5 nm.

Standard range of fraction concentrations: 0–50000 cm<sup>-3</sup>.

Standard deviation of fraction concentration noise: 1 cm<sup>-3</sup> (conditions: 5-minute average, clean insulators, low radon concentration, and low dust concentration).

## REFERENCES

- Hörrak, U., Salm, J., and Tammet, H. (2000). Statistical characterization of air ion mobility spectra at Tahkuse Observatory: Classification of air ions. *J. Geophys. Res. Atmospheres* 105:9291–9302.
- Iida, K., Stolzenburg, M., McMurry, P., Dunn, M. J., Smith, J. N., Eisele, F., and Keady, P. (2006). Contribution of ion-induced nucleation to new particle formation: Methodology and its application to atmospheric observations in Boulder, Colorado, *J. Geophys. Res.* 111:D23201.
- Incropera, F. P., and Dewitt, D. P. (2002). *Fundamentals of Heat and Mass Transfer*, Fifth Edition, John Wiley & Sons, New York.
- Israël, H. (1970). *Atmospheric electricity*, vol. I. Israel Program for Sci. Transl. & NSF, Jerusalem.
- Junninen, H., Hulkkonen, M., Riipinen, I., Nieminen, T., Hirsikko, A., Suni, T., Boy, M., Lee, S.-H., Vana, M., Tammet, H., Kulmala, M. (2008). Observations on nocturnal growth of atmospheric clusters, *Tellus 60B*:365–371.
- Kays, W., Crawford, M., and Weigand, B. (2005). *Heat and Mass Transfer*, Fourth Edition, McGraw-Hill, Boston.
- Kulmala, M. and Tammet, H. (2007). Finnish–Estonian air ion and aerosol workshops, *Boreal Environ. Res.* 12:237–245
- Labowsky, M. and Fernández de la Mora, J. (2006). Novel ion mobility analyzers and filters. *J. Aerosol Sci.* 37:340–362.
- Loscertales, I. G. (1998). Drift Differential Mobility Analyzer. *J. Aerosol Sci.* 29:1117–1139.
- Mirme, A., Tamm, E., Mordas, G., Vana, M., Uin, J., Mirme, S., Bernotas, T., Laakso, L., Hirsikko, A., and Kulmala, M. (2007). A wide-range multi-channel Air Ion Spectrometer, *Boreal Environ. Res.* 12:247–264.
- Parts, T.-E. and Luts, A. (2004). Observed and simulated effects of certain pollutants on small air ion spectra: I. Positive ions. *Atmos. Environ.* 38:1283–1289.
- Rosell-Llompart, J., Loscertales, I. G., Bingham, D., and Fernández de la Mora, J. (1996). Sizing nanoparticles and ions with a short differential mobility analyzer, *J. Aerosol Sci.* 27:695–719.
- Tammet, H. (1970). *The aspiration method for the determination of atmospheric ion-spectra*. Israel Program for Sci. Transl. & NSF, Jerusalem. Available online at <http://ael.physic.ut.ee/tammet/am/>.
- Tammet, H. F., Jakobson, A. F., and Salm, J. J. (1973). Multi-channel automatic air ion spectrometer (in Russian). *Acta Comm. Univ. Tartu* 320:48–75.
- Tammet, H. (1975). Dependence of the spectrum of small ion mobilities on the trace admixtures in air (in Russian). *Acta Comm. Univ. Tartu* 348:3–15.
- Tammet, H.F., Hilpus, A.O., Salm, J.J., and Üts, E.J. (1977). An air ion spectrometer for the detection of some admixtures in air (in Russian). *Acta Comm. Univ. Tartu* 409:84–88.
- Tammet, H. (1995). Size and mobility of nanometer particles, clusters and ions. *J. Aerosol Sci.* 26:459–475.
- Tammet, H. (2003). Method of inclined velocities in the air ion mobility analysis. In *Proceedings of the 12th International Conference on Atmospheric Electricity, Vol. 1*, Versailles, 399–402.
- Tammet, H. (2006). Continuous scanning of the mobility and size distribution of charged clusters and nanometer particles in atmospheric air and the Balanced Scanning Mobility

- Analyzer BSMA. *Atmos. Res.* 82:523-535.  
<http://dx.doi.org/doi:10.1016/j.atmosres.2006.02.009>.
- Tammet, H. (2009). A joint dataset of fair-weather atmospheric electricity. *Atmos. Res.* 91:194-200, <http://dx.doi.org/doi:10.1016/j.atmosres.2008.01.012>.
- Tammet, H., Hörrak, U., Kulmala, M. (2009). Negatively charged nanoparticles produced by splashing of water. *Atmos. Chem. Phys.* 9:357-367,  
<http://www.atmos-chem-phys.net/9/357/2009/>.
- Tammet, H. (2011) Symmetric inclined grid mobility analyzer for the measurement of charged clusters and fine nanoparticles in atmospheric air. *Aerosol Sci. Technol.*, 45:468-479. <http://dx.doi.org/10.1080/02786826.2010.546818>.
- Von der Weiden, S.-L., Drewnick, F., and Borrmann, S. (2009). Particle Loss Calculator – a new software tool for the assessment of the performance of aerosol inlet systems. *Atmos. Meas. Techniques.* 2:479–494.