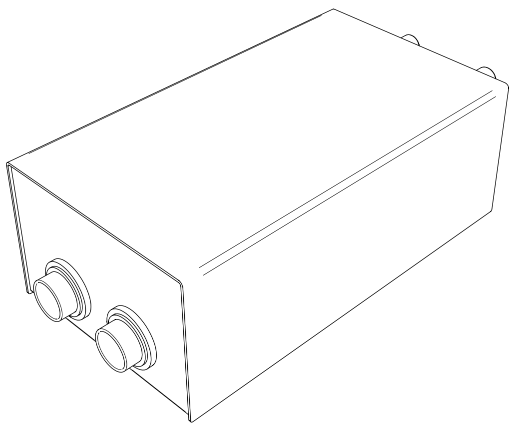
CIC

Model 201

Cluster Ion Counter

Operation Manual



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Airel

Contents

CIC Manual

Operation Manual for Airel Cluster Ion Counter (CIC) instruments.

Date: 2019-12-13

1 Overview

The Cluster Ion Counter (CIC) is an instrument for measuring the total concentration of both positive and negative cluster ions. The instrument is designed to be simple and robust to provide reliable cluster ion measurements for both long term field monitoring as well as laboratory experiments.

1.1 Specifications

Measurement range	positive and negative cluster ions z > ±0.5 cm2/V/s
Sample flow rate	10 – 60 l/min per polarity
Noise level	20 #/cm^3 total concentration at 40 l/min sample flow
Time resolution	1 Hz or better, depending on signal level
Dimensions	20 x 20 x 40 cm
Power consumption	DC 15 V, 0.5 A
Interface	USB

1.2 Principles

The CIC uses two independent first-order cylindrical differential mobility analyzers [1] to measure the ions of positive and negative polarities in parallel

The measured ions entering the analyzers are repelled by a central electrode, which is held at a steady voltage. Charged particles deposit on the outer wall of the analyzer which is divided into three separate collecting electrodes. The electric current produced by the deposited ions is measured using high precision integrating electrometers.

The electrometer signals are measured at a rate of 30 samples per second. The zero level currents and noise level estimates of the electrometers are periodically measured by switching on a high voltage electrical inlet filter, which prevents ions from entering the analyzer.

The outlets of the analyzers are internally connected to flow meters followed by software controlled blowers. This allows sample flow rates of both analyzers separately to be freely specified in the range from 10 l/min to 60 l/min depending on the requiremens of the experiment and available signal level. The central electrode voltages are automatically adjusted to keep the detected ion mobility range constant.

The instrument includes air pressure sensors to take into account the relation between particle mobility and air pressure. This allows the instrument to operate onboard aircraft and in chamber experiments.

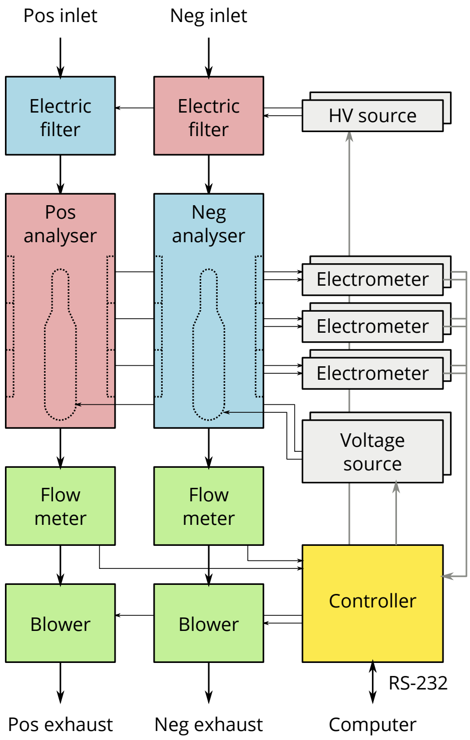

Figure 1.1: The principal schematic of the CIC.

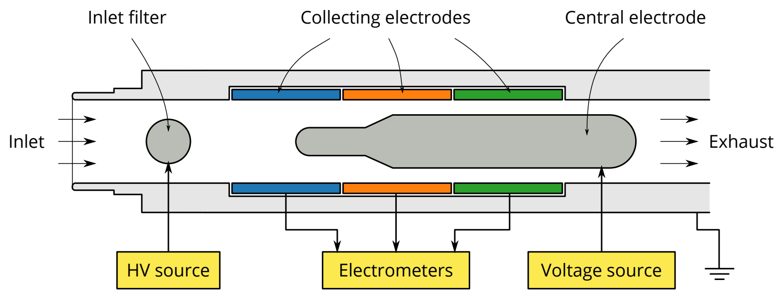

Figure 1.2: The schematic of one of the analysers in the CIC.

In contrast to second-order differential mobility analyzers, for example as used in the Neutral cluster and Air Ion Spectrometer (NAIS), the CIC does not use a separate sheath air flow. This significantly simplifies the construction of the instrument and allows for low inlet losses and high time resolution. This also results in a very low size resolution and makes the instrument primarily useful as an integral counter.

However, the three separate electrodes allow the instrument to acquire additional information about the ion mobility distribution.

The limiting mobilities of the collecting sections are chosen so that the signals from the first and second electrodes can be used to estimate roughly the average cluster ion mobility and air conductivity. The third electrode is used to find the signal of larger ions beyond the cluster ion band and subtract it from the total concentration.

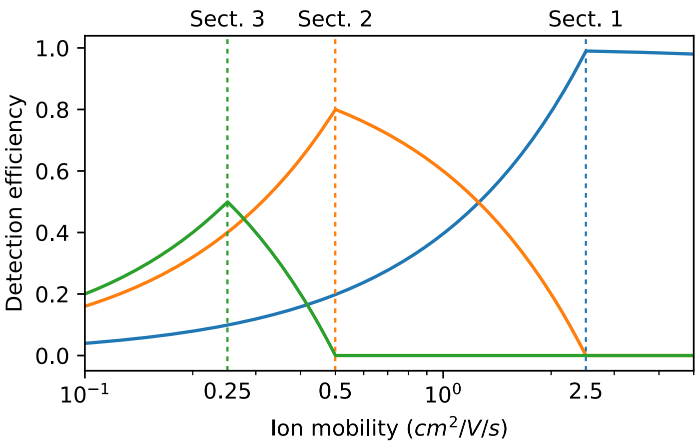

Figure 1.3: The theoretical transfer functions of the three collecting sections without considering ion diffusion losses. The colors corresponding to sections match Figure 1.2.

2 System Setup

2.1 Package contents

- Cluster Ion Counter
- Power supply
- USB cable

2.2 Instrument placement

The instrument should be placed on a firm, non-vibrating, level surface. The instrument can tolerate vibration when measuring (e.g. onboard a moving vehicle), however any vibration will increase the noise level of the measurements.

2.3 Inlet considerations

The inlet tube can significantly affect the quality of the measurement results of the CIC by increasing particle losses.

- The inlet tube should be as short as possible. When the inlet tube is longer than 1 m then particle loss estimates should be considered before drawing conclusions from the data.
- The diameter of the inlet tube should be about 30 mm.
- The tube should be smooth inside. Corrugated tubes should be avoided.
- The inlet tube must be electrically conductive. Use a metal pipe or a conductive rubber hose.
- For outdoor measurements, a metal mesh with 1 – 2 mm cell size should be placed on the end of the inlet tube to keep insects out.

The mobility analyzer is sensitive to insects and fibers that may deposit on the electrodes and cause electric noise and parasitic currents.

Make sure that rain does not get into the instrument. Choose the angle of the inlet accordingly. Add a bent tube pointing downwards at the end of a horizontal inlet.

2.4 Earthing

Proper electrical earthing of the CIC is critical for reliable cluster ion measurements. Without earthing, the body of the instrument may be at an electric potential, which will significantly increase particle losses.

The power supply of the CIC does not provide a grounding or earthing connection. An additional earthing connector is provided for that on the back side of the instrument.

2.5 Temperature and water condensation

When the temperature of the instrument is lower than the sample air then there is a danger of water condensation inside the instrument. The risk is highest in a hot and humid climate when the CIC is placed in an air-conditioned room and sample air is pulled from the outside. Such a situation must be avoided. Water condensation inside the CIC can and will severely damage the instrument.

If it is not possible to prevent the negative temperature difference between the instrument room and outside then it is recommended to place thermal isolation around the CIC and avoid a direct flow of cool air onto the instrument (e.g. when the instrument is placed below an air-conditioner).

2.6 Data connection

The CIC uses a USB port for data communication. The instrument will appear as a virtual serial port. Typically Linux and newer Windows computers should recognize and find working drivers for the device automatically.

If the device is not recognized, please refer to the FTDI Chip website: https://www.ftdichip.com/Drivers/VCP.htm.

2.7 Software installation

There are two programs in the measurement software package provided with the CIC.

Spectops for running the measurements and viewing live data.\

Retrospect for viewing and reprocessing the results later.

In addition, each instrument has individual instrument configuration files that are necessary for running measurements. These contain calibration info and other instrument-specific data.

To install the program on a computer, please follow the steps:

1. Create a folder on your computer where you want the software to reside.

   Usually, the measurement results will be stored into a sub-folder of that folder. So make sure that there is sufficient free disk space.

2. Download the instrument configuration package and the compatible measurement software package for your instrument.

   Please send an email to Airel Support support@airel.ee if you don't have access to the measurement software pages.

3. Extract both files into the same folder.

4. Run the Spectops program that was just extracted.

5. Open the measurement setup file in Spectops (Menu: File ⟶ Open...).

6. Choose the serial port corresponding to the CIC.

7. Specify the measurement cycle or use the default.

   For example: "ions 90, offset 30"

8. Run the measurements.

9. Optional: Use "Create shortcut..." from File menu to create a shortcut that will automatically start measurements with the current measurement setup file.

   Place the shortcut into the Windows Startup folder to start the measurement automatically when the computer starts.

Note: For browsing the measurement results using Retrospect the instrument configution files are not needed.

2.8 First run

The instrument needs a few minutes and at least three measurement cycles to "warm-up". Before that, the software may show diagnostic warnings and the data may not be correct.

The blowers will start and stabilize immediately at startup, so first check that the blowers are working and airflows are not obstructed.

If you are unsure whether the instrument is operating correctly, collect at least 1 hour of data and send it to Airel Support (support@airel.ee). Make sure that you send all the data files (records and log). Please submit only block average files initially.

Further checks and diagnostics can be carried out via remote access to the measurement computer (for example, using Teamviewer or AnyDesk).

3 Measurement Process

For normal measurements, the user must specify the measurement cycle periods and flow rate values for both polarities. Otherwise, the measurement process of the CIC is fully automatic.

The measurement software controls the instrument according to the measurement cycle, receives data from the instrument, processes it and produces measurement records. The data is continuously stored in data files. The software continuously performs diagnostic checks and notifies the user if something might require attention.

3.1 Connection

The measurement software will always try to establish a connection with the instrument and start measuring unless the program is stopped manually. If the connection is lost for any reason the software will keep trying to reconnect until it succeeds.

It is safe to switch the instrument on and off or disconnect it from the computer/network while the measurement software is running. When the instrument is switched on or reconnected, then the software will reestablish communication and the measurements will be correctly resumed.

3.2 Measurement cycle

The operation of the CIC is determined by the user-specified measurement cycle. The measurement cycle lists the order and durations of the operating modes that the instrument should run in.

The CIC has only two operating modes: ions and offset.

- **Ions mode** is the normal measurement mode of the instrument when cluster ions are detected.
- **Offset mode** is used to measure the zero level currents and noise level estimates of the electrometers. A high voltage electrical inlet filter is switched on during the offset mode, which prevents ions from entering the analyzer. (See also Electric Current Measurement).

A typical measurement cycle consists of a 30 second offset measurement and from 30 to 210 second ions measurement.

When the instrument switches operating modes it takes up to 10 seconds for the changes to settle before proper measurement results are produced. The settling time is included in the durations given in the measurement cycle. Therefore it is recommended that the instrument remains in each operating mode for at least 30 seconds. Otherwise, a large amount of measurement time is lost just waiting for settling.

3.3 Records

The measured data is represented as data records. Each record corresponds to a period of time and contains aggregate values of all the data fields that have been measured from the instrument or used to control the instrument during that time period.

The data records of the CIC are made up of:

- Begin time
- End time
- Operating mode
- Processed average electrometer currents
- Electrometer signal fields
- Data fields
- Diagnostic flags

Electrometer signals are presented as four data vectors:

- Average electrometer voltages

  Raw output voltages of the electrometer. See Electric current measurement section for more details.

- Raw average electrometer currents

  Raw electric currents calculated directly from the raw output voltages without any processing. Offset signal is not subtracted.

- Processed average electrometer currents

  The final, fully processed electrometer currents.

- Electrometer current variance estimates

Other signals and variables have mostly self-explanatory names. There are typically several data fields related to each parameter of the instrument. Field types include:

- **Sensor voltages**: The actual voltages output from sensors as measured by the data acquisition system.
- **Physical values**: The physical value of the parameter what the sensor measures.
- **Control signals**: The output signals used to control some component of the instrument (e.g., blower power)
- **Target values**: Target or setpoint values of parameters that are automatically controlled by the instrument. These are always paired with a input field and a control output field.

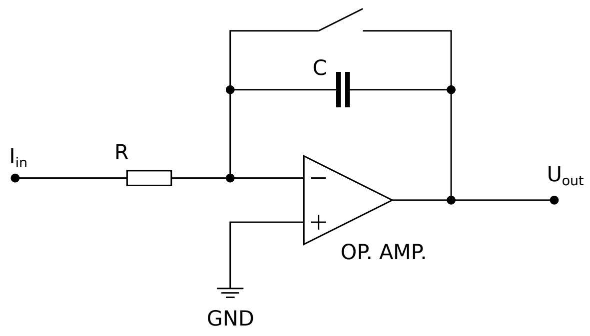

Figure 3.1: Integrating amplifier circuit

3.4 Data acquisition and processing

The instrument continuously measures all electrometer signals and other input channels about 30 times per second and produces **raw records**. The raw records are processed and turned into **averaged records** by the measurement program.

The software produces **block average** records and fixed-length averaged records. Block averages correspond to the entries in the measurement cycle. Fixed length averages can be chosen by the user. Typically 1 second and 10 second averages are used in addition to the block averages.

Averaged records are produced continuously. At first the records are are considered preliminary. Records are reprocessed and marked as final after the next offset measurement has completed and the offset signal estimates have been updated. Preliminary results are not stored to output files, they are only visible in the measurement program. The finalized data is saved. Preliminary records will be stored immediately when the program is stopped to avoid data loss.

3.5 Electric current measurement

The electric currents produced by the deposited particles on the collecting electrodes are very small, often in the range of 1 − 3 fA.

The CIC uses integrating electrometric amplifiers where the fluxes of electric charge are collected on high quality electrical capacitors (Figure 3.1). The output voltages of the amplifiers are proportional to the collected electric charge and the change of the voltage is proportional to incoming charge i.e to the aerosol current (Figure 3.2).

The integrating measurement principle allows for the best possible signal to noise ratio for electric current measurements. Also, the signal is collected continuously almost without any breaks – no signal is missed regardless of measurement frequency.

The voltage from the amplifier outputs is read around 30 times per second. This raw signal is passed through several signal processing steps before the average signal for a time period is calculated (Figure 3.3).

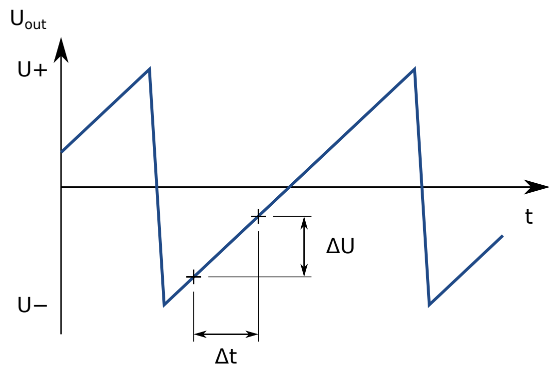

Figure 3.2: Integrating amplifier principle

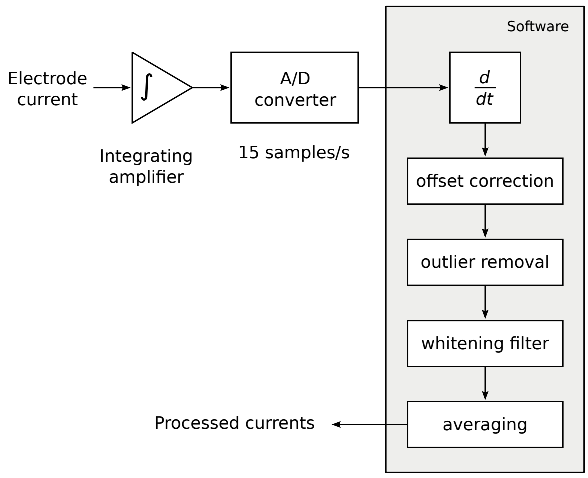

Figure 3.3: Signal-processing flow diagram of the NAIS

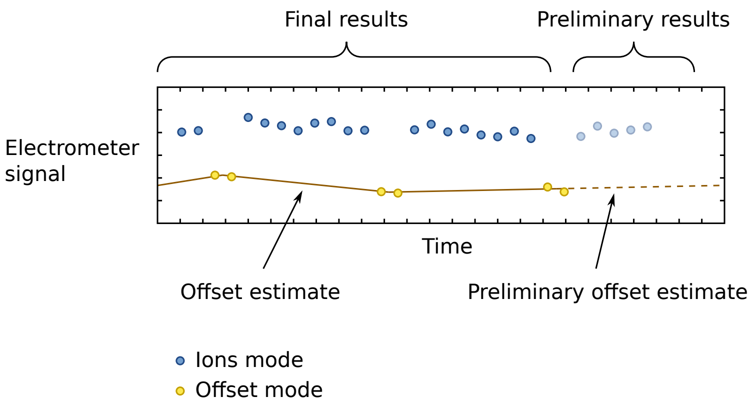

Figure 3.4: Offset estimates are subtracted from the raw measurement signal. The measurement results are considered preliminary until the subsequent offset measurement has been completed. After that, the a final offset current estimate is calculated, the records are updated and stored

3.5.1 Offset correction

First, the electric current values are corrected for the offset currents measured periodically during the offset operating mode. Offset measurements also provide noise level estimates for the electrometers.

The offset signal is estimated using linear regression on the current measurements from one preceding and one succeeding offset measurement cycle (Figure 3.4). This means that the final measurement result will be available with a delay – after the immediately following offset measurement cycle has been completed. The noise estimates are calculated from the difference between the regression estimate and actual offset signals.

3.5.2 Electrometer resets

The collected charge on the capacitors needs to be cleared when the capacitor voltage reaches a limit. In the CIC, the electrometers will automatically reset when the output signal passes −3.5 V or +3.5 V. After a reset, the electrometer needs about 10 seconds of settling time before the measurement results can be considered reliable. The software will ignore the signal for that duration.

3.6 Concentrations

Particle concentrations from the three collecting electrodes in both polarities are given as “Neg concentration #” and “Pos concentration #” fields. The ion mobilities corresponding to the peak of the transfer functions (Figure 1.3) are given as “Neg mobility #” and “Pos mobility #” variables.

The software additionally calculates rough estimates for air conductivity and average cluster ion mobility.

3.7 Air flows and ion mobilities

The limiting mobilities of the Cluster Ion Counter are determined by the geometry, the airflow rate and the central electrode voltage of the analyzer. The geometry of the analyzer has been chosen so that at 10 l/min flow rate and 6.5 V voltage the limiting mobilities of the three collecting sections are 2.5, 0.5 and 0.25 $cm^2/V/s$. The limiting mobilities will stay constant when the air flow rate and voltage are changed by the same factor, e.g. 30 l/min and 19.5 V.

Both the air flow rates and central electrode voltages are software controllable and independent for the two polarities. During normal operation, the user should select the desired air flow rates and the instrument will automatically choose the correct voltage. The recommended flow rate range is from 10 to 40 l/min for each polarity.

The flow rates can be adjusted from the "Adjust parameters" window that opens by clicking on the "Parameters" button on the toolbar.

Any change of the central electrode voltage will induce a pulse of electric current on the collecting electrodes. The pulse will disturb the measurements for a few seconds. When the voltage change is large, the electrometers may saturate, reset and require an additional settling time of up to 10 seconds.

The central electrode voltage sources may slightly drift over time. When the deviation has become significant, the instrument will automatically correct the voltage values. These corrections may happen more often immediately after the instrument has been powered on and when there are rapid temperature changes. During normal operation the corrections should be rare.

Particle electrical mobility z is dependent on air pressure P [2].

$$z \propto \frac{\sqrt{T}}{P}$$

The CIC uses air pressure sensors and corrects the flow rates so that the limiting mobilities stay constant at any air pressure. Hence the actual sample flow rate Φ_{real} may differ from the selected flow rate Φ_{selected}. At a lower air pressure than 1000 hPa, the flow rate is higher than the selcted value and vice versa.

$$\Phi_{\text{real}} = \Phi_{\text{selected}} \cdot \frac{1000\text{hPa}}{P}$$

During normal atmospheric measurements, the change in flow rates is small, typically below 5%.

Bibliography

[1] H. Tammet. *The aspiration method for the Determination of Atmospheric-Ion Spectra*. The Israel Program for Scientific Translations Jerusalem. Washington, D.C.: National Science Foundation, 1970.

[2] S. Mirme et al. "Atmospheric sub-3 nm particles at high altitudes". In: *Atmospheric Chemistry and Physics* 10.2 (2010), pp. 437–451. DOI: 10.5194/acp-10-437-2010. URL: http://www.atmos-chem-phys.net/10/437/2010/.