Charge-Sensing Particle Detector
PN 2-CB-CDB-PCB-001-011

Introduction
The charge-sensing particle detector (CSPD, Figure 1) is a highly charge-sensitive device intended to detect molecular ions directly. In some features, CSPD shows much differing from the conventional ion detectors:

- No high vacuum is required; Ambient usage is available
- No high voltage is required for supplementary
- Low power consumption (< 0.5 W, Vcc @ 5 to 12Vdc)
- Inert to the mobility or m/z of molecular ions
- Low noise level
  (< 3 mVrms at sampling rate of 200k Hz, input bandwidth of 540kHz)
- Highly charge-sensitive (~62 e/mV for event width < 30 μs)
- Wide charge dynamic range (>20dB) of charge measurement
- Un-ambiguous bipolarity of charge measurement

Beside of working principle & figure-of-merits of the CSPD, this document also provides information of dimension, inter-connectivity, ... specifications of all accessories for the (CSPD).

Figure 1. Charge-sensing particle detector
The charge-sensing particle detector (CSPD) senses the current variation of incoming ion packet and represents it as a pulse signal. **Figure 2** illustrates an equivalent circuit of the CSPD. When the charged particles approach the Faraday tray, the 1st stage circuit of CSPD makes sure the induced current is represented as the following,

\[ i = -\frac{V_c}{R} - C \frac{dV_c}{dt} \]

*Eqn 1*

where \( i \) denotes the current induced by incoming charges, \( V_c \) denotes the cross voltage of the \( C \), and the \( R \) denotes the discharging resistor. For a sharp ion packet or a highly multiple-charged particle, the \( i \) is majorly accumulated in the capacitor (C) which is few Pico Farad only and then discharges slowly via a parallel resistor (R) of extremely large resistance. The 1st-stage output, which is proportional to the \( V_c \) and a DC bias, is then shaped as a narrow peak (the final output).
Base on the basic differential equation (Eqn 1) and proper re-sampled window, one numerical rectifier has also been developed to recover the induced current via signal processing of 1st stage output. Figure 3a & Figure 3b show a section of raw signal from 1st stage output and its processed outcome by a numberical rectifier, respectively.

The RC circuit takes 50 ms at least to release the charges accumulated at the C. Therefore, if the duration between two incoming events is shorter than 50 ms, the voltage increment across the C of the latter event can be effected a bit. Usually, the event width is much shorter than the RC time constant (e.g. 100 μs), this effect can be neglected.

The 1st stage output reads out a waveform which looks like an error function, while the distribution of incoming charges is a Gaussian in time. So, a series of error functions is used as test-input function for the response of shaping circuit (Figure 4). Figure 4a depicts the response strength versus the event width of incoming ion packet, characterized by a plateau if the event width is less than about 20 μs. That is, the incoming packet is better with an event duration less than 20 μs to reach the best detection sensitivity. Also, Figure 4b illustrates the linearity of the CSPD while the event width keeps the same. Besides, the peak-tailing after the shaping circuit is about 200 μs. Thus, if the off-duration between two events is less than 200 μs, the response of the latter event might be effected in quantification.

In brief, to use the CSPD properly, it’s to recommend the event width of incoming packet to be less than 20 μs and the off-duration between events not shorter than 200 μs. Moreover, for the peak heights of events can be comparable, their event widths must be well less than 20 μs. The test report for each CSPD shall be individually attached, regarding to its layout quality, e.g., its parasitic capacitance.

The background noise of CSPD is < 3 mVrms at a sampling rate of 200 kHz and bandwidth < 540 kHz. Figure 4c shows a signal section of the CSPD final output. The standard deviation of signal is around 2.1 mV. In other words, for sensing a ion packet with a event width under 20 μs under this acquisition condition, the CSPD has a noise level of ~130 elemtreay charges (e). That implies a detection limit of ~390 e, with respect to a 95% confidence interval.
Figure 4. Properties of charge-sensing particle detector

(A) Peak height / charge number - Event width

(B) Peak height - Input charges

(C) Signal intensity vs. time
Dimensions and pin definition of CSPD

**Figure 5.** Dimensions of charge-sensing particle detector.

<table>
<thead>
<tr>
<th>J1</th>
<th>A connector connects to a connection board via a Ribbon cable &amp; 10-position rectangular receptacle connector.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer:</td>
<td>Amphenol FCI</td>
</tr>
<tr>
<td>Part number:</td>
<td>20021521-00010T1LF</td>
</tr>
<tr>
<td>Description:</td>
<td>10-position Header, Shrouded Connector 0.050&quot; (1.27mm) Surface Mount Gold</td>
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**Pinout**

<table>
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<tr>
<th>1: Test Input</th>
<th>2: Ground</th>
</tr>
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<tbody>
<tr>
<td>3: +Vcc</td>
<td>4: -Vcc</td>
</tr>
<tr>
<td>5: Shielding Ground</td>
<td>6: Final output</td>
</tr>
<tr>
<td>7: Ground</td>
<td>8: No connect</td>
</tr>
<tr>
<td>9: Ground</td>
<td>10: 1st stage output</td>
</tr>
</tbody>
</table>

Faraday tray A copper plate used to sense the charges carried by ions.

Copper ring A copper ring to connect the shielding ground.
Connection board
PN 2-CB-SFB-PCB-001-011

The connection board (shown in Figure 6) plays two important roles for the CSPD in a mass spectrometer: feedthrough of vacuum chamber and re-arrangement for cabling. Figure 7 shows its dimension in a unit of millimetre.

**Figure 6. Connection Board**

**Figure 7. Dimensions and pinout of connection board**

<p>| | |</p>
<table>
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<td>6: Final output</td>
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<tr>
<td>7: Ground</td>
<td>8: N/C</td>
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<tr>
<td>9: Ground</td>
<td>10: 1st stage output</td>
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J2 SMA connector, NC
J3 SMA connector, NC
J4 SMA connector for test input
J5 SMA connector for final output
J6 Power connector
1. +5 to +12 V DC
2. 0 V
3. -5 to -12 V DC
R1 Should be shorted across each terminal.
R2 Be shorted across each terminal to inter-connect the shielding ground and the signal ground.
Mounting mechanism for connection board

The mounting of the connection board onto the vacuum chamber, consists of a through hole for the Ribbon cable connection, a groove for placing an O-ring, and few tapped holes. **Figure 8** depicts the detail mechanism: in an unit of millimetre, a hole of 16 mm x 10 mm x R3, an O-ring groove for JIS P17 which is used to seal the leakage between the connection board, and the mounting-in-itself. To assure the design, the thickness of mounting mechanism should be larger than 5 mm and the material (e.g. Brass) should be with good surface smoothness, electric conductivity and mechanical strength. The surface roughness of the groove should be below 15 μm for a good sealing condition of the o-ring.

**Figure 8.** Drawing of an example for mounting of connection board
Connection cable

**PN 2-CS-CDC-CBL-001-011**

Figure 9 illustrates a shielded connection cable to connect the connection board and the CSPD. It is simply a flat Ribbon cable within a braided metal mesh. AcroMass provides the connection cable with a length between 100 mm and 500 mm.

**Figure 9. Connection cable between the connection board and the CSPD**

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<tr>
<td>1</td>
<td>10 Position Rectangular Receptacle Connectors</td>
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<td>Manufacturer</td>
</tr>
<tr>
<td></td>
<td>Part number</td>
</tr>
<tr>
<td>2</td>
<td>Braided metal mesh</td>
</tr>
<tr>
<td>3</td>
<td>Flat Ribbon cable</td>
</tr>
<tr>
<td></td>
<td>Pitch</td>
</tr>
<tr>
<td></td>
<td>Wire Gauge</td>
</tr>
<tr>
<td>4</td>
<td>Soldering, between the shielding mesh and the grounding cable</td>
</tr>
<tr>
<td>5</td>
<td>Additional grounding cable</td>
</tr>
</tbody>
</table>
Reinforced-housing of CSPD

In order to use the CSPD in the environment full of electrical noises, additional metal housing for the CSPD is necessary to strengthen the reduction of electromagnetic interference. The metal housing blocks both front side and backside of the CSPD (as depicted in Figure 10) and serves the CSPD as a Faraday cage. In the cases for mass spectrometer, a fine metal mesh is soldered onto a hollow circle frame, right onto the CSPD front side to reduce the interference of AC field coming from rf electrodes.

**Figure 10.** Charge-sensing particle detector and its reinforce housing

- **Front shell**
  - PN 3-MP-PDM-CDH-001-012
- **Hollow circle frame with fine mesh**
  - PN 2-CS-MET-FFM-001-011
  - Lines per inch: 100
  - Opening width: 234μm
  - Line width: 20μm
  - Max transmission: 85%
  - Material: Copper
- **Back shell**
  - PN 3-MP-PDM-CDC-001-012
- **Plastic M3 screws**
- **CSPD**
- **Metal M3 screws**

The reinforced housing is connected to the shielding ground of the CSPD. Be careful to get away any conductive interference to this metal housing. To avoid further unwanted ground-loop coupling, the supporting mechanism is better made of electrically insulating materials.

Since the reinforced housing cannot completely block the near-field interference from other power sources, one more grounded metal cage such as a chamber can improve its shielding condition.
Setup of Charge-Sensing Particle Detector

**Figure 11** shows the setup of the CSPD; it connects the CSPD and connection board via the cable. Moreover, the braided metal mesh of connection cable should connect to the chamber via a screw. That braided metal mesh of connection cable serves to avoid the AC interference.

**Figure 11.** Setup of charge-sensing particle detector

*Figures 11 and 12 are diagrams showing the setup and circuit setup of charge-sensing particle detector.*

1. CSPD with reinforced housing
2. M3 screw fixing the additional grounding cable onto the mounting
3. Connection cable
4. Mounting mechanism on chamber
5. O-ring: JIS P17
6. Connection board
7. Reinforced housing

**Figure 12.** Circuit setup of charge-sensing particle detector

The current loop of the signal should be considered carefully. As shown in the above figure, the reference ground of the signal is solely connected to the mounting mechanism, which is right fixed onto a grounded metal chamber, to prevent coupling from other ground loops.
Furthermore, a differential measurement scheme is highly recommended rather than using single-ended measurement scheme.

**Keynotes of setup**

- The CSPD is exceedingly sensitive to AC fields. To avoid the interference coming from AC sources, the mounting mechanism of connection board should be connected to case ground with a low electrical impedance.

- To avoid further unwanted ground loop interference, the supporting mechanism between reinforced housing and measurement apparatus should be made of electrically insulating materials.

- An isolated low-noise (< 1 mV_{pp}) bipolar DC power supply of +12V/0V/-12V is required.

- Differential measurement of data acquisition is highly recommended.
Functional test

**Figure 13.** (a) Test result in 2ms span. (b) Test result in 200ms span. (c) Test result in 200ns span.

Yellow line: Square wave for functional test
Green line: Signal readout of 1st stage output
Pink line: Signal readout of final output

Here is an example process called functional test to identify the working status of CSPD. A square wave of 10 Hz and 1 Vpp (Yellow line, **Figure 13**) is sent into the test input of CSPD.
One 100th of this square wave is AC-coupled (via a 1 pF capacitor) to transmit a sharp current impulse into the 1st stage circuit for charge-to-voltage conversion. Correspondingly, the 1st stage output (Green line, Figure 13) reads out a voltage increment of about 44 mV with a long falling tail. After a CR-RC-CR network for signal shaping, the final output (Pink line, Figure 13) depicts a much narrower peak of width for about 36 us (Figure 13a).

Window of Improper span may not help to depict the data (Figure 13b, the pink line is too thin). The current impulse is assured within duration for about 20 ns (Figure 13c). For each CSPD, the result (Figure 13a. Test result in 2ms span) will be attached in the test report. User can adopt the same test setup to check the proper status of CSPD.