FENNO-AURUM

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<tr><th colspan="4">ESA STUDY CONTRACT REPORT</th></tr>
<tr><td>ESA Contract No
4000123857/18/NL/CRS</td><td colspan="2">SUBJECT: Gas Drift Detector for X-Ray Applications</td><td>CONTRACTOR:
Fenno-Aurum Oy Ltd</td></tr>
<tr><td>ESA CR ( ) No</td><td>DATE
15.2.2019</td><td>No of volumes
1/1</td><td>Contractor’s Reference
ESA FA -ESR,
Issue 1.0</td></tr>
<tr><td colspan="4">ABSTRACT:

Executive Summary Report

This document concisely summarises the work performed and the findings of the Contract.</td></tr>
<tr><td colspan="4">The work described in this report was done under ESA Contract. Responsibility for the contents resides in the author or the organisation that prepared it.</td></tr>
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DIV:
DIRECTORATE:</td><td colspan="2">ESA BUDGET HEADING</td></tr>
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1. BACKGROUND AND OBJECTIVES

There is a great need for **large-area X-ray detectors** due to the fact that there is an ever-growing demand for **faster chemical and elemental analysis** of material samples, especially in high-speed on-line applications where the analyser is measuring a constant, rapid material flow, as on conveyor belts and pipelines in mining operations, recycling and sorting operations, sulphur-in-oil analysis, waste-water analysis, food production analysis, cement production analysis, etc.

In space-science applications the large detection area reduces collection times, thus enabling faster and more efficient X-ray astronomy and astrophysics when studying faint X-ray sources of the deep space.

With the commonly used XRF analysers (X-Ray Fluorescence) the analysis time can be shortened significantly by using an X-ray detector with larger active area. Currently, the commercially available semiconductor X-ray detectors are typically quite small with active areas ranging from 10 mm^2 to 100 mm^2.

Our objective was to develop a novel type of X-ray detector that combines two of the most important detector parameters; large active area and good energy resolution. These two parameters are usually contradictive and very difficult to realise in the same detector device, so that silicon-based X-ray detectors have very low noise but are small in size, whereas gas-filled X-ray detectors (e.g. proportional counters) can be manufactured having large detection areas, but with poorer noise performance.

Our novel X-ray detector is of gas-filled type, but its internal structure is similar to a semiconductor SDD (Silicon Drift Detector), thus combining the best of both worlds. This "GDD structure" (**Gas Drift Detector**) is a cylindrical metallic chamber containing a P-10 gas mixture (90%Ar + 10%CH_4) and at the bottom an insulating alumina board and a printed circuit board with concentric metallic biasing rings, along with a small spherical golden anode in the centre. The internal electric field is arranged in such a way that the electrons created by an X-ray event drift rapidly to the small central anode, and the much slower positively-charged ions drift to the walls of the metallic detector box. This results in a very fast signal pulse at the small-capacitance anode that is directly wire-bonded to an integrated low-noise preamplifier chip called "CUBE" developed by the Italian company XGLab.

The GDD design is mechanically scalable, so that it can be manufactured with any active area ranging from tens of mm^2 to thousands of mm^2, or even larger.

2. DETECTOR DESIGN AND MANUFACTURE

The Inner Box that contains the P-10 gas volume was designed to be a cylindrical metallic chamber with inner diameter of 50 mm. The bottom of the Inner Box consists of a low-loss FR-4 circuit board with the CUBE preamp chip attached to it, along with insulating low-loss alumina (Al_2O_3) boards. The small golden spherical anode sits on top of a small Teflon stud inserted through the alumina board and it is wire-bonded to the CUBE preamp input pad with a thin golden bonding wire going through the board stack.

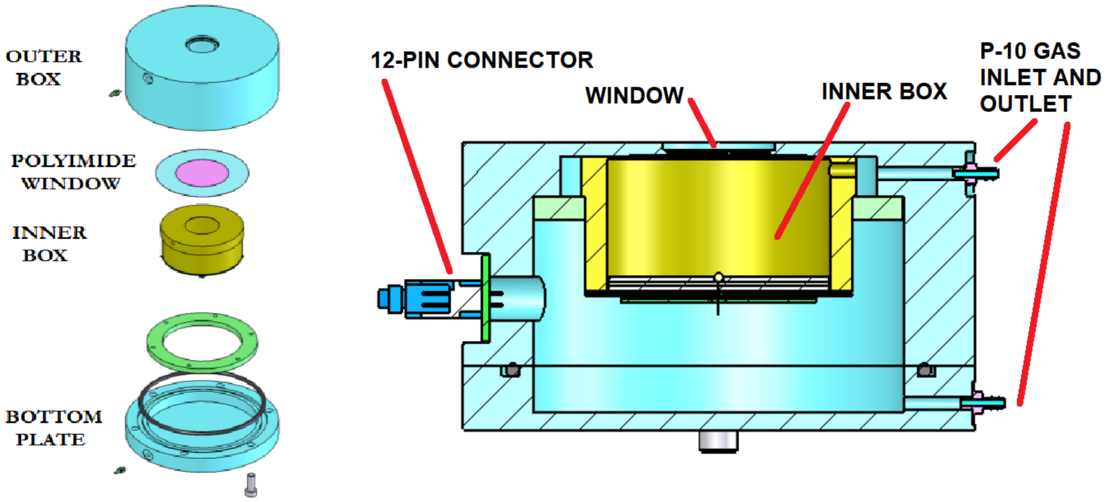

Figure 1. Exploded view and cross section view of the GDD structure.

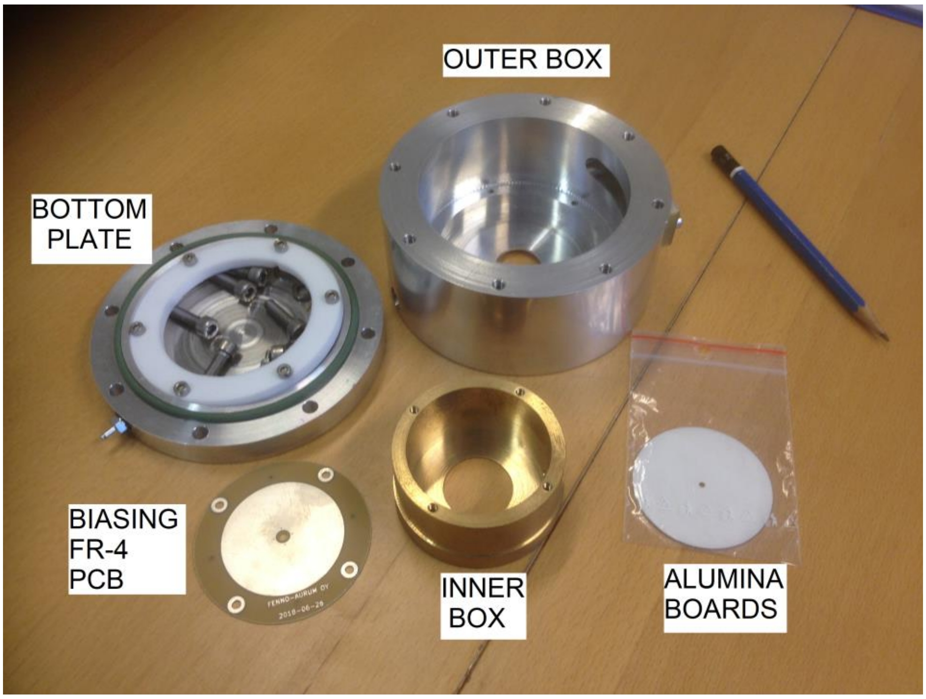

Figure 2. Manufactured mechanical parts of Gas Drift Detector.

3. DETECTOR TEST RESULS

The spectrometric tests and characterization of the Gas Drift Detector were carried out at Fenno-Aurum facilities in Otaniemi, Espoo.

The test equipment consisted of the following:

- High Voltage Supply: Stanford Research Systems PS-325
- Preamplifier: CUBE (type PRE_033 for electron collection)
- Digital Shaping and MCA: Amptek DPP DP5 (with 80 MHz ADC)
- Interface: XGLab Bias Board XGL-CBB-1CH
- Oscilloscope: Tektronix TDS
- Isotope source: Fe-55 (5.9 keV radiation energy)
- Gas mixture: P-10 (a.k.a. 90%Ar + 10%CH_4)
- X-ray tube: Amptek Mini-X

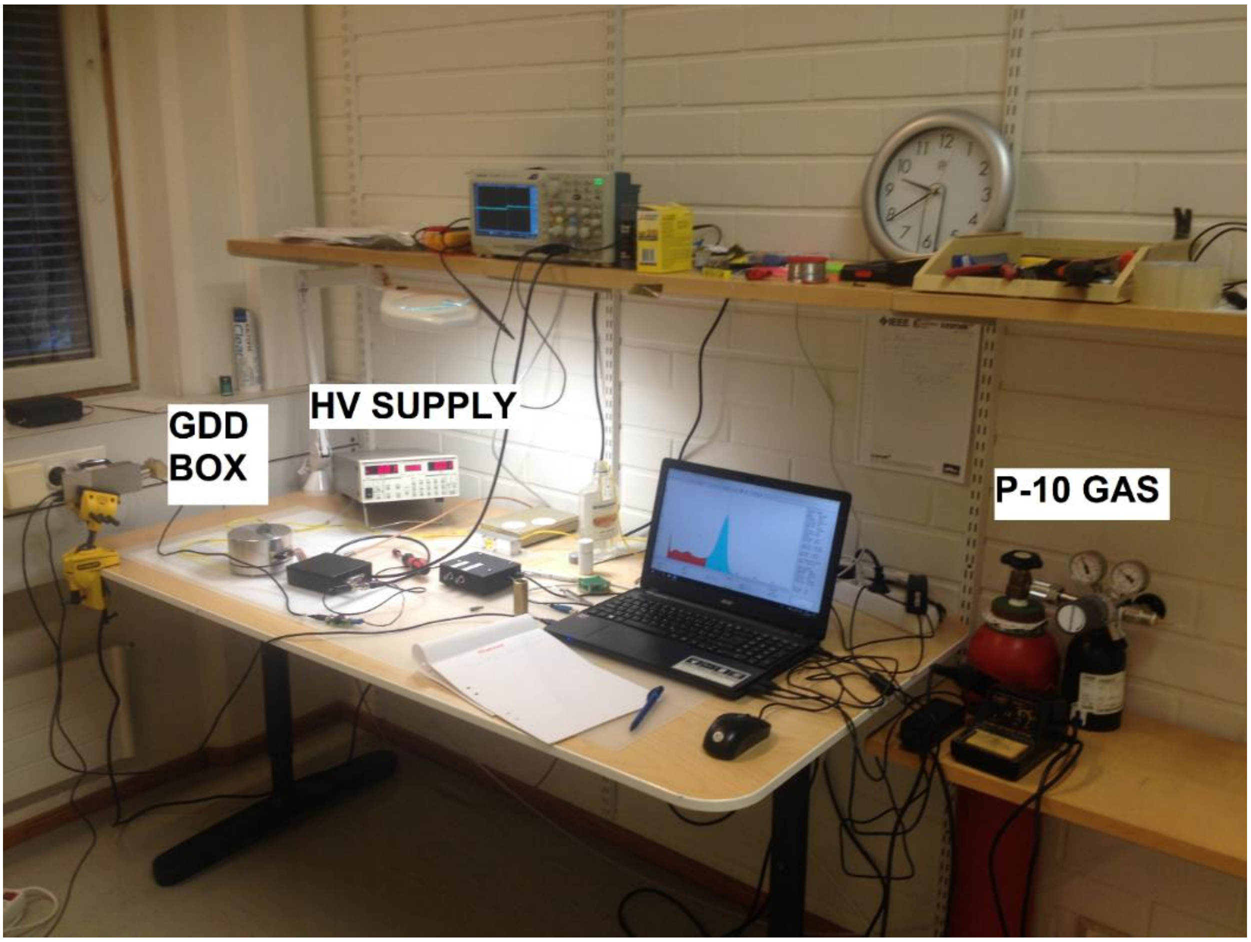

Figure 3. The spectrometric test setup at Fenno-Aurum facilities.

The Gas Drift Detector prototype was tested extensively using different High Voltage biasing values (HV -400 V to -900 V), and various digital pulse shaping time constants. A typical measurement result using Fe-55's 5.9 keV radiation line is shown in Fig. 4.

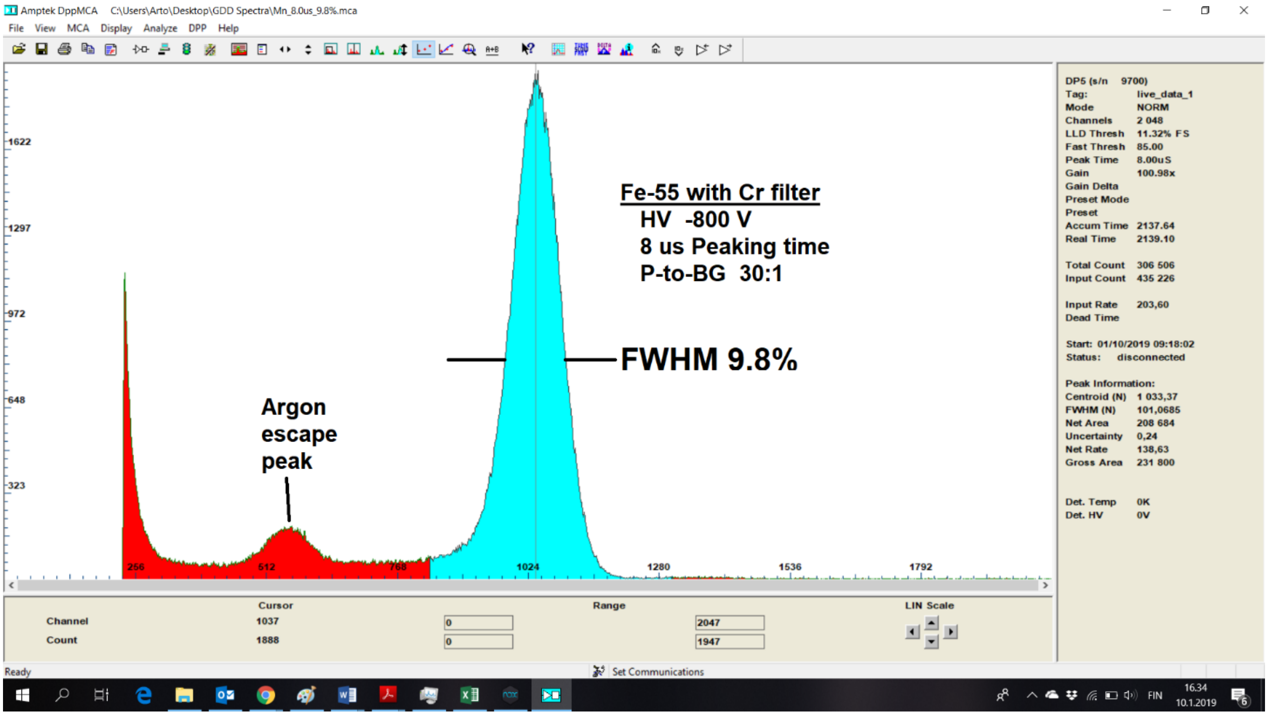

Figure 4. Fe-55 spectrum measured with the Gas Drift Detector at HV -800 V.

The FWHM energy resolution at 5.9 keV was measured to be 9.8% (580 eV), and to our knowledge this is the best ever result measured with any gas-filled X-ray detector. Commercially available gas-filled detectors (proportional counters) typically have energy resolutions between 14% and 19%, so the improvement is significant.

The detector was operated at low electric field strength in the Ion Chamber region without gas amplification, which minimizes the detector ageing effects and enables production of very long-life detectors. The detector works well even at short shaping time constants down to 0.25 µs which enables very high count-rate operation of close to Million counts per second with good gain stability. The detector showed no microphonic effects which enables operation in acoustically noisy and/or vibrational environments. In addition, the GDD detector is inherently tolerant to radiation damage.

However, despite of the good energy resolution, it can be seen in the spectrum that the background under the Fe-55 peak is higher than expected at about 30:1 peak-to-background ratio. This could be due to a weak or distorted electric field somewhere inside the GDD gas-filled box (most likely at the bottom or at the corners), thus causing some incomplete charge collection at the anode. Also, diffusion might cause rise-time variations in the signal pulses. We will investigate this further.

4. CONCLUSIONS

The testing and characterisation of the first prototype Gas Drift Detector system was successful, and we can highlight several positive observations:

- Good energy resolution of 9.8% (580 eV) at 5.9 keV is (to our knowledge) the best ever measured with any gas-filled X-ray detector
- The integrated CUBE preamp chip was used for the first time ever with a gas-filled radiation detector
- The GDD was operated at low electric field strength well below the normally used gas-amplification (proportional) region, and once again, this might have been the first time ever that the Ion Chamber region was used for collection of X-ray spectra
- Since gas amplification is not used, the detector ageing effects are negligible, thus enabling production of very long-life detectors
- The GDD works well even at short shaping times down to 0.25 µs, thus enabling very high count rate operation of close to 1 Million cps
- Since electron collection is used for the signal pulse (instead of the normally-used gas ions in proportional counters that have about 1000 times slower drift velocity) the signal is very fast, thus enabling good timing characteristics
- Excellent peak position stability at count rates of at least up to 200,000 cps
- No microphonic effects at all, thus enabling operation in acoustically noisy or vibrational environments
- The GDD design is inherently radiation tolerant, so it will be a good candidate for high-flux radiation environments, including space missions

However, there is still plenty of room for improvement in the GDD design:

1) The peak-to-background ratio (due to incomplete charge collection) can be improved by more careful mechanical design of the Inner Box with the help of electric field simulations and numerical calculations. We have some testable ideas for reducing the corner-effects by curving the bottom part of the Inner Box, or even making it of hemispherical shape.
2) The energy resolution (i.e. electronic noise) can be improved by removing all “lossy” dielectric materials from the vicinity of the anode/preamp input node, including the drop of glue, and by minimising all the unwanted stray capacitances in the anode-preamp connection.

All these issues will be studied and improved in the next phase of "ITI Type B" activity, where we can design and manufacture improved versions of the GDD design. Eventually, this type of an X-ray detector can readily be used in space applications, and we are prepared to continue this development work for all suitable future ESA programmes and missions.

In addition, in the Type B activity we will be able to study the use of different gas mixtures with more favourable parameters, including Ar-C_2H_2 and Xenon.

We believe that the GDD detector will find numerous applications in commercial markets and ESA missions because of its competent performance parameters. We are looking forward to commercialising this product.