A New Implementation of Non-destructive Differential Mode Electric Ion Trap Mass Spectrometry for Fourier Transform Analysis (FTMS)

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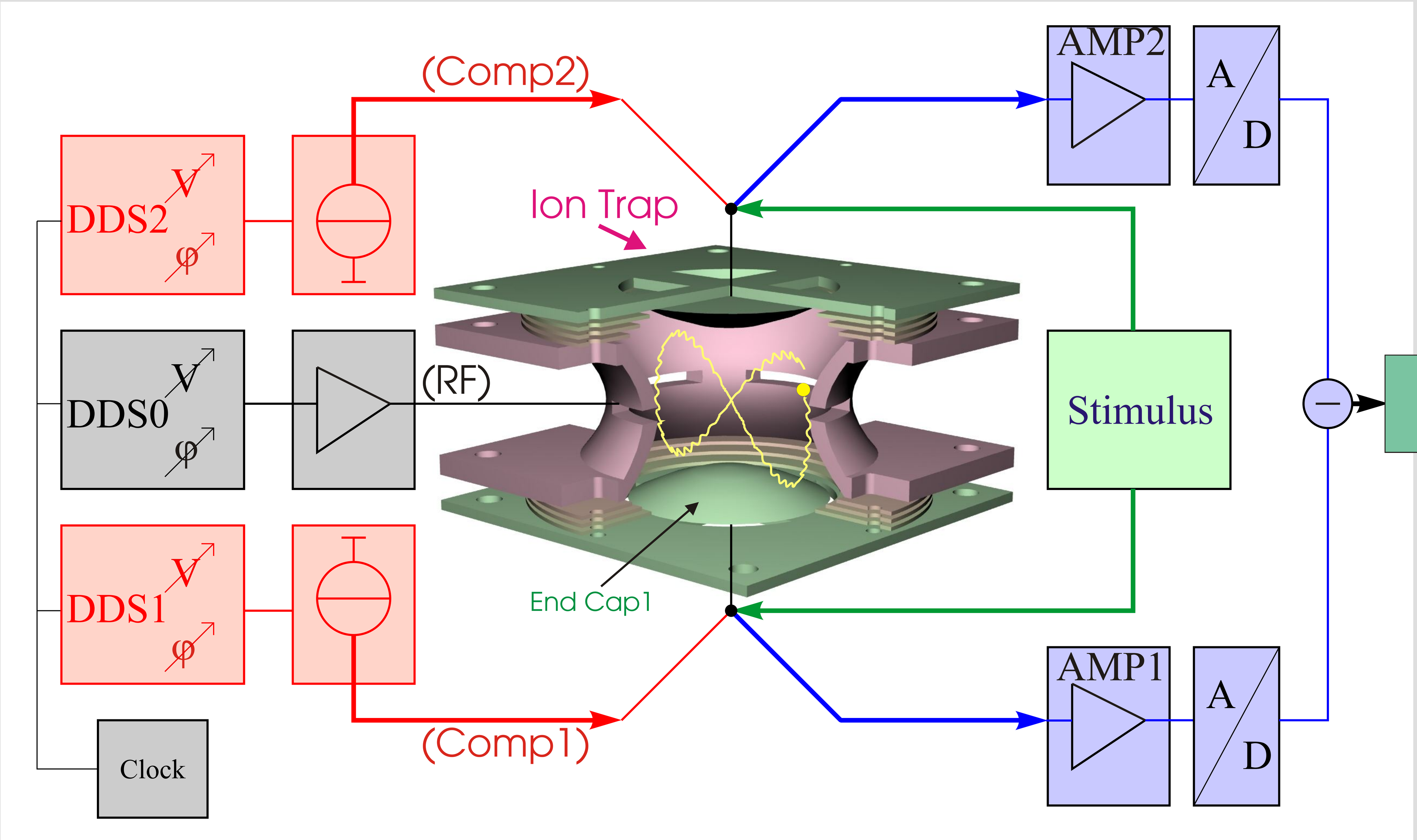
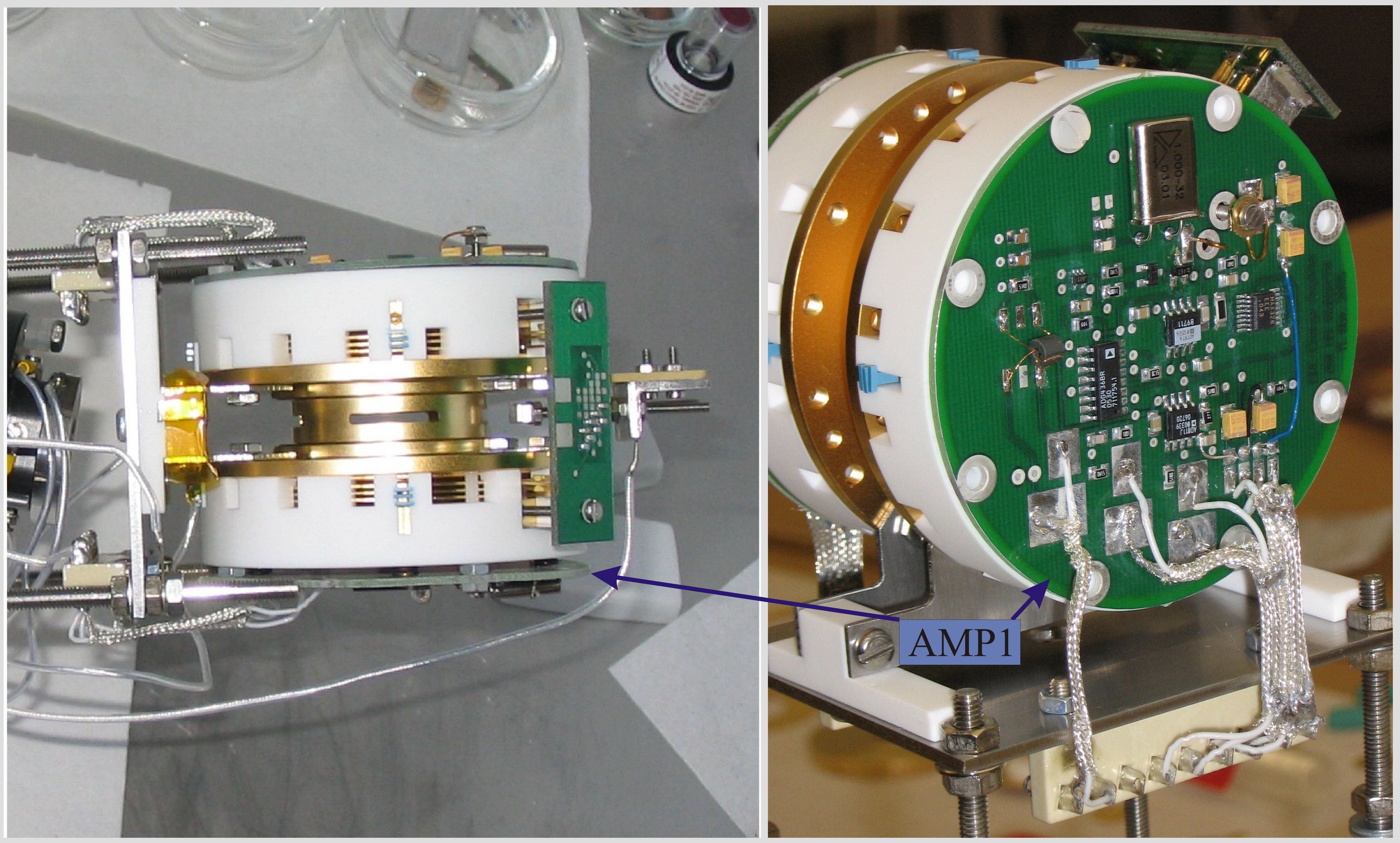
Design goals: Portable design with compact size, lightweight and low power consumption;
FTMS with non-destructive wideband analysis, high precision and high dynamic range.

Application Fields: Aerospace, Environmental Monitoring, Bio-Medical Analysis, etc.

Block-Diagram of the Ion Trap Electronic



Prototype of the Electric Ion Trap Mass Analyser



Introduction

Non-destructive high precision wideband Fourier Transform Mass Spectrometry can be performed with a modified Paul ion trap.

The ion-image currents are detected by a fully symmetrical design which allows high sensitivity, low noise, low distortion and high accuracy mass analysis similar to magnetic ICR but with a very compact size.

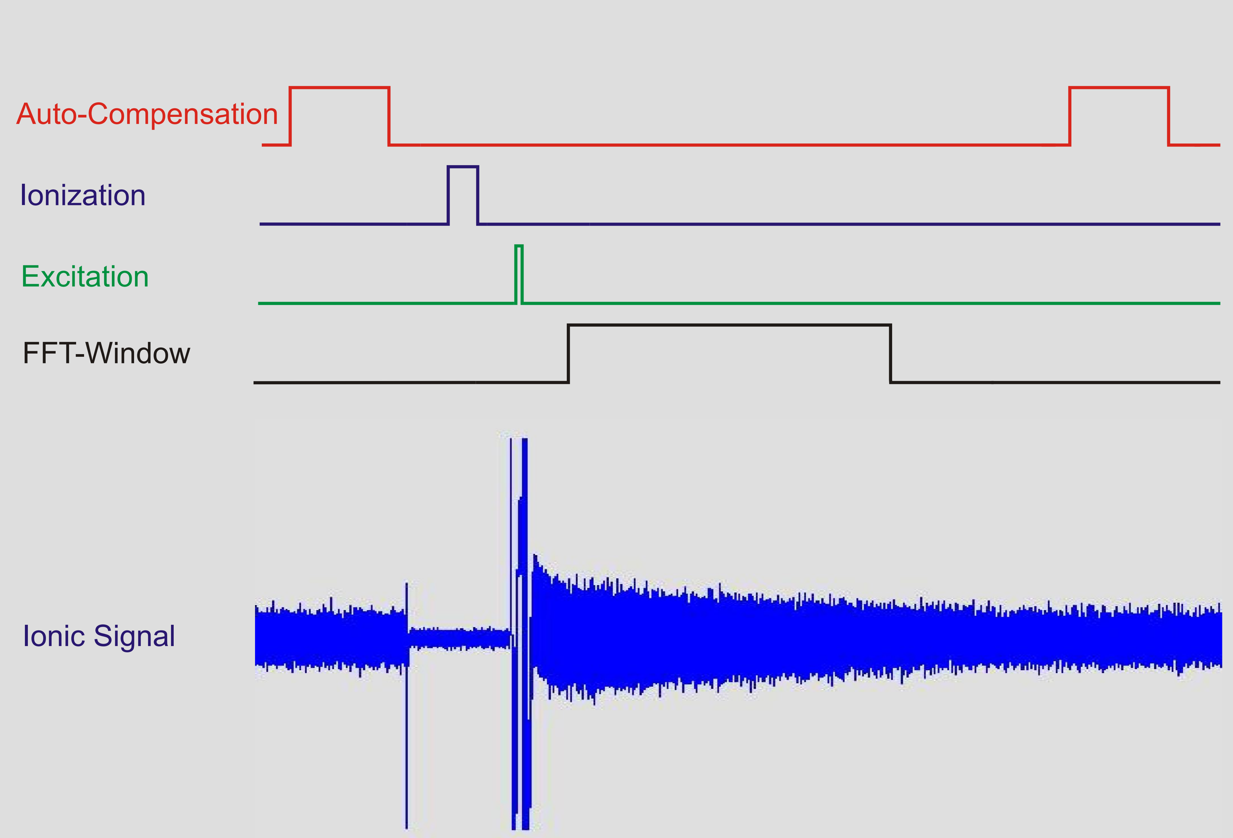
Applied Methods and preliminary results

- Modified Ion Trap keeps high the field accuracy, reduces the crosstalk of the Radio Frequency (RF) High Voltage (HV) by 30 dB.
- Additive RF-HV crosstalk Compensation based on Direct Digital Synthesis techniques (DDS1 & DDS2) achieves a further Reduction of 50 dB;
- Fully symmetrical ion stimulation (Stimulus) and detection (End Caps) provide high linearity, high sensitivity and optimal noise cancellation.
- Ion-image currents are recorded via a two-channel wideband low-noise charge amplifier unit (AMP1 & AMP2)
- Specific Mass Resolution > 10^6 amu^{-1}, Maximal Non-Linearity Distortion < 1%, Equivalent Noise Level ≈ 3 ions, Dynamic Range ≈ 10^4 (single shot)

Instrumentation Data	
Dimension	60x60x40 mm^3
Total Power consumption	< 3 W
Specific Mass Resolution	> 10^6 amu^{-1}
Maximum Non-Linearity	< 1%
Dynamic Range ([1]one shot)	> 10^4
Equivalent Noise Level ([1])	< 3 ions / sqrt(Hz)

Test Conditions	
Residual gas pressure	10^{-8} mbar
Test Gas Partial Pressure	> 5.0 10^{-8} mbar
Electron beam ionization:	
- Current	2 µA for 10 ms
- Energy	> 80 eV
RF-HV Storage Field:	
- Frequency	1 MHz
- Amplitude	0.2..1 kVpp
Excitation Level (Stimulus)	1 Vµs..25 Vµs

Measurement Timing Diagram



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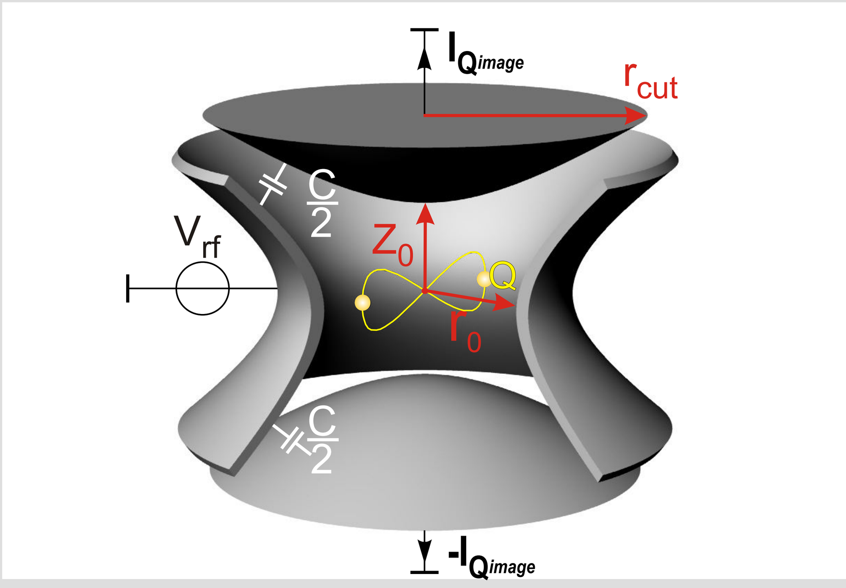
(FTMS)

Preliminary investigation for high sensitivity and high linearity

Crosstalk capacitance calculation

Ion trap radius with r_0 = 15 mm, $z_0 = r_0 \cdot$ sqrt(2)

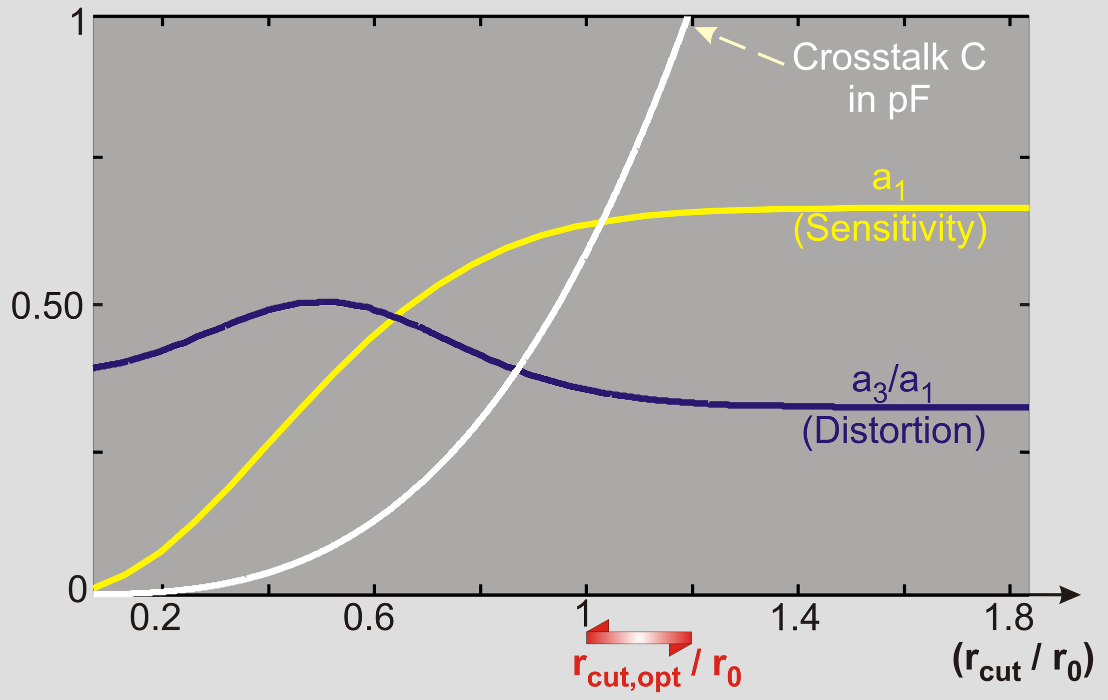
$C = \text{sqrt}(2) \cdot \pi\varepsilon r_0 \cdot (r_{cut} / r_0)^3$



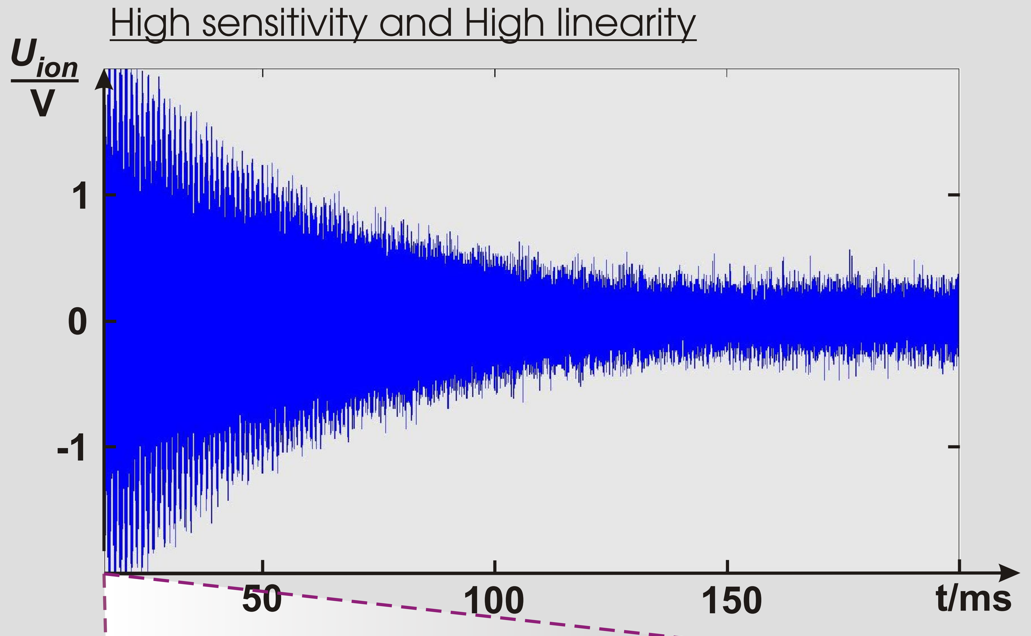
Optimal cutting radius determination

Ion image charge as function of the axial displacement (z_Q/z_0):

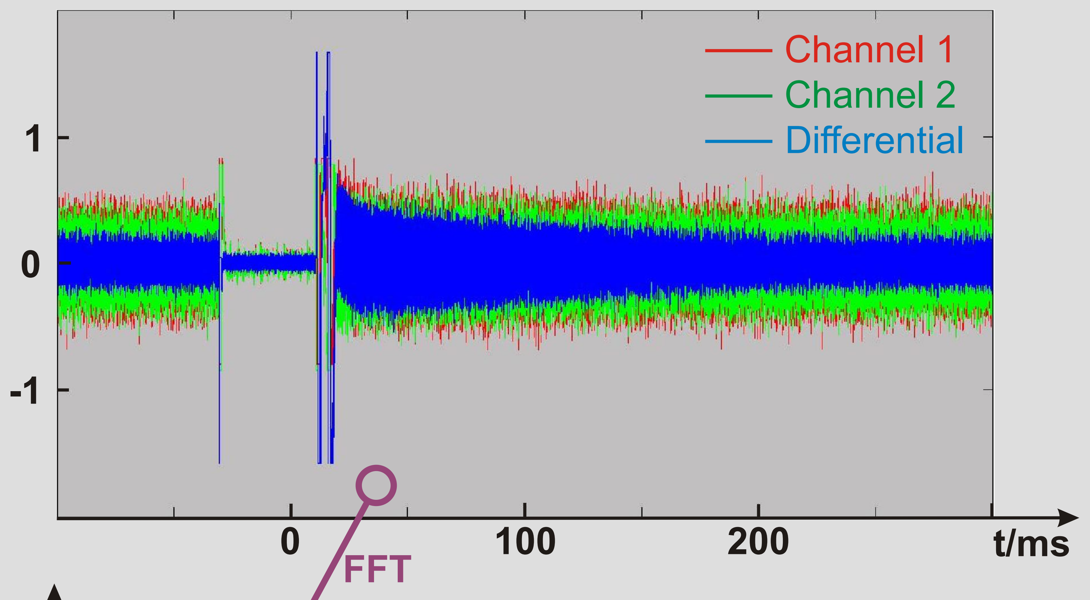
$Q_{image}/Q = 2a_1 \cdot (z_Q/z_0) + 2a_3 \cdot (z_Q/z_0)^3 + ...$

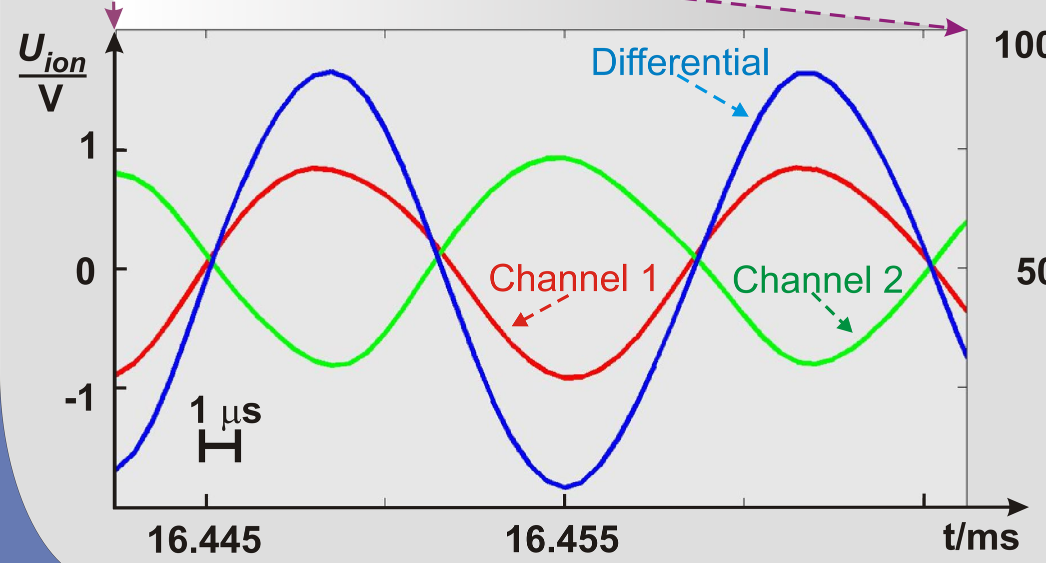


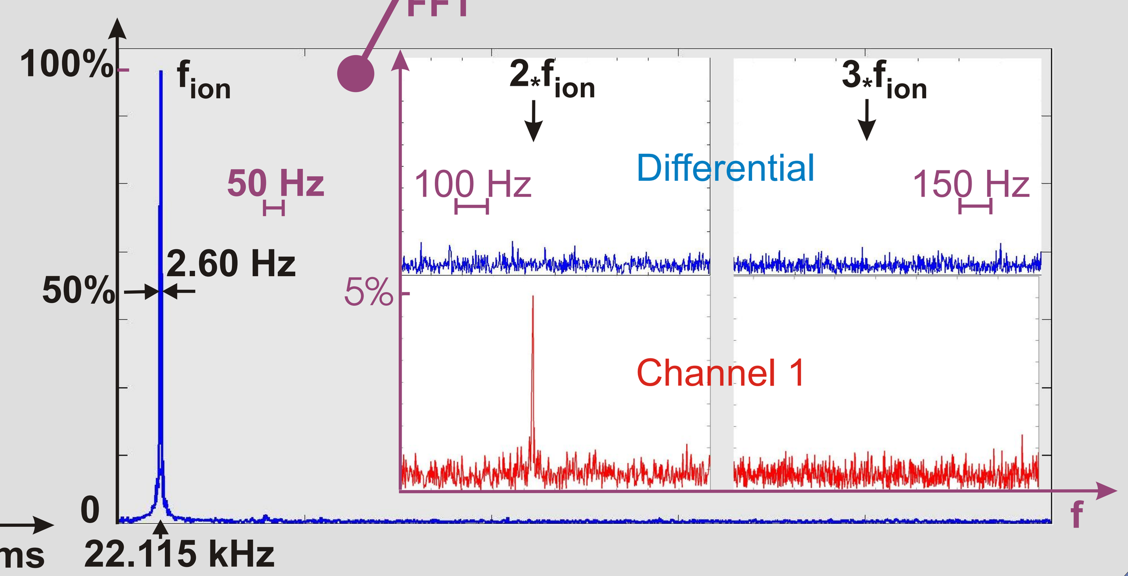
High sensitivity and High linearity



Optimal noise cancellation

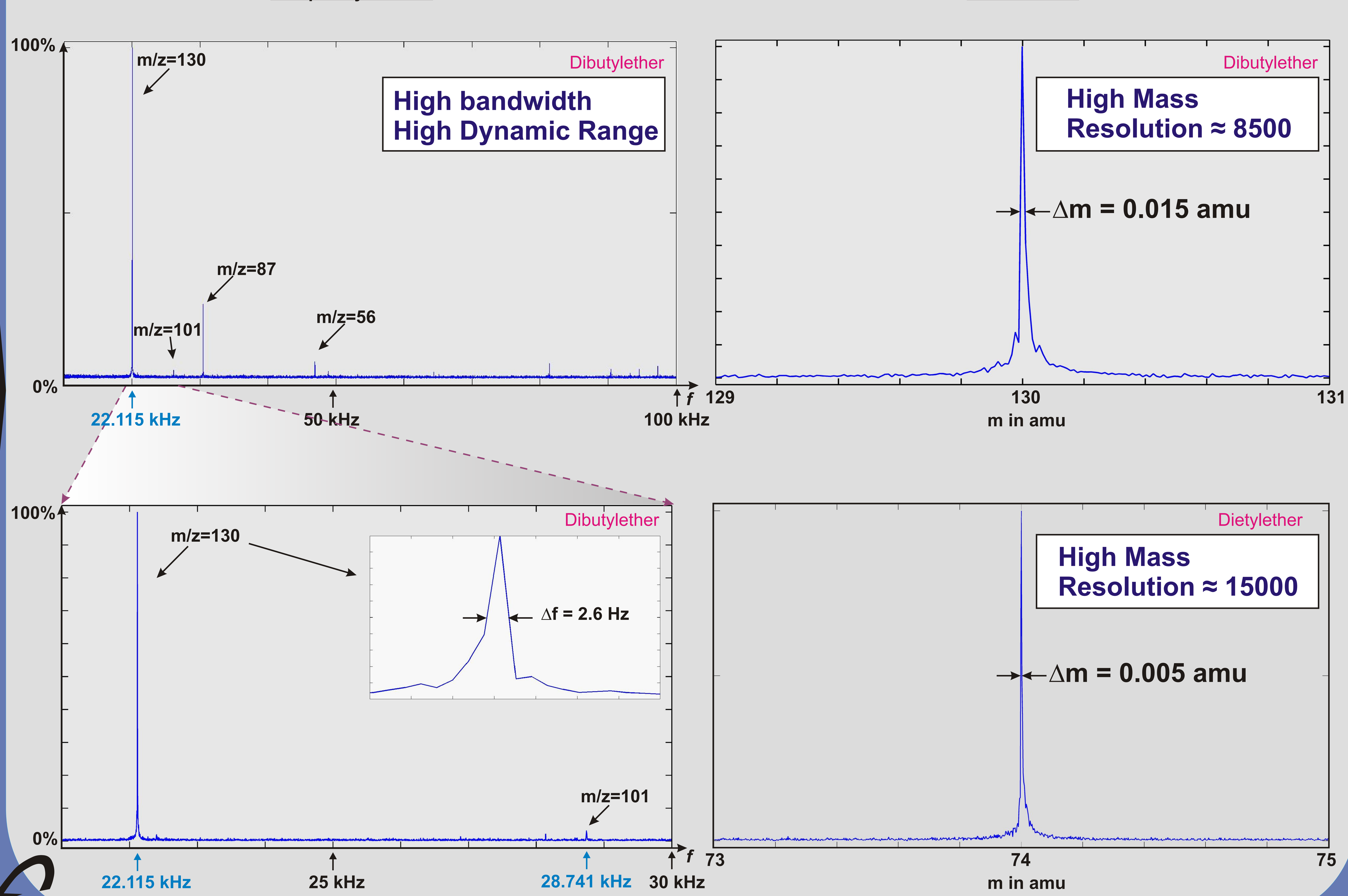






Measurement results

Dibutylether ($C_4H_9OC_4H_9$) and Dietylether ($C_2H_5OC_2H_5$) traped at $6.0 \cdot 10^{-8}$ mbar.
Excitation Level: 4V·5µs = 20Vµs



Results and Discussion

- High sensitivity and high linearity in the differential measuring mode:

  - Improvement of the sensitivity by 6 dB
  - Suppression of the second order harmonics
  - Rejection of common mode noise

- Mass analysis in a wide mass range with the same ion-population (one shot mode)

- High specific Mass Resolution $M_{res,spec}$:

  - Mass Resolution at mass m/z=130 amu (Dibutylether):
    $M_{res} \approx f_{ion}/\Delta f = (m/z)/\Delta m = 8500$
  - Mass Resolution at mass m/z=74 amu (Dietylether):
    $M_{res} \approx f_{ion}/\Delta f = (m/z)/\Delta m = 15000$

  - $M_{res,spec} \approx (m/z)^2/\Delta m$ = 1105000 (Dibutylether), 1110000 (Dietylether) > 10^6 amu^{-1}

Conclusions and outlook

High accuracy differential mode non-destructive mass analysis with a modified ion trap is demonstrated using a novel and fully symmetrical design.

High sensitivity and high dynamic range are achieved while keeping the distortion low. The automatic compensation of the RF-HV crosstalk based on DDS techniques makes possible wideband low noise ion detection.

Generally, space charge effects, either in electric or magnetic traps, can considerably affect the instrument performances if the ion population exceed a given amount, which also depends on the size of the trapping cell.

Due to the non-destructive character of the applied method, the same ion population can be analyzed multiple times: This re-measurement possibility for a small ion population analysis improves the signal to noise ratio and reduces space charge effects. In addition, SWIFT mode excitation techniques (Storage Waveform Inverse Fourier Transform) can be used in order to trap only the ion population of interest.

The compact size and the light weight of the instrument makes it ideal for Aerospace, Environment Monitoring and Bio-Medical applications.