Ion trap Fourier-transform mass spectrometer with induced current detection and arbitrary storage waveforms

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Introduction

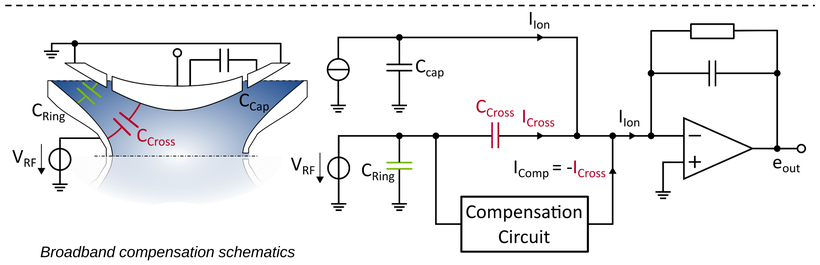
Overview:

Quadrupole ion traps can achieve a great performance when using non-destructive ion detection by induced current measurement.
In typical applications the ion trap is operated with fixed frequency sinewaves to generate the required trapping field.
In the past years the so-called digital ion trap (DIT), which operates with a rectangular waveform (DIT), has evolved. It was shown that resolution and scan speed can be increased, in instability mode driven DITs.
Using an arbitrary waveform rather than a sine wave offers several advantages to an ion trap **FT-MS**, too;

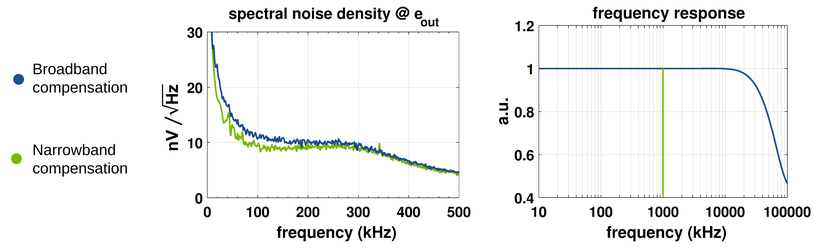
- Simple waveform generation and shaping
- Increased mass range
- Selectivity adjustable by modifying the boundaries of ion stability

Crosstalk Compensation

- FT ion trap mass spectrometer suffer from a capacitive coupling between the trap electrodes that leads to crosstalk currents
- The crosstalk currents need to be compensated so that the charge amplifier is not overdriven
- Existing instruments are working with fixed frequency sine wave storage waveforms and thus a narrowband compensation (very good noise characteristics)
- In order to use arbitrary storage waveforms a broadband compensation has been developed:

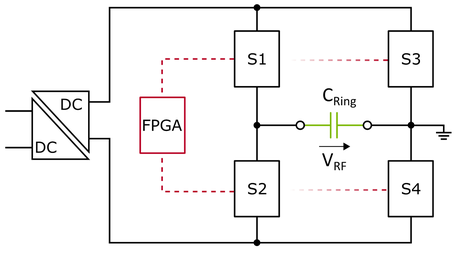


Broadband compensation schematics



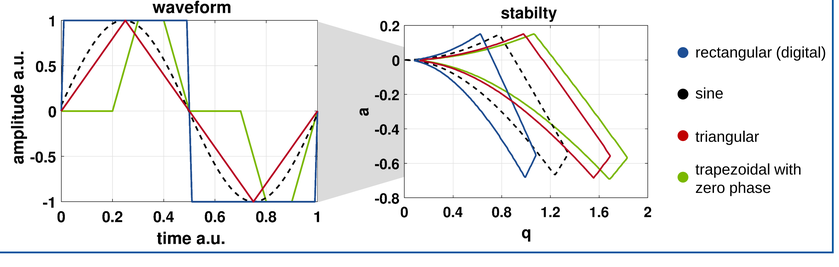
Introduced noise through new broadband compensation exceeds narrowband methods by **15 – 20 %** but **BW > 10 MHz!**

Storage Waveform Generation



- Custom-built isolated DC source with output amplitudes up to some hundreds of Volts and full-bridge circuit
- The full-bridge circuit allows for simple generation of rectangular waveforms with variable frequency
- Frequency range 0 Hz to 1 MHz
- By using suitable control schemes triangular, trapezoidal or other shaped waveforms can be created

- As it was demonstrated earlier with rectangular storage waveforms [4],[5] et. al., regions of stable ion motion may be altered by the shape of the storage waveform
- This can help isolating designated ion populations or suppressing background gas (N_2 etc.), and thus increase dynamic range

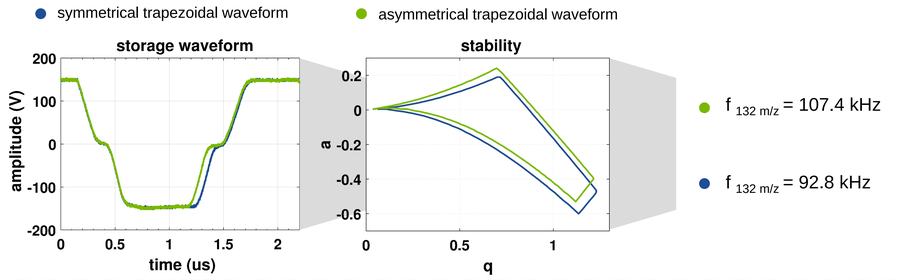


Results

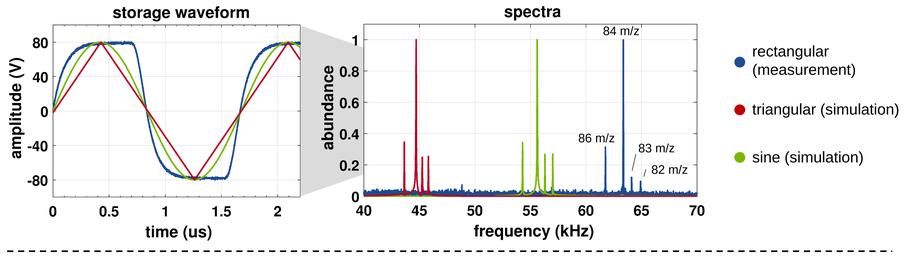
Some options offered by a varying storage waveform are outlined in the following measurements:

- **Xenon with trapezoidal storage waveform**

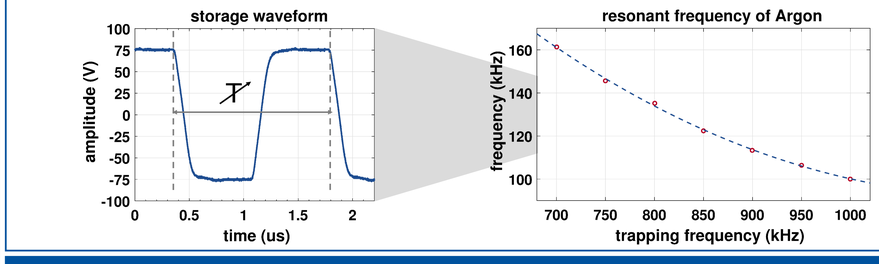
By varying the switching times of the full bridge circuit an asymmetry was introduced. The corresponding stability diagrams are displayed below



- **Krypton with different storage waveforms**



- **Argon at 4·10^{-7} mbar**



Mass Range

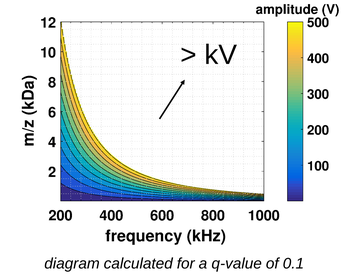


diagram calculated for a q-value of 0.1

- To store ions in the kDa range in a standard-size ion trap, amplitudes of multiple **kV** are needed (@ 1 MHz)
- With the new setup, besides changing the waveform shape, frequency can be varied easily
- Small amplitudes are sufficient for an enhanced mass range
- Low power requirement < 150 W (increase with V_{RF}^2)

Conclusions

Arbitrary waveform ion trap FTMS:

- A new broadband compensation has been developed to enable image current measurement with arbitrary trapping waveforms
- Low-noise characteristics of the charge amplifier could be maintained
- A custom-built waveform generator allows for creation of trapping fields of arbitrary frequency composition
- The frequency of the generated signal can be varied since the waveform is generated non-resonantly
- The mass range can be enhanced by reducing the trapping frequency

Outlook:

- Improvements in waveform shaping/generation
- Further analysis of the benefits of arbitrary waveforms in the FT-MS
- Coupling with different ion sources

References

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[4] G. F. Brabeck, P. T.A. Reilly: Mapping ion stability in digitally driven ion traps and guides *Int. J.Mass.Spec 2014*

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