Automatic Crosstalk Compensation Techniques for Fourier Transform Mass Spectrometry with an Electric Ion Resonance Trap (ACC)

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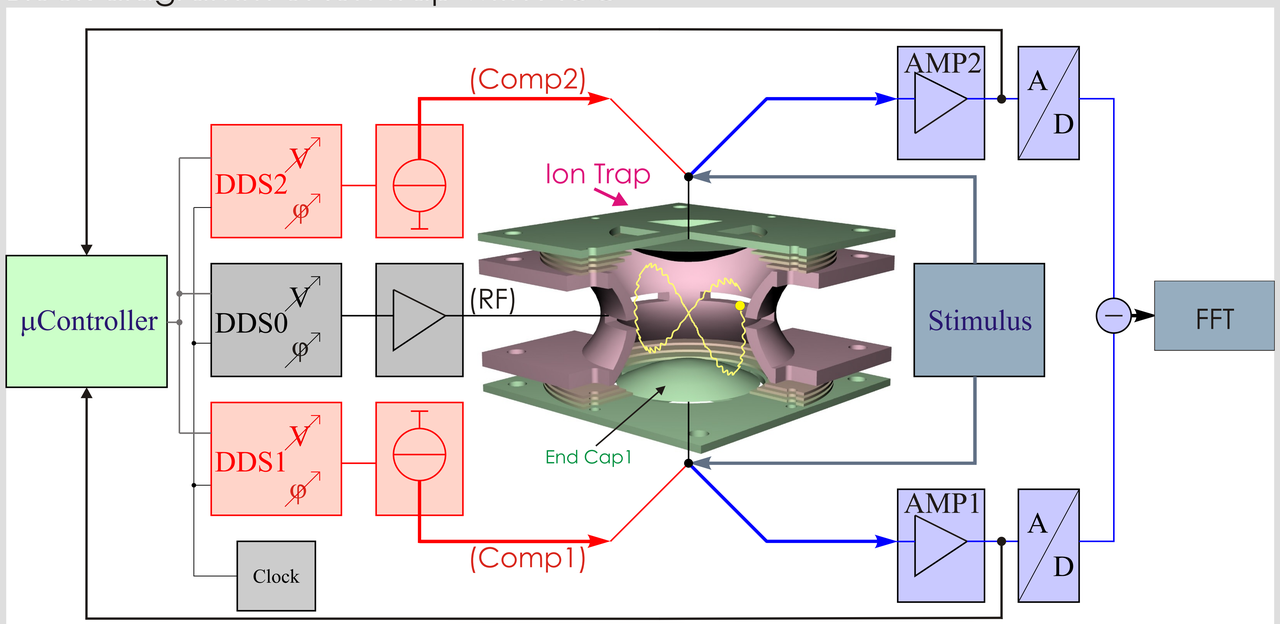
Goals: Broadband, low noise, high sensitive and non-destructive ion detection for high precision and high dynamic range Fourier Transform Mass Analysis

Designed for: Portable mass analysers for aerospace, Environmental, Bio-Medical Applications, etc.

Block diagramm of Ion Trap with ACC



Introduction

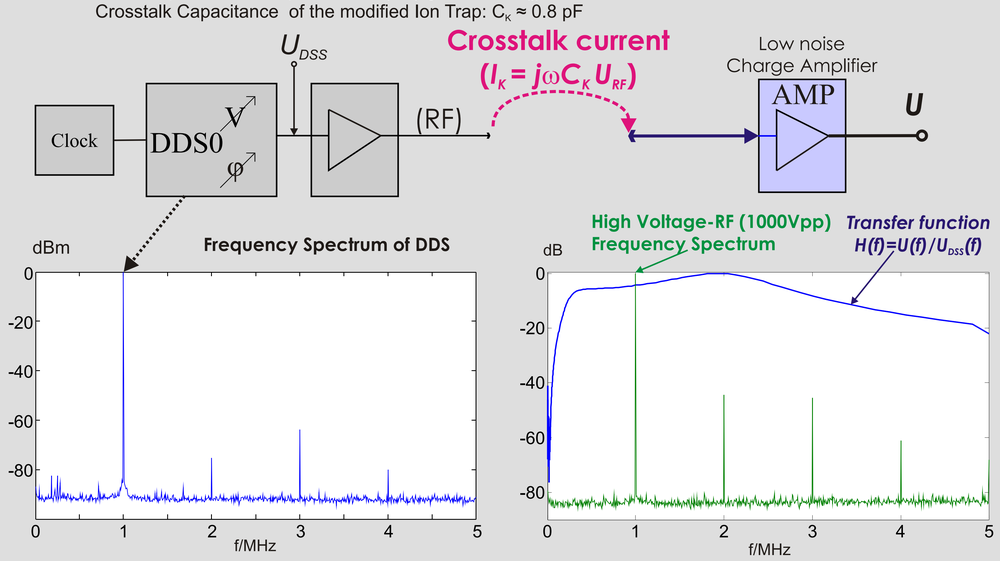
One of the major tasks to be performed for the use of a wideband non-destructive electric ion trap mass analyser consists of cancelling the very strong crosstalk current of the radio frequency storage source (RF) on the end cap electrodes, which is superimposed to the ion image currents by a factor of about 1 billion (180 dB!). The presented crosstalk cancellation techniques also called compensation enable wideband and low noise influence charge measurements for Fourier Transform mass analysis. In order to eliminate drift effects and to allow fast changes in the measuring parameters with minimal dead time an Automatic Crosstalk Compensation (ACC) including a high quality RF-generator is proposed.

Discussed Aspects

- ☑ **1. High quality Radio Frequency (RF) generation based on Direct Digital Synthesis (DDS) techniques**
- ☑ **2. Low noise compensation signal generation based on DDS-techniques**
- ☑ **3. Effects of compensation on ion signals**
- ☑ **4. Automatic Crosstalk Compensation (ACC)**

1. High quality Radio Frequency (RF) generation based on DDS

Radio Frequency (RF) amplitude range: $\hat{U}_{RF,pp} \leq 1000$ Vpp
Maximal power consumption of the (RF)-generator: $P_{tot} \leq 1.5$ W
Crosstalk Capacitance of the modified Ion Trap: $C_K \approx 0.8$ pF



- Low harmonics level at maximum RF-amplitude (1000 Vpp) < -45 dB
- High Frequency stability
- Low drift in amplitude and phase: < 1% in temperature range 25°C-80°C
- High Signal to Noise Ratio in the ion frequency band (1kHz-300kHz)

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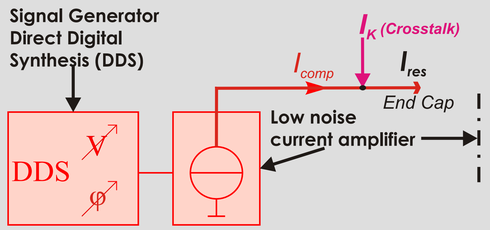
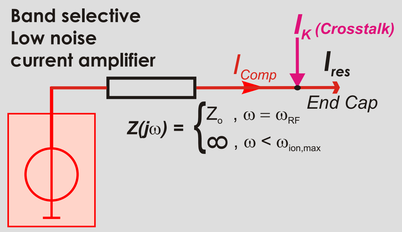
(ACC)

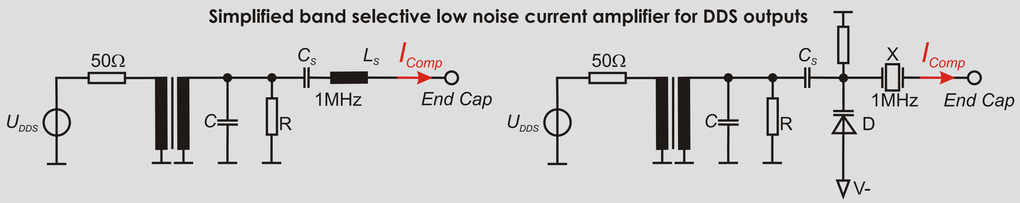
2. Low noise compensation signal generation based on DDS



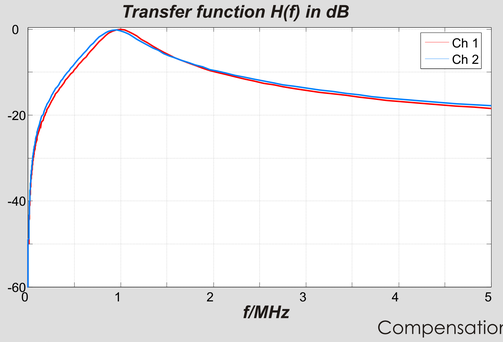


Optimal compensation: $\hat{I}_{Res} = \sqrt{\hat{I}_K^2 + \hat{I}_{Comp}^2 + 2.\hat{I}_K.\hat{I}_{Comp}.\cos(\varphi_K - \varphi_{Comp})} = 0$ => $\hat{I}_{opt} = \hat{I}_K$ and $\varphi_{opt} = \varphi_K - \pi + 2k\pi$ (2.1)

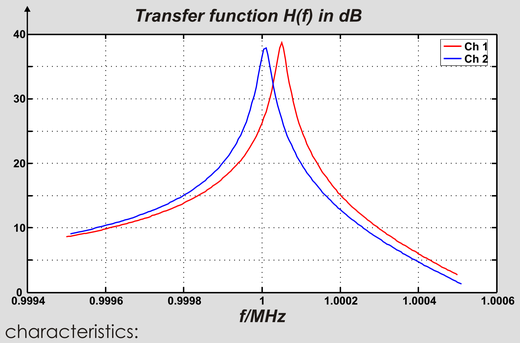
Simplified band selective low noise current amplifier for DDS outputs



a) with LC-filtering method



b) with Quartz filtering method



Compensation characteristics:

a)

- High noise rejection
- Low temperature drift in phase and amplitude
- Low harmonics rejection
- Low current amplification factor

b)

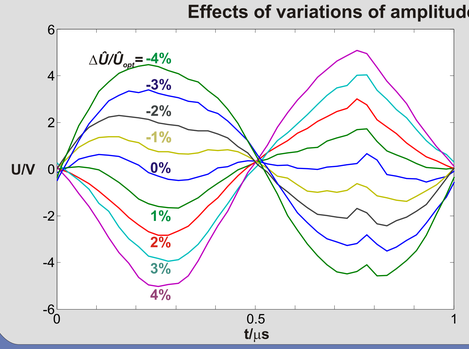
- Very high noise and harmonics rejection
- Very high Frequency stability
- High temperature drift in phase and amplitude
- Sensitive to variations of the RF-amplitude

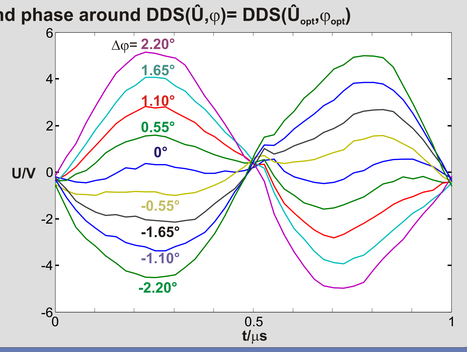
Results and Discussion

3. Effects of compensation on Ion signals

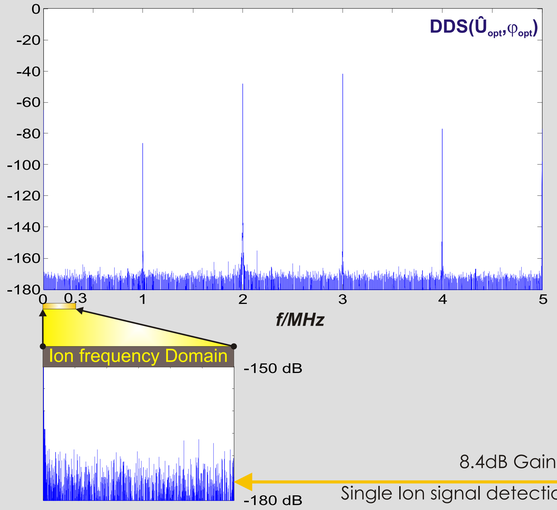
Measurements conditions:
U_{RFpp}= 544 Vpp, f_{RF}= 1MHz
Optimal Compensation achieved for DDS($\hat{U}$,φ)= DDS($\hat{U}_{opt}$,φ_{opt}) (3.1)

Effects of variations of amplitude and phase around DDS($\hat{U}$,φ)= DDS($\hat{U}_{opt}$,φ_{opt})

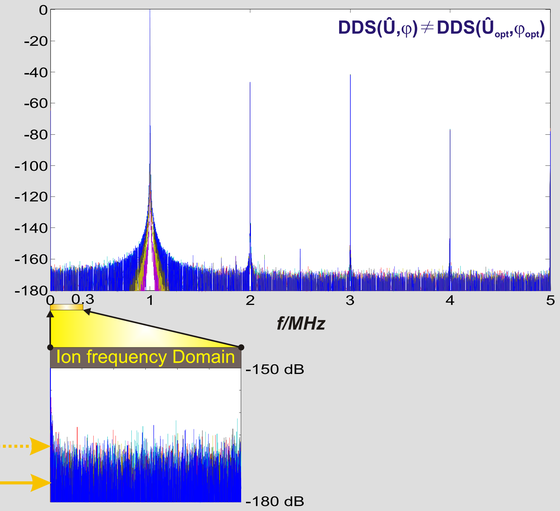




Compensation Frequency Spectrum/dB (optimum)



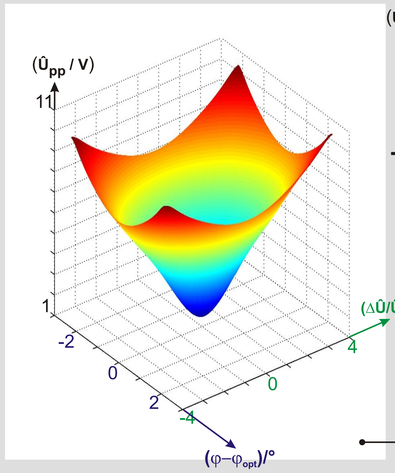
Compensation Frequency Spectrum/dB (not optimal)

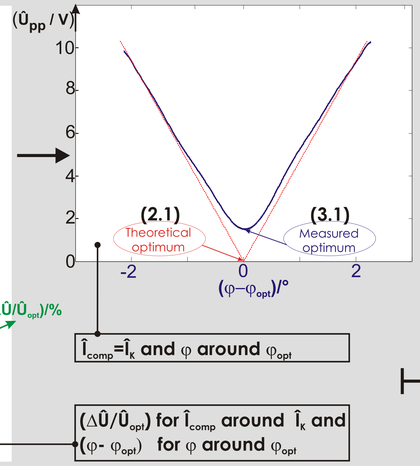


8.4dB Gain

Single Ion signal detection level

4. Automatic Crosstalk Compensation (ACC)

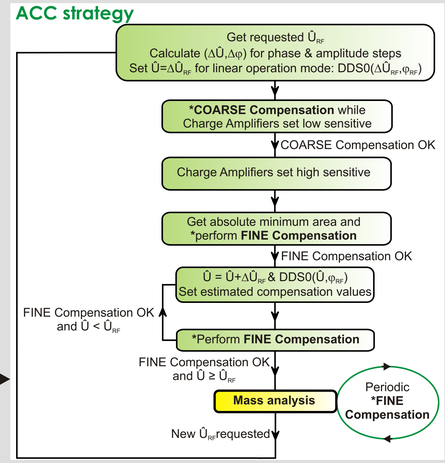




$\hat{I}_{comp} = \hat{I}_K$ and φ around φ_{opt}

$(\Delta\hat{U}/\hat{U}_{opt})$ for $\hat{I}_{comp}$ around $\hat{I}_K$ and $(\varphi - \varphi_{opt})$ for φ around φ_{opt}

ACC strategy



*: DDS1 & DDS2 active

- The compensation response is linear in a given area around $(\hat{U}_{opt},\varphi_{opt})$
- The DDS compensation curve is close to the theoretical optimal compensation function
- Overloading of the charge amplifiers (AMP1 & 2) occurs out of a small area around $(\hat{U}_{opt},\varphi_{opt})$
- Non-linearity terms strongly increase with the overloading of the charge amplifiers
- ACC strategy should include coarse and fine compensation algorithms

Conclusions and outlook

Online cancellation of the strong crosstalk of the radio frequency storage source (RF) in a two-channel Electric Ion Trap is demonstrated by using an Automatic Crosstalk Compensation (ACC) based on DDS techniques designed for Fourier Transform Mass Spectrometry. The ACC-unit also includes a high quality low drift Radio Frequency generator.
This method allows the use of high sensitive wideband and low noise charge amplifiers for ion image current detection.
ACC starts with a 3-dimensional COARSE Compensation map for a given RF-Amplitude to locate the optimal compensation area while the charge amplifiers are switched low sensitive to avoid overloading. The optimal compensation grade is maintained by a periodic FINE Compensation task.

ACC also considerably increases the dynamic range of the mass analysis by keeping low the input noise level of the charge amplifiers.
An adaptive ACC should bring more flexibility and allow faster changes of the RF-parameters.