Poster Reprint

ASMS 2018
WP-405

Ion Transmission Through Dual Field Tapered Multipoles: Cyclone Ion Guide and Vortex Collision Cell

Laura L. Pollum, Haopeng Wang, Kenneth R. Newton, Shane E. Tichy

Agilent Technologies, Santa Clara, CA

Introduction

High performance has been achieved in Agilent Technologies' reduced footprint Ultivo LC/TQ in part through next generation multipole technology.

The Cyclone ion guide[1] (which collects ions after they pass through the capillary and skimmer and transfers them to MS1) is made of a twisted and tapered dual field dodecahexapole, as shown in Figure 1.

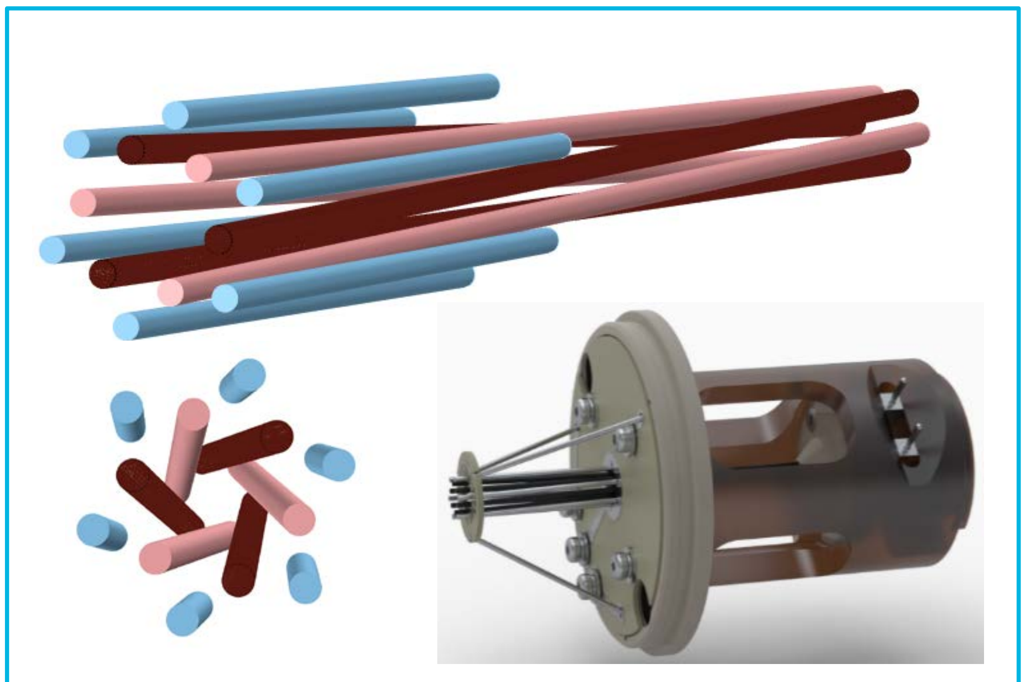

Figure 1. Cyclone ion guide electrodes, shown top and left. Outer rods are shown in blue. Inner rods are shown in pink and maroon. The full cyclone assembly is shown on the lower right.

The cyclone ion guide has a resistive inner hexapole energized with confining RF voltages and a DC bias voltage to prevent ion stalling. The inner hexapole is geometrically twisted and tapered, which enables phase space compression of the ion beam for efficient acceptance in to the quadrupole mass filter. The entrance end of the cyclone ion guide has superimposed outer rods that extend over only a fraction of the overall length. A second confining RF voltage can be applied to the outer rods.

The cyclone ion guide passes through three pressure stages, with a 10,000 fold pressure drop from the front to the back of the device.

As shown in Figure 2, applying two opposing phases of RF voltage to the inner rods produce a hexapole field, while applying one phase of RF voltage to the outer rods creates a dodecapolar field.

The optimization of the RF amplitude and frequency applied to the inner and outer rods is presented in this poster. Ion transmission as a function of inner and outer RF voltage amplitude is also shown. The inner and outer RF voltages are optimized to ensure efficient ion transmission across the mass-to-charge range of Ultivo LC/TQ.[2,3]

Experimental

Ion transmission across the RF amplitude and frequency space was characterized experimentally using two separate variable frequency RF voltage generators.

Ion abundances for Agilent Technologies ESI-L tuning mix ions (approx. *m/z*: 118, 322, 622, 922, 1222) ionized using an Agilent JetStream ion source in positive ion mode were recorded as a function of inner hexapole RF amplitude and frequency with no RF voltage applied to the outer rods. The inner hexapole RF voltage was generated using a variable frequency driver consisting of a signal generator and broadband power amplifier driving a tunable LC resonant voltage step-up circuit. During operation the signal generator is set to the chosen frequency and then the resonant circuit is manually tuned to that same frequency to efficiently generate the required voltage. Ion abundance at unit resolution for each *m/z* were recorded at each combination of RF amplitude and frequency.

Next, ion abundance as a function of outer rod RF voltage amplitude and frequency were recorded in a similar manner. During these measurements, the inner hexapole RF voltage amplitude and frequency was set to transmit ions across the *m/z* range, as ion signal is not observed without RF applied to the inner rods.

Finally, ion abundance as a function of inner and outer RF amplitudes at the optimized frequencies were recorded, with the inner and outer RF voltages generated resonantly using standard circuitry in Ultivo.

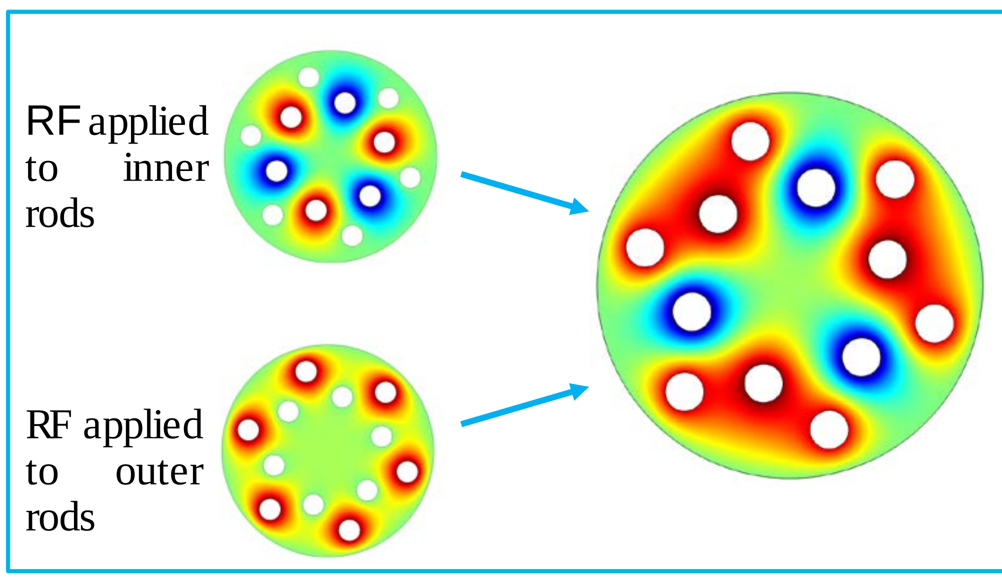

Figure 2. Electric potential within cyclone rod structure at one RF phase. Red is positive potential and blue is negative potential. The inner rods produce a hexapole field, and the outer rods interact with the inner rods to produce a dodecapole field.

Application of appropriate inner and outer RF voltages enables efficient transmission of ions across the mass to charge range of Ultivo.

Normalized ion abundance as a function of inner RF frequency and amplitude for ions with different mass to charge ratios are shown in Figure 3. With no RF applied to the outer rods, high frequencies show low abundance and therefore poor transmission efficiency for high mass over the amplitude range tested. At low frequencies, low mass to charge ions are lost at high amplitude.

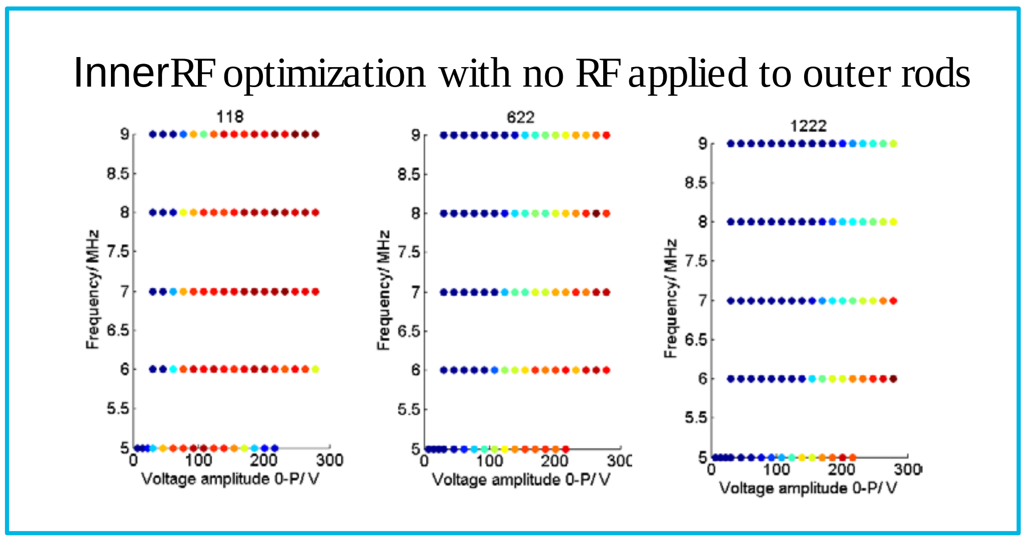

Figure 3. Normalized ion abundance through Cyclone ion guide as a function of Inner RF frequency and amplitude with no RF applied to outer rods. Deep red is maximum abundance and deep blue is zero signal.

Ion abundance as a function of outer frequency and amplitude are shown in Figure 4. The inner frequency and amplitude was fixed to a setting that transmits ions across the mass range. At high outer frequency, high amplitude RF confines across the mass to charge range. At low frequency, low mass to charge ions are lost

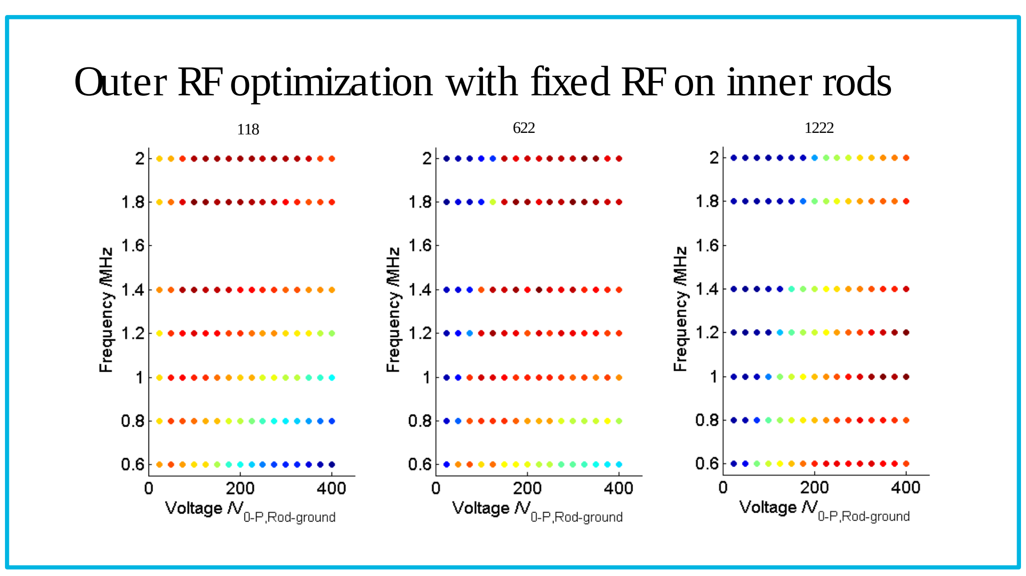

Figure 4. Normalized ion abundance as a function of outer RF frequency and amplitude applied to Cyclone ion guide. Deep red is maximum abundance and deep blue is low signal.

With the addition of an optimized RF voltage applied to the outer rods, the response of ions to the inner RF frequency and amplitudes changes, as can be seen by comparing Figures 3 and 5. The high *m/z* ion requires lower inner RF to transmit with high efficiency at high frequency when appropriate RF is applied to the outer rods. The low *m/z* ion transmission as a function of inner RF frequency and amplitude shows little change when the optimized outer RF is applied.

Thus, the presence of the outer RF helps to confine high *m/z* ions.

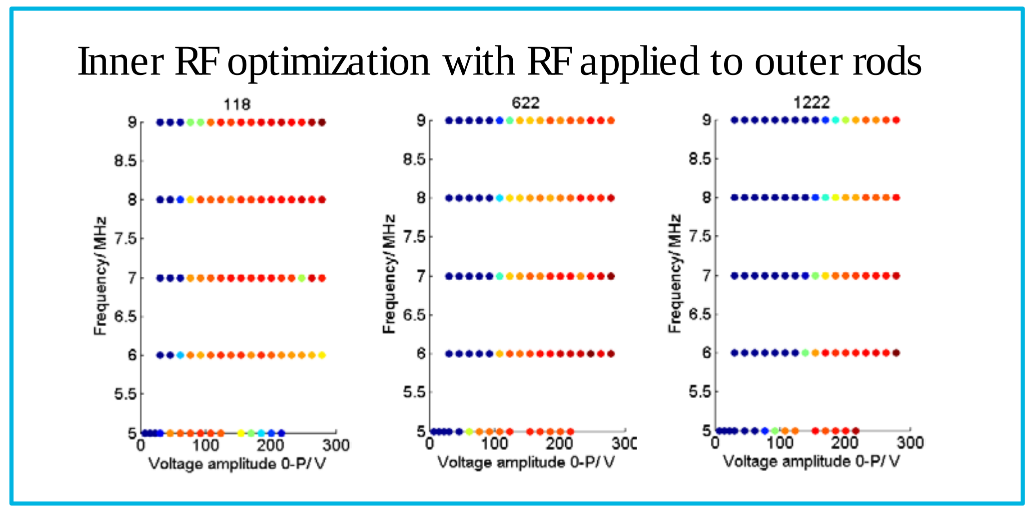

Figure 5. Normalized ion abundance through Cyclone ion guide as a function of Inner RF frequency and amplitude with optimized RF voltage applied to the outer rods. Deep red is maximum abundance and deep blue is zero signal.

Ion transmission as a function of inner and outer RF amplitude shows that achieving efficient transmission of ions through cyclone relies on confinement from both the inner and outer RF, as shown in Figure 6.

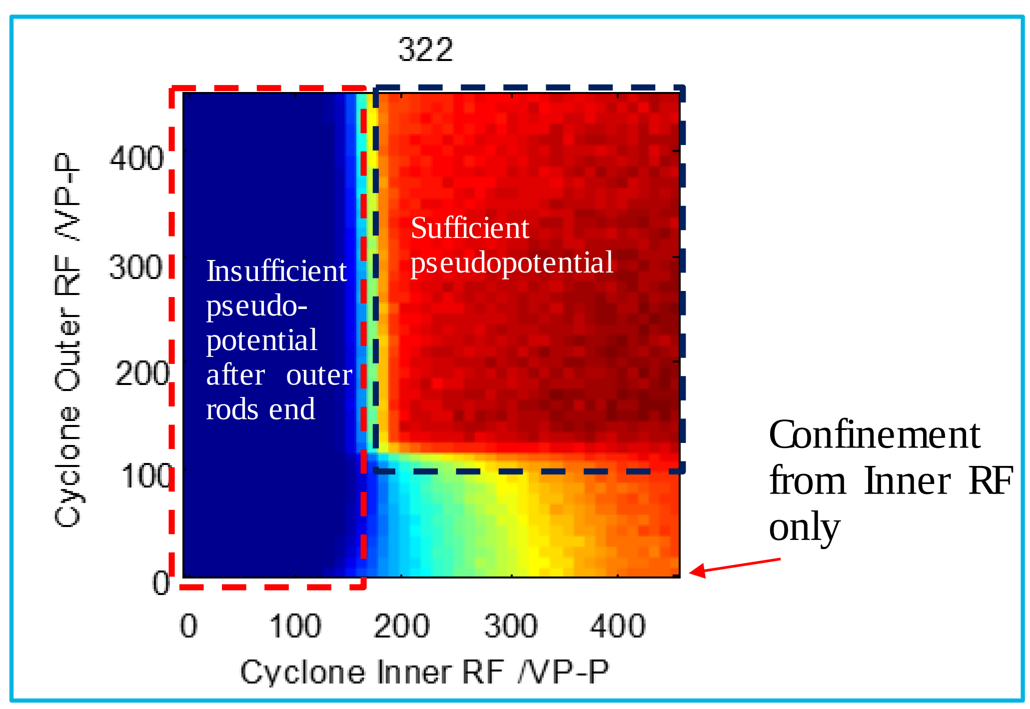

Figure 6. Normalized ion abundance as a function of inner and outer RF amplitudes in cyclone ion guide with overlaid explanation of features. Deep red is maximum abundance and deep blue is zero signal.

Results and Discussion

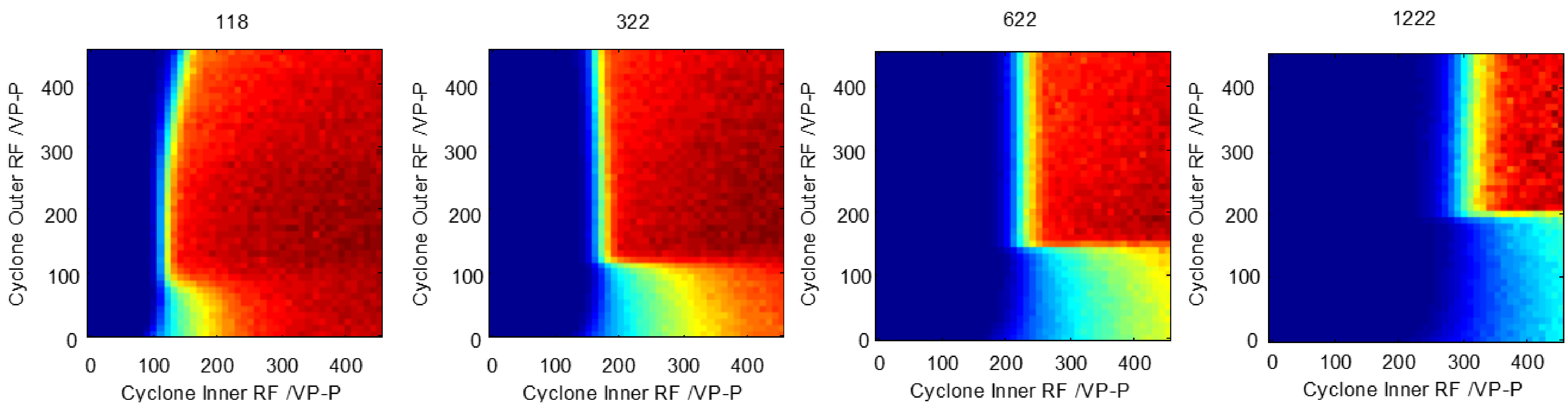

Figure 7. Normalized ion abundance as a function of inner and outer RF amplitudes in cyclone ion guide for several different *m/z*. Deep red is maximum abundance and deep blue is zero signal. High transmission efficiency for all ions across the *m/z* range of the instrument can be achieved with one combination of inner and outer voltages, indicating that a dynamic ramp of cyclone voltages is not necessary.

At low inner RF voltage, ions are not transmitted through the cyclone regardless of the voltage applied to the outer rods. This is because the outer rods extend over only a fraction of the overall length of the device, so ions will be lost after the outer rods end unless sufficient RF is applied to the inner rods.

At high inner and outer RF voltages, sufficient pseudopotential is provided to transmit ions with very high efficiency. Once sufficient pseudopotential is achieved, a broad and flat optimum is achieved with substantial overlap across the mass to charge range of the instrument. See Figure 7. Thus, one combination of inner and outer RF voltages can be applied to the cyclone to transmit all ions with no dynamic ramping required.

At high inner voltage and low outer voltage, pseudopotential from both the inner and outer rods contribute to radial confinement of the ions.

Mid-to-high mass-to-charge ions show a substantial improvement of transmission efficiency with at least moderate (>200 V_{P-P}) Cyclone outer RF voltage amplitude, which can be seen by comparing normalized ion abundance as a function of inner RF amplitude with no outer RF applied versus with high outer RF amplitude.

The enhancement observed from the outer RF is dependent on the mass-to-charge ratio of the ion, as shown in Figure 7. Low mass-to-charge ions achieve sufficient confinement from high amplitude inner RF only, while higher mass-to-charge ratio ions do not achieve sufficient confinement from the inner RF over the voltage range tested.

Conclusions

Cyclone ion guide is a dual field tapered multipole that provides efficient radial confinement and transmission of ions across the mass to charge range of Agilent Technologies' Ultivo LC/TQ

- Mid-to-high mass to charge ions show large transmission efficiency improvements in Cyclone ion guide when an appropriate RF voltage is applied to the outer rods. Lower mass to charge ions are well confined with only an appropriate inner RF voltage, so they show little change with increasing outer RF amplitude.
- The presence of the outer RF modifies the response of high mass to charge ions to voltage applied to the inner RF.

References

[1]Bertsch JL, Newton KR, Howard L. US Patent No. 9,449,804 B2. Sep. 20, 2016.

[2] Zekavat B, Pollum LL, Wang H, Nguyen H, Bui H, Tichy SE. ASMS Annual Concerence 2018.

[3] Batoon PM, Wang H, Zekavat B, Pollum LL, Tichy SE. ASMS Annual Concerence 2018. MOA am