Plasma Response to Amplitude Modulation of the Microwave Power on a 14 GHz Electron Cyclotron Resonance Ion Source

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Abstract

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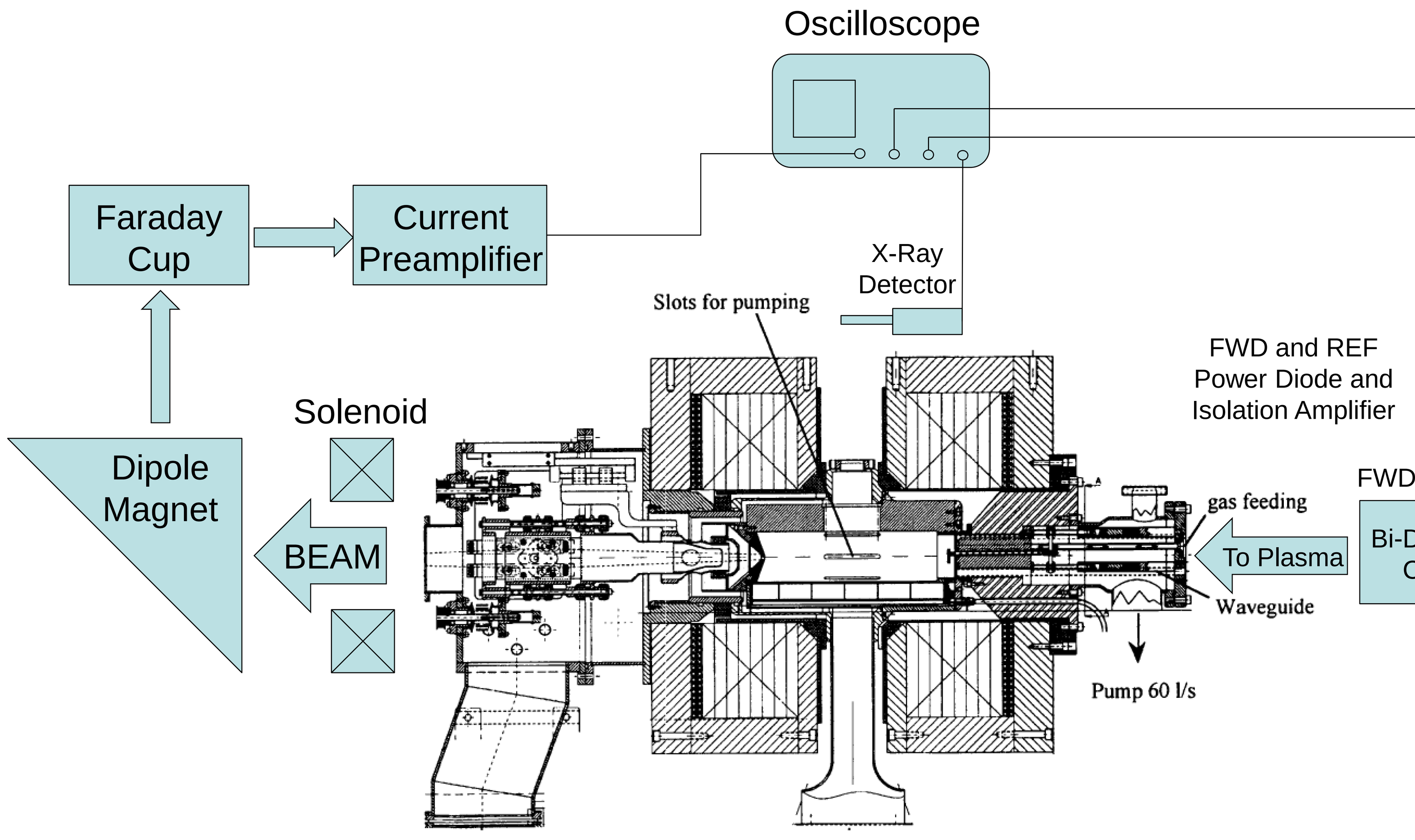
This paper reports the effects of sinusoidal microwave power Amplitude Modulation (AM) on the performance of Electron Cyclotron Resonance (ECR) ion sources. The study was conducted on the 14 GHz ECR ion source ECR2 at the University of Jyväskylä. The klystron output was intentionally altered by a variable frequency sinusoidal amplitude modulation. The average microwave power 350 W was modulated between 530 W and 180 W from 0.011-25 kHz. The integrated x-ray energy, the mass analyzed beam current and the forward and reflected microwave power were measured. The energy integrated x-ray signal responded linearly with microwave power and the modulation was no longer observable at approximately 2.2 kHz where signal strength became solely dependent on the time averaged power. Similarly, the beam current from the ECR ion source responded strongly to low frequency modulation, but the modulation amplitude decreased with increasing frequency beyond 400 Hz. The solenoidal magnetic field was found to play an important role in defining the largest AM frequency observable in the beam current. In all cases, the beam current amplitude modulation disappeared or was strongly suppressed for frequencies above 10 kHz regardless of source tuning, magnetic field, or charge state. Qualitatively, we found source tuning parameters for which AM effects were reduced also produced the highest currents of Ne^{8+} in Continuous Wave (CW) mode. Furthermore, these parameters are typically used for optimized beam injection into the K130 cyclotron. The dependency of beam current and the x-ray signal modulation on AM frequency for different magnetic fields are reported. A qualitative interpretation of the results will be given.

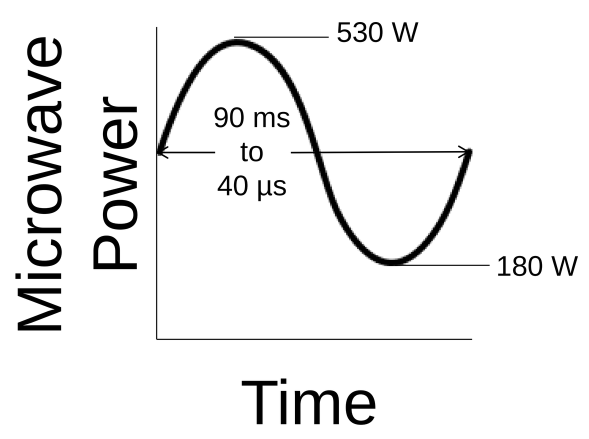
Introduction

We pursue the development of a novel perturbative method for probing electron and ion lifetimes that is less destructive than afterglow [1] and does not introduce metallic contaminants to the plasma [2, 3].

Experimental Set-Up

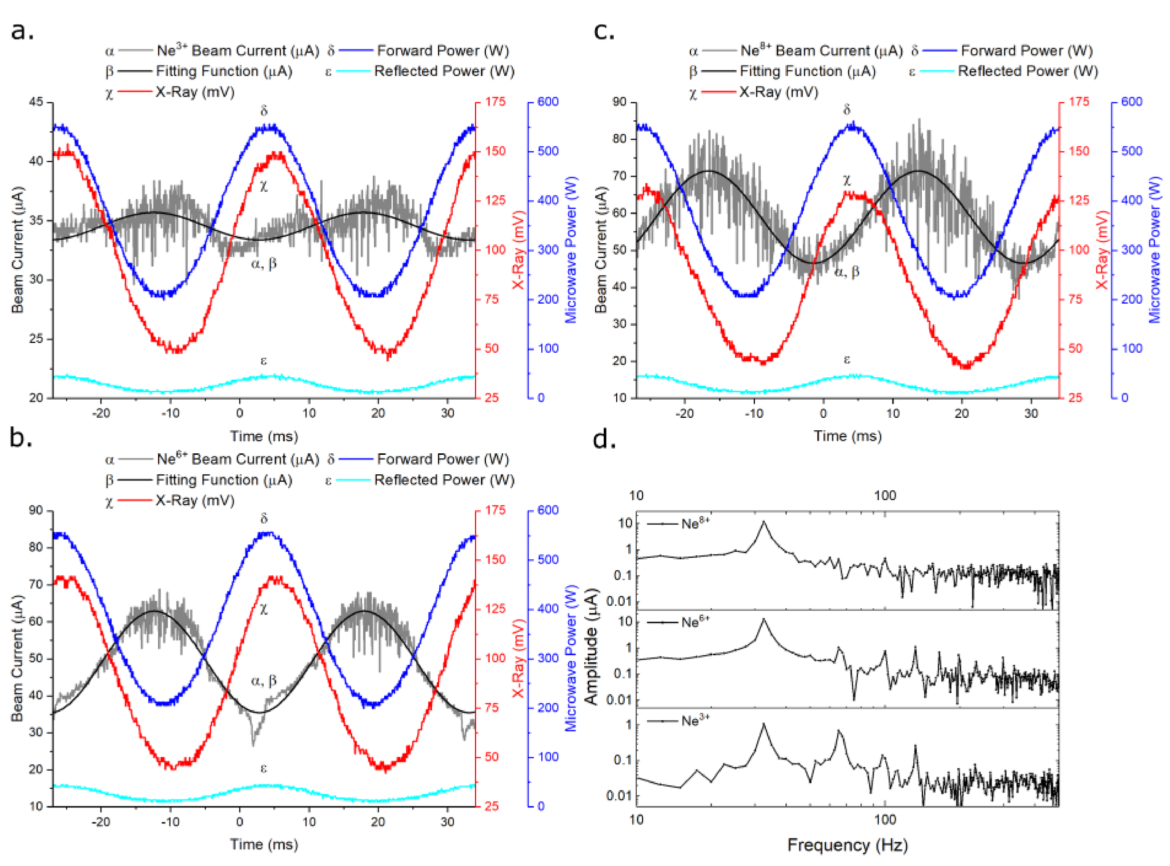
- 14 GHz Electron Cyclotron Resonance (ECR) Ion Source [4].
- Microwave power modulated with sinusoidal waveform.
- Beam current and energy integrated x-rays measured.
- Modulation frequencies increased exponentially until beam modulation was no longer observable.





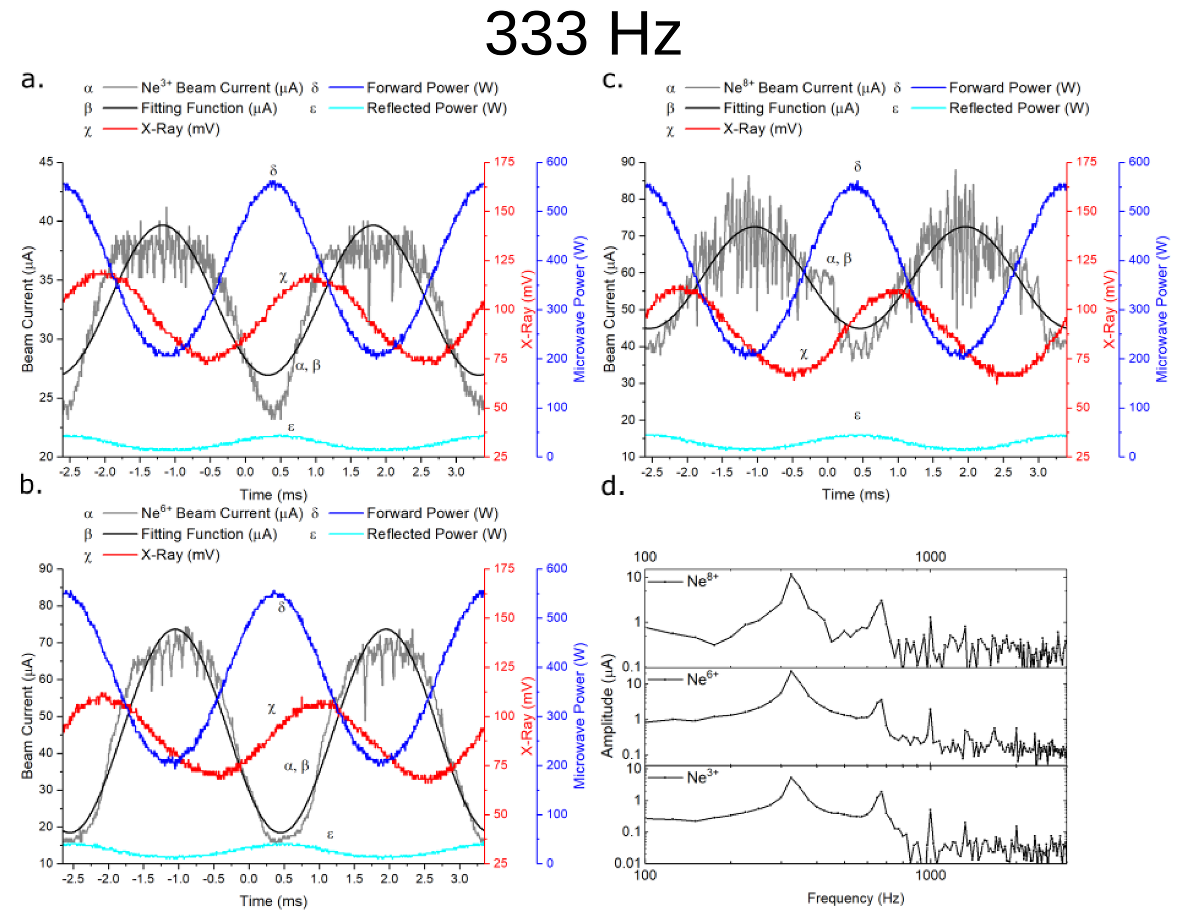
On Left: A schematic of ECR2 [4] and our experimental set-up. Mass resolved beam current was measured on a faraday cup and current preamplifier. Bremsstrahlung was sampled with a BGO scintillator and PMT operated in current (DC) mode [5]. Forward and reflected microwave power was sampled from a bi-directional coupler and measured individually with power diodes isolated with amplifiers of gain=1.

33 Hz



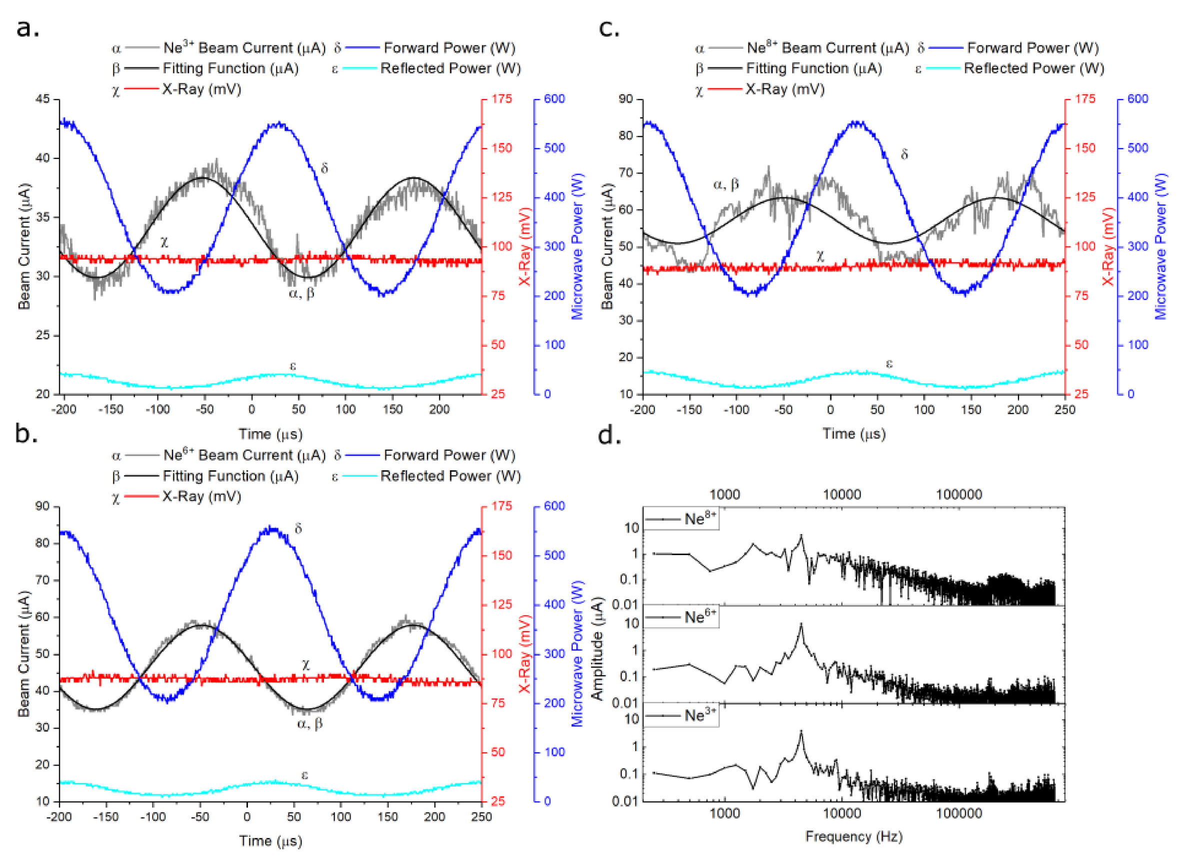
Above Left: Beam current of three charge states Ne^{3+} (a), Ne^{6+} (b), and Ne^{8+} (c) plotted together with the fitting function, microwave power, and x-rays responding at 33 Hz and for a magnetic field with B_{min}/B_{ecr} =0.78. FFT of beam current (d) is shown for the total sampled time of 400 ms.

333 Hz



Above Center: Beam current of three charge states Ne^{3+} (a), Ne^{6+} (b), and Ne^{8+} (c) plotted together with the fitting function, microwave power, and x-rays responding at 333 Hz and for a magnetic field with B_{min}/B_{ecr} =0.78. FFT of beam current (d) is shown for the total sampled time of 40 ms.

4440 Hz



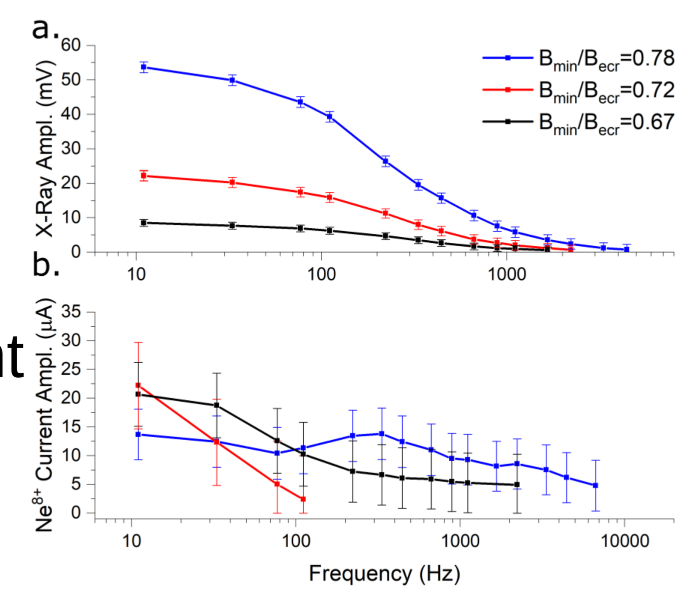
Above Right: Beam current of three charge states Ne^{3+} (a), Ne^{6+} (b), and Ne^{8+} (c) plotted together with the fitting function, microwave power, and x-rays responding at 4.44 kHz and for a magnetic field with B_{min}/B_{ecr} =0.78. FFT of beam current (d) is shown for the total sampled time of 4 ms.

Results

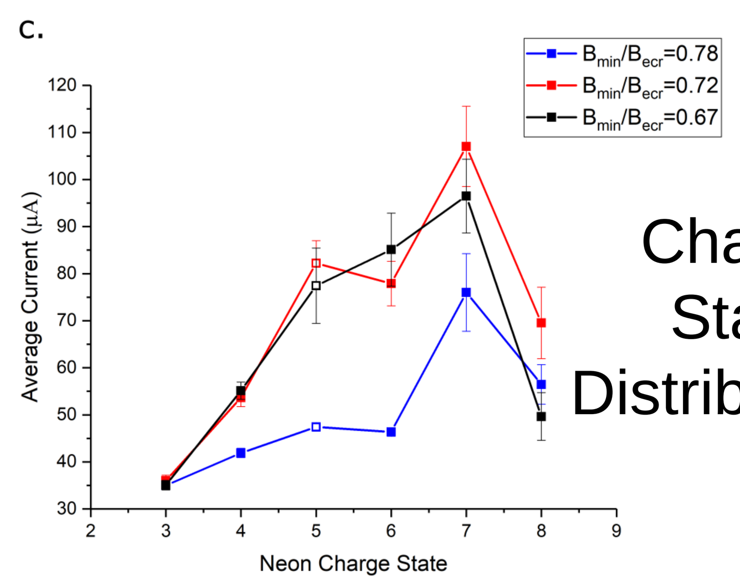
- X-rays oscillated up to a maximum frequency between 1.6-3.3 kHz regardless of magnetic field.
- Ne^{8+} current frequency response changed dramatically with magnetic field.
- The field that produced the most Ne^{8+} current stopped modulating at the lowest frequency.

X-Ray Amplitude

Ne^{8+} Current Amplitude



Charge State Distributions



On Left: X-ray amplitude (a) and Ne^{8+} beam current (b) as a function of applied modulation frequency for three different magnetic fields. Neon charge state distributions sampled at 350 W (for the same three fields) are shown in (c). The lines drawn between points are to aid the reader. Ne^{5+} has artificially more current because it overlaps with O^{4+} and is the reason for a different symbol.

Discussion

We observed the x-rays to follow the microwave power time delayed by around 0.5 ms. Its interesting to note that 2.22 kHz (oscillation period of 0.45 ms) was often the point beyond which no modulation was observable. Some estimates for electron lifetimes [6] are close to this value. As the plasma is modulated beyond about 2 kHz instabilities that arise on the crest of the beam current waveform no longer significantly appear. The frequency response of Ne^{8+} current changed significantly with magnetic field and interestingly the field that minimized beam current modulation, B_{min}/B_{ecr} =0.72 and generated the most CW current has an ecr zone that is 5.0 times the vacuum wavelength at the driving frequency of 14.056 GHz. It is possible that tuning the magnetic field for efficient heating produces a denser population of hot ion confining electrons (lowering potential dip) and suppresses Ne^{8+} modulation at higher frequencies.

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