Radio Frequency (RF) Trap for Confinement of Ion Plasmas in Antimatter Propulsion Systems Using Rotating Wall Electric Fields

Dr. William Herbert Sims III
NASA, Marshall Space Flight Center
Bldg 4487 / ED18
MSFC, AL 35812
(256) 544-8581
(256) 544-8483
herb.sims@msfc.nasa.gov

Abstract

Perturbations associated with a rotating wall enable the confinement of ions for periods approaching weeks. This steady state confinement is a result of a radio frequency manipulation of the ions. Using state-of-the-art techniques it is shown that radio frequency energy can produce useable manipulation of the ion cloud (matter or antimatter) for use in anti-matter drive propulsion systems. Current research into the feasibility of anti-matter propulsion systems for future deep-space flight as well as a detailed description and operation of the RF trap are explored.

Purpose of the Paper

The purpose of this paper is twofold. First, to incorporate existing RF technologies used exclusively in the communication regime into magnetic trap applications. This is accomplished by combining current RF methodologies with new and innovative techniques to increase the overall storage capabilities – the key enabling technology.

Second, to develop new design and fabrication techniques for the basic handling and manipulation of antiprotons. This is accomplished by proper transmission of RF and microwave power throughout the antimatter trap system.

Significance of Study

The annihilation of antiprotons with protons (P-P*) represents the highest energy density of any known reaction in modern physics. The typical conversion from matter to energy for the P-P* is 10^8 MJ/g, or 10 orders of magnitude above that of current chemical systems).

This energy density represent a very attractive energy storage means, with potential to significantly benefit NASA propulsion missions and is show graphically in Figure 1.

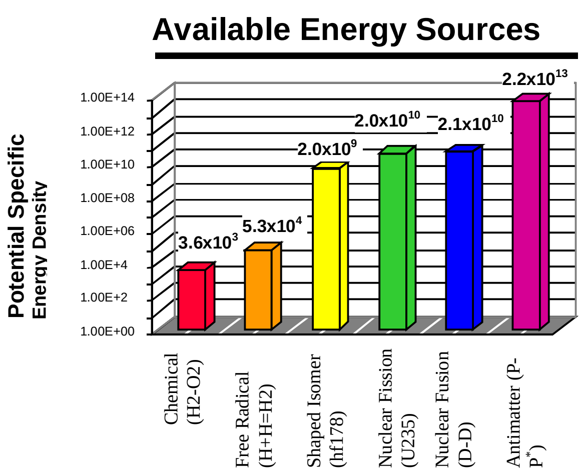

Figure 1. Available Energy Sources.

Summary

In this paper, innovative and unique methods are developed and known to overcome limitations of current state-of-the-art electromagnetic containment and manipulation of antimatter clouds. These methods include creation of new types of RF antennas that are capable of propagating an RF/microwave signal within the antimatter cloud. This unique subsystem was designed and developed using current Penning-Malmberg trap topologies as a model with significant modifications to allow the accurate transmission/reception of the RF signal.

With new results from this research incorporated into a Penning-Malmberg trap significant improvement in the control and manipulation of the antimatter cloud will be observed. This improvement is enough to have a large favorable impact on any system with a Penning –Malmberg trap using rotating electric fields.

History of the Penning-Malmberg Trap

The Penning-Malmberg trap concept has been in existence since the early *s. The trap incorporates static magnetic and DC electric fields along with an ultra-high vacuum (typically 10^{-11} torr range or lower. Figure 2 shows the classical Penning trap.

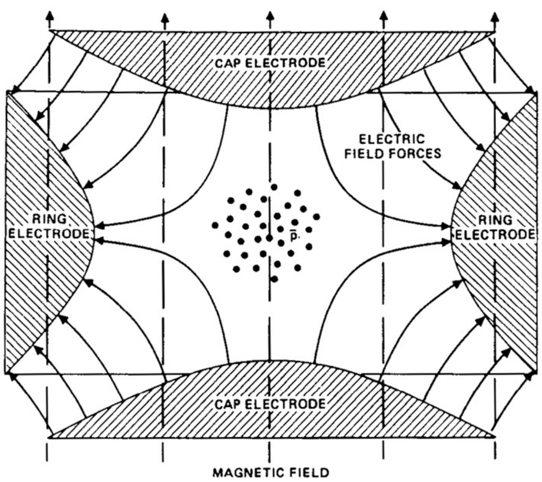

Figure 2. Classic Penning Trap.

The Penning Trap exhibits a hyperbolic electronic design, small spherical containment zone, and is typically used as a precision measurement device.

The Penning-Malmberg trap, show in Figure 3, is configured in a cylindrical shell design. The cloud forms an oblate spheroid (football shaped), and exhibits larger trap sizes with associated storage volumes.

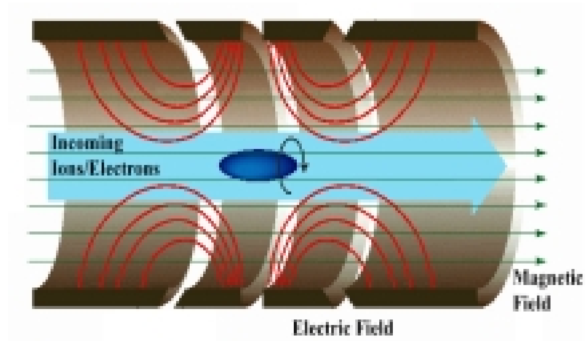

Figure 3. Penning-Malmberg Trap.

The High Performance Antiproton Trap (HiPAT) hardware, shown in Figure 4, uses a Penning-Malmberg layout and provided a capacity of 10^{12} antiprotons with a minimum storage lifetime of 18 days and is portable.

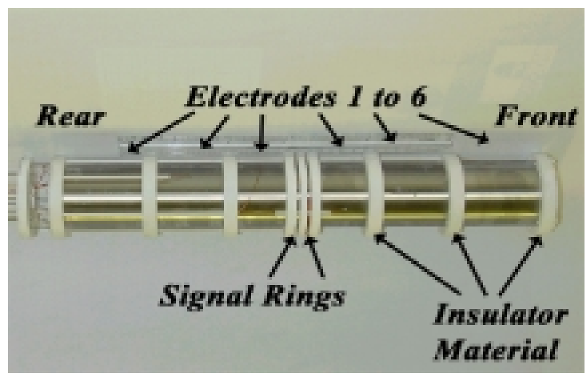

Figure 4. HiPAT Penning-Malmberg Trap.

The general features of the HiPAT trap include:

•A trapping region approximately 30-cm in length and 6-cm in diameter,

•A four Tesla magnetic field - by way of a superconductor magnet system,

• High voltage (25-kV) system, and

•A 10^{-11} Torr vacuum system.

Figure 5 shows how the high voltage system generates the antiproton containment zone.

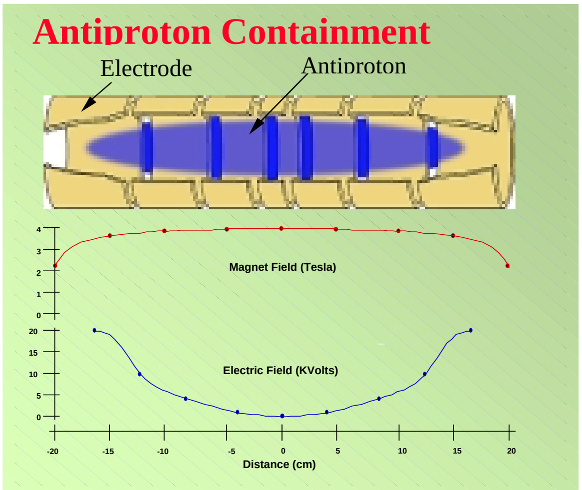

Figure 5. Antiproton Containment Zone.

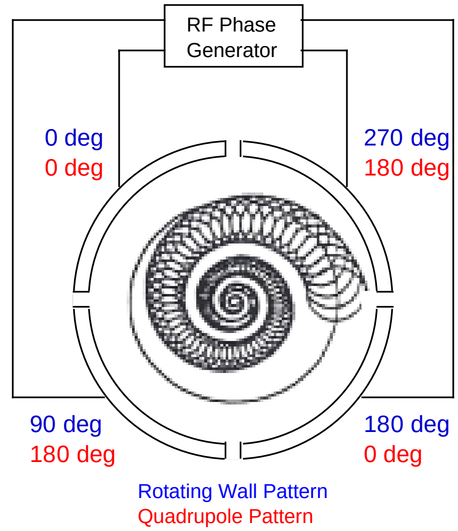

Figure 6. Rotating/Quadrapole Pattern.

Several fundamental motions (frequencies) exist for antiprotons trapped within the electromagnetic confinement region. They are Axial, Cyclotron and Magnetron/Rotational frequencies.

The axial frequency is caused by an oscillation within the high electric fields, is a function of the mass of the antiproton, and is on the order of 2-MHz in frequency.

The cyclotron frequency is caused by the circular rotation around a magnetic field line (Lorenz force), is a function of the magnetic field, ion charge and mass, and is on the order of 60-MHz.

The magnetron/rotational frequency is caused by the rotational drift around the trap axis, and is on the order of 30-KHz to 30-MHz.

The static confinement fields used within the typical Penning trap cannot maintain an ion indefinitely due to loss factors – most significant is increasing entropy of the system.

A process known as radio frequency stabilization provides the capability to reduce or eliminate diffusion and misalignment losses and also provides the required antiproton heating to minimize annihilation losses - this is accomplished by a rotating wall (or Quadrapole RF) in which selected frequency and amplitude adds energy to the system. As a result the ions are driven inward as energy is added to the system. Figure 6 shows both the rotating wall and Quadrapole patterns.

The RF subsystem is comprised of an RF signal generator to which a 90-degree hybrid coupler is connected. The outputs of the hybrid coupler are then fed into two baluns to generate the required 0-, 90-, 180-, and 270-degree RF signals. The four outputs from the baluns are then fed into a –6-dB directional coupler to the wall of the vacuum chamber. Internal to the chamber the coaxial cables are replaced with twisted pair Kevlar coated wire and then to the rings within the modified Penning-Malmberg trap. The –6-dB directional couplers are used to receive the signal emanating from the anti-proton cloud when it interacts with the transmitted signal. A simplified schematic is shown in Figure 7.

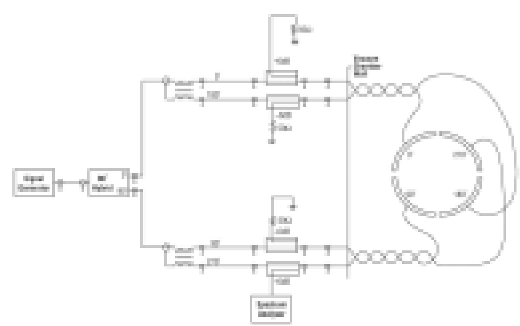

Figure 7. Modified Penning-Malmberg Trap with RF Pickup Subsytem.

A typical Penning-Malmberg trap uses two sets of RF rings. One set is for the transmitted signal, while the second set is used for the received signal. In the MSFC modified Penning-Malmberg trap a single set of rings that is capable of both reception and transmission of the RF signals is used. The directional couplers will allow the received signal from the antiproton cloud to be routed to either a spectrum analyzer or network analyzer for analysis. Figures 8 and 9 shows the MSFC modified Penning-Malmberg trap prior to incorporation into the ultra-high vacuum chamber.

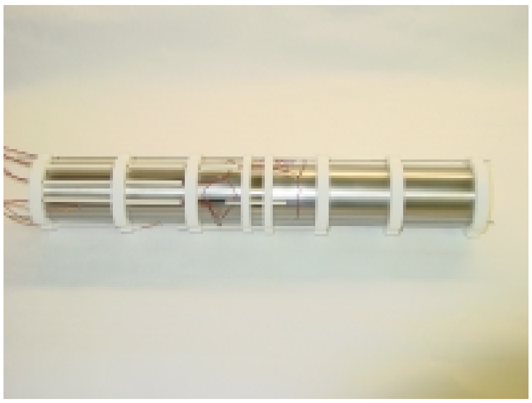

Figure 8. MSFC Modified Penning-Malmberg Trap.

Figure 9. Close-up of MSFC Modified Penning-Malmberg Trap.

Experimental Analysis

Summary

The actual modified Penning-Malmberg trap was designed and produced at the Marshall Space Flight Center. A systematic measurement program validated the theoretical aspects of the rotating wall methodology. Tests included *. From these measurements, the overall operation of the experimental system was found to agree favorably with computer simulations.

Recommendations

Overall, for a new design of a Penning-Malmberg trap, the outcomes were positive. In this paper, it was shown that **. To further exploit these results, three recommendations for future work are offered.

The first recommendation is the need to increase the long-term storage capability of the trap, the idea that shows the most promise is the radio frequency stabilization.

The second recommendation is to increase the sensitivity of the overall system to detect the axial, cyclotron and magnetron/rotational frequencies. Special techniques had to be incorporated trap configuration to generate realizable results.

The third recommendation is for more work on the advancement of higher voltage traps. Currently, the internal components within the trap begin to break down at * Volts.

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