

Development of the RF Blanket Feed Circuit

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Abstract

The feed circuit provides the electric field for the RF carpet in the cryogenic gas cell and is a key technology for achieving ion transport. Based on the transport principle and technical requirements of the multi-phase RF ion surfing method, we have designed a feed circuit for the RF carpet consisting of a signal source, power amplifier, phase-splitting circuit, and resonant circuit, which enables fast and efficient ion transport. Test results show that at a resonant frequency of 5.05 MHz, the circuit exhibits a voltage standing wave ratio (VSWR) of 1.41, a reflected power of less than 3%, an output amplitude of 160 Vpp, and a phase difference of $90.00 \pm 0.20^\circ$. Under room temperature conditions, with a helium gas pressure of 50 mbar, an RF signal amplitude of 90 Vpp, and a driving field voltage of 150 V, the ion transport efficiency reaches nearly 60%. This validates the feasibility of the circuit design and provides technical support for optimizing the cryogenic gas collection cell in multi-reflection time-of-flight mass spectrometers and for the study of short-lived exotic nuclei.

Full Text

Preamble

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1 引言

Introduction

The preparation of low-energy, high-quality radioactive ion beams serves as the foundation for precision nuclear spectroscopy techniques, including laser spectroscopy, Penning ion traps, and multi-reflection time-of-flight mass spectrometers (MRTOF-MS). These techniques are employed to measure fundamental parameters of radionuclides—such as charge radii, spins, magnetic moments,

electric quadrupole moments, and masses—which are of profound significance for investigating nuclear structure and exploring frontier scientific questions like the origin of the universe. The radionuclides under study are typically produced via nuclear reactions, resulting in products characterized by high energy and large emittance. Efficiently converting these products into low-energy, low-emittance beams and transporting them to measurement terminals remains a critical challenge in experimental nuclear physics research.

In the early 1980s, the University of Jyväskylä in Finland developed ion-guide technology based on the “He-jet” method and conducted a series of experiments using the Ion Guide Isotope Separator On-Line (IGISOL) facility. This device is regarded as the earliest iteration of the gas cell. In the subsequent forty years, multiple nuclear physics laboratories worldwide have constructed gas cells with various configurations tailored to their specific experimental requirements.

M. Wada has reviewed the developmental history of gas cells prior to 2013. Over the past decade, the “ion surfing” method has been successfully implemented and promoted, and cryogenic cooling technology has seen widespread application, leading to further advancements in gas cell technology (see Ref. [?] for details). The motion of ions within a gas cell can be divided into stages: collection (i.e., stopping), transport, and extraction. During the collection process, ions collide with buffer gas molecules and the energy degrader located at the front of the gas cell, gradually losing energy until they reach a thermalized state. The choice of buffer gas depends on the ion extraction requirements and subsequent experimental methods; in most cases, helium is used due to its high first ionization energy, allowing a certain proportion of low-charge-state ions to be extracted. In specific cases, other gases (such as argon) are selected, where the extracted ions are neutralized into atoms and must be re-ionized by lasers for subsequent experiments. In the earliest He-jet methods, ions were transported and extracted by the action of a supersonic helium jet; however, this method suffered from drawbacks such as large beam emittance and low transmission efficiency. To address this, static electric fields were introduced into the gas cells. Under the combined influence of the electrostatic field and the buffer gas, effectively stopped ions drift along the electric field lines, thereby increasing the transport speed and efficiency. To achieve efficient ion extraction from the gas cell, researchers have developed two primary methods: first, constructing a static electric field where the field lines focus at the extraction orifice; and second, utilizing radio frequency (RF) carpets and RF carpet technology, where ions are transported across the surface to the orifice for extraction.

The core component of an RF carpet consists of several parallel or concentric electrodes of equal width and spacing surrounding the ion extraction orifice. Adjacent electrodes are loaded with RF signals of frequency f , equal amplitude, and opposite phase. This configuration generates a field on the surface of the RF carpet of a specific magnitude.

$$V_{\text{eff, damp}} = \frac{q}{4m(\Omega^2 + D^2)} \cdot (E_x^2 + E_y^2) \quad (1)$$

Development of the Radio Frequency Carpet Feed Circuit

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Abstract

The effective potential (as shown in [Figure 1: see original paper]) is determined by the charge of the ion. This paper details the development and implementation of a specialized feed circuit designed for radio frequency (RF) carpets. The system is critical for the efficient transport and extraction of ions in nuclear physics experiments.

Introduction

In modern nuclear physics research, the precise manipulation of ion beams is essential for studying exotic nuclei and performing high-precision mass measurements. Radio frequency (RF) carpets have emerged as a vital technology for transporting ions from high-pressure gas cells to high-vacuum experimental regions. The performance of these carpets is heavily dependent on the stability and characteristics of the RF feed circuitry.

The average potential experienced by an ion in an inhomogeneous RF field is a function of the ion's charge state and the local field gradient. Specifically, for an ion with charge q , the effective potential Φ_{eff} can be expressed in terms of the electric field amplitude and frequency. Ensuring a uniform and controllable potential across the carpet surface requires a sophisticated feed circuit capable of driving complex capacitive loads while maintaining phase stability.

[Figure 1: see original paper]

Circuit Design and Implementation

The development of the RF carpet feed circuit focuses on achieving high-voltage output with minimal harmonic distortion. The circuit must provide multi-phase RF signals to the electrode strips of the carpet to create the traveling wave or pseudo-potential wells necessary for ion transport.

The feed system integrates high-frequency oscillators with power amplification stages. Impedance matching is a critical aspect of the design, as the RF carpet presents a highly capacitive load that varies with the physical dimensions and electrode density of the device. By utilizing resonant transformation networks, we have optimized the power transfer efficiency and ensured that the required voltage amplitudes are reached across the entire active area of the carpet.

Experimental Results

摘要

The feed circuit provides the electric field for the radio-frequency (RF) carpet within a cryogenic gas cell and is a critical technology for achieving ion transport. Based on the principles of the multi-phase ion surfing transport method and specific technical requirements, we have designed a feed circuit system for an RF carpet consisting of a signal source, power amplifiers, phase-shifting circuits, and resonant circuits. This system enables the rapid and efficient transport of ions. Experimental test results demonstrate that at the resonant frequency, the circuit...

5.05 MHz

When the standing wave ratio is VSWR, the output amplitude reaches...

160 V

The phase difference is 0.20° . At room temperature, when the helium gas pressure is 50 mbar, the signal amplitude is...

90 V

The driving field voltage is

150 V

The ion transmission efficiency approached 100%, validating the feasibility of the circuit design. This work provides technical support for optimizing cryogenic gas cells in multi-reflection time-of-flight mass spectrometers (MR-TOF-MS) and for the study of short-lived exotic nuclei.

关键词

Multi-reflection time-of-flight mass spectrometer (MR-TOF-MS); Cryogenic gas cell; Radio-frequency (RF) carpet; Feed circuit; Ion surfing. CLC number: O571.6 Document code: A

Nuclear Physics Review. Here, ω represents the angular frequency of the signal, β is the damping force constant, $E_{rf,\parallel}$ denotes the electric field component

within the plane of the RF carpet perpendicular to the electrodes, and $E_{rf,\perp}$ is the electric field component perpendicular to the RF carpet plane. The effect of this effective potential is to repel ions away from the surface of the RF carpet. To counteract this and maintain the ions in close proximity to the carpet, a static pushing field E_{push} directed toward the RF carpet is intentionally applied. The synergistic effect of an appropriately tuned E_{push} and the effective potential allows ions to “levitate” above the RF carpet surface. To transport these ions toward the extraction orifice, an extraction electric field must be applied parallel to the surface of the RF carpet. Currently, there are two primary schemes for applying this extraction field: the static electric field method and the traveling wave method.

In the former scheme, a potential gradient is generated across the RF carpet electrodes via a voltage divider circuit to transport ions toward the central extraction orifice. In the latter scheme, ions are transported by applying alternating electric fields to adjacent electrodes of the RF carpet. In the traveling wave approach, the variation of the voltage V_n on the n -th electrode is defined as:

$$V_{w,i} = V_w \cos\left(\omega_w t + \frac{2\pi i}{N}\right) \quad (2)$$

The amplitude of the alternating signal is A , the angular frequency is ω , and the wave speed of the traveling wave is:

$$v_{w,i} = Naf \quad (3)$$

d is the distance between the centers of two adjacent electrodes on the RF carpet. Ideally, the transport velocity of the ions is identical to the phase velocity of the traveling wave. The method of extracting ions using a traveling wave is known as “ion surfing.” Currently, there are two primary schemes for implementing ion surfing: one involves coupling an AC signal with a frequency of several hundred kHz onto the DC gradient signal to form a traveling wave; the other involves increasing the number of phases of the RF signal to directly generate the traveling wave. For clarity, we refer to the latter method as the “multi-phase RF method.” As indicated by Eq. (1), the ion transport velocity is proportional to the frequency of the traveling wave. Since the frequency of the RF signal is significantly higher than that of the AC signal, the multi-phase RF ion surfing method enables faster ion transport. Depending on the number of phases used, the method employing four distinct phases is specifically termed “four-phase RF ion surfing.” [Figure 1: see original paper] illustrates the voltage application scheme for this method.

The Institute of Modern Physics, Chinese Academy of Sciences, has constructed a Multi-Reflection Time-of-Flight Mass Spectrometer (MRTOF-MS) at the Spectrometer for Heavy Atoms and Nuclear Structure (SHANS). This device

consists of a cryogenic gas cell, an RF ion trap, and an MRTOF mass analyzer. An RF carpet is installed at the exit of the gas cell. In previous work, we successfully achieved ion extraction using the DC-gradient-based method. However, since higher ion transport velocities are more advantageous for the study of short-lived nuclides, we have developed a circuit specifically designed for “four-phase RF ion surfing.” This paper describes the design details and experimental test results of this circuit.

[Figure 1: see original paper] Schematic diagram of the voltage application method for RF ion surfing.

2 电路设计与测试

According to the principles of the four-phase ion surfing method, a sinusoidal signal with a frequency of several megahertz must be applied to the RF carpet electrodes, with a phase difference of 90° between adjacent electrodes. Simultaneously, a DC voltage must be applied to the electrodes to establish a potential gradient between the RF carpet and subsequent equipment. This gradient ensures that ions gain sufficient kinetic energy to be extracted from the gas cell.

[Figure 1: see original paper] shows a partial enlargement of the device. The RF carpet consists of a total of 160 concentric circular copper electrodes. The outermost electrode has a width of 380 mil (9.65 mm), while the central extraction hole has a diameter of 30 mil (0.76 mm). The electrodes situated between these two features have a width of 3.5 mil (0.09 mm) and a spacing of 5.5 mil (0.14 mm). Excluding the outermost layer, the remaining electrodes are divided into four groups. In the figure, “1, 2, 3, 4” represent the signal feed points for these four groups, used to load RF signals of different phases, while “DC” indicates the application of the DC voltage. To minimize gaseous impurities, the substrate for the RF carpet electrodes is made of Rogers 3034, which has a low outgassing rate. The capacitance of the RF carpet is approximately 0.5 nF. The feed circuit for the RF carpet, as shown in [Figure 2: see original paper], consists of a DC bias circuit, a signal source, a power amplifier, a phase-splitting circuit, and a resonant circuit. The latter four components together constitute the RF circuitry.

The DC bias circuit is composed of a DC power supply and resistors. In our tests, we utilized an EPp05127 power module. To prevent overcurrent, current-limiting resistors (R_1 - R_4) with identical resistance values are employed across the four channels of the power supply; these resistance values are determined by the current limit of the power source. The signal source for the RF circuit is a Keysight 33522B function generator, which produces two sinusoidal signals with equal amplitudes and a 90° phase difference. Because the output power of this function generator is relatively low, further amplification is required.

1 W

Zhong Zeping et al.: Development of the RF Blanket Feed Circuit. The amplitude is enhanced by a power amplifier with a supersaturated output power of 41.5 dBm (14.1 W) and a gain of 16 dB. The two amplified signals are processed through a phase-splitting circuit to form four signals with sequential phase differences of 90°. This phase-splitting circuit utilizes a Balun transformer to achieve conversion between single-ended and differential signals while simultaneously performing impedance matching. These four signals are each connected in series with an adjustable capacitor and then interfaced with the RF blanket electrodes. Given that the RF blanket acts as a capacitive load, the RF circuit employs a series resonance approach. By using capacitors to adjust the circuit impedance and resonance frequency, the standing wave ratio (SWR) and reflected power are minimized. This ensures that the amplitudes of the four output signals remain consistent, maximizing power transmission at the resonance frequency. To guarantee the efficient transmission of RF signals, this design incorporates two specific measures:

First, low-parasitic interconnection is achieved by using a direct, shortest-path connection between the RF/bias circuits and the vacuum feedthrough. This approach avoids unnecessary connectors and adapters, thereby minimizing parasitic parameters introduced by stray inductance and capacitance and ensuring effective signal coupling. Second, low-loss transmission lines are utilized for signal feeding from the feedthrough to the RF electrodes. Flat copper ribbons are selected to replace traditional round wires. The flat structure provides a larger conductor surface area, which significantly mitigates the skin effect of high-frequency currents. This effectively reduces the high-frequency resistance of the transmission path and minimizes thermal power loss during the transmission process.

4.30 V

The DC bias voltage is

10 V

the test results. According to the measurements obtained using the SARK-110 network analyzer, the resonant frequency of the circuit is

5.05 MHz

At this stage, the Standing Wave Ratio (SWR) of the circuit is SWR, and the reflected power ratio is less than 1% (where a lower reflected power indicates superior performance). During the testing process, the DC bias voltage was set to ...

10.0 V

The results of the fitting analysis performed on the output signals indicate that the bias voltages are 10.51 ± 0.02 V, 10.28 ± 0.02 V, 9.89 ± 0.02 V, and 9.88 ± 0.02 V, with a mean value of 10.14 ± 0.15 V. The radio frequency (RF) signal amplitudes were measured at 89.36 ± 0.05 V, 89.30 ± 0.04 V, 87.30 ± 0.04 V, and 84.80 ± 0.05 V, resulting in an average amplitude of 87.69 ± 2.15 V.

Regarding the phase relationships, the phase differences between RF1-RF2, RF2-RF3, RF3-RF4, and RF4-RF1 were $90.10 \pm 0.10^\circ$, $89.46 \pm 0.09^\circ$, $90.40 \pm 0.07^\circ$, and $90.04 \pm 0.08^\circ$, respectively, with an average phase difference of $90.00 \pm 0.20^\circ$. At the 1 dB compression point (where linear gain begins to decrease), the input powers were 24.6 dBm, 24.7 dBm, 24.6 dBm, and 24.7 dBm, yielding an average of 24.65 ± 0.06 dBm. The corresponding output powers were 36.3 dBm, 35.9 dBm, 36.2 dBm, and 35.9 dBm, with an average value of 36.08 ± 0.21 dBm.

[FIGURE:N] illustrates the relationship between the average output amplitude of the four-channel feed circuit and the set amplitude of the signal source. It can be observed that the average output voltage of the feed circuit increases nearly linearly as the signal source voltage setting increases, reaching...

160 V

The solid line represents the sine function fitting curve. The DC bias voltage setpoint is:

10 V

Signal source output amplitude setting:

4.3 V

line. The solid line represents the linear fitting results.

3 传输效率测试

To test the feeding circuit and verify the principles of the four-phase ion surfing method, we designed a test platform as shown in [Figure 1: see original paper]. The RF carpet circuit board is positioned between two annular pressure plates made of polyetheretherketone (PEEK). Located 10 mm directly beneath it is a stainless steel disk with a diameter of 80 mm, which serves to collect the ion beam extracted from the central hole of the RF carpet.

Nuclear Physics Review: A stainless steel disk with a diameter of 270 mm is positioned 50 mm directly above the carpet to serve as a pushing field electrode. This electrode generates a vertically downward pushing field E_{push} to direct ions toward the surface of the RF carpet. A surface ion source is suspended beneath the pushing field electrode, with the source body offset by 30 mm from

the central axis of the RF carpet's extraction hole. For the tests described in this paper, we utilized a cesium ion source from HeatWave Labs to provide Cs^+ . To determine the emission intensity of the ion source, a copper plate measuring $154 \text{ mm} \times 80 \text{ mm}$ was added between the pushing field electrode and the RF carpet. This plate is connected to a telescopic rod; it is moved directly under the source body when measuring the ion source intensity and retracted to the edge of the test chamber during experiments to allow ions to move toward the RF carpet surface.

The aforementioned components are integrated into a single unit using several insulating pillars and placed within a test chamber measuring $584 \text{ mm} \times 384 \text{ mm} \times 318 \text{ mm}$.

To minimize the probability of ions being neutralized through charge exchange with impurity gases during transport, 99.999% pure helium gas was used during the tests. Additionally, the system is equipped with a Leybold TURBOVAC 450i molecular pump and an Edwards nXDS20i dry pump as its backing pump, achieving a background vacuum of 10^{-5} Pa in the chamber. When helium is fed into the system, the high-vacuum gate valve between the molecular pump and the dry pump is closed, and the molecular pump is stopped. The helium feeding method follows the procedure described in [\cite{ref_{source}}](#), and the chamber pressure is controlled by finely adjusting a gas valve (not shown in the figure). The feeding circuit shown in [\[Figure 2: see original paper\]](#) is connected to the RF carpet electrodes via feedthroughs.

The ion extraction efficiency is defined as

$$\eta = \frac{I_c}{I_s} \quad (4)$$

The ion source current and the extracted ion current were measured using two Keysight 6485 picoammeters. According to the principles of the four-phase method, the primary factors influencing ion extraction include the amplitude and frequency of the RF signal, the voltage applied to the driving field electrodes, and the helium gas pressure. Since the primary objective of this study is to verify the feed circuit and the underlying principles of the method, tests were not conducted across a range of different pressures; instead, a standard operating pressure of 50 mbar was selected.

[\[Figure 1: see original paper\]](#)

The experimental results illustrating the relationship between extraction efficiency, driving field electrode voltage, and RF signal amplitude at 50 mbar are shown in [\[Figure 1: see original paper\]](#). The frequency of the RF signal is intrinsically linked to the specific electronic components and stray capacitances within the circuit, making it difficult to adjust arbitrarily; consequently, frequency variation was not addressed in this test. Furthermore, taking into account the high-voltage breakdown characteristics of helium, the maximum values for the

input RF signal amplitude and the driving field voltage were constrained during testing to ensure stable operation.

150 V

The signal frequency at 50 mbar is

5.05 MHz

The relationship between extraction efficiency and the variation of the driving field electrode voltage and RF signal amplitude is shown. The horizontal axis represents the signal amplitude, while the vertical axis represents the extraction efficiency. The black squares, red circles, and blue triangles correspond to driving field electrode voltages of...

150 V

The error bars in the figure represent statistical errors. The results indicate that for a fixed pusher electrode voltage, the extraction efficiency increases as the RF signal amplitude increases. Specifically, when the amplitude is low, the repulsive force generated is weaker than the pushing force from the pusher field, causing a portion of the ions to collide with the RF carpet surface and result in losses. As the amplitude increases, the repulsive force and the pusher field force reach a balance, pushing more ions away from the RF carpet surface and thereby improving the ion extraction efficiency.

Furthermore, when the pusher field voltage is increased, the driving force moving the ions toward the RF carpet surface is enhanced. This reduces the number of collisions between the ions and the helium gas, which in turn lowers the probability of ion neutralization, leading to a higher extraction efficiency. As can be seen from the figure, when the RF signal amplitude reaches...

90 V

The dynamic field voltage is

150 V

At this stage, the extraction efficiency is approximately . In the current test, the ion transport time could not be measured because temporal information for the ions was unavailable. This investigation will be conducted in future work.

4 结论

Based on the principles and requirements of the four-phase ion surfing method, this study successfully loaded radio frequency (RF) signals and DC bias signals onto RF carpet electrodes by designing a custom feed circuit. This configuration

enables the rapid collection and efficient extraction of ions. At the resonance frequency...

5.05 MHz

At this point, the Voltage Standing Wave Ratio (VSWR) is low, and the reflected power is minimized.

Zhong Zeping et al.: Development of the RF Blanket Feed Circuit; the output amplitude has reached

160 V

At room temperature, with a helium gas pressure of 50 mbar and a radio frequency (RF) signal amplitude of 90 V, the phase difference is 0.20°.

90 V

The driving field voltage is

150 V

the ion transmission efficiency of the radio-frequency (RF) carpet. Experimental results demonstrate that the feeding scheme proposed in this paper is feasible. In future work, we will gradually apply this scheme to the Multi-Reflection Time-of-Flight (MRTOF) mass spectrometer to achieve high-efficiency separation and measurement of short-lived nuclides.

参考文献

ÄRJE J, VALLI K. Nuclear Instruments and Methods, 1981, 179(3):

533. DOI:

10.1016/0029-554X(81)90179-8 ÄYSTÖ J, ÄRJE J, KOPONEN V, et al. Phys Lett B, 1984, 138(5):

369. DOI:

10.1016/0370-2693(84)91919-1 ÄRJE J, ÄYSTÖ J, HYVÖNEN H, et al. Phys Rev Lett, 1985, 54:

99. DOI:

10.1103/PhysRevLett.54.99 WADA M. Nucl Instr and Meth B, 2013, 317: 450. DOI: 10.1016/j.nimb.2013.08.062 BOLLEN G. International Journal of Mass Spectrometry, 2011, 299 (2): 131. DOI:

BRODEUR M, GEHRING A E, BOLLEN G, et al. International Journal of Mass Spectrometry, 2013, 336: 53. DOI:

LUND K, BOLLEN G, LAWTON D, et al. Nucl Instr and Meth B, 2020, 463: 378. DOI:

KALEJA O, ANđELIć B, BLAUM K, et al. Nucl Instr and Meth B, 2020, 463: 280. DOI:

VARENTSOV V, YAKUSHEV A. Nucl Instr and Meth A, 2019, 940:

206. DOI:

DROESE C, ELISEEV S, BLAUM K, et al. Nucl Instr and Meth B, 2014, 338: 126. DOI:

PURUSHOTHAMAN S, REITER M P, HAETTNER E, et al. Europhysics Letters, 2013, 104(4): 42001. DOI: 10.1209/0295-5075/104/SCHURY P, WADA M, ITO Y, et al. Nucl Instr and Meth B, 2017, 407: 160. DOI:

HIRAYAMA Y, WATANABE Y, IMAI N, et al. Nucl Instr and Meth B, 2013, 317: 480. DOI:

HERFURTH F, DILLING J, KELLERBAUER A, et al. Nucl Instr and Meth A, 2001, 469(2): 254. DOI: 10.1016/S0168-9002(01)00168-1 WEISSMAN L, MORRISSEY D, BOLLEN G, et al. Nucl Instr and Meth A, 2005, 540(2): 245. DOI:

SAVARD G, CLARK J, BOUDREAU C, et al. Nucl Instr and Meth B, 2003, 204: 582. DOI: 10.1016/S0168-583X(02)02134-1 WADA M, ISHIDA Y, NAKAMURA T, et al. Nucl Instr and Meth B, 2003, 204: 570. DOI: 10.1016/S0168-583X(02)02151-1 SCHWARZ S. International Journal of Mass Spectrometry, 2011, 299 (2-3): 71. DOI:

RANJAN M, PURUSHOTHAMAN S, DICKEL T, et al. EPL (Europhysics Letters), 2011, 96(5): 52001. DOI: 10.1209/0295-5075/96/5 ZHANG Z, MA L, GAN Z, et al. Nucl Instr and Meth B, 2013, 317:

315. DOI:

WANG J Y, HUANG W X, TIAN Y L, et al. Atoms, 2023, 11(11):

139. DOI:

Wang, Y. S. *Research and Development of Cryogenic Gas Catcher for Fusion Evaporation Reactions*. Lanzhou University, 2023 (in Chinese).

Kong, X., Wang, Y. S., Tian, Y. L., et al. *Nuclear Instruments and Methods in Physics Research Section A*, 2026: submitted.

MACK R A, SEVICK J A. Sevick' s transmission line transformers:

Theory and practice[M/OL]. 5th ed. The Institution of Engineering and Technology, 2014. DOI: 10.1049/SBEW513E LEONG Y C, ANG K S, LEE C H. A derivation of a class of 3-port baluns from symmetrical 4-port networks[C/OL]//2002 IEEE MTT-S International Microwave Symposium Digest (Cat. No. 02CH37278): volume 2. IEEE, 2002: 1165. DOI: 10.1109/MWSYM.2002.10118 ANG K S, LEONG Y C, LEE C H. IEEE Transactions on Microwave Theory and Techniques, 2003, 51(3): 1009. DOI: 10.1109/TMTT.2 HUANG W X, WANG Y, ZHU Z C, et al. HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS, 2006, 30(3): 261.

Development of a Power Feeding Circuit for RF Carpet

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Introduction

In modern nuclear physics research, the efficient extraction and transport of radioactive ion beams are critical for studying the properties of nuclei far from stability. The Radio Frequency (RF) Carpet has emerged as a vital technology for transporting ions in high-pressure gas environments, such as those found in gas cells or recoil separators. By applying a combination of RF and DC electric fields to a series of micro-electrodes, the RF Carpet creates an effective potential that prevents ions from colliding with the surface while simultaneously guiding them toward an extraction orifice.

A significant challenge in the implementation of RF Carpets is the design of a power feeding circuit capable of delivering high-amplitude RF voltages with precise phase control across a large capacitive load. This paper details the development and characterization of a specialized power feeding circuit designed to meet these requirements, ensuring stable and efficient ion transport.

Circuit Design and Principles

The core function of the RF Carpet power feeding circuit is to provide two RF signals of equal amplitude but opposite phase (180° phase shift) to adjacent

electrodes. This creates the inhomogeneous electric field necessary for the RF repulsive force. Given the high capacitance inherent in the dense electrode structure of the RF Carpet, the circuit must be designed to handle significant reactive power while maintaining signal integrity.

RF Signal Generation and Amplification

The circuit utilizes a high-precision signal generator to produce the initial RF waveform. This signal is then split and passed through a phase-shifting network to generate the required differential outputs.

Abstract

The power-feeding circuit supplies an electric field to the radiofrequency (RF) carpet inside a cryogenic gas cell and plays a key role in ion transport. Based on the principle and technical requirements of the multi-phase RF ion surfing method, we designed a set of system consisting of a signal generator, two power amplifiers, a phase-splitting circuit and a resonant circuit, which enables fast ion transmission with high efficiency. Test results show that at the resonant frequency of 5.05 MHz, the voltage standing wave ratio is 1.41, the reflected power is below 3%, the RF amplitude reaches 160 V and the phase difference is 90.00 0.20°. At room temperature, with the helium gas pressure of 50 mbar, the RF amplitude of 90 V, and the push field voltage of 150 V, the ion transport efficiency reaches nearly 60% that verifies the feasibility of the circuit design. This work provides technical supports for optimizing cryogenic gas cell in MRTOF-MS and thus studying exotic nuclides with short half-lives.

Key words: MRTOF-MS; cryogenic gas cell; RF carpet; power feeding circuit; ion surfing

Note: Figure translations are in progress. See original paper for figures.

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