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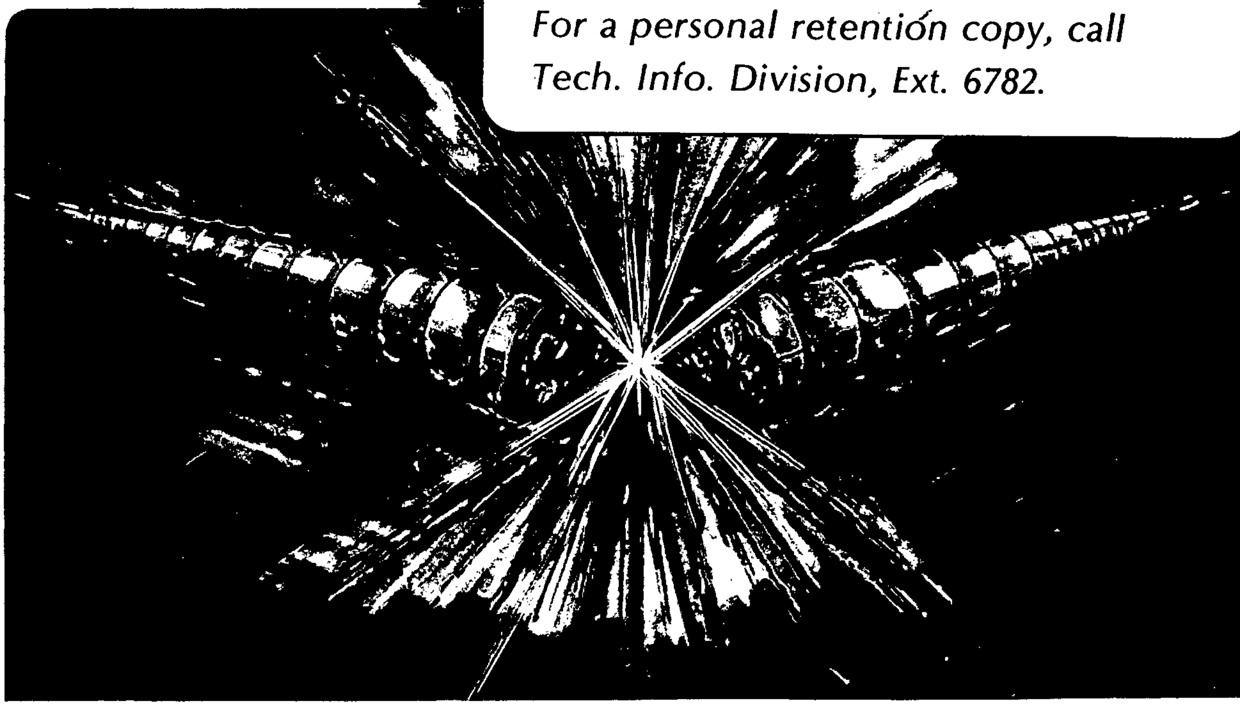

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LOOP COUPLING TO A RADIO FREQUENCY QUADRUPOLE RESONATOR (RFQ)*

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Abstract

Providing radio frequency energy to an RFQ resonator using a coupling loop instead of a slot gives more freedom in vane size design (smaller space occupied by the loop) and the possibility of tight coupling to ease operational problems.

Included is a discussion of various techniques to eliminate or separate the TE_{110} mode from the desired TE_{210} mode.

Results on a model designed to test these techniques will be discussed.

Introduction

The RFQ structure has attracted the attention of linac designers because of its unique ability to simultaneously bunch, focus, and accelerate low-beta ions.

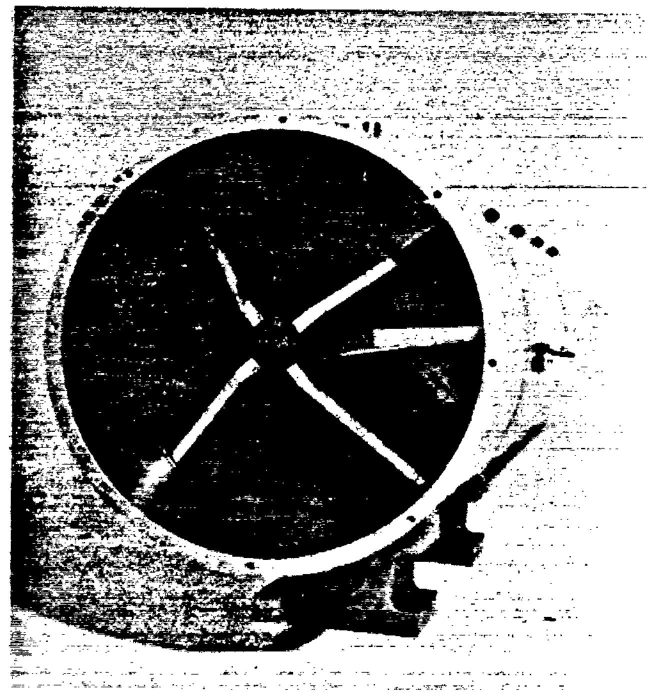
The recent successes at Los Alamos National Laboratory[1] have moved the RFQ through the stages of "exciting concept" to a practical accelerator.

Backed by a proven concept, the authors have attempted to simplify the construction and still maintain all the electrical properties of a practical accelerator by using the technique of loop coupling employed for driving most linear accelerating structures for ions. The advantages of loop coupling—small size, impedance matching, adjustable drive, phase locking, tight "resonant" coupling, etc.—have been demonstrated in the frequency range to ~400 MHz. Therefore, the purpose of these tests was to see if the RFQ resonator has properties which preclude this drive method, such as unwanted modes that are simultaneously excited with the quadrupole mode.

Besides the above-mentioned features of loop coupling, the small size of the loop would allow the utmost flexibility in vane shape design, cooling, and vacuum pumping. To explore possible problems with loop coupling, a simple model was constructed.

RFQ Test Model

The test model cavity is constructed from 8 inch-ID extruded-aluminum pipe. As might be expected, it is neither round nor longitudinally symmetrical. The pipe is "faced" to a length of 31.29 inches, and has twelve holes for inductive probes. There are three holes per quadrant which are equally spaced and longitudinally centered.



The vanes are 1/4-inch aluminum plate with the ends rough cut at 45° to the cavity wall, and are installed in quadrature with an RF gasket. The vane edges that make up the gaps are machined to make an inner radius, from the cavity center to the vane edge, of .519 inches. The vane ends are machined to be equidistant and .645 inches from the end walls.

The end walls are 1/8-inch aluminum plate with two tapped 1/4-20 holes that are placed 180° apart and centered over the vane ends to provide capacitive end tuning.

Although it is a very rough structure, the purpose of the cavity is to observe the various modes and affects upon them as modifications are made to the cavity, and different loop drive methods are employed.

Modes

Initial mode measurements are done with all probes oriented to drive or detect a longitudinal magnetic field. A sweep generator drives a center probe while other probes are checked for an amplitude response with a diode detector and log amplifier. Once the resonant frequency is determined, the cavity is driven CW while the probes are checked for relative phase and amplitude to determine the specific mode.

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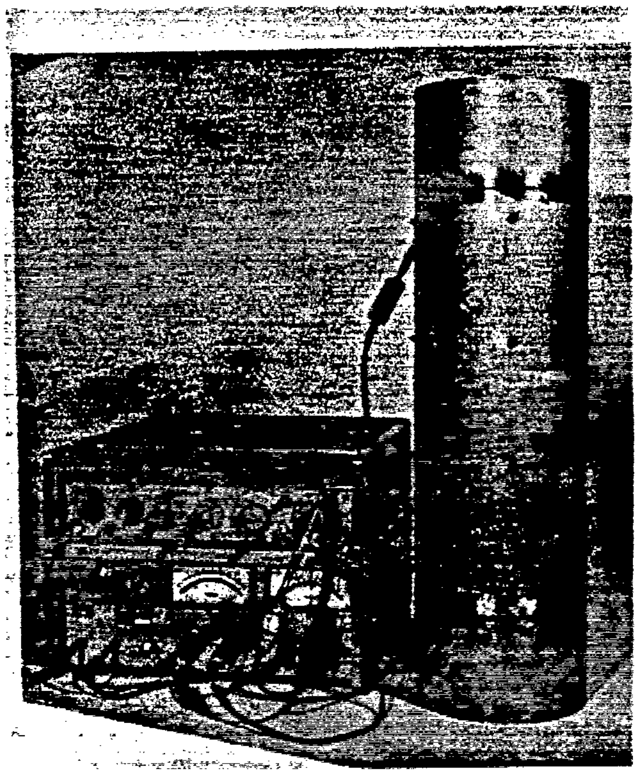
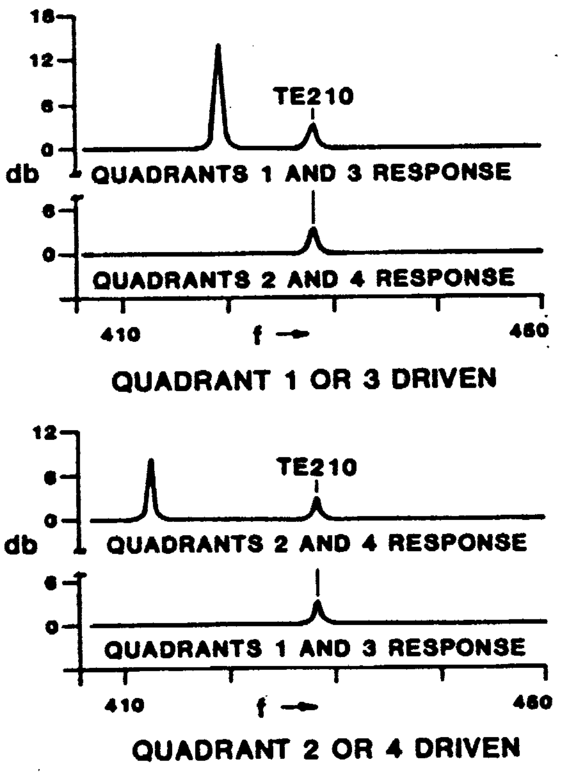


The untuned cavity exhibited three modes[2] with poor amplitude balance and no longitudinal phase changes. They were TE_{110} at 412.5 MHz, TE_{110} at 415.75 MHz, and TE_{210} at 428.5 MHz, as indicated by quandrant phases. This agrees well with the TE_{210} frequency calculated[3] for the model dimensions.



When aluminum tape was added to the appropriate cavity walls in an attempt to more closely balance the quadrant amplitudes in the TE_{210} mode, the TE_{110} modes disappeared, and two dependent modes appeared at approximately the same frequencies as their TE_{110} counterparts. These modes approximate the cross section of a conical line resonator,[4] and are dependent upon drive to one of the cones.

The aluminum tape was removed and closer balance was attempted by capacitively end loading the vanes by empirically adjusting the tuning slugs (1/4–20 bolts). The three original modes appeared with quadrant balance somewhat improved in the TE_{210} mode, and, as expected, the three modes were at lower frequencies.

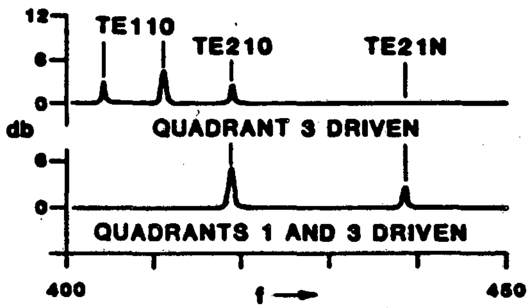
Dipole Mode Reduction

The effective elimination or reduction of a particular mode in a resonator can result from a simultaneous excitation pattern. With drive loops in opposite resonators of an RFQ, the quadrupole mode can be enhanced, and the dipole mode reduced. Quadrupole modes with longitudinal variations (TE_{21n}) can be reduced by driving with several loops spaced longitudinally. These could be excited using a resonant manifold.[5]

Model Test Results

To insure simultaneous drive to equally sized and oriented loops, both phase and amplitude must be matched at the input to the loops. This is accomplished by a phase-coherent power divider, equal cable lengths, and "in-line" attenuators at the loops. Drive phase relationships of 180° are satisfied by loop rotation.

Two methods of simultaneous drive were tried. The first, quadrature sections driven 180° out of phase, did little more than increase the amplitudes of the conical line resonator, TE_{110}, and the TE_{210} modes. The second method, opposite sections driven in phase, removed the conical line resonator and/or the TE_{110} modes, and, as expected, increased the amplitude in the TE_{210} mode. An unexpected, but not surprising, result was the generation of TE_{21n}, a longitudinal quadrupole mode. Since the two opposing sections are driven only at their centers, the longitudinal mode is not suppressed. Tests with longitudinally-spaced drive loops have not been done.



RESPONSE FROM ALL QUADRANTS

Mode Separation

In devices which depend on the proper excitation of several resonators (e.g., magnetrons), it is common to strap, or short together, points on the resonators with the same potential to insure proper excitation.

When properly excited and balanced, the opposite vanes of an RFQ should be at the same potential. Placing a strap between opposite vanes should not disturb the quadrupole mode, but should move the dipole mode to a far different frequency.

Model Test Results

One pair of opposing vanes were shorted at one end, as were their quadrature counterparts at the other end of the cavity. Shorting of both pairs of opposing vanes at one or both ends was not tried as it was felt capacitive end loading in a practical accelerator would be excessive. The result was apparent TE_{110} modes at each end, and longitudinal variation in the two opposing quadrants. Further investigation of this technique is planned.

References

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2 "An RF Power Manifold for the Radio Frequency Quadrupole Linear Accelerator," James M. Potter, Proc. of the 1979 Linear Accelerator Conference, Montauk, New York, (Sept. 1979) p. 138-143.

3 "An Analytical Solution for the Electrical Properties of a Radio-Frequency Quadrupole (RFQ) with Simple Vanes," H. Lancaster (see these proceedings).

4 "Fields and Waves in Modern Radio," Ramo and Whinnery, p. 440, D.

5 Ferd Voelker, private communication, September 1981.

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