DESIGN OF 4-8 GHz BUNCHED BEAM STOCHASTIC COOLING ARRAYS FOR THE FERMILAB TEVATRON

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Abstract--Pickup and kicker electrodes that function in the 4-8 GHz frequency range were designed for bunched beam cooling applications in the Fermilab TEVATRON. The electrodes are planar and are fabricated with photolithographic techniques on woven Teflon board. The electrodes also have a variable transverse aperture ranging from 0.75" to 4" to accommodate the changing beam size in the TEVATRON during acceleration. To accommodate the plunging action of the electrodes, a unique flexible microwave transition piece was also incorporated into the design.

I. INTRODUCTION

A prototype bunched beam betatron stochastic cooling system was built for the Fermilab TEVATRON to increase the beam lifetime by combating emittance growth [1]. The 4-8 GHz frequency band was chosen as a compromise between a high cooling rate and low bad mixing between pickup and kicker. A cooling system is comprised of microwave pickup and kicker electrodes and an amplifier chain between the pickup and kicker. This paper will concentrate on describing the design of the pickup and kicker electrodes.

II. PLANAR LOOPS

A bunched beam produces a large longitudinal coherent signal that could saturate the electronics in the amplifier chain. The pickup and kicker electrodes are both comprised of two identical arrays that are positioned transversely to the beam axis. One way to reduce longitudinal signal is to build the two arrays to be as identical as possible so that the longitudinal signal induced on side of the pickup is cancelled by the signal on the other side of the pickup. This requirement can be met if the arrays consist of planar loops [2]. Planar loops, which are formed with photolithographic techniques, can be held to very small mechanical tolerances. Also, since planar loops require very little machining, the fabrication costs of planar arrays can be less than more conventional stripline arrays.

As shown in Figure 1, the planar loop is fabricated on a woven Teflon circuit board and is a coplanar waveguide line composed of two slots in a ground plane oriented parallel to the beam. Terminating the coplanar waveguide is another set of transverse slots, one upstream and one downstream. In the center of both transverse slots is a via-hole that is connected to a microstrip line located on the reverse side of the ground plane.

The behavior of the planar loop is similar to the behavior of the microstrip loop. If the planar loop is acting as a pickup, the image current flowing on the ground planes is intercepted by the upstream and downstream slots forming a doublet response. The Fourier transform of a doublet response is:

$$Z(f) \propto \sin(2\pi f\tau) \qquad (1)$$

where τ is the effective transit time for a signal to travel from one end of the electrode to the other end. The response has a maximum when the loop is a quarter wavelength long. The 3 dB bandwidth of the response is about one octave.

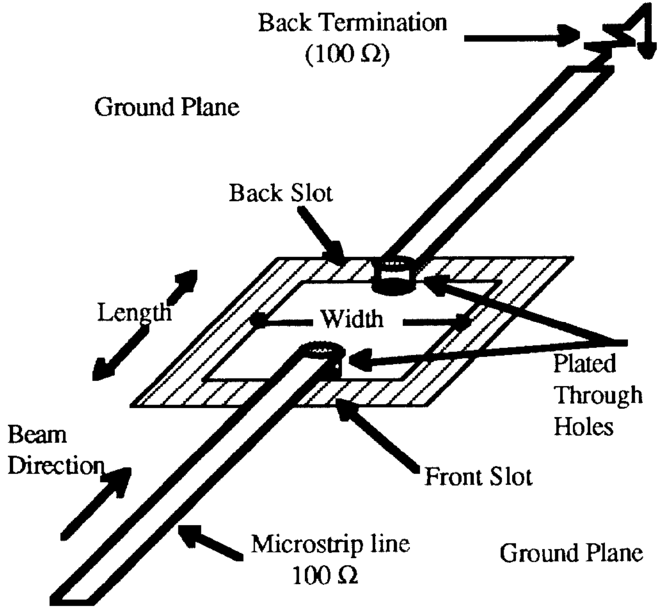

Fig. 1 Schematic view of a planar loop. The beam is on the other side of the ground plane.

The effect of pulse spreading [3] can be incorporated into the design by examining the image current density flowing on the ground planes surrounding the planar loop [2]. If the width of the slots in the ground plane is much smaller than a wavelength, then the slot lines may be modeled as non-dispersive transmission lines as shown in Figure 2. Since the field pattern in the slots is non TEM, the characteristic impedance of the slot lines is not uniquely defined. This paper will use the power impedance as the definition of the characteristic impedance of the slot lines. In the range from 4 to 8 GHz, a power impedance of 200 Ω and an effective dielectric constant of 1.2 can be obtained for a slot width of 1.9 mm patterned on a Teflon substrate thickness of 1.14 mm with a dielectric constant of 2.22.[4] Because the slot impedance changes very slowly with increasing slot width, impedances greater than 200 Ohms are difficult to obtain.

The width of the planar loop was made as large as possible to intercept the maximum amount of image current density flowing on the ground plane. The length of the planar loop was then adjusted so that the frequency response of the

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electrode has a maximum at 6 GHz. These dimensions are shown in Figure 3. The input impedance of the loop is 100 Ω. The back termination of the loop was tapered from 100 Ω to 50 Ω and terminated with a commercial stripline termination. The input reflection coefficient of a single planar loop was less than -15 dB across the entire 4-8 GHz band.

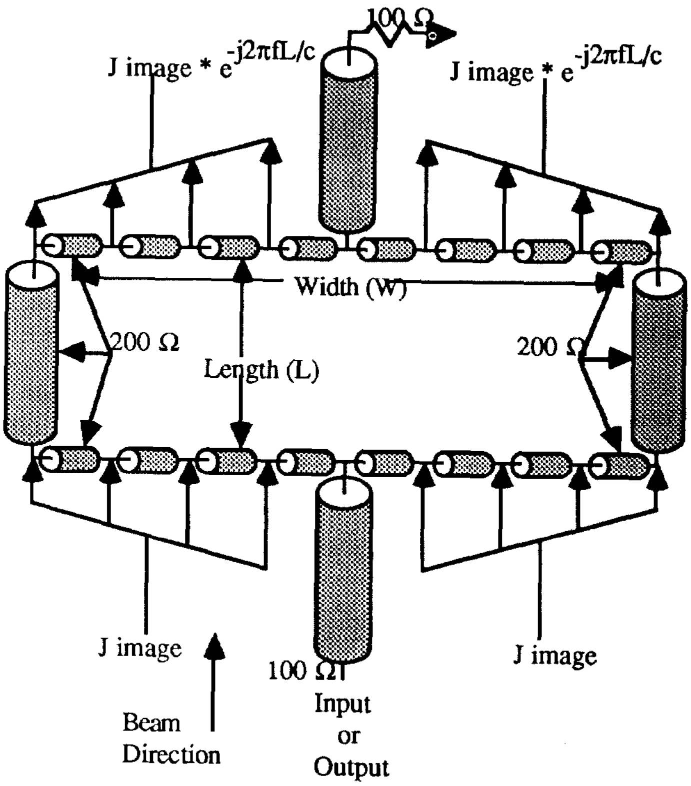

Fig. 2 Equivalent electrical circuit of a planar loop.

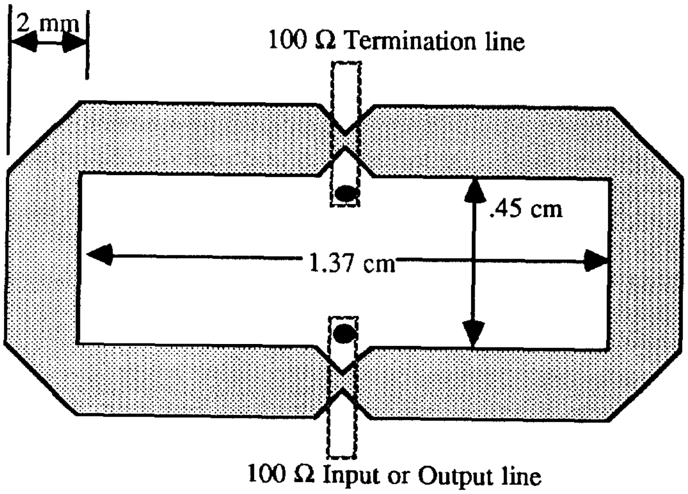

Fig. 3 Dimensions of planar loop used in the 4-8 GHz bunched beam cooling array.

III. ARRAY DESIGN

The array of planar loops is shown in Figure 4. The number of loops in an array is 16. On the reverse side of the array, the loops are combined in a binary tree as shown in Figure 5. The impedance transformation of 50-100Ω between different combiner levels are comprised of three 1/4 wave sections. Since a loop spacing greater than 1/2 wavelength will permit the combiner board to have a potential resonance in band, the spacing of the loops was selected to be 0.65 inches. This spacing is less than 1/2 wavelength for the entire 4-8 GHz band. The response of the array to a stretched wire measurement [3] is shown in Figure 6.

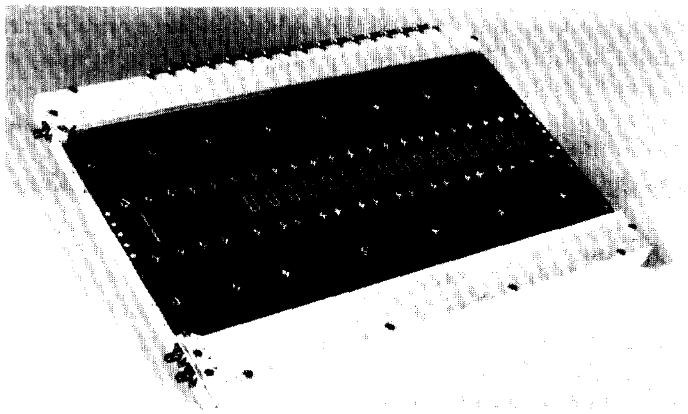

Fig. 4. Photo of 4-8 GHz planar loop array. This side faces towards the beam.

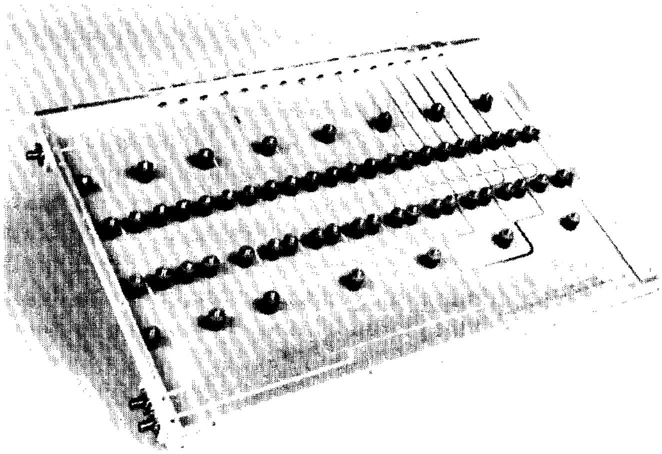

Fig. 5 Photo of the 4-8 GHz planar loop combiner board.

At the downstream end of each array are two beam position (BP) electrodes. The principle of operation of the BP electrodes is similar to the planar loops except that one of the slots at the end of the electrode is shorted. This makes the electrode sensitive to a beam travelling in either direction so that the position of both the proton and antiproton beams can be monitored simultaneously. The length of the BP electrodes was chosen so that the response has a maximum at about 200 MHz, which is close to a harmonic of the 53 MHz accelerating frequency of the TEVATRON.

The transverse separation between arrays in a tank can be varied from 0.75" to 4" so that the arrays would not scrape the beam during acceleration. The arrays were moved using a ball screw arrangement attached to a worm gear driven by a stepping motor. The transverse spacing resolution was well under 0.001".

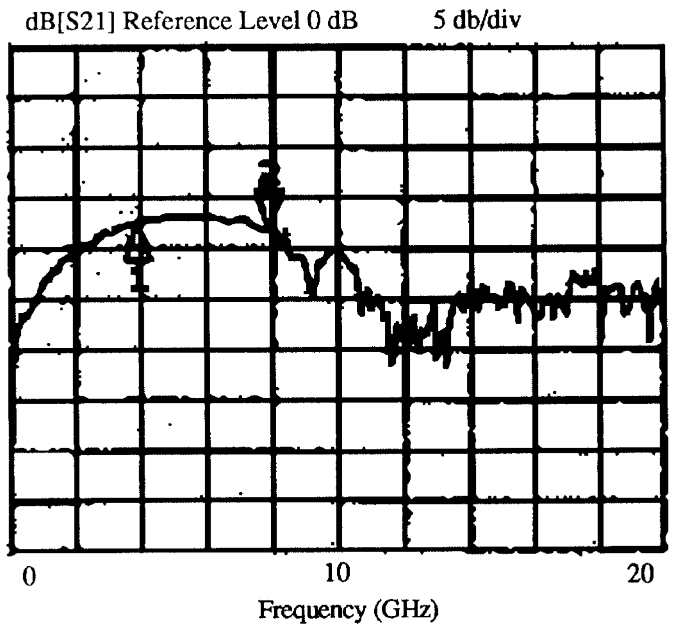

Fig. 6 Response of the 4-8 GHz array to a stretched wire measurement. Markers 1 and 2 border the 4-8 GHz band.

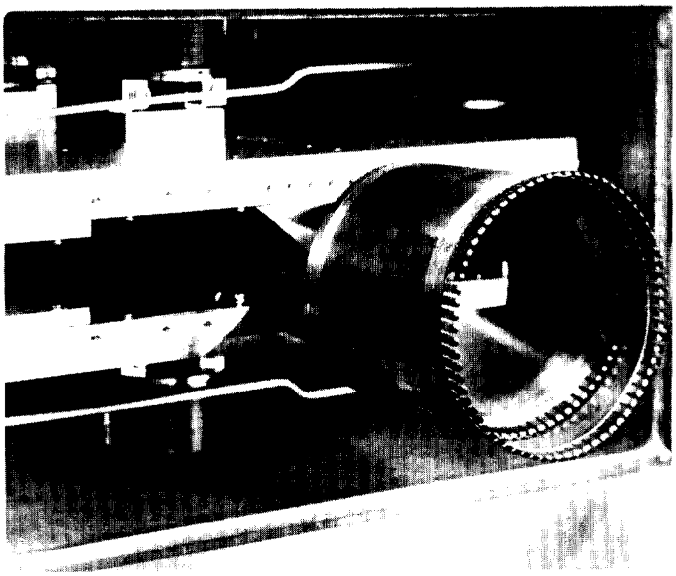

Fig. 7 End view of the stochastic cooling vacuum tank.

Microwave modes that could screen the Schottky signals will be excited if the image currents due to the beam encounter sharp discontinuities in the beam pipe. To minimize these effects, a flexible transition piece is placed between the ends of the array and the beam pipe as shown in Figure 7. The transition piece consists of a beryllium copper (BeCu) sleeve that fits over the bellows convolutions in the tank flange. Beryllium copper spring fingers line the edge of the sleeve to insure a conduction path for the image currents. Inside the sleeve is a pair of flexible BeCu flappers that transform the cylindrical geometry of the beam pipe to the parallel plate geometry of the array. The flexible flappers can follow the arrays throughout the entire range of motion.

To minimize the undesired microwave modes between the two arrays, a resistive material with an impedance of 300Ω/square was sprayed on a sheet of kapton and stretched between the two arrays as shown in Figure 7. Also, microwave modes inside the array are damped by placing ferrite washers around the screws as shown in Figure 5. Because these ferrite washers can be machined to tight tolerances, the washers also form the support for the teflon circuit board.

IV. RESULTS

An actual Schottky spectrum of a bunched beam in the TEVATRON is shown in Figure 8. More detail on the measurements can be found in Ref. 5.

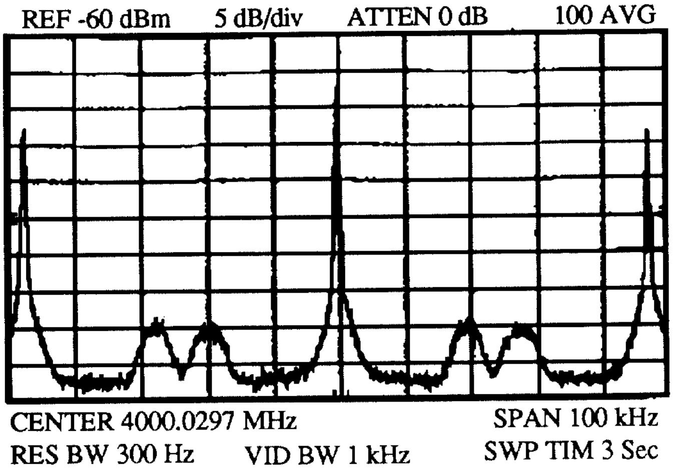

Fig. 8 Schottky signal response measured using the 4-8 GHz array. The lines at the center and edges of the graph are longitudinal lines. The other lines are the vertical betatron Schottky signals.

REFERENCES

1. G. Jackson "Bunched Beam Stochastic Cooling," Proceedings of this conference.
2. J. Petter, D. McGinnis, and J. Marriner,"Novel Stochastic Cooling Pickups and Kickers," Proceedings of the 1989 IEEE Particle Accelerator Conference, Vol. 1, 636, March 1989.
3. D. McGinnis, J. Petter, J. Marriner, and S. Y. Hsueh,"Frequency Response of 4-8 GHz Stochastic Cooling Electrodes," Proceedings of the 1989 IEEE Particle Accelerator Conference, Vol. 1, 639, March 1989.
4. R. Janaswamy, D. H. Schaubert, "Characteristic Impedance of a Wide Slotline on Low Permittivity Substrates," IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-34, No.8., 901-902, August 1986.
5. G. Jackson, etal. "A Test of Bunched Beam Stochastic Cooling in the Fermilab TEVATRON Collider," Proceedings of this conference.