PBAR NOTE 564

DEBUNCHER 4-8 GHZ PICKUP TESTS

Dave McGinnis

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Introduction

A 4-8 GHz slow wave slot pickup and a 2-4 GHz planar loop array pickup were installed in the 30 sector of the Debuncher. The purpose of this test was to measure the sum and difference mode sensitivities of these pickups. Both pickups were installed to measure vertical betatron oscillations. The 2-4 GHz array shown in Figure 1 is composed of sixteen 100 Ω loops so the maximum sensitivity is 1600 Ω.

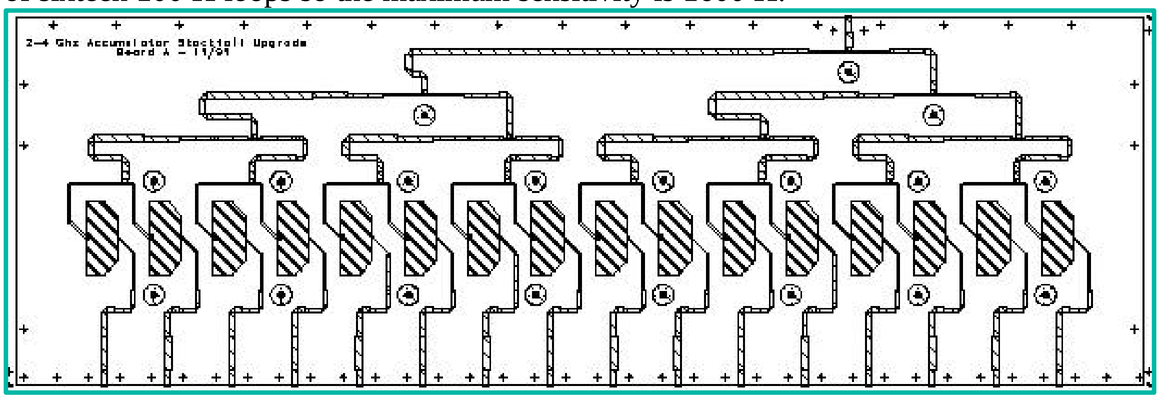

Figure 1. 2-4 GHz Planar Loop Array.

The 4-8 GHz slow wave slot pickup is shown in Figure 2. The pickup consists of 50 slots. The length of each slot is 0.690 inches and the width is 0.080 inches. The metal spacing between each slot is 0.120 inches. The waveguide height is 0.800 inches and the width is 1.600 inches. The beam pipe height and width is 1.600 inches.

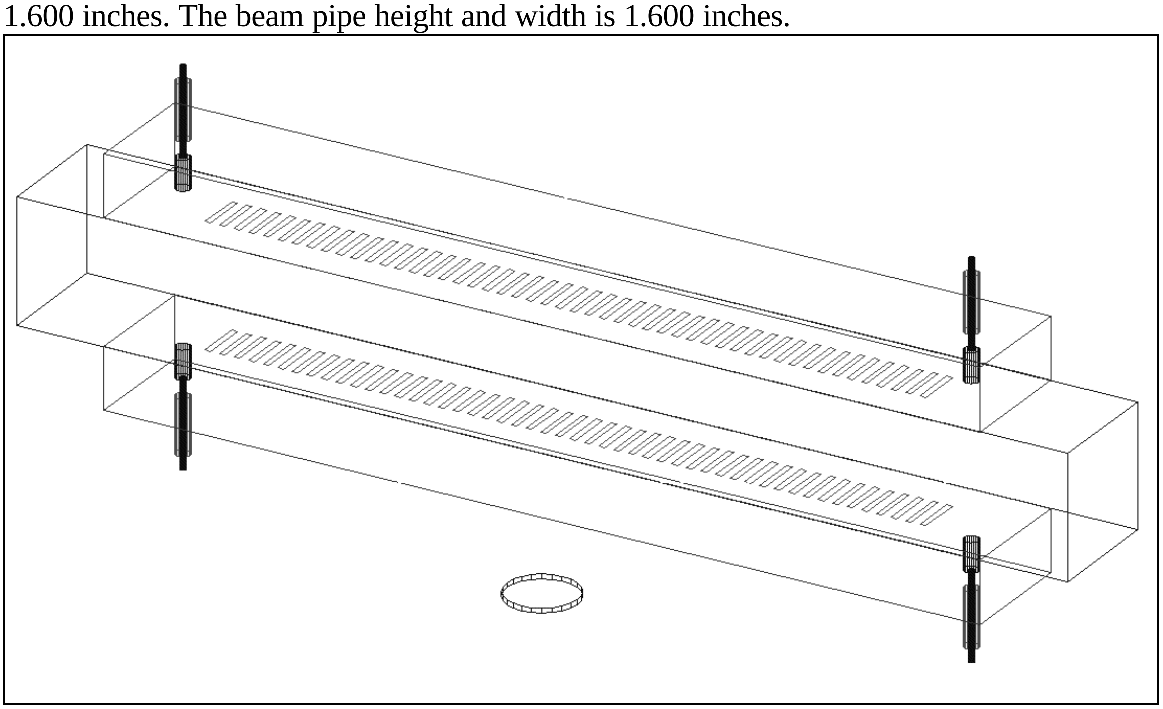

Figure 2. Schematic of the 4-8 GHz slow wave pickup.

The equivalent impedance of a slow wave pickup used in the difference mode is defined as:

$$P_\Delta = 2Z\left\langle i_b{}^2 \right\rangle \left(\frac{y}{d}\right)^2 \tag{1}$$

where P_Δ is the total power out of the output of the difference port, d is the spacing between the upper and lower slots, y is the transverse position of the beam measured from the center of the beam pipe and $\langle i_b^2 \rangle$ is the rms beam current squared. The equivalent impedance of the slow wave pickup in the sum mode is defined as:

$$P_\Sigma = \frac{1}{2} Z\left\langle i_b{}^2 \right\rangle \tag{2}$$

where P_Σ is the total power out of the output of the sum port. The sum and difference mode impedances for the 50 slot array shown in Figure 2 was calculated using a moment method program. The results are shown in Figure 3.

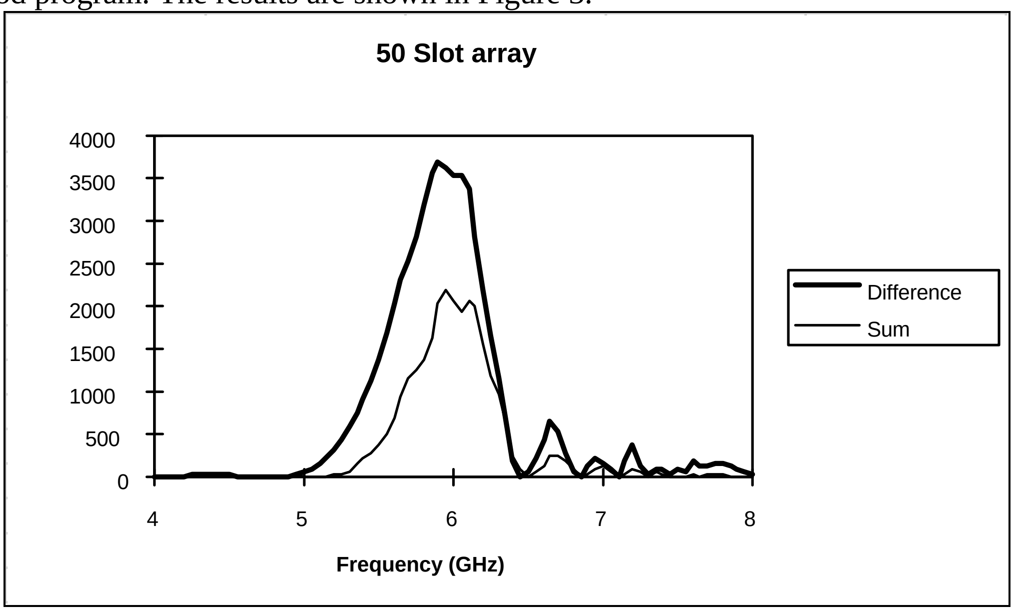

Figure 3. Theoretical calculations for the 50 slot slow wave pickup.

Measurements

The output of the pickups where connected to a Petter sum and difference mode hybrid. The outputs of the hybrid were amplified with low noise amplifiers and the signals were cabled to the AP30 service building where they were again amplified. The final signal was fed into a microwave spectrum analyzer. The loss/gain of the amplifier chain is shown in Table 1.

Tank Cable #1	-0.75 dB
Tank Cable #2	-0.25 dB
Outside Cable to hybrid	-0.65 dB
Sum Mode hybrid insertion loss.	-0.5 dB
Difference Mode hybrid insertion loss	-0.75 dB
Sum mode pre-amp	31 dB
Difference mode pre-amp	29.7 dB
Pre-amp Noise Figure	1 dB
Tunnel to Upstairs Cable	-3 dB
Upstairs Amplifier	36 dB

Table 1a. Gain/loss of 4-8 GHz amplifier chain measured at 6 GHz

Outside Cable to hybrid	-0.45 dB
Sum Mode hybrid insertion loss.	-0.5 dB
Difference Mode hybrid insertion loss	-0.5 dB
Sum mode pre-amp	26.8 dB
Difference mode pre-amp	25.7 dB
Pre-amp Noise Figure	1 dB
Tunnel to Upstairs Cable	-2.25 dB
Upstairs Amplifier	32.7 dB

Table 1b. Gain/loss of 2-4 GHz amplifier chain measured at 3 GHz

The schottky spectrum of the beam was measured with the spectrum analyzer. To remove the effects of the momentum distribution of the beam, the resolution bandwidth was set to 3 MHz which is much wider than the 590 kHz spacing of the schottky bands. For the sum mode signal, the power received in one schottky band due only to the beam is:

$$P_{\Sigma} = e f_r I_{dc} Z \qquad (3)$$

where e is the charge of a single proton, f_r is the revolution frequency I_{dc} is the DC beam current and Z is the sum mode impedance of the pickup. For the difference mode signal, the power received in one schottky band (which includes both betatron lines) due only to the beam is:

$$P_{\Delta} = 2 e f_r I_{dc} \left(\frac{\sigma}{d}\right)^2 Z \qquad (4)$$

where σ is the transverse rms beam size and d is the aperture of the pickup. For both the sum and difference mode, the power received in one schottky band when there is no beam in the machine is:

$$P_{noise} = N_f S_{therm.} f_r \tag{5}$$

where N_f is the noise figure of the pre-amp and S_{therm} is the power spectral density of white thermal noise which is equal to -174 dBm/Hz at room temperature. The ratio of the power per band when there is beam in the machine to when there is no beam in the machine is:

$$g = \frac{P_{beam} + P_{noise}}{P_{noise}} \tag{6}$$

The sum mode impedance of the pickup can be determined from:

$$Z_{\Sigma} = (g-1)\frac{N_f S_{therm.}}{eI_{dc}} \tag{7}$$

The difference mode impedance can be determined from:

$$Z_{\Delta} = (g-1)\frac{N_f S_{therm.}}{2eI_{dc}\left(\frac{\sigma}{d}\right)^2} \tag{8}$$

To measure the sensitivity of the pickups, 3-5 mA of reverse protons was injected into the Debuncher and stored. The beam was heated transversely by turning on the Debuncher dampers with the damper pickups disconnected and using the thermal noise of the power amp. The vertical transverse distribution was measured by scrapping the beam with the vertical scrapper D:TJ308. The vertical beta function at the scraper is 14 m. The beam current versus scraper position is shown in Figure 4.

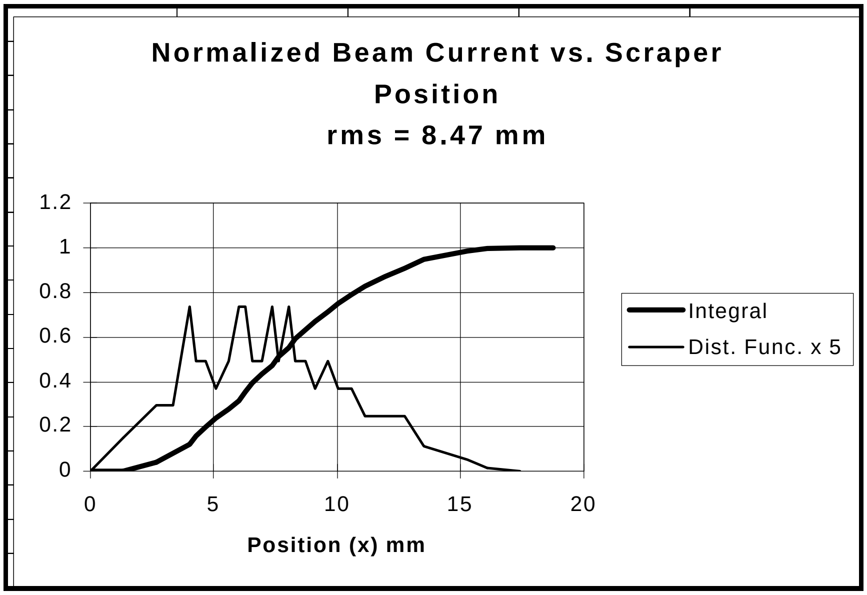

Figure 4. Beam current vs scraper position.

The rms value of the vertical beam size for these measurements was calculated to be 8.47 mm at the scraper. The rms beam size at the pickup is related to the beam size at the scraper by:

$$\sigma_{pu}{}^2 = \frac{\beta_{pu}}{\beta_{sc}} \sigma_{sc}{}^2 \qquad (9)$$

The vertical beta function at the pickup is about 7 m. The measured 2-4 GHz pickup impedance is shown in Figure 5. The measured 4-8 GHz sum and difference mode impedance is shown in Figure 6 and 7 respectively. Along with the measured impedance, the theoretical impedance multiplied by a factor of 0.35 is also plotted.

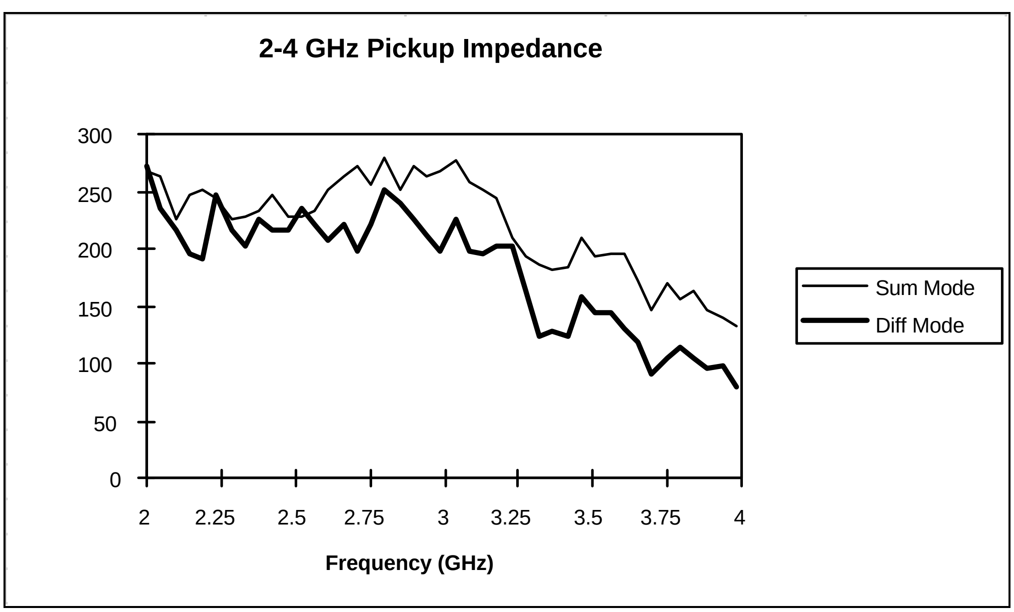

Figure 5. The 2-4 GHz measured pickup impedance.

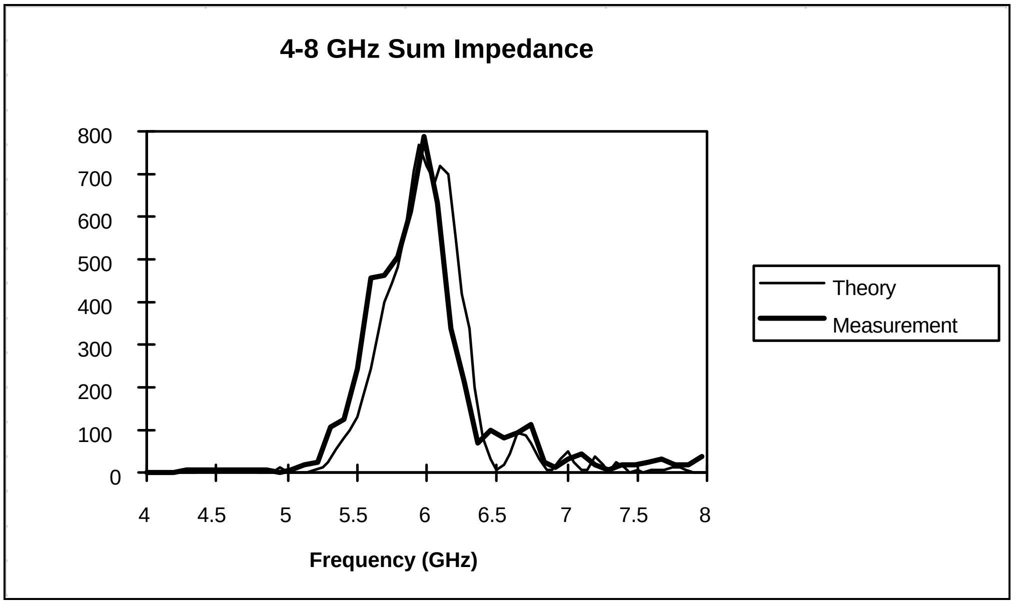

Figure 6. 4-8 GHz sum mode impedance. The theory curve has been multiplied by a factor of 0.35.

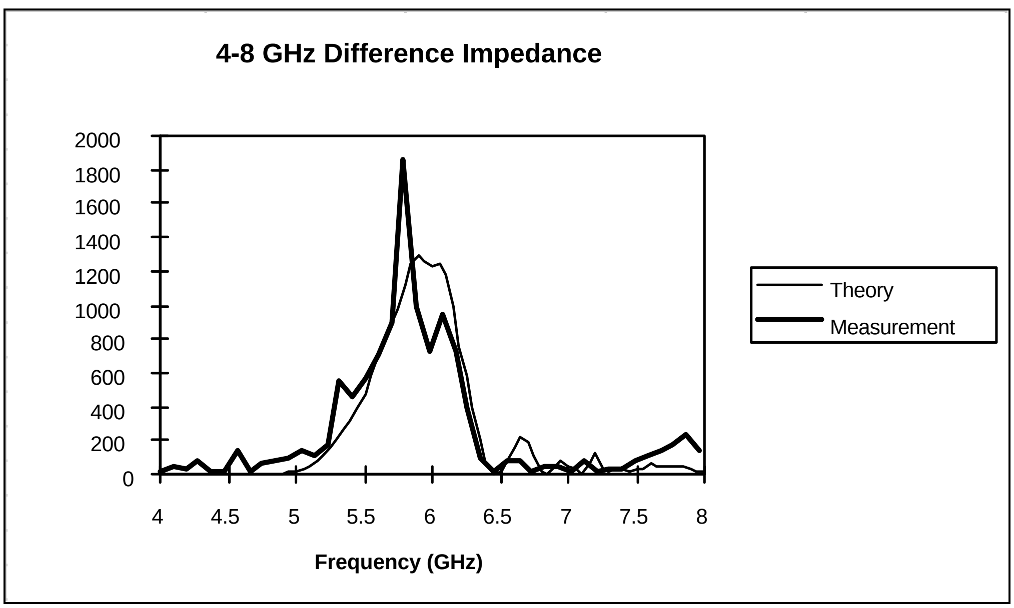

Figure 7. 4-8 GHz difference mode impedance. The theory curve has been multiplied by a factor of 0.35.

The measured impedance of the 4-8 GHz arrays are down by a factor of about 2.8 (4.5 dB) from the calculated values. The calculations did not include loss in the coaxial lines between the pickup and the hybrid (including the insertion loss of the hybrid.) This can account for about 2.4 dB. Part of the remaining 2.1 dB might be traced to the reduction in pickup sensitivity for particles on the horizontal edge of the beam. Since the slots do not extend all the way to the edge of the horizontal aperture, particles at the edge of the horizontal aperture will not induce a strong as signal in the slots as particles in the center of the beam pipe would. Figure 8 shows the array impedance as a function of horizontal beam location and frequency. (0 mm being the center of the beam pipe.) Figure 9 shows the pickup impedance at 6 GHz as a function of horizontal beam position.

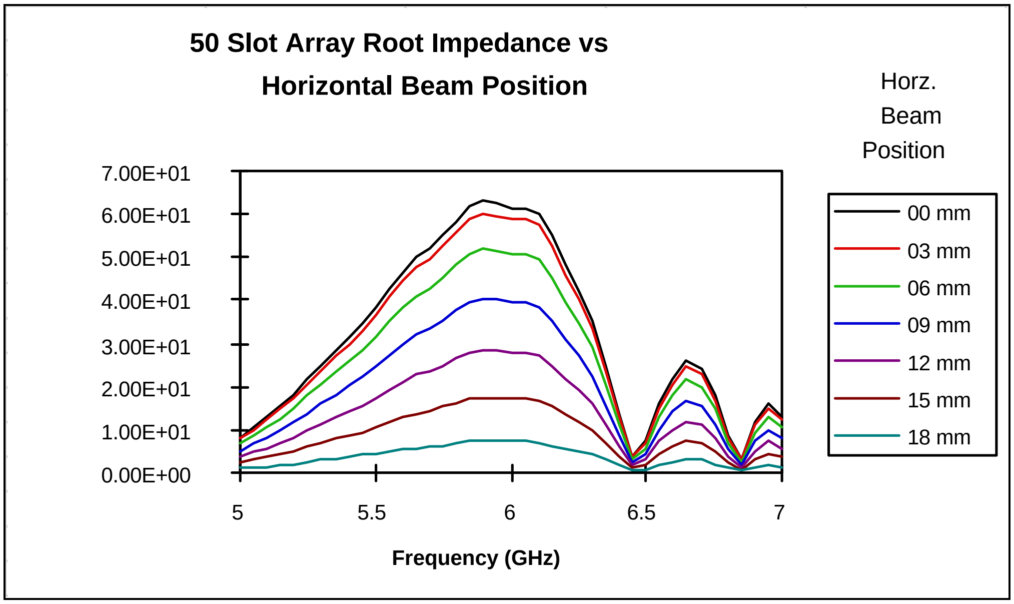

Figure 8. Calculated Pickup impedance as a function of horizontal beam position and frequency. Note that the impedance scale is in square root Ohms.

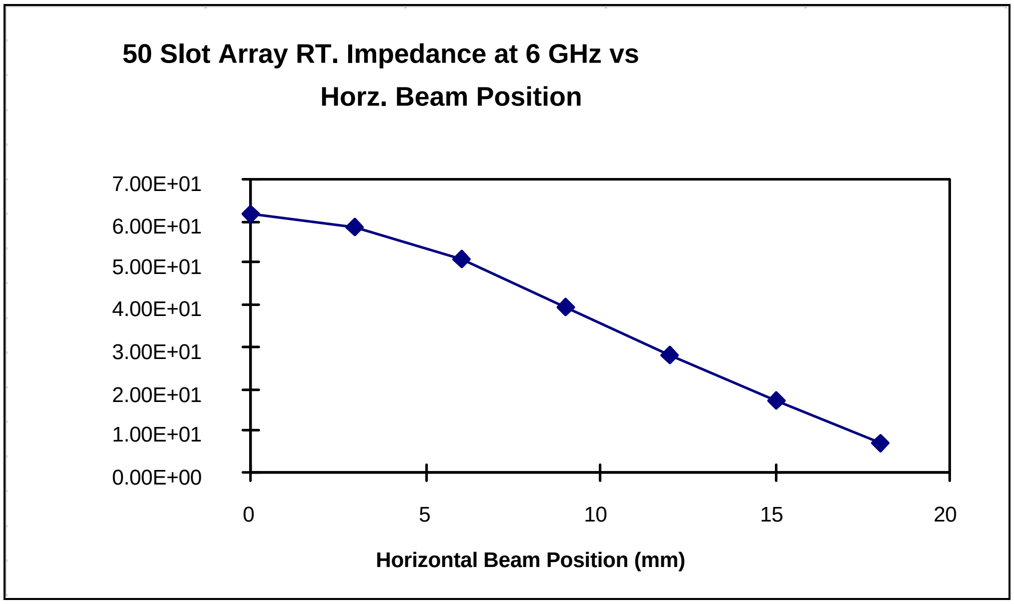

Figure 9. Calculated Pickup impedance as a function of horizontal beam at 6 GHz. Note that the impedance scale is in square root Ohms.

The effective impedance of the array could be calculated to be:

$$Z_{eff} = \int_{-\infty}^{\infty} \left(\sqrt{Z(x)}\right)^2 \psi(x)\, dx \tag{10}$$

where $\psi(x)$ is the horizontal distribution of the beam. If the distribution is assumed to be a guassian:

$$\psi(x) = \frac{1}{\sigma_h \sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x}{\sigma_h}\right)^2} \tag{11}$$

where σ_h is the rms beam size, then the effective drop in sensitivity can be calculated. This reduction in sensitivity is shown in Figure 10.

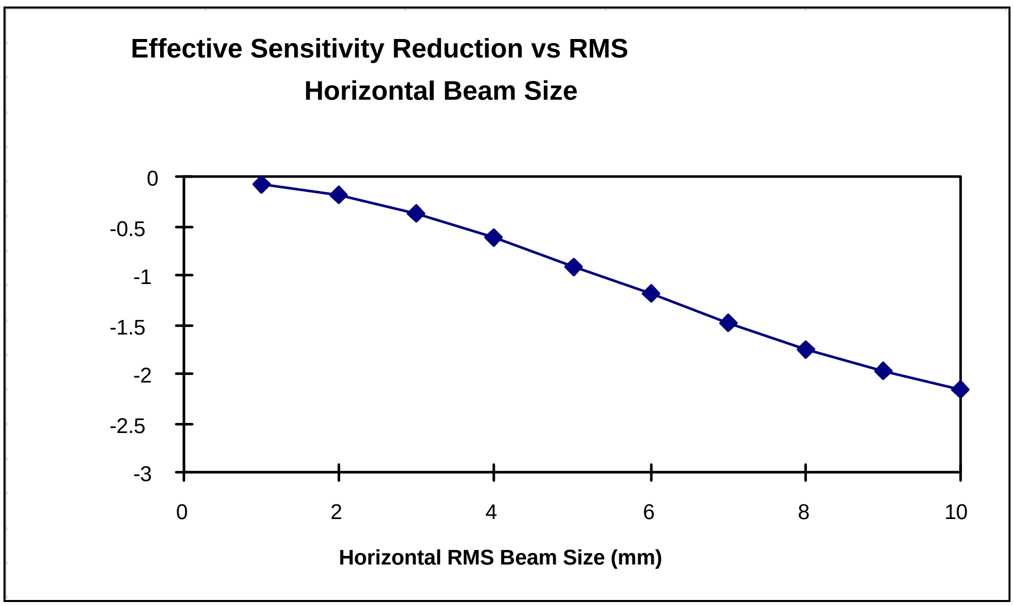

Figure 10. Calculated reduction of 4-8 GHz pickup sensitivity versus the rms value of the horizontal beam size.

The most striking results of the test is the amount of microwave modes in the 4-8 Ghz pickup. This is not surprising because no mode absorbers were incorporated into the 4-8 GHz design. Figures 11 and 12 shows the raw spectrum analyzer output of the 2-4 Ghz pickup for the sum and difference modes respectively. Figures 13 and 14 shows the raw spectrum analyzer ouput of the 4-8 GHz pickup for the sum and difference modes repectively. Some of the mode lines in the 4-8 Ghz difference mode spectrum turned out to be strong longitudinal mode lines that could not be reduced by centering the pickup.

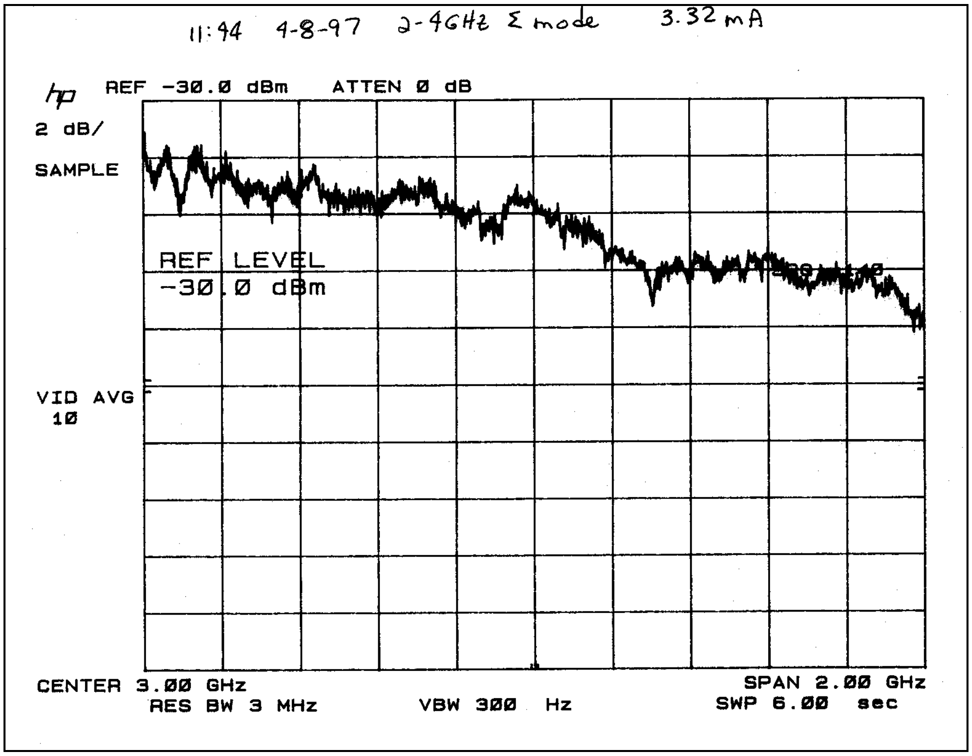

Figure 11. Sum mode spectrum plot of the 2-4 GHz pickup. The span is from 2-4 GHz and the vertical scale is 2 dB/div. The resolution bandwidth is 3 MHz.

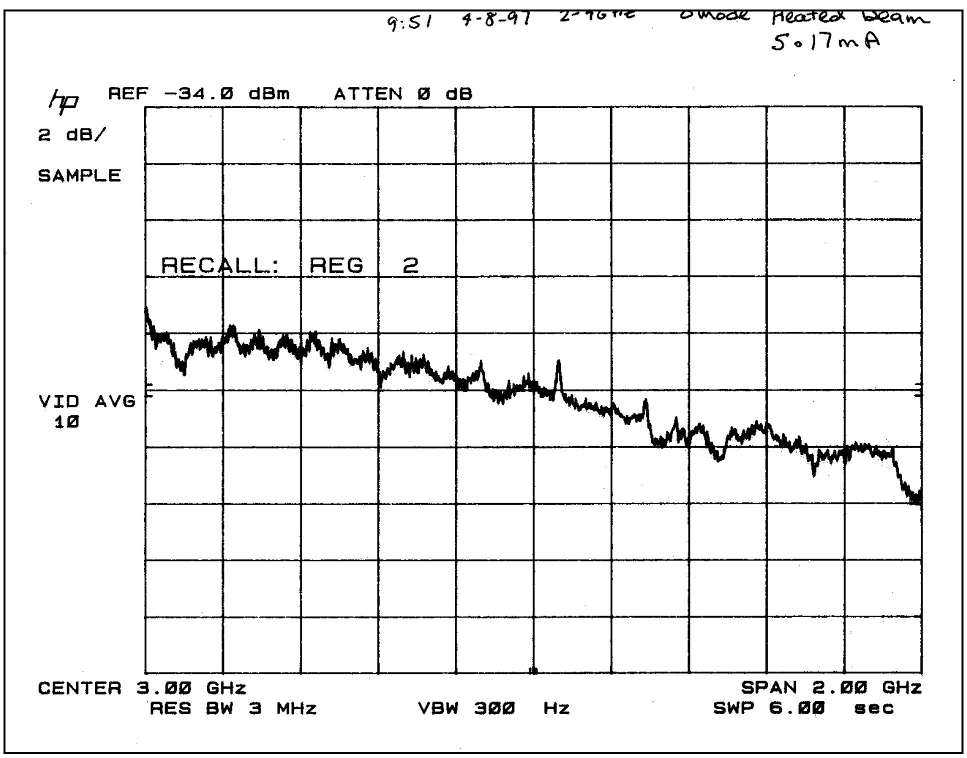

Figure 12. Difference mode spectrum plot of the 2-4 GHz pickup. The span is from 2-4 GHz and the vertical scale is 2 dB/div. The resolution bandwidth is 3 MHz.

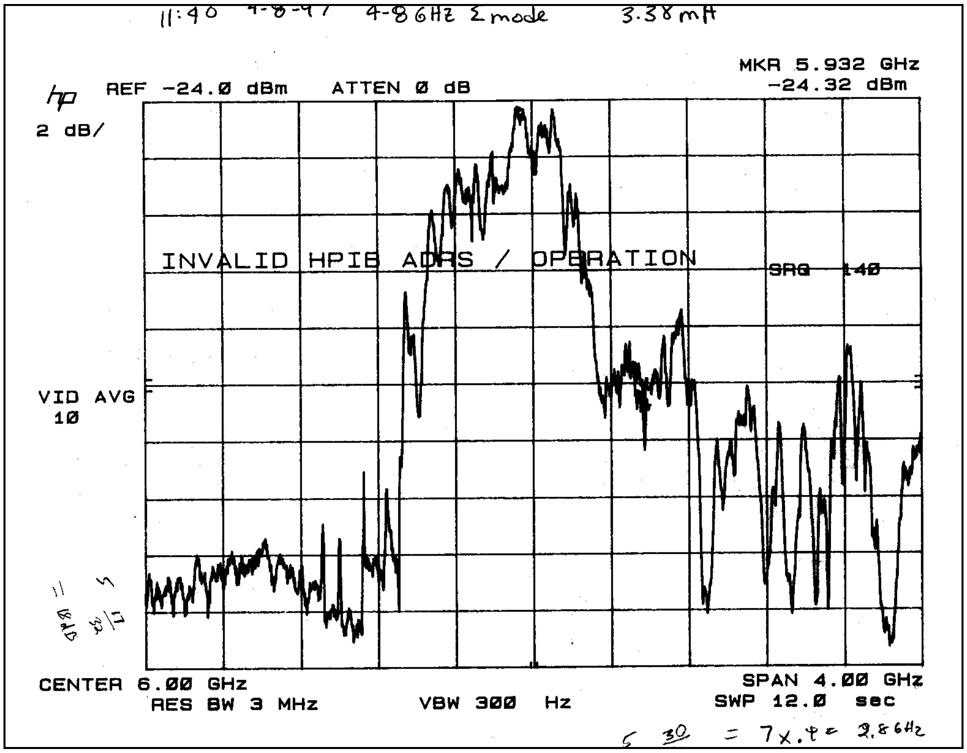

Figure 13. Sum mode spectrum plot of the 4-8 GHz pickup. The span is from 4-8 GHz and the vertical scale is 2 dB/div. The resolution bandwidth is 3 MHz.

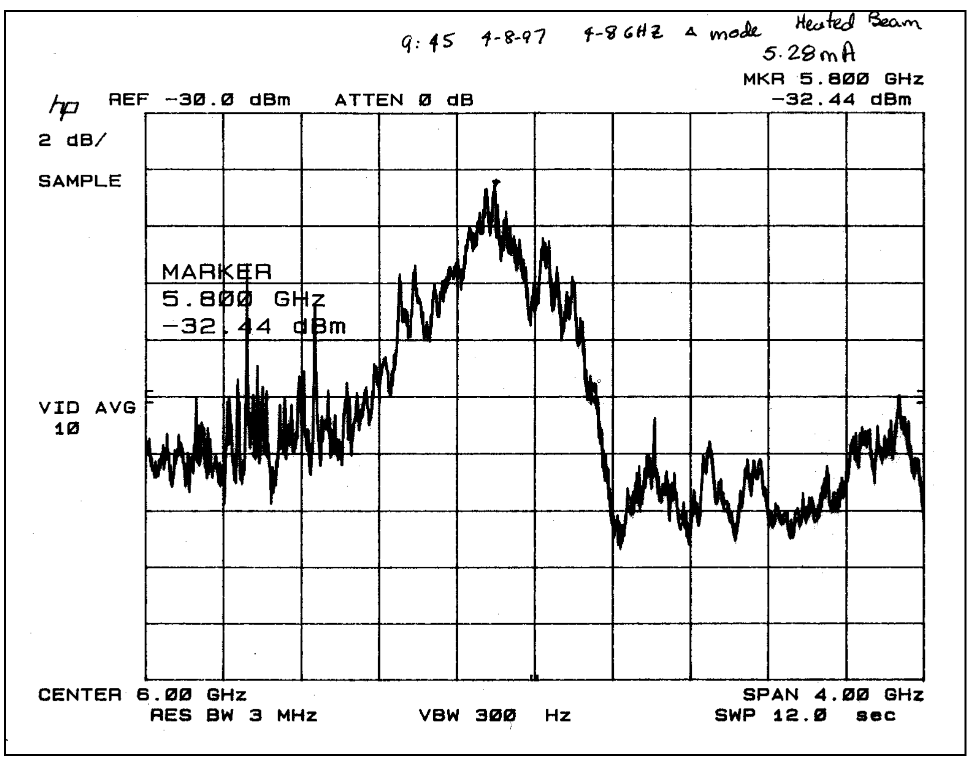

Figure 14. Difference mode spectrum plot of the 4-8 GHz pickup. The span is from 4-8 GHz and the vertical scale is 2 dB/div. The resolution bandwidth is 3 MHz.