PBAR Note 651
Common Mode Rejection Calculations on the Debuncher Upgrade

Dave McGinnis

February 2, 2001

INTRODUCTION

The 4-8 GHz Transverse Debuncher Cooling Systems are power limited. Misalignments and imperfections in the transverse pickup arrays will generate a longitudinal signal in addition to the betatron signal. This longitudinal signal can use up a significant fraction of the precious TWT power if the imperfections are large enough. This note will summarize calculations of the contributions to the longitudinal signal observed in the transverse systems of the 4-8 GHz Debuncher slow-wave pickup arrays due to various misalignments and imperfections.

THEORY

The beam travelling off-center through the pickup array can be de-composed into sum mode and difference modes as shown in Figure 1. (Taken from Figure 4 of PBAR Note 575.) The difference mode power obtained by a beam travelling offset from the center of the beam-pipe is:

$$P_{\Delta} = \frac{1}{2} Z_{off}\, i_b^2 y_{off}^2 \tag{1}$$

where P_{Δ} is the <u>total</u> power received from the pickup, i_b is the beam current, and y_{off} is the distance between the beam and the mid-plane of the pickup. Note that the Z_{off} has units of Ohms/mm^2. The impedance Z_{off} can be calculated by moment method techniques (PBAR Note 575).

The difference mode power for the beam travelling skewed to the centerline of the beam-pipe is:

$$P_{\Delta} = \frac{1}{2} Z_{tilt} i_b^2 y_{tilt}^2 \tag{2}$$

where the transverse distance between the beam and the center line of the beam pipe as a function of longitudinal position (s) in the pickup is:

$$y_b(s) = 2 y_{tilt} \frac{s}{L} \tag{3}$$

where **s** runs along the length of the pickup L.

$$-\frac{L}{2} \le s \le \frac{L}{2} \tag{4}$$

If there were no dispersion in the output waveguides, then no signal would be induced by a skewed beam trajectory because the downstream end of the pickup would cancel the upstream end of the pickup. For a slow wave pickup, which has dispersion, this cancellation occurs only at one frequency when the phase velocity of the output waveguides matches the beam velocity. Again Z_{tilt} can be calculated using moment methods.

The signal induced by a delay, phase, and amplitude imbalance between the output waveguides is due to the sum mode impedance only because we are assuming that the beam trajectory is perfectly aligned to the center of the beam pipe. The sum mode impedance is defined as (PBAR Note 578):

$$P_\Sigma = \frac{1}{2} Z_{\Sigma pu} i_b^{\,2} \tag{5}$$

and can be calculated via moment method techniques. The longitudinal signal induced in the difference mode due to a delay, phase, and amplitude imbalance is

$$P_\Delta = \frac{1}{2} Z_{\Sigma pu} i_b^{\,2} \left(\frac{1-G}{2}\right)^2 \sin^2\left(\frac{\omega\tau}{2} + \frac{\theta}{2}\right) \tag{6}$$

where τ is the delay difference, θ is the phase difference, and G is the amplitude difference between the two output waveguides.

The difference mode impedance due to a betatron signal is defined as:

$$P_\Delta = \frac{1}{2}\left(Z_{\Delta pu}\right) i_b^{\,2} \frac{\varepsilon_b}{1\pi - \mathrm{mm} - \mathrm{mrad}} \tag{7}$$

where P_Δ is the total power received from the pickup, i_b is the beam current, ε_b is the un-normalized beam emittance.

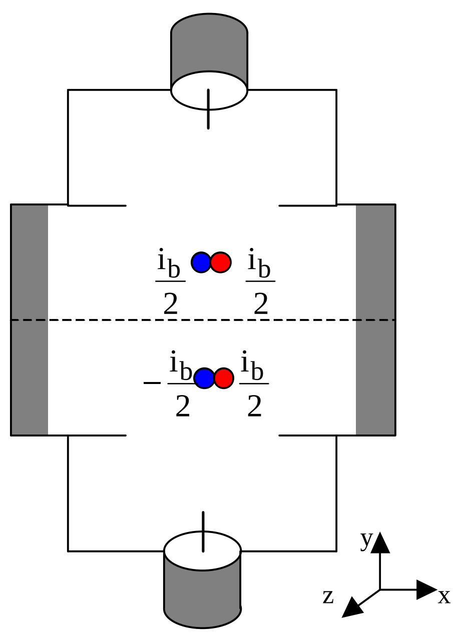

Figure 1. Decomposition of an off-center beam into the sum and difference modes

RESULTS

Tables 1 and 2 display the alignment error needed for the longitudinal signal to produce the same integrated power in the difference mode as a 5 π-mm-mrad (95%, unnormalized) beam. To calculate the values in these tables, the signal power was only integrated in the frequency span that covered the major lobe of the difference mode impedance. It is assumed that out-of-band signal would be eliminated by the front-end band-pass filters (PBAR Note 625). Figures 2 through 6 are graphical displays of Tables 1 and 2. Appendix A displays the frequency response of the alignment tolerances tabulated in Tables 1 and 2.

Band	1L	1U	2L	2U	3L	3U	4L	4U
Offset (mm)	2.60	3.23	3.19	2.48	2.51	3.00	2.62	2.15
Tilt (mm)	5.03	6.42	6.36	4.83	4.88	5.93	5.21	4.04
Delay (pS)	7.84	8.63	8.57	6.31	4.96	5.40	4.69	3.31
Phase (degrees)	12.09	14.68	16.04	12.80	11.07	13.09	12.50	9.43
Amplitude (dB)	2.05	2.56	2.84	2.19	1.86	2.25	2.13	1.56

Table 1. Alignment error for the horizontal pickup arrays needed to produce the same integrated power as the betatron signal for a 5 π-mm-mrad beam (95% unnormalized)

Band	1L	1U	2L	2U	3L	3U	4L	4U
Offset (mm)	2.60	3.09	2.82	2.41	2.13	2.74	2.72	2.11
Tilt (mm)	5.03	6.37	5.79	4.77	4.11	5.38	5.41	3.95
Delay (pS)	7.90	8.58	7.99	6.23	4.21	4.96	4.83	3.17
Phase (degrees)	12.19	14.60	14.95	12.64	9.42	12.03	12.87	9.04
Amplitude (dB)	2.07	2.55	2.62	2.16	1.56	2.04	2.21	1.49

Table 2. Alignment error for the vertical pickup arrays needed to produce the same integrated power as the betatron signal for a 5 π-mm-mrad beam (95% unnormalized)

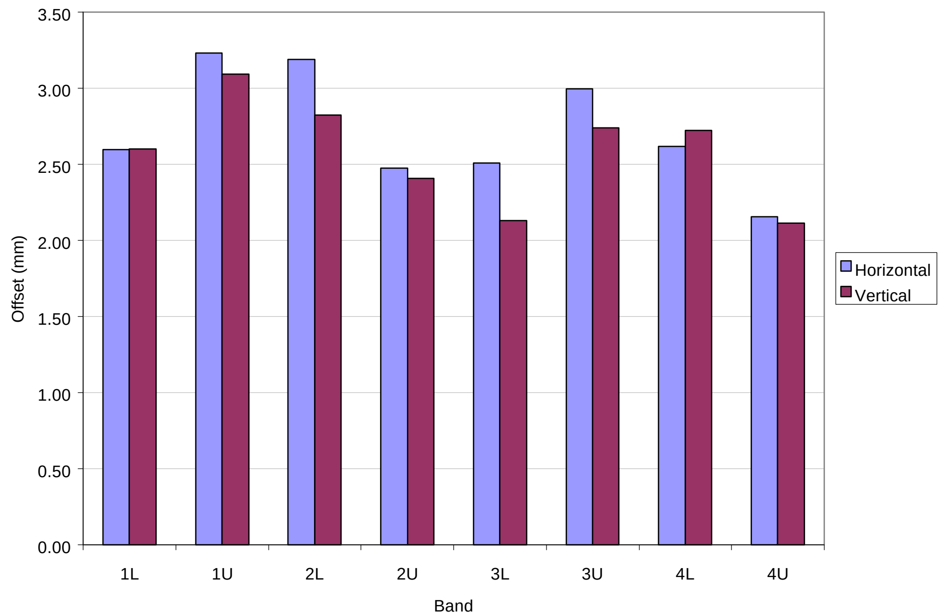

Figure 2. The amount the center of the arrays needed to be offset from the beam to provide the same integrated power as the betatron signal for a 5 p-mm-mrad beam (95% unnormalized)

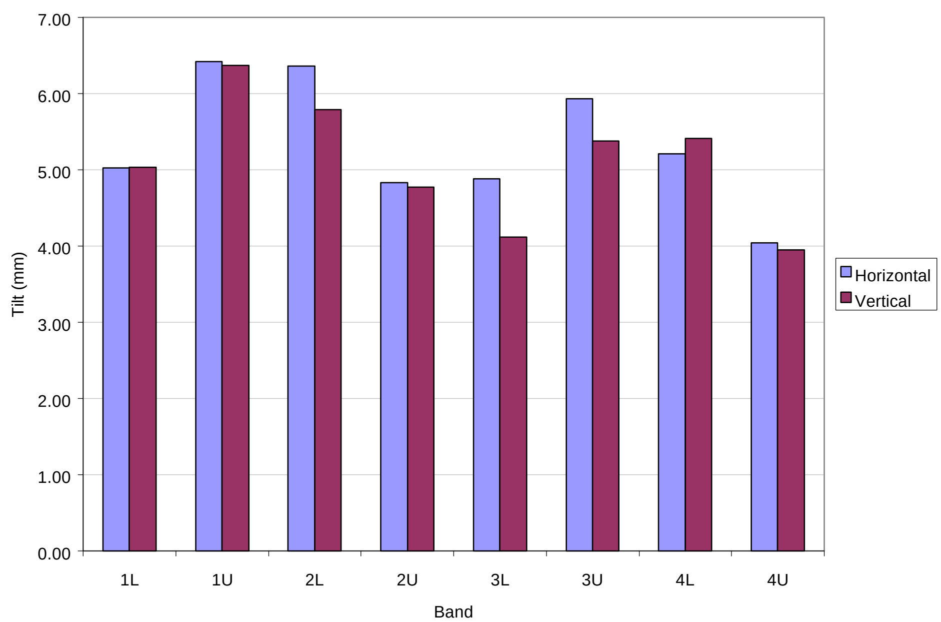

Figure 3. The amount the arrays needed to be tilted from the beam trajectory to provide the same integrated power as the betatron signal for a 5 p-mm-mrad beam (95% unnormalized). The tilt is defined as the distance between the beam center to the array center at the outside slots.

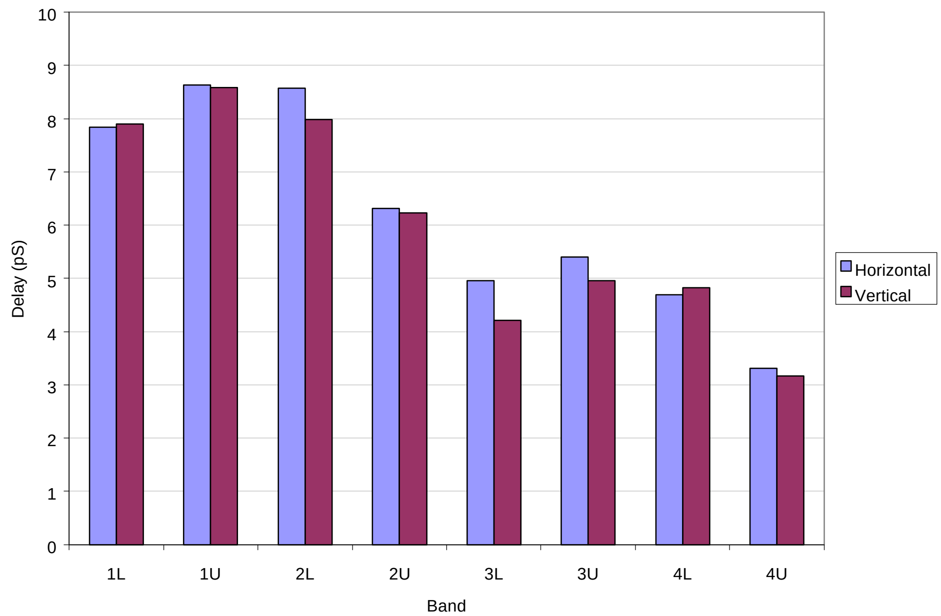

Figure 4. The delay difference needed between the output waveguides to provide the same integrated power as the betatron signal for a 5 p-mm-mrad beam (95% unnormalized)

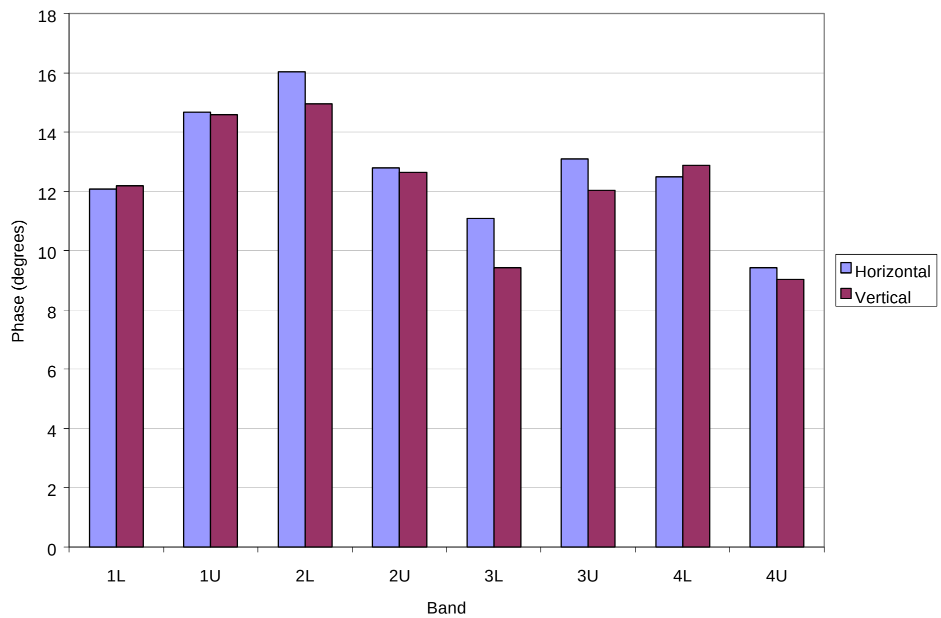

Figure 5. The phase difference needed between the output waveguides to provide the same integrated power as the betatron signal for a 5 p-mm-mrad beam (95% unnormalized)

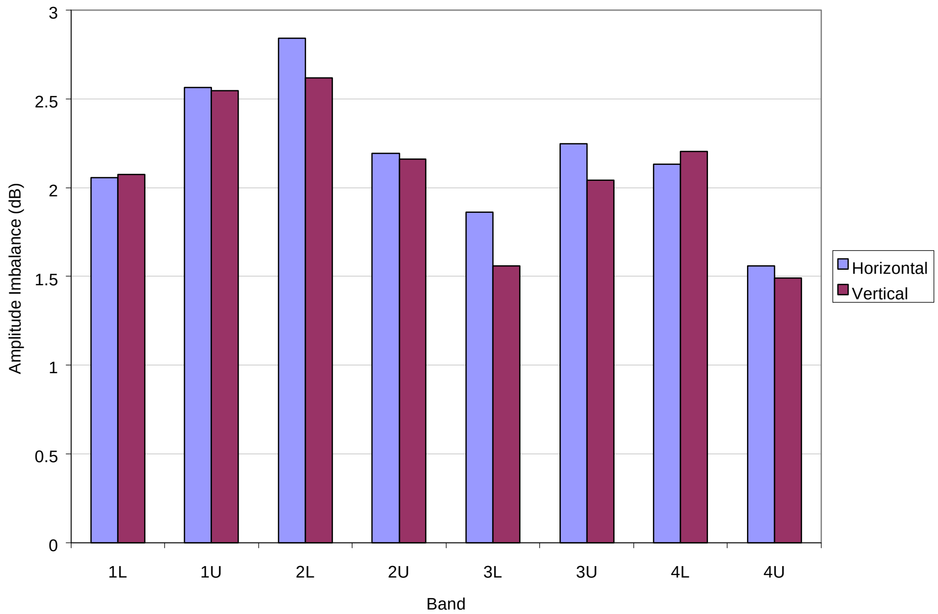

Figure 6. The amplitude imbalance needed between the output waveguides to provide the same integrated power as the betatron signal for a 5 p-mm-mrad beam (95% unnormalized)

Appendix A

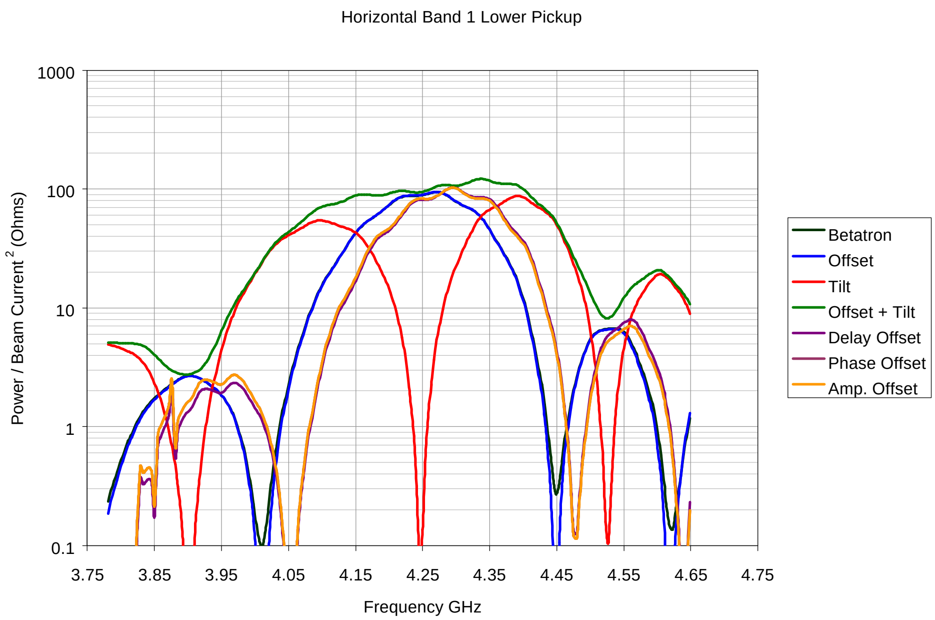

Figure A1. Horizontal Band 1 Lower Pickup

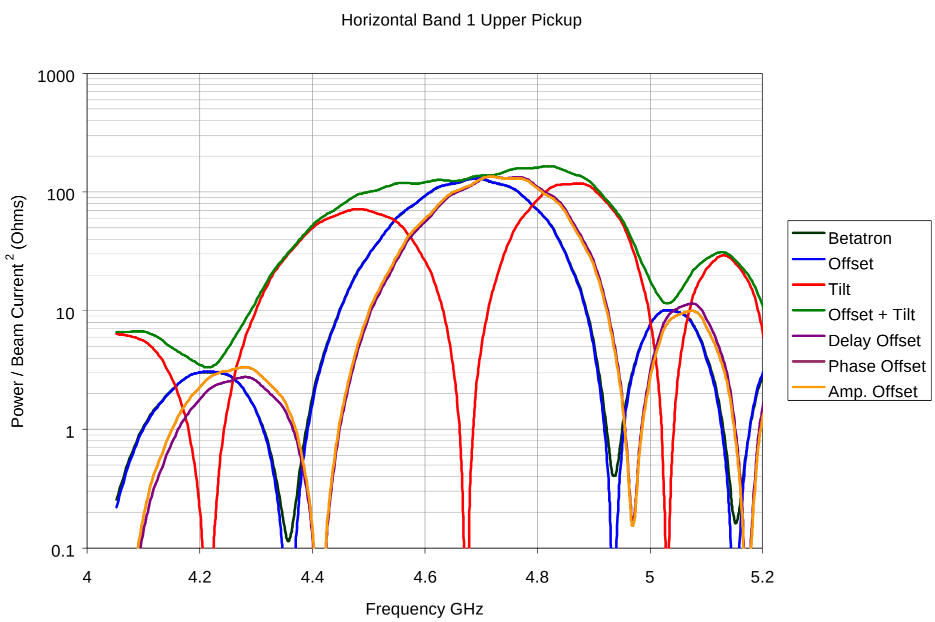

Figure A2. Horizontal Band 1 Upper Pickup

Appendix A

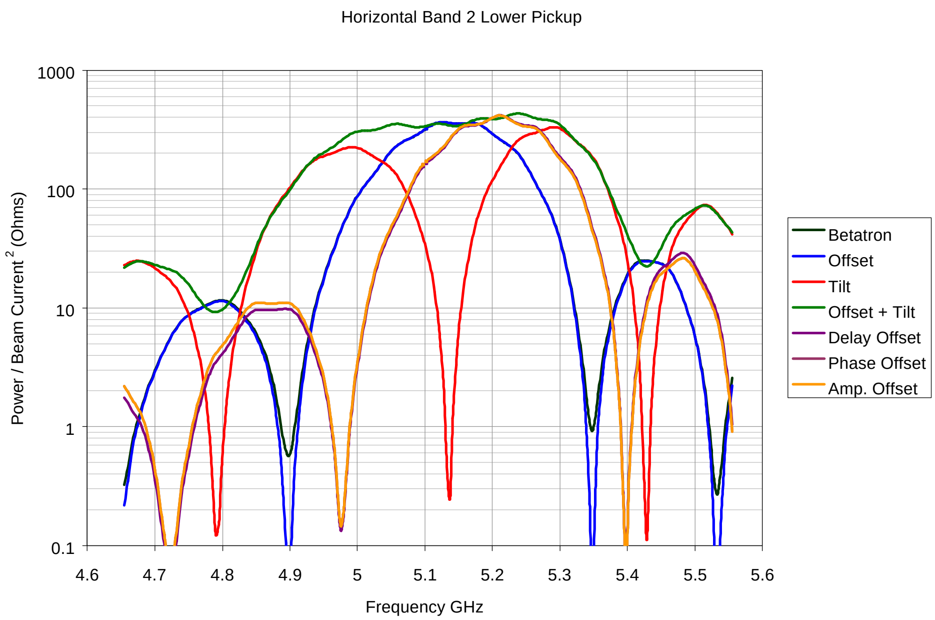

Figure A3. Horizontal Band 2 Lower Pickup

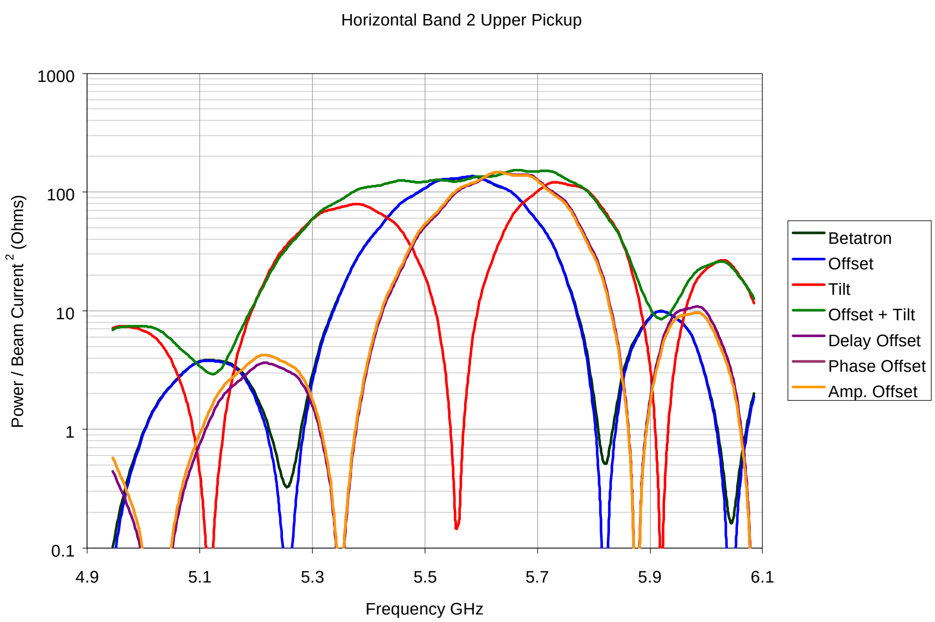

Figure A4. Horizontal Band 2 Upper Pickup

Appendix A

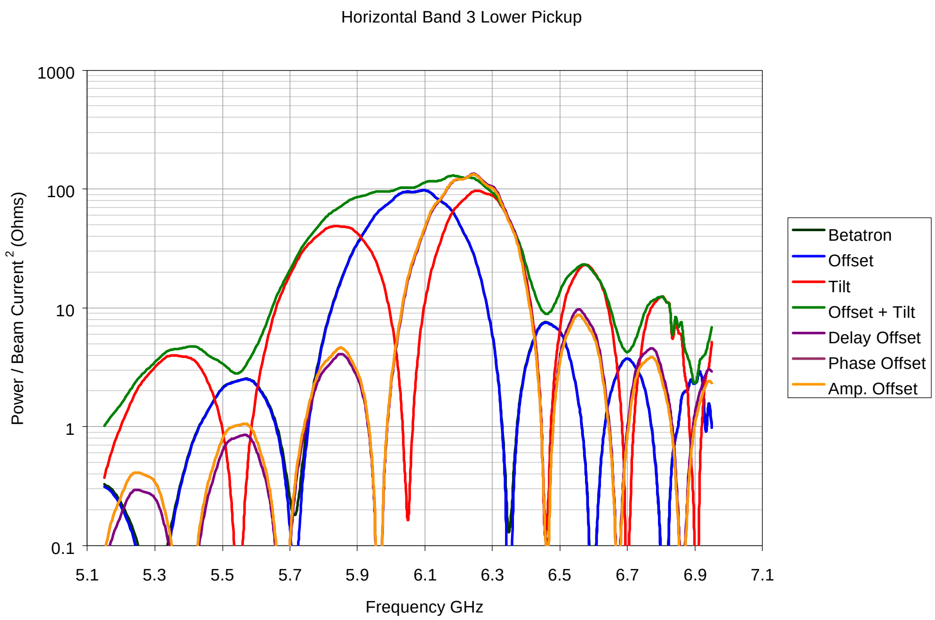

Figure A5. Horizontal Band 3 Lower Pickup

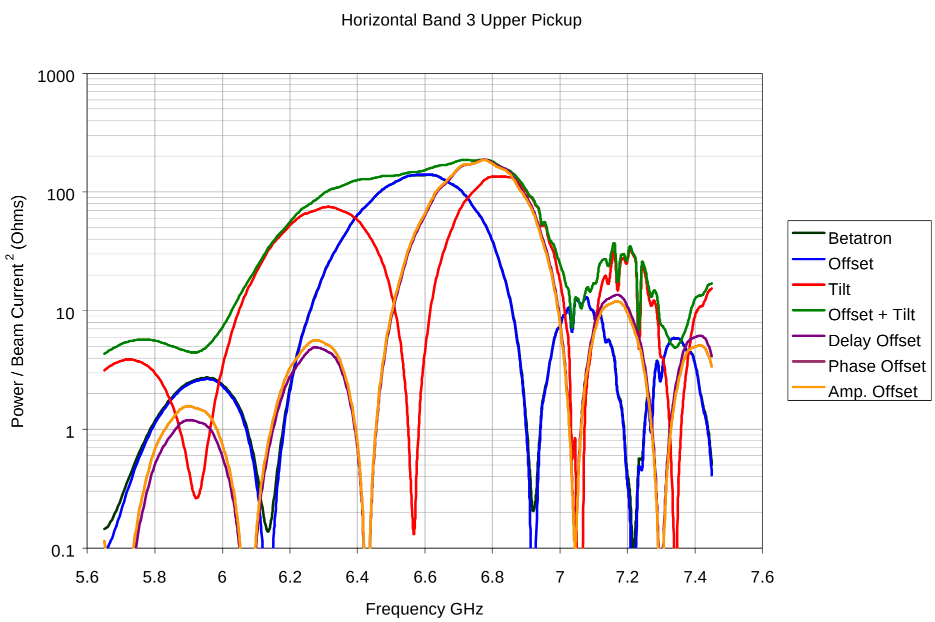

Figure A6. Horizontal Band 3 Upper Pickup

Appendix A

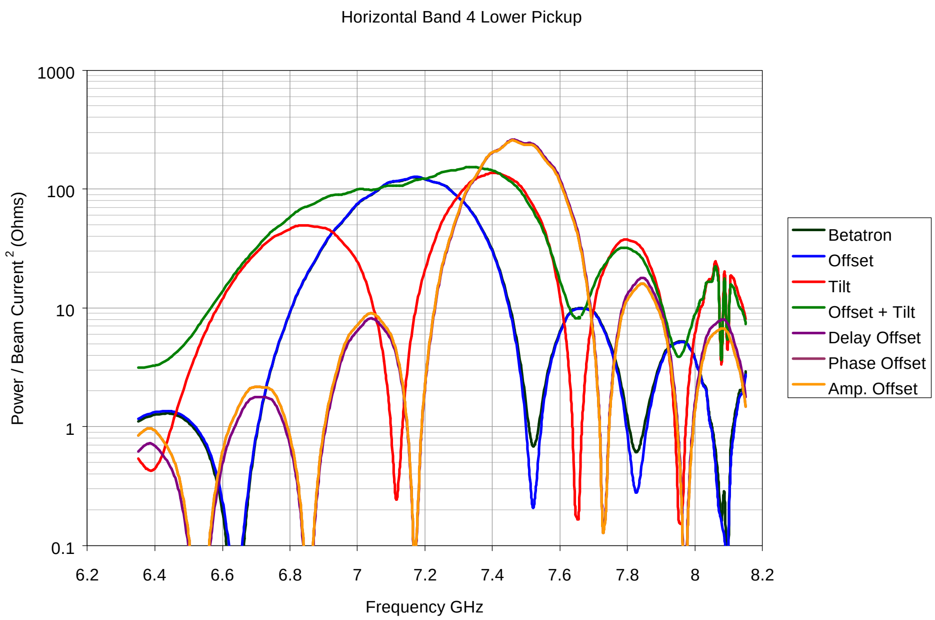

Figure A7. Horizontal Band 4 Lower Pickup

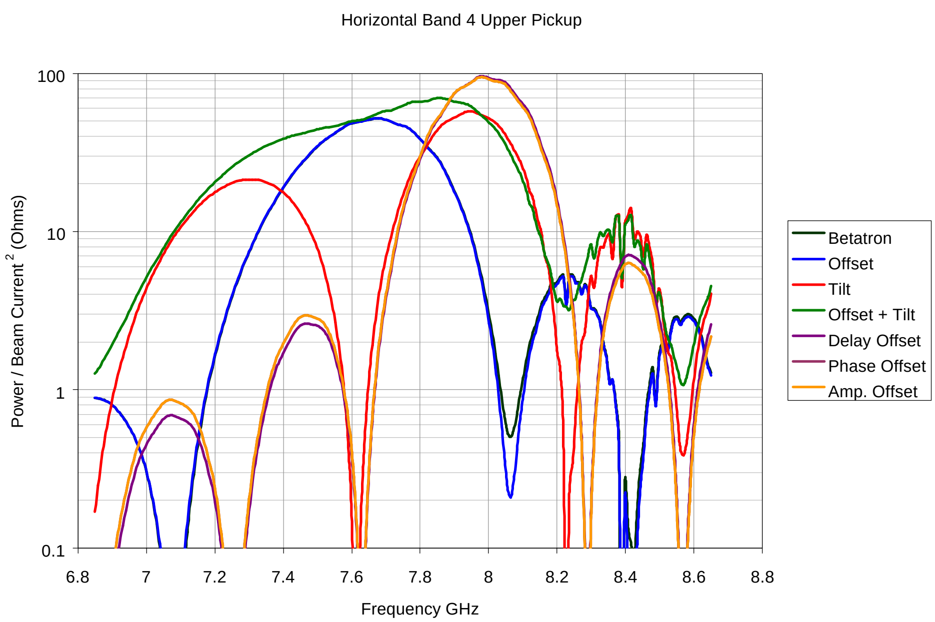

Figure A8. Horizontal Band 4 Upper Pickup

Appendix A

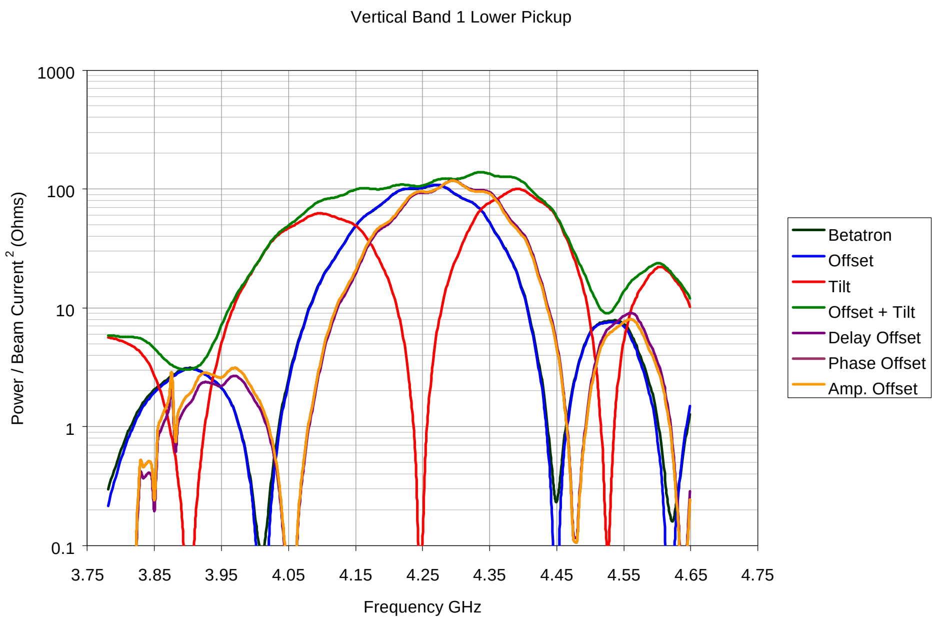

Figure A9. Vertical Band 1 Lower Pickup

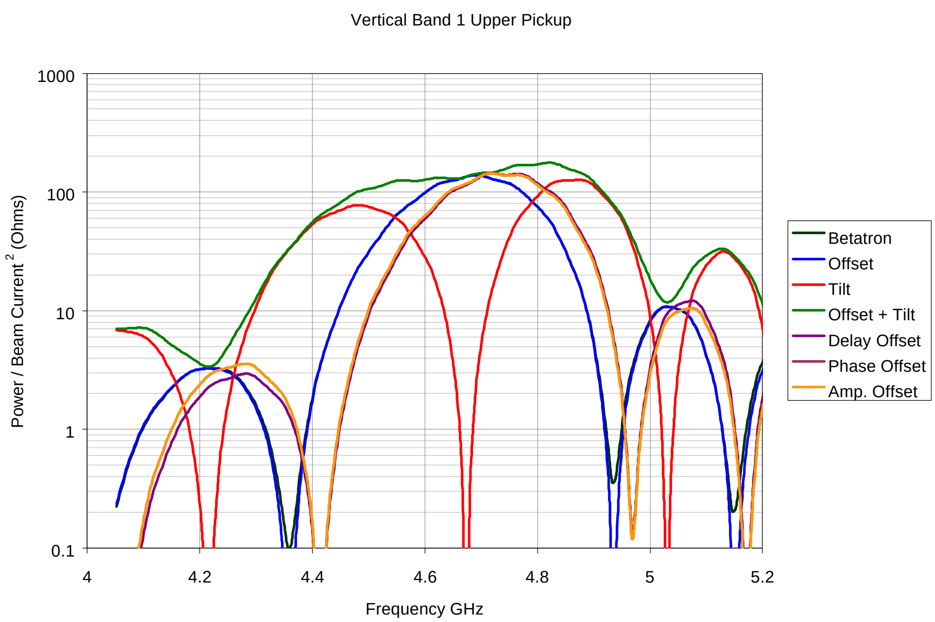

Figure A10. Vertical Band 1 Upper Pickup

Appendix A

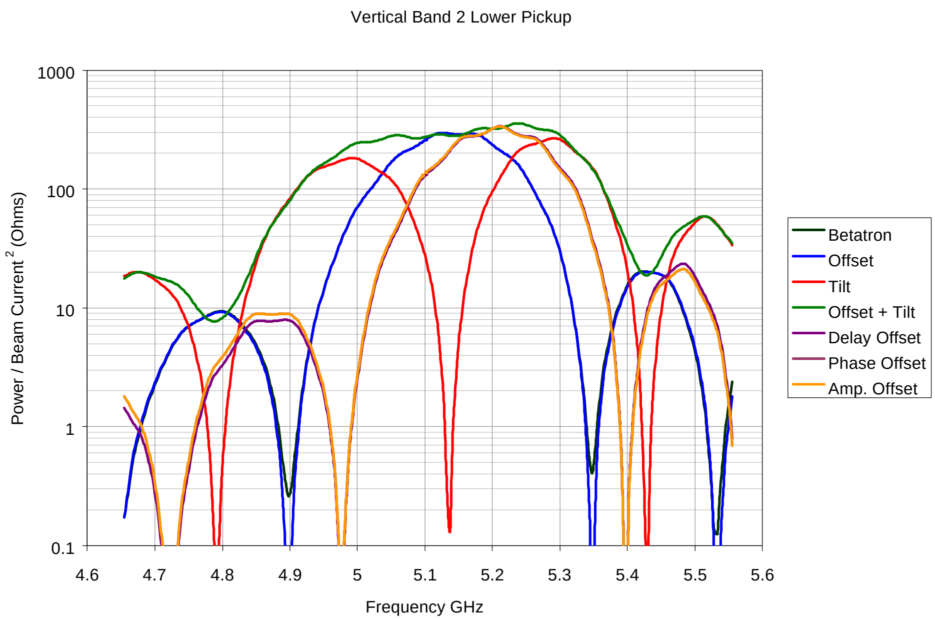

Figure A11. Vertical Band 2 Lower Pickup

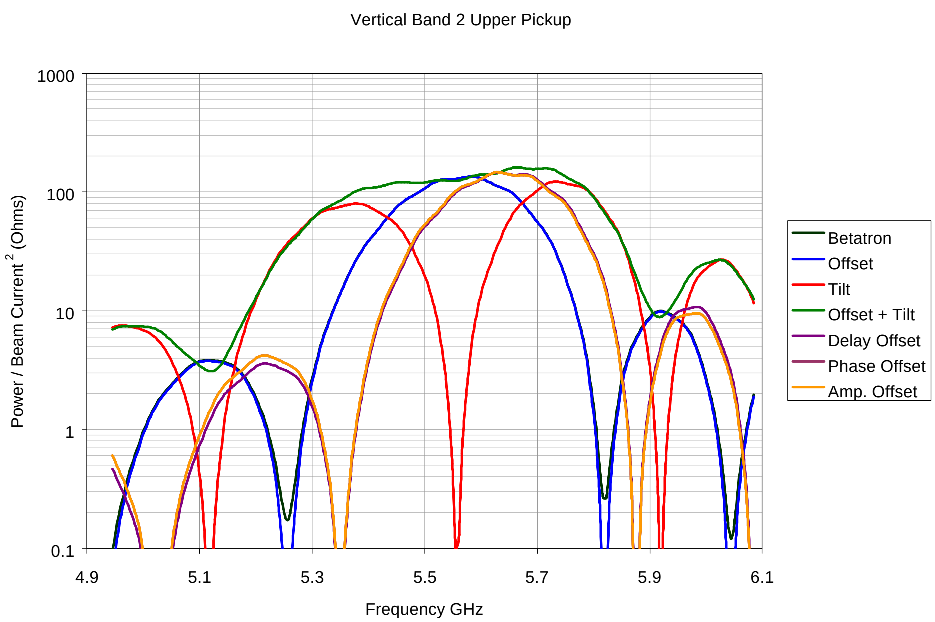

Figure A12. Vertical Band 2 Upper Pickup

Appendix A

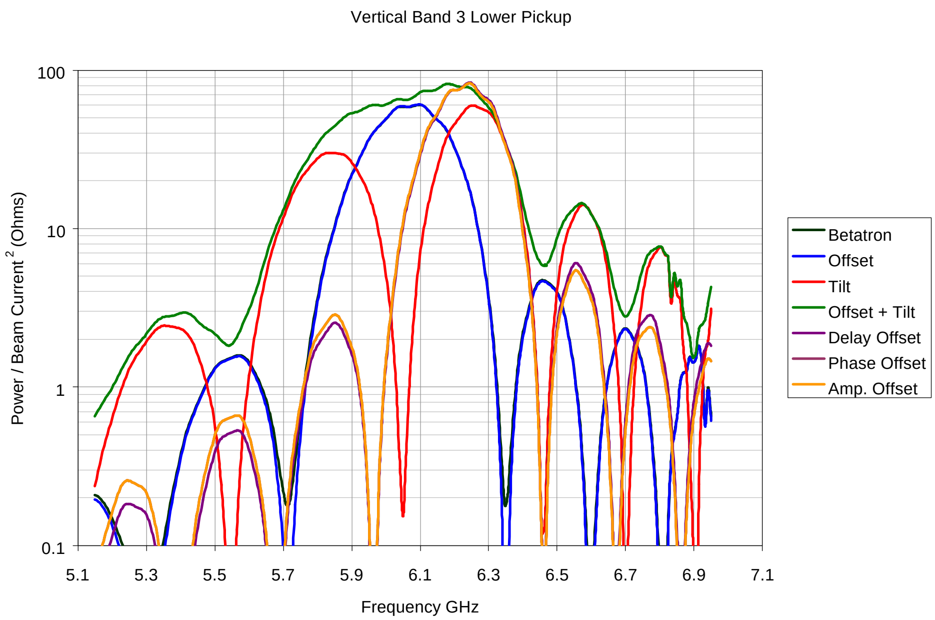

Figure A13. Vertical Band 3 Lower Pickup

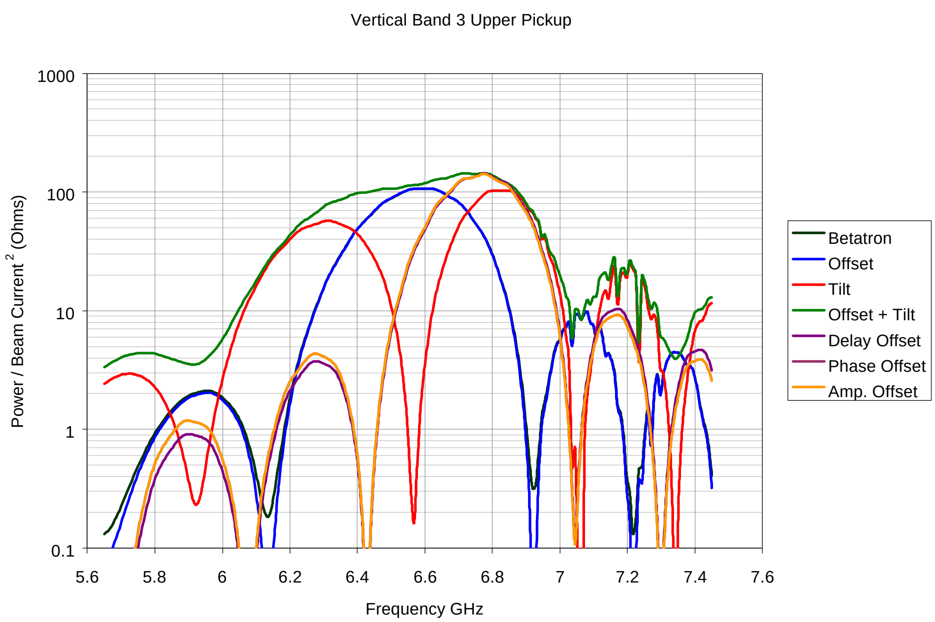

Figure A14. Vertical Band 3 Upper Pickup

Appendix A

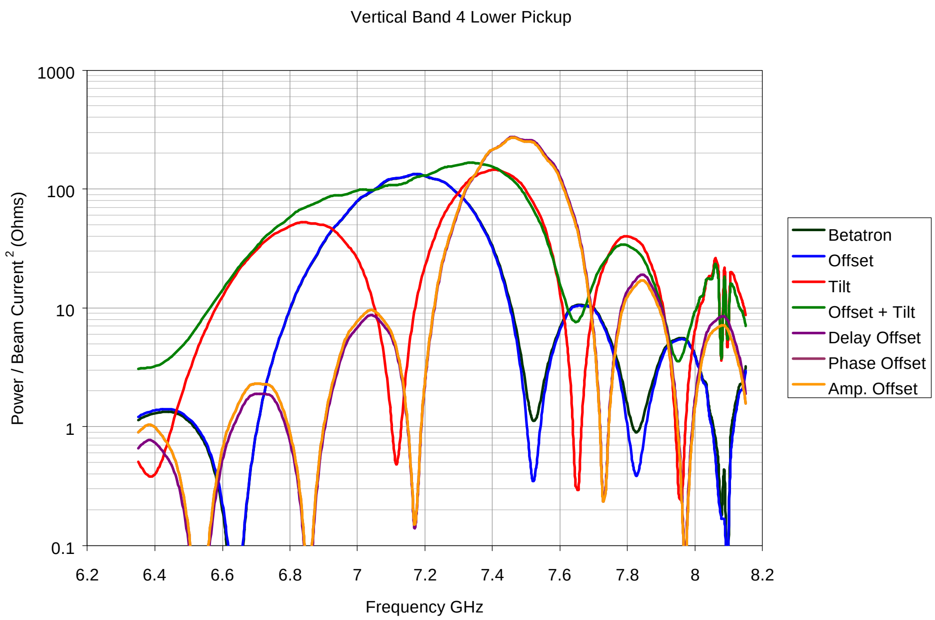

Figure A15. Vertical Band 4 Lower Pickup

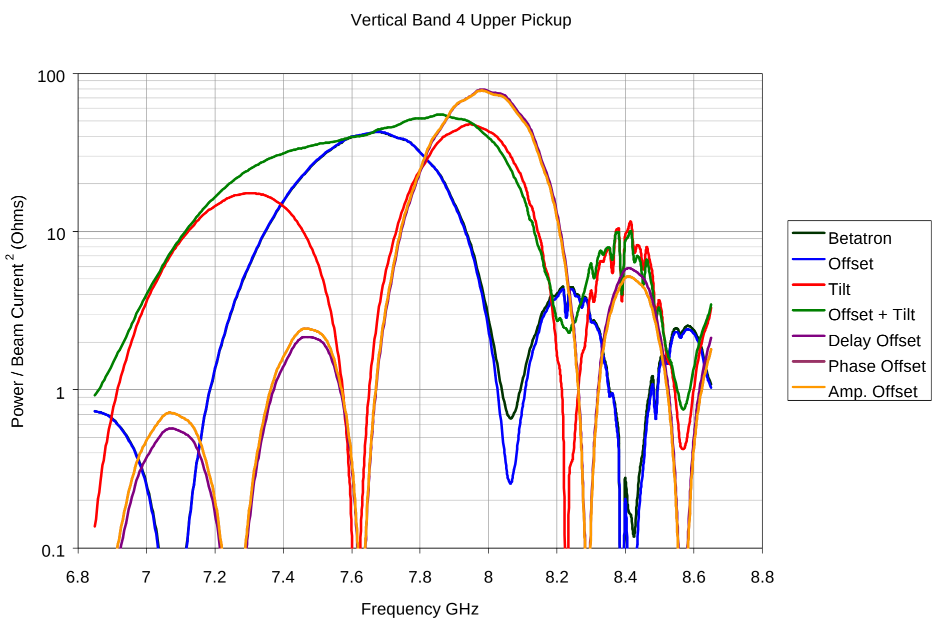

Figure A16. Vertical Band 4 Upper Pickup