THE FERMILAB ANTIPROTON STACK TAIL SYSTEM

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A stack tail sytem has been designed for the anti-proton accumulator of the $\bar{p}$ source.[1] The design follows the design principles used for the anti-proton accumulator at CERN.[2] A substantial amount of R&D has been completed and will be reported here and in the following papers.

The design parameters of the stack tail system are given in Table I.

Table I

Flux		3×10^7 $\bar{p}$/sec
Fill time (4×10^{11} $\bar{p}$'s)		4 hrs
Refill time (2×10^{11} $\bar{p}$'s)		2 hrs
Δp density	initial	7 eV^{-1}
	final	10^5 eV^{-1}
ε (H and V)	initial	< 10 mm-mrad
	final	$\sim$ 3 mm-mrad
System frequency		1-2 GHz

The design bandwidth is 4 times that of the CERN design and the design flux is 3 times greater.

The theory of van der Meer (ref. 1) suggests that the voltage gain per second should be $V \propto 1/\psi$ (ψ = density dN/dE) and that V should be exponential. In practice a number of considerations including phases and signal to noise ratios modify the naive model. The actual design is accomplished with cut and try procedures. The result of the design study is the stack profile shown in fig. 1. The gain for a schottky band near 1.5 GHz is shown in fig. 2. Both the density and the voltage gain follow a roughly exponential shape. The cooling is proportional to the real part of the phase. The phase shown in fig. 2 is within 45° of 180° except near the core (where the stack tail amplitude is very small). The exponential gain shape is established mostly by strip line pickups whose asymptotic response is $\exp(-\pi x/h)$ where x is the horizontal displacement and h is the full gap.

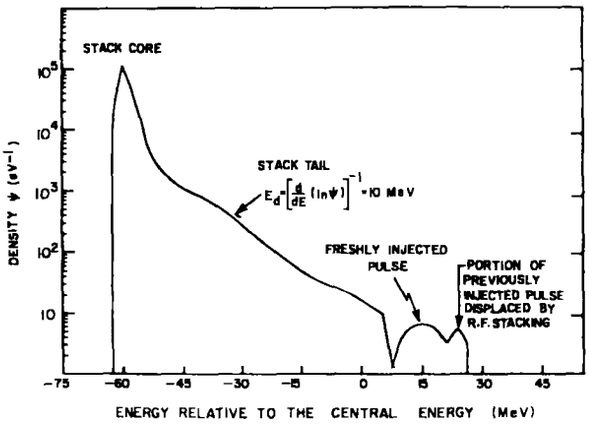

Fig. 1 Stack Density Profile

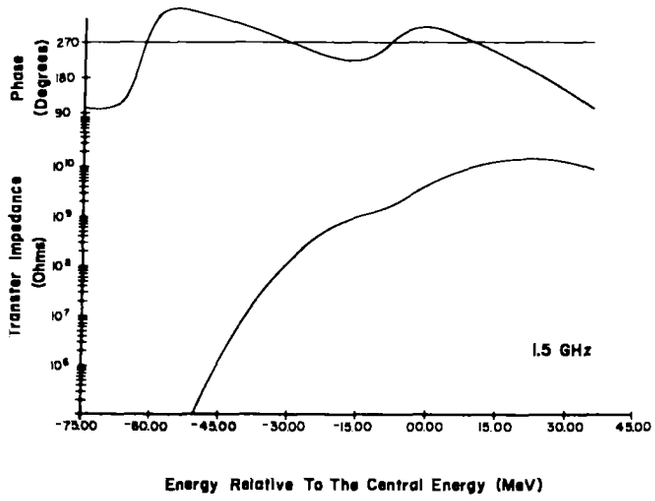

Fig. 2 Gain (in ohms) for a schottky band near 1.5 GHz

A block diagram of the stack tail system is shown in fig. 3. There are 3 sets of pickups and 3 filters. An argument for a series of pickups and filters is given in fig. 4. The schottky power (solid line) from the pickup decreases as the energy approaches that of the core. By using a large number of pickups and low noise amplifiers, it is possible to make the schottky signal (solid line on fig. 4) 10 dB above the noise level (wavy line). However, since the schottky signal decreases exponentially with energy and since the noise signal is independent of energy, the noise signal is much larger than the schottky power at the core energy. In order for the core not to be heated excessively it is required for the power to be down in the core by the ratio of densities of particles in the tail to the core, namely 10^4. In order to reduce the thermal noise a notch filter is introduced. The notch filter has little attenuation at the maximum of the pickup sensitivity but large (> 40 db) attenuation at the core. This modifies the response so that the noise

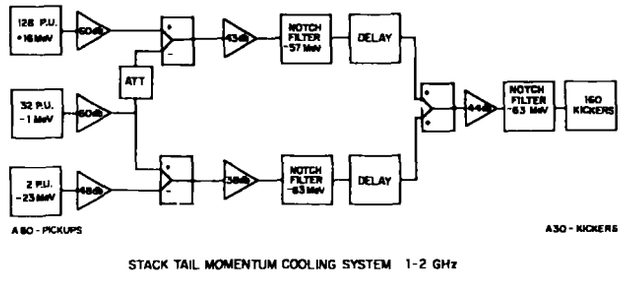

Fig. 3 System Block Diagram

*Operated by Universities Research Inc., under contract with the United States Department of Energy.

level is small enough at the core (dotted line on fig. 4). However, the schottky signal is still far below the noise level as the core is approached and it is necessary to add another set of pickups whose maximum sensitivity is closer to the core. The notch filters unfortunately have the side effect of introducing unavoidable phase errors in the gain profile (fig. 1). The precision of the notch spacings can be estimated from the full width of the core $\Delta f/f_o = 10^{-5}$, where Δf is the width and f_o is the revolution frequency.

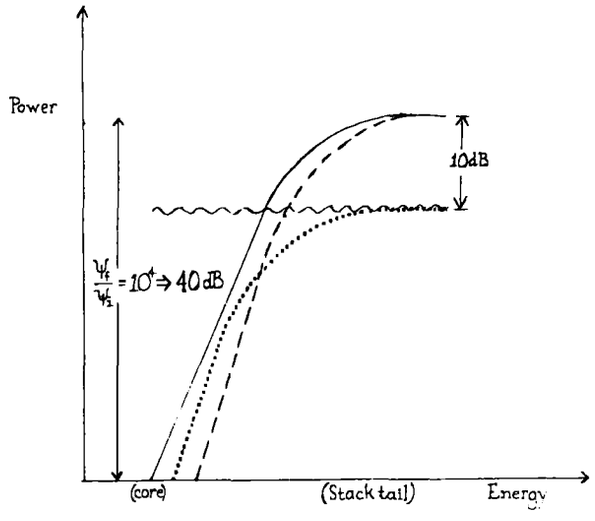

Fig. 4 Schematic representation of schottky signal and thermal noise power levels

Some characteristics of the hardware for the stack tail system are given in Table II.

Table II

Frequency	1-2 GHz
No. pickup pairs	160
PU characteristic impedance	100 Ω
PU coupling impedance	42 Ω
PU resistor temperature	80°K
Amplifier noise temperature	80°K
System gain	145 db
Number of TWT's	40
Number of filters	3
Power Schottky	1400 W
Thermal	200 W
No. kickers	160

The design amplifier noise temperature (80°K) has already been obtained with commercial GAsFet amplifiers cooled to -50°C. We expect to do better with models capable of being cooled to 77°K. A prototype with an average noise temperature of about 30°K has been built at LBL.

The travelling wave tubes (TWT's) have been studied extensively for both linear gain and non-linear distortion properties. An understanding of the properties of TWT's and kickers is crucial to maintaining the required 40 db dynamic range between stack tail and core. Typical TWT's for the 1-2 GHz band have a bandwidth of about 1 GHz at a gain of 6 dB down from the peak. The phase varies about ±20° over this range. The gain variation is not terribly significant because the cooling rate has a broad maximum as a function of gain. Naively the cooling rate is parabolic: a cooling term proportional to gain and heating terms proportional to gain squared. The phase error is normally of little consequence (cooling is reduced by cos of the phase error). However, the stack tail filters produce errors of the order of 45°; an additional 20° would reduce performance substantially. Fortunately, both the phase and amplitude response can be substantially improved with simple filters. It remains to be determined how well phase errors can be controlled in the complete system.

The non-linear response of the travelling wave tubes causes frequency mixing. If the filters are placed before the travelling wave tubes the frequency will fill in the notches. It is therefore desireable to place some of the filtering action after the TWT's. This point is discussed in more detail in Ralph Pasquinelli's article.

Acknowledgements

The design of the system was accomplished through the efforts of a large number of people. Among them are W. Kells, G. Lambertson, C. Leeman, A. Ruggiero, and J. Simpson. I would also like to acknowledge the efforts of Ann Marriner in preparing the figures for this manuscript.

References

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2. S. van der Meer, "Stochastic Stacking in the Antiproton Accumulator," CERN/PS/AA/78-22 (1978), unpublished and D. Mohl, et. al. Physics Reports C, 58 (1980) 73-119.