Pbar Note 602
Effective Noise Temperature for the Accumulator Stacktail System

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ABSTRACT
The effective noise temperature calculation for the Accumulator Stacktail cooling system is documented. Under the assumption that all elements inside the cooling tanks are kept at 80 K, the effective temperature is 124 K. Other scenarios for temperature distribution inside the tanks and the resulting effective temperatures are also detailed

1. Effective Noise Temperature

The effective noise temperature, T_{efff}, combines the effects of resistor, cable, and amplifier characteristics into one number to characterize the total noise in the system. It includes the operating temperatures, insertion losses, and noise figures. The total noise power in the system is expressed as $kT_{eff}B$, where k is the Boltzmann constant (1.38 x 10^{-23} joules/Kelvin) and B is the bandwidth of the system (in Hz).

2. Noise Temperature Algorithm

I follow the algorithm detailed in Pbar 370 [1]. The following diagram summarizes the situation for the Accumulator Stacktail cooling system:

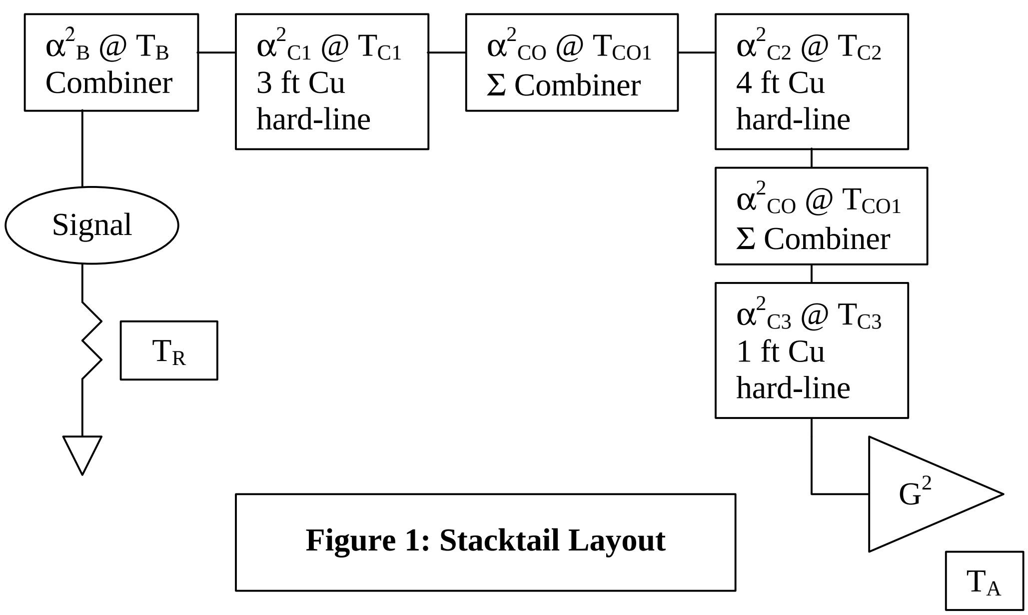

Figure 1: Stacktail Layout

This diagram contains the important pieces on the front end for the calculation of the effective noise temperature. The termination resistor is at the temperature T_R. The combiner board (summing 16 loops) has insertion loss α^2_B at temperature T_B. There are 3 segments of Cu hard-line cable (a 3 ft section, a 4 ft section, and a 1 ft section) with insertion losses α^2_{C1}, α^2_{C2}, and α^2_{C3} at temperatures T_{C1}, T_{C2}, and T_{C3} respectively. There are 2 Σ combiners, with insertion losses α^2_{CO1} and α^2_{CO2} at temperatures T_{CO1} and T_{C02} respectively. The amplifier has a gain G^2 and an effective temperature T_A.

The general method to calculate the effective noise temperature is to calculate the ratio S'/N', where S' is the initial signal, scaled by the losses and amplifier gain, and N' is the total noise power. Defining S'/N' = S/N_{eff}, where N_{eff} is the effective noise power, the effective temperature can easily be deduced.

In the Accumulator stacktail system described in Figure 1, the effective noise temperature reduces to the following equation:

$$T_{eff} = \frac{T_R}{a_B^2} + \frac{T_{C1}(1-a_{C1}^2)}{a_B^2 a_{C1}^2} + \frac{T_{CO1}(1-a_{CO}^2)}{a_B^2 a_{C1}^2 a_{CO}^2} + \frac{T_{C2}(1-a_{C2}^2)}{a_B^2 a_{C1}^2 a_{CO}^2 a_{C2}^2}$$
$$+ \frac{T_{CO2}(1-a_{CO}^2)}{a_B^2 a_{C1}^2 a_{CO}^2 a_{C2}^2 a_{CO}^2} + \frac{T_{C3}(1-a_{C3}^2)}{a_B^2 a_{C1}^2 a_{CO}^2 a_{C2}^2 a_{CO}^2 a_{C3}^2}$$
$$+ \frac{T_A}{a_B^2 a_{C1}^2 a_{CO}^2 a_{C2}^2 a_{CO}^2 a_{C3}^2}$$

where the α^2 terms are the insertion losses and T terms are absolute temperatures (K). This situation will be referred to as **CASE** 1. **CASE 2** places the amplifier immediately downstream of the first combiner (C01). In this case, the number of amplifiers needed is doubled and it is necessary to place the amplifier inside the vacuum tank. The effective temperature in the second case reduces to the following equation:

$$T_{eff} = \frac{T_R}{a_B^2} + \frac{T_{C1}(1-a_{C1}^2)}{a_B^2 a_{C1}^2} + \frac{T_{CO1}(1-a_{CO}^2)}{a_B^2 a_{C1}^2 a_{CO}^2} + \frac{T_A}{a_B^2 a_{C1}^2 a_{CO}^2},$$

a much simpler expression.

3. Inputs to Calculation

In the equations above, there are terms for the insertion loss in the cables, the Σ combiner, and the combiner board. I made measurements of the cable and have previous measurements of the Σ combiner. I estimated the combiner board insertion loss based on the LineCalc model, changing the conductivity of copper as a function of temperature.

To measure the cable insertion loss, a 10 foot section of 0.141" Cu hard-line was prepared. Measurements were made with a calibrated network analyzer at both room temperature and dumped in a liquid nitrogen bath. Table 1 summarizes the results as a function of frequency. I will use the values at 3 GHz (mid-band in the stacktail system) for the noise temperature calculations

Table 1: Cable Insertion Loss Measurements

Frequency (GHz)	Insertion Loss Warm (dB)	Insertion Loss Cold (dB)
2.0	-1.634	-0.574
3.0	-2.077	-0.704
4.0	-2.455	-0.805
6.0	-3.085	-1.003
8.0	-3.667	-1.114

4. Results

For the calculations of effective noise temperature, I assume that the cable insertion loss scales linearly with temperature, using the measurements from Table 1 as the inputs. For the combiner board, I use the estimated loss from LineCalc for a copper conductivity of 0.215 x 10^{-8} Ωm. The simulation calculates a loss of –0.0847 dB/ft. The longest path out on the combiner board is approximately 21 inches, resulting in a total loss of –0.15 dB. I have taken an average of the 10 best amplifiers and have used a noise temperature of 20 K when the amplifier physical temperature is 80 K. The results for different possible temperature scenarios are presented below in Table 2. In all cases, I have assumed that the termination resistors and amplifiers are kept at 80 K.

Table 2: Effective Temperature Results. All temperatures are in Kelvin; all losses represented as fractional loss.

CASE 1 Additional combining inside tank

T_eff	T_R	α^2_B	T_C1	α^2_C1	T_CO1	α^2_CO	T_C2	α^2_C2	T_CO2	α^2_CO	T_C3	α^2_C3	T_A
124	80	0.97	80	0.95	80	0.97	80	0.94	80	0.97	80	0.98	20
130	80	0.97	100	0.94	80	0.97	100	0.93	80	0.97	100	0.98	20
137	80	0.97	120	0.94	80	0.97	120	0.92	80	0.97	120	0.98	20
145	80	0.97	140	0.93	80	0.97	140	0.91	80	0.97	140	0.98	20
155	80	0.97	160	0.92	80	0.97	160	0.90	80	0.97	160	0.97	20
166	80	0.97	180	0.91	80	0.97	180	0.88	80	0.97	180	0.97	20
178	80	0.97	200	0.90	80	0.97	200	0.87	80	0.97	200	0.97	20

CASE 2 Amplifier inside tank

T_eff	T_R	α^2_B	T_C1	α^2_C1	T_CO1	α^2_CO	T_A
112	80	0.97	80	0.95	80	0.97	20
114	80	0.97	100	0.94	80	0.97	20
117	80	0.97	120	0.94	80	0.97	20
120	80	0.97	140	0.93	80	0.97	20
123	80	0.97	160	0.92	80	0.97	20
127	80	0.97	180	0.91	80	0.97	20
131	80	0.97	200	0.90	80	0.97	20

The exact temperature profile inside the tank is not known at this time, though the cables will not be colder than 80 K and probably not warmer than 200 K. With this range, the effective noise temperature varies from 124 to 178 K or a power range of 3.4 to 4.9 pW (-84.7 to –83.0 dBm). Using a value of 125 K as the effective noise temperature in the stacktail cooling simulation results in an estimate of 625 W of noise power at the kicker.

Assuming the worst scenario (cables at 200 K) results in an estimate of 890 W of noise power at the kicker. However, in **CASE 2** (where the amplifier is placed on the output of the first Σ combiner), the worst scenario has an effective noise temperature of 131 K and an estimate of 650 W of noise power. Higher noise power adversely affects stacking performance.

5. Stacking Performance

I have run the stacking simulation with the default Run II Configuration, adjusting only the effective noise temperature at the front end. With an effective noise temperature of 125 K and input 24 mA/hour, a steady state stacking rate of 20.7 mA/hour is achieved. Changing the effective noise temperature to 175 K drops the steady state stacking rate to 18.0 mA/hour. No attempt has been made to optimize the system at the higher noise temperature. As the optimum gain does depend upon the signal to noise ratio, it may be possible to improve the stacking performance with the higher noise temperatures.

Figure 2: Stacking Rate vs time for 6 different effective noise temperatures (in Kelvin).

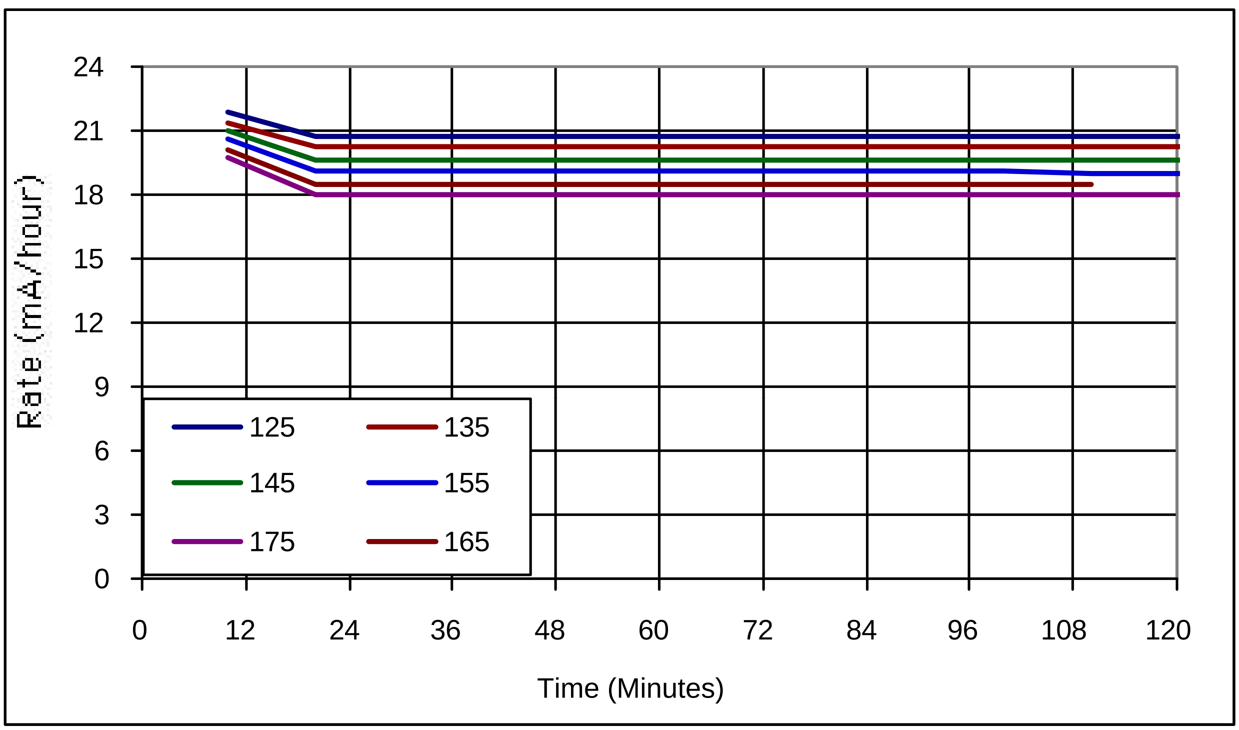

Figure 2 shows the stacking rate vs time (over a two hour period) for 6 different effective noise temperatures. There is a 14% change going from 125 K to 175 K.

1. R. Shafer, Pbar Note 370, "Signal-to-Noise Reduction by Attenuation at Various Temperatures", 1 March 1984.