PBAR NOTE 581
SIMPLE HEAT TRANSFER CALCULATIONS FOR THE MICROWAVE ABSORBER IN THE DEBUNCHER UPGRADE

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March 22, 1998

INTRODUCTION

Microwave absorber is used in the Debuncher Upgrade for two purposes. The most important purpose is to isolate adjacent arrays from "talking" to each other. The second purpose is to reduce the strength of the magnetic (sum) modes travelling in the beam pipe. For a kicker, most of the power is confined to the beam pipe. Very little power will be transmitted to the terminating resistors in the input waveguides. Therefore, the isolating absorber will have to absorb almost all of the TWT power. For a sum and difference mode system, this power will be on the order of 200 Watts per array. The space set aside for the isolating absorber is about 4 inches long. A typical aperture of a beam pipe is about 40 mm by 40 mm. The power density on the absorber surface will then be about 8 W/in^2 (12.3 kW/m^2).

THERMAL CONDUCTANCE IN THE ABSORBER

The temperature gradient caused by thermal power flowing in the positive x direction is:

$$q = -k\frac{\partial T}{\partial x} \tag{1}$$

where q is the power flow per unit area and k is the thermal conductivity. Table 1 shows the thermal conductivity of a few materials.

Material	Thermal Conductivity (Watts / meter – Kelvin)
Copper	400
Stainless Steel	15
Teflon	0.35
MF190	1.44

Table 1.

If the thermal power in the absorber is uniformly supplied along the thickness of the absorber, the temperature gradient is given as:

$$q_s = -kW\frac{\partial^2 T}{\partial x^2} \tag{2}$$

where W is the thickness of the absorber and q_s is the power per square meter dissipated in the absorber. If the walls of the beam pipe are at x=0 and a temperature T_o, and the inside wall of the absorber is at x = W, then the temperature profile in the absorber is:

$$T(x) = T_o + \frac{q_s W}{k}\left(\frac{x}{W} - \frac{1}{2}\left(\frac{x}{w}\right)^2\right) \quad (3)$$

Equation 3 assumes that all of the power is transferred to the beam pipe wall and none of the power is radiated towards the inside of the beam pipe. From Equation 3, the temperature drop across the absorber is:

$$\Delta T_a = \frac{q_s W}{2k} \quad (4)$$

A reasonable absorber thickness is 3 mm. If 8 W/in^2 where dissipated in the absorber, a 10°K temperature drop across the absorber would require the absorber to have thermal conductivity of about 1.8 W/m-K.

CONTACT RESISTANCE

The temperature gradient caused by thermal power flowing between two materials in mechanical contact is:

$$\Delta T_c = q_s R_c \quad (5)$$

where R_c is the thermal contact resistance and has units of K-m^2/W. A typical value of contact resistance for two pieces of stainless steel in vacuum pushed together with a force of 100 kN/m^2 (14.5 psi) is about 15 x 10^{-4} K-m^2/W. This contact resistance is reduced by a factor of about 6 if the contact pressure is increased by a factor of 100. If 8 W/in^2 flowed through a contact resistance of 8 x 10^{-4} K-m^2/W, a 10°K temperature gradient will develop across the interface.

THERMAL RADIATION

The power flux between two surfaces at two different absolute temperatures due to radiation is:

$$q = \varepsilon\sigma\left(T_a{}^4 - T_b{}^4\right) \quad (6)$$

where σ is the Stefan-Boltzmann constant (σ = 5.67 x 10^{-8} W/m^2-K^4) and ε is the emissivity of the surface. If T_b is 273K, then T_a would have to be 686K (413°C) in order for 8W/in^2 to flow from surface **a** to surface **b** solely by radiation (ε = 1). In other words, a power flux 0.03 W/in^2 (which is 250 times smaller than 8 W/in^2.) would cause the temperature of surface **a** to rise to 283K.