Magnetic Shielding and Ohmic Losses From Finite Thickness Faraday Shields

R. J. Kashuba[1]
McDonnell Douglas Corporation

D. N. Smithe[2] and T. Kammash
University of Michigan

In many ICRF experiments, the radiating elements have been separated from the plasma by surrounding the antenna with closely-spaced metallic strips called Faraday Shields. These shields protect the antenna from the hot plasma environment, as well as electrostatically shielding the plasma from parallel fields associated with the antenna. There is considerable flexibility in choosing a shield cross-section shape, although effective protection from plasma irradiation would generally require that the gaps between successive shields be small in at least one location. Previous theoretical investigations[3] have shown that Faraday shields reduce transmission of the heating fields by magnetically shielding the antenna current. Unfortunately, these field reductions are most severe precisely when the gaps between shields are small.

The present theory of magnetic shielding by Faraday shields involves calculation of the magnetic fields produced by an infinite array of shields surrounding a stripline antenna with uniform current along its length. For frequencies of interest to ICRF heating, the wavelength is considerably larger than the shield dimensions, so that a quasi-static approximation can be made.

We have developed a method by which the fields can be calculated for some simple cross-section shapes with finite thickness. The shield width and thickness are handled simultaneously through a conformal mapping of a quarter section of the shield cross section. No restrictions need be made concerning thickness, or the degree of shielding. Therefore, the results are valid for cases of narrow gaps and large shielding. The fundamental assumption underlying this method is that the shield periodicity length be small compared to the shield dimensions. This assumption has been widely used in previous methods, and is generally valid for shield designs currently in use.

The geometry used in the calculations is shown in Fig. 1. As a result of the calculation, each angular component of $\vec{B}$ is reduced by a factor from the unshielded case. We thus define a transmission coefficient, T_m, for the m^{th} order mode. For the m^{th} order mode

$$B_{r,\phi} \sim \frac{1}{r^{m+1}}$$

and

$$T_m = \frac{1}{1 + \frac{sm}{2\pi a}\Lambda},$$

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where Λ is a complicated function of the shield parameters and, in general, must be calculated numerically. However, for larger shielding ($\Lambda \gtrsim 10$),

$$\Lambda \simeq \pi \frac{wt}{s(s-w)} - \frac{w}{s} \ln 4.$$

In Fig. 2 we present the comparative results of the Λ calculation for a square and round cross section. Thus, the square cross section will yield a smaller transmission coefficient.

We have also incorporated the skin depth approximation to calculate the ohmic losses, i.e.,

$$\text{Losses} = \frac{I^2}{2\sigma\delta} \iint_{\text{shield}} \left| \frac{\vec{B}}{\mu_o I} \right|^2 dA.$$

In Fig. 3 we show the shield ohmic losses for a round cross section. The shield spacing to radius ratio was taken to be 1/6. A line antenna, centered at half the shield radius, was used in the calculations.

When the gap size is fairly large, $w/s \lesssim 0.7$, the ohmic losses are seen to be relatively insensitive to shield thickness, t, and the square shield losses do not differ appreciably from the round shield losses. As the gap narrows, ohmic losses increase and become sensitive to the shield thickness. The square shield losses appear to increase with shield thickness, except for very thin shields, where the skin depth approximation must be scrutinized. The round shield losses show a minimum at a thickness-to-spacing ratio of about 1/8 to 1/10. To the left of the minimum, losses increase because of larger currents, necessary to make the magnetic field bend around a sharper corner. To the right of the minimum, losses increase due to a larger area in the gap face. The minimum represents a compromise between the two opposing tendencies. For thicknesses beyond the minimum loss point, the round shield losses are 30 to 40% less than the square shield losses. This is a combined result of having rounded edges, and lesser gap area than the square shield.

Conclusions

Faraday shield design involves a trade-off between providing adequate protection from the hot plasma environment and allowing efficient transmission of the rf heating fields. When the gaps between shields are small ($w/s \gtrsim 0.8$), the transmission and ohmic losses associated with the shield are more sensitive to shield thickness and cross section shape. For example, the two shield cross sections examined in this paper give the following results for a shield with $s/a = 1/6$, $w/s = 0.8$, and $t/s = 0.1$.

Rounded shape: $T_1 = 0.94$, losses $= 0.092 \times \frac{I^2}{2\sigma\delta}$

Square shape: $T_1 = 0.91$, losses $= 0.125 \times \frac{I^2}{2\sigma\delta}$.

If the thickness is increased to a thickness ratio of 0.3, the results are

Rounded shape: $T_1 = 0.90$, losses $= 0.104 \times \frac{I^2}{2\sigma\delta}$

Square shape: $T_1 = 0.86$, losses $= 0.165 \times \frac{I^2}{2\sigma\delta}$.

The ohmic losses of the rounded shield are 26% and 37% less than that of the square blade. In cases when the ohmic losses are of the same order magnitude as the transmitted power, it may therefore be desirable to select shield cross sections which are magnetically "streamlined", having for example, well-rounded outside corners.

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[2] DOE Magnetic Fusion Energy Technology Fellow.

[3] Faulconer, D. W., Journal of Applied Physics, 54, 3817 (1983).

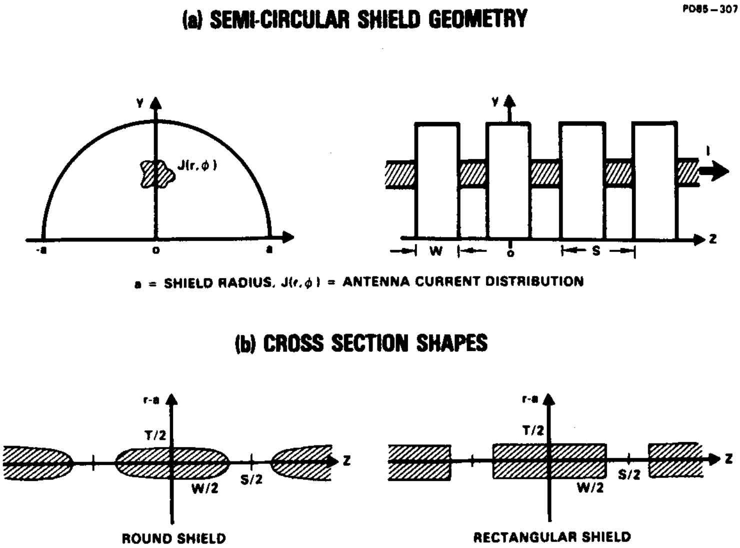

FIGURE 1. FARADAY SHIELD GEOMETRY

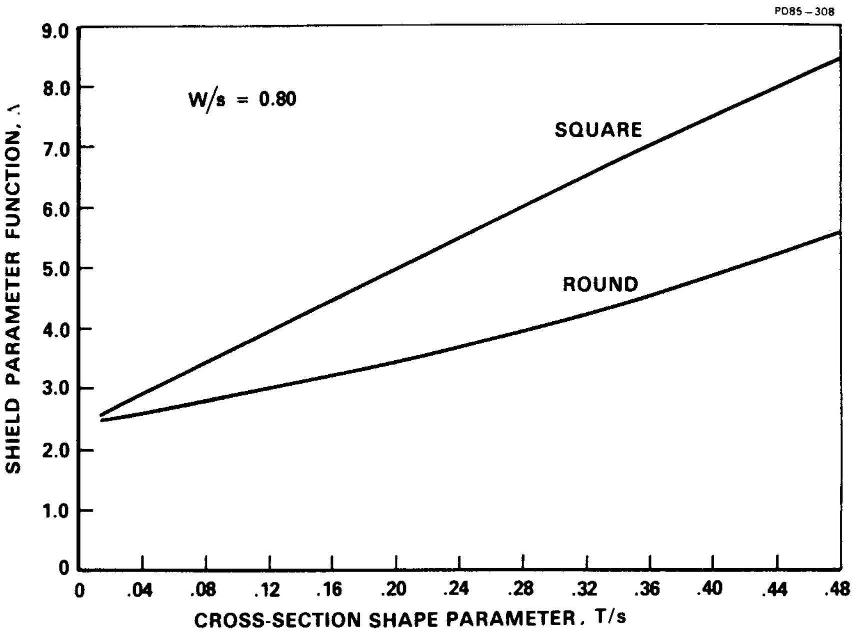

FIGURE 2. COMPARISON OF SHIELD PARAMETER FUNCTIONS (Λ)

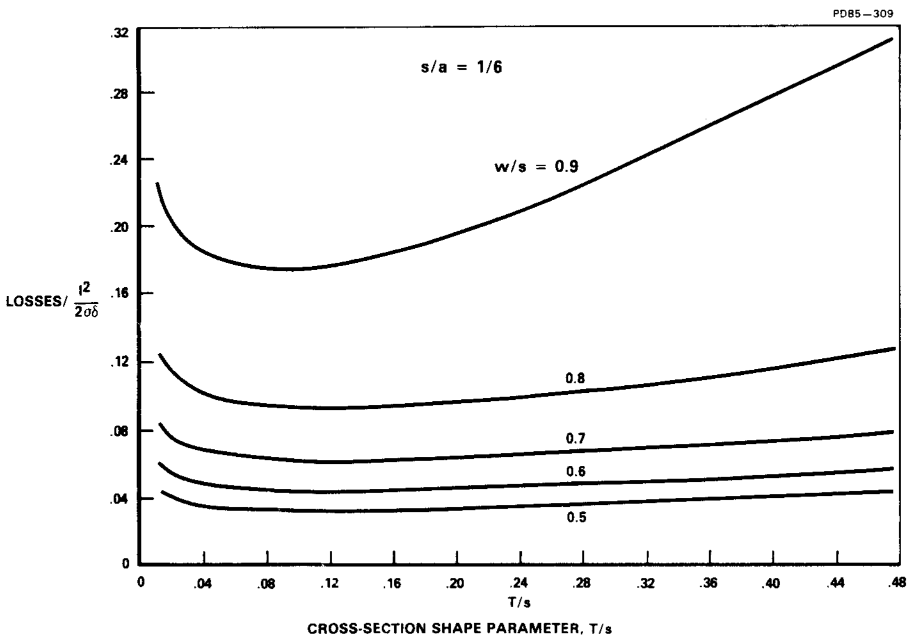

FIGURE 3. SHIELD OHMIC LOSSES FOR ROUND CROSS-SECTION