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Nomograms Simplify Calculations of Magnetic Shielding Effectiveness

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The complex equations which describe magnetic shielding effectiveness can be solved quickly and easily by using three nomographs and one graph.

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Shielding effectiveness (S_H) describes the ability of a given material to act as a shield against incident magnetic fields. It is composed of three factors: reflection losses (R_H), absorption losses (A) and secondary reflection losses (B). These factors can be calculated seperately and added as follows:

$S_H = R_H + A + B$ (all quantities in decibles).

The first two factors can be determined by using one nomograph each; however, the third is complex and requires both a nomograph and a graph. In fact, B has been so difficult to calculate in the past, that it was usually neglected. The effect of neglecting B can result in errors of up to 20 db at lower frequencies (<2 kHz), as shown in **Fig. 1** for two different shielding materials.

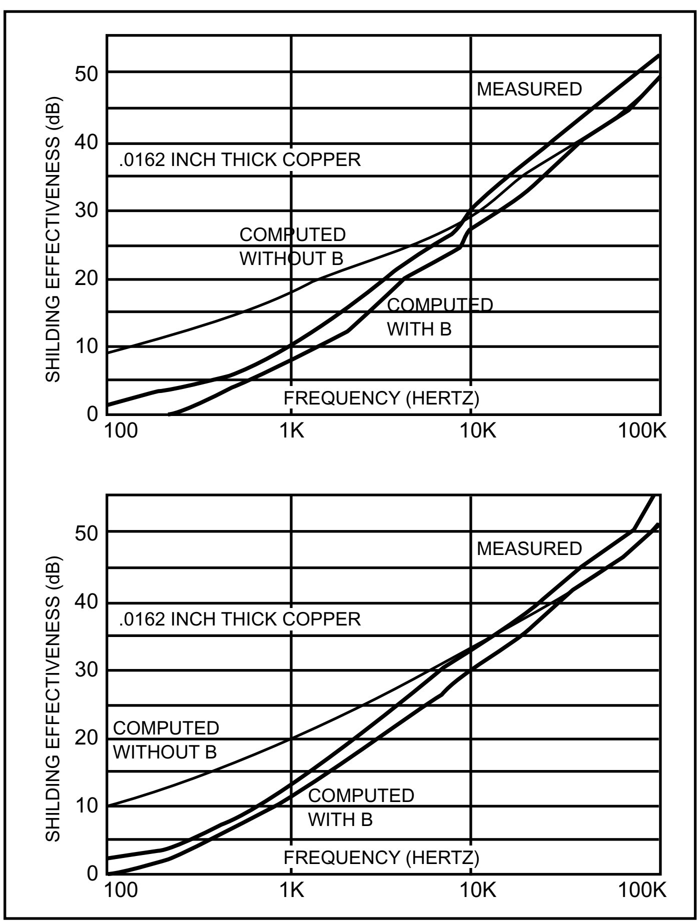

Fig. 1 – The effect of neglecting seconddary reflection losses (B) can result in errors of up to 10 dB (Test distance = 2 in.) in magnetic shielding effectiveness.

Absorption losses

Absorption losses (A) are a function of the physical characteristics of the shield and are independent of the type of source fields. For a given thickness, magnetic materials such steel provide higher absorption losses than non-magnetic materials (copper). When reflection losses are low, thicker high-permeability materials are employed to increase shielding effectiveness.

The equation used to solve for A is:

$$A = 3.334 \times 10^{-3} t\,(\mu_r \sigma_r f)^{1/2}$$

where t = metal thickness in mils,

μ_r = material permeability relative to air,

σ_r = material conductivity relative to copper,

f = frequency in Hz.

The nomograph in **Fig. 2** solves this equation for A.

Reflection losses

The compulation of reflection losses can be greatly simplified by considering shielding effectiveness for incident electric fields as a seperate problem from that of magnetic or plane waves. In the sheilding equation, r thus becomes either R_E, R_H, R_p as computed.

$$R_H = 20 \log_{10} [\, 0.462/r\,(\mu_r/f\sigma_r)^{1/2} + 0.136r\,(\mu_r/f\sigma_r)^{-1/2} + 0.354\,]$$

where r is the distance between the source of energy and the shield in inches

The nomograph in Fig. 3 solves the equation for R_H.

Secondary reflection losses

When absorption losses are very low (usually less than 6 dB), the magnetic shielding effectiveness due to reflection losses changes, and the equation for R_H is no longer accurate. The complex equation for magnetic field secondary reflection losses shown below expresses this change. The factor B can be mathmatically positive or negative (in practice it is always negative), and becomes insignificant when A > 6 dB. It is usually only important when metals are thin, and at low frequencies (i.e., below aproximately 20 kHz).

$$B \text{ (in dB)} = 20 \log_{10} \left| 1 - \left(\frac{(K-1)^2}{(K+1)^2} \right) \left(10^{-A/10} \right) \left(e^{-j.227A} \right) \right|$$

where A = Absorption losses (dB)

$|K| = |Z_s/Z_H| = 1.3\,(\mu_r/f_r^2\sigma_r)^{1/2}$

Z_s = Shield impedance

Z_H = impedance of incident of the magnetic field

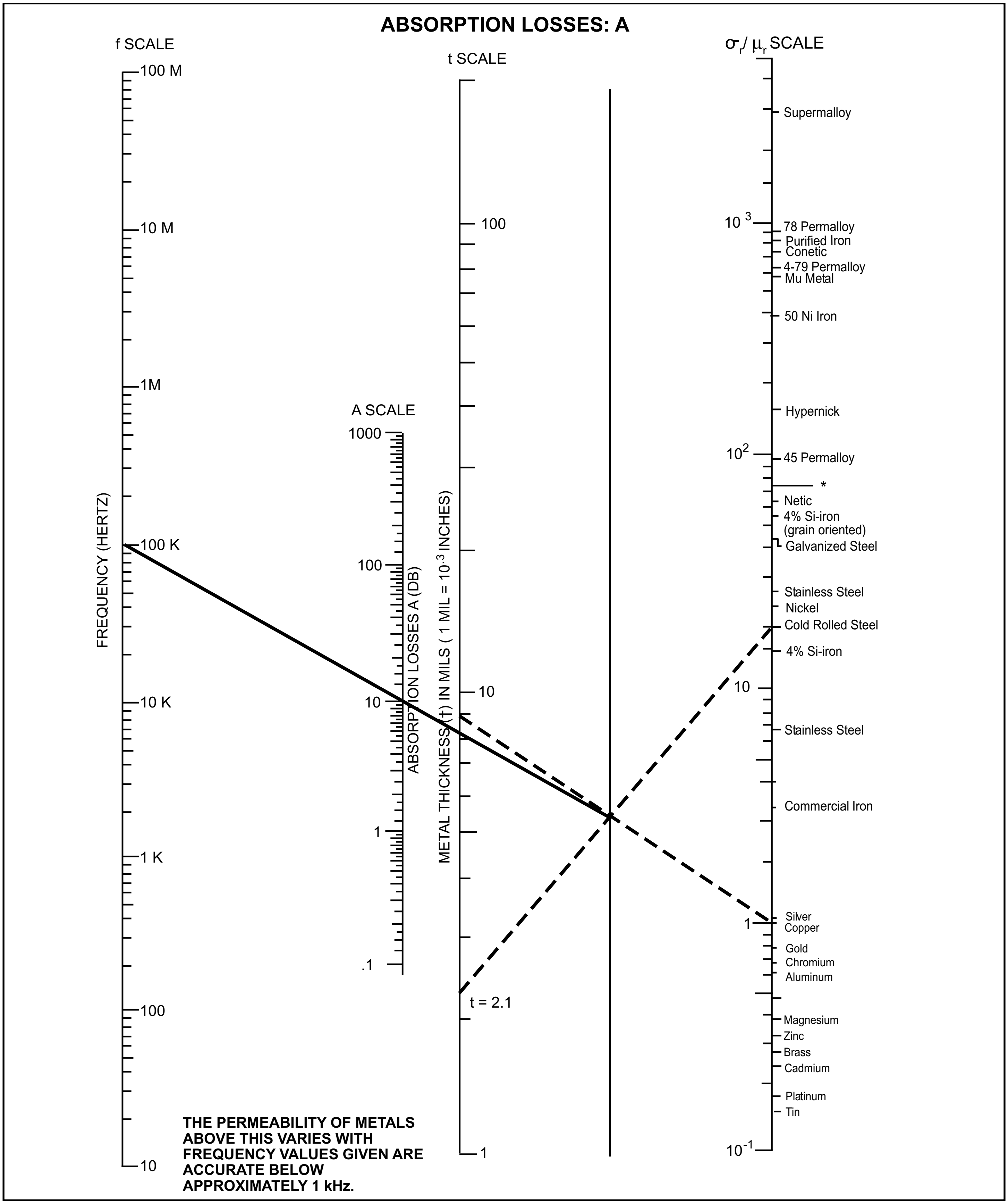

Fig. 2 – How to use the Absorption Loss nomograph. Given a desired amount of absorption loss at a known frequency, determine the required thickness for a known metal.

1) Locate the frequency on the **f scale** and the desired absorption loss on the **A scale**. Place a straightedge across these points and locate a point on the unmarked scale. (Example: A = 10 dB, f = 100 kHz.)

2) pivot the straightedge about the point on the unmarked scale to various metals noted on the **σ_r / μ_r scale**. A line connecting the **σ_r / μ_r scale** and the point on the unmarked scale will give the required thickness on the **t scale**. Example: for copper t = 9.5 mils, for cold rolled steel t = 2.1 mils.

3) The absorption loss nomograph can also be used in reverse of the above order.

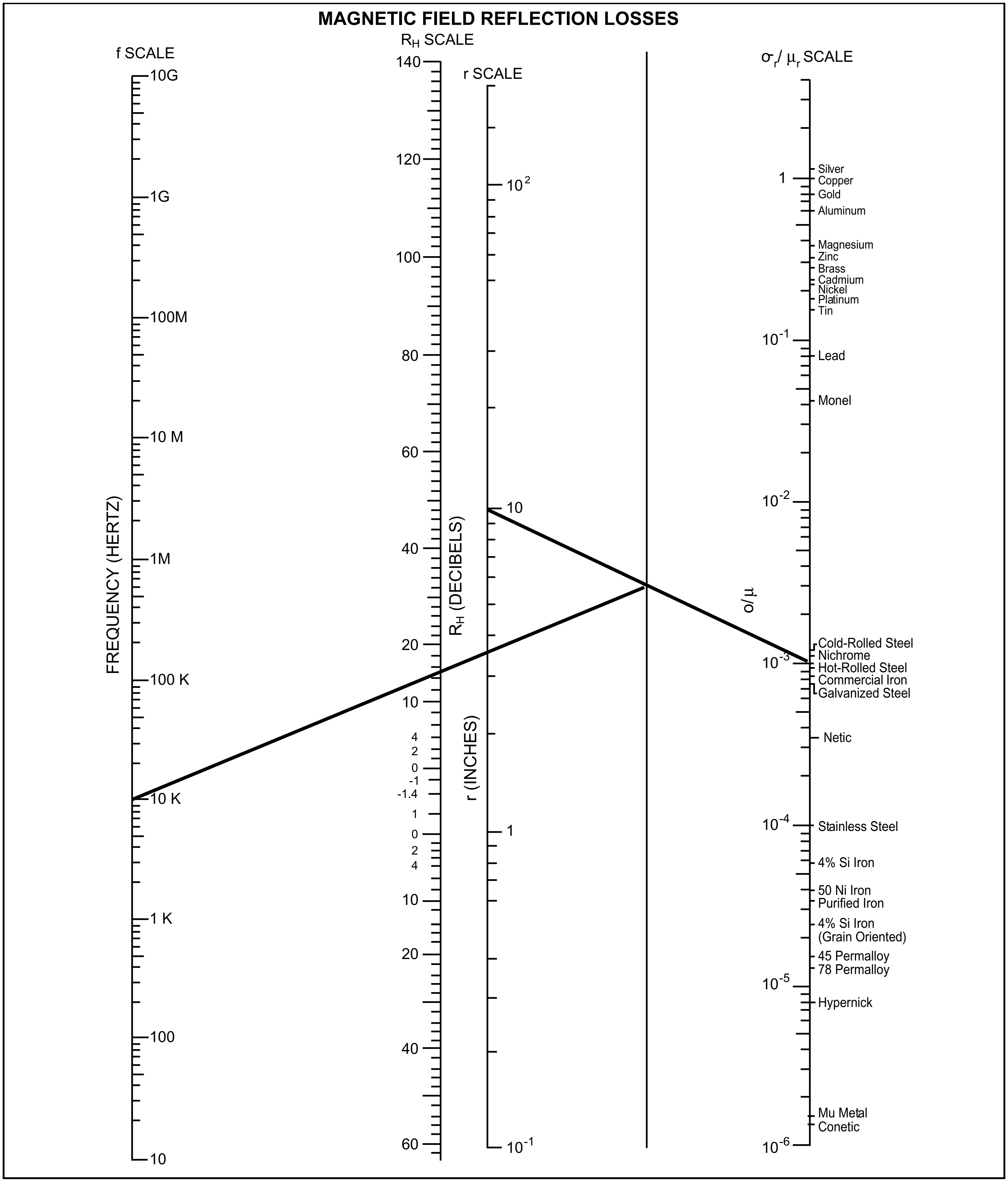

Fig. 3 – How to use the Reflection Loss nomograph.

1) Locate a point on the **σ_r / μ_r scale** for one of the metals listed. If the metal is not listed, compute σ_r / μ_r and locate a point on the numerical scale.

2) Locate the distance between the energy source and the shield on the **r scale**.

3) Place a straightedge between r and σ_r / μ_r and locate a point on the blank scale (Example: r = 10 inches for hot rolled steel).

4) Place a straightedge between the point on the blank scale and the desired frequency on the **f scale**.

5) Read the reflection loss from the **R_H scale**. (For f = 10 kHz, R_H = 13 dB).

6) By sweeping the f scale while holding the point on the blank scale, R_H versus frequency can be obtained. (For f = 1 kHz, R_H =3.5 dB).

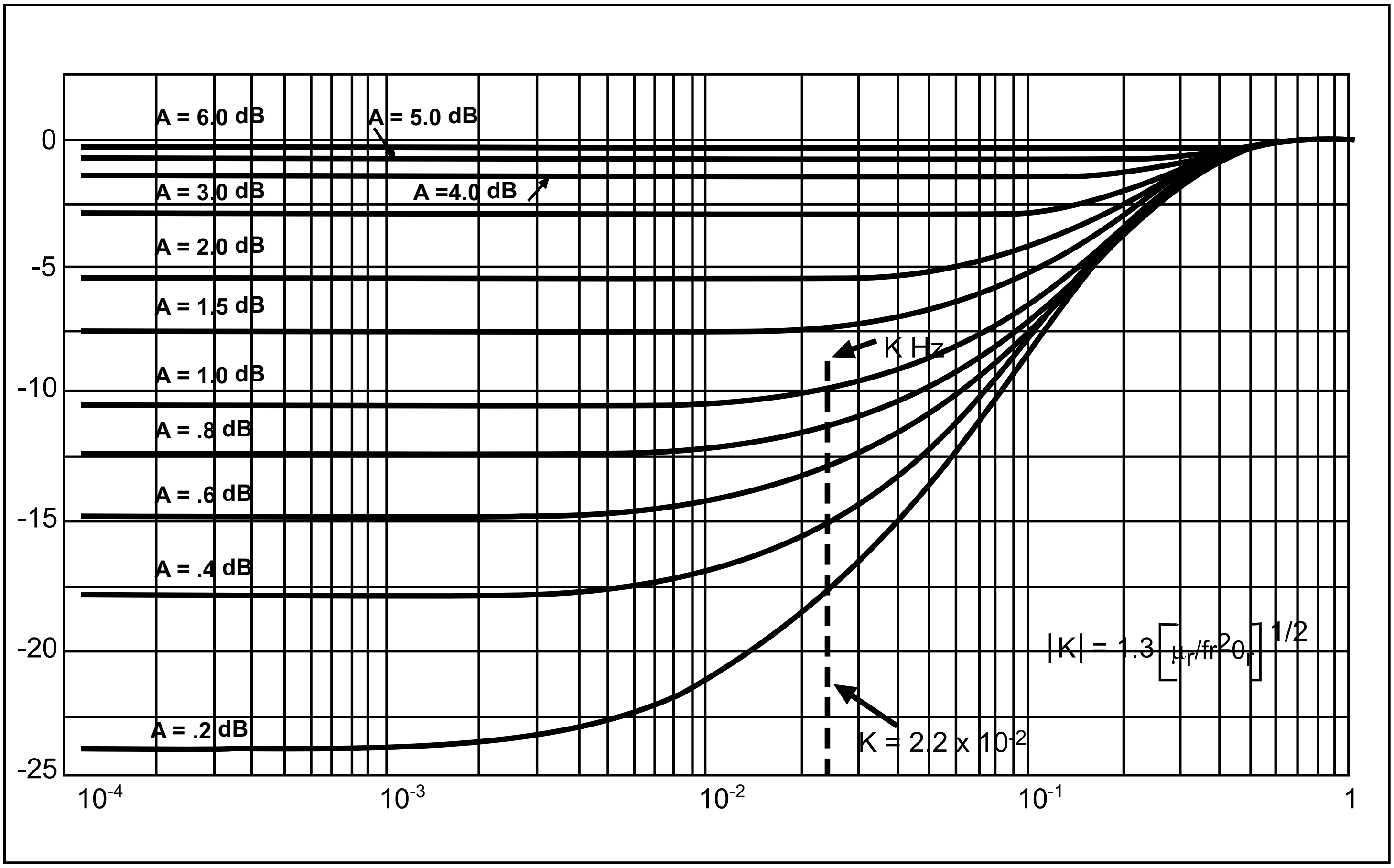

Fig. 5 – Use graph to locate B.
1) Locate |K| = 2.2 x 10^{-2} 0n the horizontal scale.
2) Move vertically to intersect the A = 1.3 curve (interpolate) and then horizontally to the left to find = -8.5 dB.

The preceeding equation was solved in two parts. A digital computer was programmed to solve for B with a preselected value of A, while |K| varied between 10^{-4} and 10^{3}. The results are ploted in **Fig. 5**.

The nomogaph shown in **Fig 4** was then designed to solve the equation for |K| above. Note that when Z_H becomes much smaller than Z_S(K > 1), large positive values of B may result. These produce very large and unrealistic computed values of S_H,and imply a low frequency limitation on the B equation. For purposes of this article, only negative values of B will be considered valid. In practical cases, absorption losses (A) must be calculated before B can be obtained.

Permeability influences shielding effectiveness

Magnetic shielding effectiveness calculations are highly dependent on the permeability (μ) of the shield. It has long been thought that permeability decreased at higher frequencies, and that saturation due to exposure to high-intensity magnetic fields also produce a loss of shield permebility.

Recent work has shown yhat this is not entirely true. The more common building metals (i.e., cold rolled steel, galvanized steel, hot rolled steel) do not change permeability with frequency, and show only a 1 to 3 dB variation in S_H when exposed to high intensity fields (2 Oersteds). Higher permeability materials, such as netic or conetic, show both a change of permeability with frequency and a 5 to 8 dB saturation loss in 2 Oersted fields.

The permeabilities and conductives shown on the nomographs have been measured and can be relied upon to provide accurate values of S_H. Calculations for high permeability materials may require about a 6 dB derating when exposed to high intensity magnetic fields of approximately 2 Oersteds. The field can be calculated for a loop radiator using the following formula:

H = 0.5 NI/1 Oersteds
where N = number of turns
I = peak current
1 = magnetic path length in inches

Databank

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(5) R. B. Cowdell, "Nomographs Solve Tough Problems of Shielding," Electronics, April 17,1967, p. 92.

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Robert Cowdell recieved his MSEE from the University of Southern California and is a member of the IEEE EMC Group.