Table 5-1. Coefficients for magnetic field reflection loss*

Coefficient	Units for distance (r)			
	Meters	Millimeters	Inches	Mils
C_1	0.0117	11.7000	0.462	462
C_2	5.350	0.0053	0.136	136

*Source: H. W. Denny, et al., Grounding, Bonding, and Shielding Practices and Procedures for Electronic Equipments and Facilities, Vol I-II, Fundamental Considerations, Report No. FAA-RD-75-215, I (Engineering Experiment Station, Georgia Institute of Technology, December 1975).

Table 5-2. Absorption loss of metals at 150 kilohertz*

Metal	Relative conductivity, g_r	Relative permeability at 150 kHz, μ_r**	Absorption loss at 150 kHz, dB/mil
Silver	1.05	1	1.32
Copper, annealed	1.00	1	1.29
Copper, hard-drawn	0.97	1	1.26
Gold	0.70	1	1.08
Aluminum	0.61	1	1.01
Magnesium	0.38	1	0.79
Zinc	0.29	1	0.70
Brass	0.26	1	0.66
Cadmium	0.23	1	0.62
Nickel	0.20	1	0.58
Phosphor-bronze	0.18	1	0.55
Iron	0.17	1000	16.9
Tin	0.15	1	0.50
Steel, SAW 1045	0.10	1000	12.9
Beryllium	0.10	1	0.41
Lead	0.08	1	0.36
Hypernick	0.06	80,000	88.5***
Monel	0.04	1	0.26
Nu-Metal	0.03	80,000	63.2***
Permalloy	0.03	80,000	63.2***
Stainless steel	0.02	1000	5.7

*Source: Engineering Design Handbook--Electromagnetic Compatibility, DARCOM-P-706-410 (U.S. Army Materiel Command, March 1977).

**The relative permeability of metals changes somewhat with frequency, but becomes decreasingly important at higher frequencies.

***Obtainable only if the incident field does not saturate the metal.

Table 5-3. Absorption loss of solid copper, aluminum, and iron shields at 60 hertz to 10,000 megahertz*

Frequency	Copper		Aluminum		Iron		Absorption loss, db/mil		
	g_r	μ_r	g_r	μ_r	g_r	μ_r **	Copper	Aluminum	Iron
60 Hz	1	1	0.61	1	0.17	1000	0.03	0.02	0.33
1000 Hz	1	1	0.61	1	0.17	1000	0.11	0.08	1.37
10 kHz	1	1	0.61	1	0.17	1000	0.33	0.26	4.35
150 kHz	1	1	0.61	1	0.17	1000	1.29	1.0	16.9
1 MHz	1	1	0.61	1	0.17	700	3.34	2.6	36.3
15 MHz	1	1	0.61	1	0.17	400	12.9	10.0	106.0
100 MHz	1	1	0.61	1	0.17	100	33.4	26.0	137.0
1500 MHz	1	1	0.61	1	0.17	10	129.0	100.0	168.0
10,000 MHz	1	1	0.61	1	0.17	1	334.0	260.0	137.0

*Source: Engineering Design Handbook--Electromagnetic Compatibility, DARCOM-P 706-410 (U.S. Army Materiel Command, March 1977).

**Other values of μ for iron are: 3 megahertz, 600; 10 megahertz, 508; 1000 megahertz, 50.

Table 5-4. Reflection loss*

	Electric field, db**			Magnetic field, dB**			Plane wave, dB***,+		
Frequency	Copper	Aluminum	Iron	Copper	Aluminum	Iron	Copper	Aluminum	Iron
60 Hz	279	--	241	22	--	-1	150	148	113
1000 Hz	242	--	204	34	--	10	138	136	100
10 kHz	212	--	174	44	--	8	128	126	90
150 kHz	177	175	--	56	54	19	117	114	79
1 MHz	152	150	116	64	62	28	108	106	72
15 MHz	117	115	83	76	74	42	96	94	63
100 MHz	92	90	64	84	82	56	88	86	60
1500 MHz	++	--	++	++	--	++	76	74	57
10,000 MHz	++	--	++	++	--	++	68	66	60

*Source: Engineering Design Handbook--Electromagnetic Compatibility, DARCOM-P 706-410 (U.S. Army Materiel Command, March 1977).

**For signal source 12 inches from shield. Wave impedance much greater than 377 ohms. (For distances much greater smaller than 12 inches, recalculate the reflection loss using the formulas given in text.)

***If penetration loss is less than 10 decibels total, reflection loss must be corrected by use of B-factor.

+Signal source greater than 2 from the shield.

++At these frequencies, the fields approach plane waves with an impedance of 377 ohms .

Table 5-5. Shield effectiveness in magnetic field (wave impedance much smaller than 377 ohms) of solid copper, aluminum, and iron shields for signal source 12 inches from the shield at 150 kilohertz to 100 megahertz*

Frequency, MHz	Copper (10 mils)					Aluminum (10 mils)					Iron (10 mils)				
	A (dB)	+	R (dB)	=	SE (dB)	A (dB)	+	R (dB)	=	SE (dB)	A (dB)	+	R (dB)	=	SE (dB)
0.15	13	+	56	=	69	10	+	54	=	64	169	+	19	=	188
1.0	33	+	64	=	97	26	+	62	=	88	363	+	28	=	391
15	129	+	76	=	205	100	+	74	=	174	1060	+	42	=	1102
100	334	+	84	=	418	260	+	82	=	342	1370	+	56	=	1426

*Source: Engineering Design Handbook--Electromagnetic Compatibility, DARCOM-P 706-410 (U.S. Army Materiel Command, March 1977).

Table 5-6. Shielding effectiveness in plane wave field (wave impedance equal to 377 ohms) of solid copper and iron shields for signal sources greater than 2 inches from the shield at 150 kilohertz to 100 megahertz*

Frequency, MHz	Copper (10 mils) A (dB)	+	R (dB)	=	SE (dB)	Iron (10 mils) A (dB)	+	R (dB)	=	SE (dB)
0.15	13	+	117	=	130	169	+	79	=	248
1.0	33	+	108	=	141	363	+	72	=	435
15.0	129	+	96	=	125	1060	+	63	=	1123
100.0	334	+	88	=	422	1370	+	60	=	1430

*Source: Engineering Design Handbook--Electromagnetic Compatibility, DARCOM-P 706-410 (U.S. Army Materiel Command, March 1977).

Table 5-7. Shielding effectiveness in electric field (wave impedance much greater than 377 ohms) of solid copper, aluminum, and iron shields for signal source 12 inches from the shield at 0.15 megahertz to 100 megahertz*

Frequency, MHz	Copper (10 mils)					Aluminum (10 mils)					Iron (10 mils)				
	A (dB)	+	R (dB)	=	SE (dB)	A (dB)	+	R (dB)	=	SE (dB)	A (dB)	+	R (dB)	=	SE (dB)
0.15	13	+	176	=	189	10	+	175	=	185	169	+	139	=	308
1.0	33	+	152	=	185	26	+	150	=	176	363	+	116	=	479
15.0	129	+	116	=	245	100	+	115	=	215	1060	+	83	=	1143
100.0	334	+	92	=	426	260	+	90	=	350	1370	+	64	=	1434

*Source: Engineering Design Handbook--Electromagnetic Compatibility, DARCOM-P 706-410 (U.S. Army Materiel Command, March 1977).

Table 5-8. Re-reflection (B)-factors in electric, magnetic, and plane wave fields of solid copper and iron shields* (sheet 1 of 2)

Shield thickness (mils)	60 Hz	100 Hz	1 kHz	10 kHz	100 kHz	1 MHz
Copper, μ = 1, g = 1, magnetic fields						
1	-22.22	-24.31	-28.23	- 9.61	-10.34	-2.6
5	-21.30	-22.07	-15.83	- 6.98	- 0.55	+0.14
10	-19.23	-18.59	-10.37	- 2.62	+ 0.57	0
20	-15.35	-13.77	- 5.41	+ 0.13	- 0.10	-
30	-12.55	-10.76	- 2.94	+ 0.58	0	-
50	- 8.88	- 7.07	- 0.58	0	-	-
100	- 4.24	- 2.74	+ 0.50	-	-	-
200	- 0.76	+ 0.05	0	-	-	-
300	+ 0.32	+ 0.53	-	-	-	-
Copper, μ = 1, g = 1, electric fields and plane waves						
1	-41.52	-39.31	-29.38	-19.61	-10.33	-2.61
5	-27.64	-25.46	-15.82	- 6.96	- 0.55	+0.14
10	-21.75	-19.61	-10.33	- 2.61	+ 0.57	0
20	-15.99	-13.92	- 5.37	+ 0.14	- 0.10	
30	-12.73	-10.73	- 2.90	+ 0.58	0	-
50	- 8.81	- 6.96	- 0.55	+ 0.14	-	-
100	- 4.08	- 2.61	+ 0.51	0	-	-
200	- 0.62	+ 0.14	0	-	-	-
300	+ 0.41	+ 0.58	-	-	-	-
Iron, μ = 100, g = 0.17, magnetic fields						
1	+ 0.95	+ 1.23	- 1.60	- 1.83	-	-
5	+ 0.93	+ 0.89	- 0.59	0	-	-
10	+ 0.78	+ 0.48	+ 0.06	-	-	-
20	+ 0.35	+ 0.08	0	-	-	-
30	+ 0.06	- 0.06	-	-	-	-
50	0	0	-	-	-	-

Table 5-8. Re-reflection (B)-factors in electric, magnetic, and plane wave fields of solid copper and iron shields* (sheet 2 of 2)

Shield thickness (mils)	60 Hz	100 Hz	1 kHz	10 kHz	100 kHz	1 MHz
Iron, μ = 1000, g = 0.17, electric fields and plane waves						
1	-19.53	-17.41	- 8.35	- 1.31	-	-
5	- 6.90	- 5.17	+ 0.20	0	-	-
10	- 2.56	- 1.31	+ 0.36	-	-	-
20	+ 0.16	+ 0.54	0	-	-	-
30	+ 0.58	+ 0.42	-	-	-	-
50	+ 0.13	0	-	-	-	-

*Source: Engineering Design Handbook--Electromagnetic Compatibility, DARCOM-P 706-410 (U.S. Army Materiel Command, March 1977).

Table 5-9. Shielding effectiveness in electric, magnetic, and plane wave fields of copper shield (7 mils thick) for signal source 165 feet from the shield at 30 hertz to 10 gigahertz*

Frequency	Plane wave, dB	Electric field, dB	Magnetic field, dB
30 Hz	122	213	32
60 Hz	122	207	39
100 Hz	122	202	42
500 Hz	123	189	57
1 kHz	123	183	63
10 kHz	123	163	83
50 kHz	123	149	98
150 kHz	124	140	108
1 MHz	131	--	--
3 MHz	144	--	--
10 MHz	172	--	--
15 MHz	187	--	--
100 MHz	322	--	--
1000 MHz	818	--	--
1500 MHz	981	--	--
10 GHz	2408	--	--

*Source: Engineering Design Handbook--Electromagnetic Compatibility, DARCOM-P 706-410 (U.S. Army Materiel Command, March 1977).

Table 5-10. Shielding effectiveness in electric, magnetic, and plane wave fields of steel shield (1 mil thick) for signal source 165 feet from the shield at 30 hertz to 10 gigahertz*

Frequency	Plane wave, dB	Electric field, dB	Magnetic field, dB
30 Hz	85	175	4
60 Hz	86	171	6
100 Hz	86	166	10
500 Hz	86	152	21
1 kHz	86	146	26
10 kHz	86	125	46
50 kHz	87	113	61
150 kHz	89	105	73
1 MHz	98	--	--
3 MHz	110	--	--
10 MHz	136	--	--
15 MHz	142	--	--
100 MHz	164	--	--
1000 MHz	287	--	--
1500 MHz	186	--	--
10 GHz	164	--	--

*Source: Engineering Design Handbook--Electromagnetic Compatibility, DARCOM-P 706-410 (U.S. Army Materiel Command, March 1977).

Table 5-11. Shielding effectiveness in electric, magnetic, and plane wave fields of steel shield (50 mils thick) for signal source 165 feet from the shield at 30 hertz to 10 gigahertz*

Frequency	Plane wave, dB	Electric field, dB	Magnetic field, dB
30 Hz	121	211	31
60 Hz	123	208	39
100 Hz	125	205	46
500 Hz	138	204	73
1 kHz	151	211	91
10 kHz	249	289	210
50 kHz	455	481	430
150 kHz	725	741	709
1 MHz	1465	--	--
3 MHz	2311	--	--
10 MHz	3801	--	--
15 MHz	4140	--	--
100 MHz	5338	--	--
1000 MHz	11,850	--	--
1500 MHz	6547	--	--
10 GHz	5338	--	--

*Source: Engineering Design Handbook--Electromagnetic Compatibility, DARCOM-P 706-410 (U.S. Army Materiel Command, March 1977).

Table 5-12. Sample calculations of shielding effectiveness for solid metal shield* (sheet 1 of 2)

	10 kHz-10 mils					
	Magnetic field		Electric field		Plane wave	
	Copper	Iron	Copper	Iron	Copper	Iron
Reflection	44.2	8.0	212.0	174.0	128.0	90.5
Absorption	3.6	43.5	3.3	43.5	3.3	43.5
B-factor	-2.6	0	-2.6	0	-2.6	0
Total loss (dB)	45.2	51.5	212.7	217.5	128.7	134.0

	60 Hz-magnetic					
	1 mil		10 mils		300 mils	
	Copper	Iron	Copper	Iron	Copper	Iron
Reflection	22.4	-0.9	22.4	-0.9	22.4	-0.9
Absorption	0.03	0.33	0.26	3.34	7.80	100.0
B-factor	-22.2	+0.95	-19.2	+0.78	+0.32	0
Total loss (dB)	0.23	0.38	3.46	3.22	30.52	99.1

	10 kHz - 30 mils - magnetic		1 kHz - 10 mils - magnetic	
	Copper	Iron	Copper	Iron
Reflection	44.20	8.0	34.2	0.9
Absorption	10.02	130.5	1.06	13.70
B-factor	+0.58	0	-10.37	+0.06
Total loss (dB)	54.80	138.5	24.89	14.66

Table 5-12. Sample calculations of shielding effectiveness for solid metal shield* (sheet 2 of 2)

	10 mils-copper					
	150 kHz			1 MHz		
	Electric	Plane waves	Magnetic	Electric	Plane waves	Magnetic
Reflection	176.8	117.0	56.0	152.0	108.2	64.2
Absorption	12.9	12.9	12.9	33.4	33.4	33.4
B-factor	+0.5	+0.5	+0.5	0	0	0
Total loss (dB)	190.2	130.4	69.4	185.4	141.6	97.6

*Source: Engineering Design Handbook--Electromagnetic Compatibility, DARCOM-P 706-410 (U.S. Army Materiel Command, March 1977).

Table 5-13. Peak voltage induced on 10-meter radius loop inside 10-meter radius spherical shield by the high-altitude EMP (by diffusion through the walls only)*

Shield thickness, mm	Internal voltage induced in loop		
	Copper (5.8×10^7 mho/m)	Aluminum (3.7×10^7 mho/m) $\mu_r = 200$	Steel (6×10^6 mho/m)
0.2	0.34 V	0.85 V	0.076 V
1.0	2.6 mV	6.4 mV	1.1 mV
5.0	21 μV	51 μV	15 μV

*Source: E. F. Vance, "Electromagnetic Interference Control," IEEE Transactions on Electromagnetic Compatibility, Vol EMC-22 (Institute for Electrical and Electronic Engineers, November 1980).

Table 5-14. Effectiveness of nonsolid shielding materials against low-impedance and plane waves*

Impinging wave	Form General	Form Detail	Material	Thickness, mils	Nominal effectiveness, dB 0.1 kHz	1 kHz	10 kHz	85 kHz	1 MHz	10 MHz
Low impedance	Mesh (screening)	2 layers 1 in. apart	Cu (oxidized)	--	2	6	18	--	--	--
		No. 22	Cu	--	--	--	--	31	43	43
		No. 16	Bronze	--	--	--	--	18	--	--
		No. 4	Galvanized steel	--	--	--	--	10	17	21
Plane	Perforated sheet	45-mil diam 225 sq in.	Al	20	3040 MHz		9380 MHz			
					60		62			
Plane					200 kHz		1 MHz		5 MHz	100 MHz
	Mesh (screening)	No. 16	Al	diam = 13	34		36		--	--
		No. 22	Cu	diam = 15	118		106		100	80

*Source: Electromagnetic Compatibility Design Guide for Avionics and Related Ground Support Equipment, NAVAIR AD1115 (U.S. Department of the Navy, Naval Air Systems Command).

Table 5-15. Effectiveness of nonsolid shielding materials against high-impedance waves*

Form								
General	Detailed	Material	Thickness, mils	Nominal effectiveness (14 kHz to 1000 MHz), dB	%	Open area, in. of water / 200 cu ft/min	Air-flow static pressure, in. of water / 400 cu ft/min	Air-flow static pressure,
Hexcell	1/4-in. cell, 1-in. thick	Al	3	>90		--	0.06	0.26
TV shadow mask (photo-etched)	9-mil holes, 28-mil centers	95% Cu	7	>90		12	>2	--
		5%				50	0.2	--
		100%	3	>90			0.2	--
Lektromesh	40 count	Cu-Ni	7	>90		36	0.4	1.7
	25 count	Cu-Ni	5	78		49	0.2	0.5
	40 count	Cu	3	78		57	0.2	0.5
	25 count	Cu				56	0.2	0.4
Perforated sheet	1/8-in. diam 3/16-in. centers	Steel	60	58			0.27	>0.6
	1/4-in. diam, 5/16-in. centers	Al	60	48		46	--	--
	7/16-in. diam, 5/8-in. centers	Al	37	35		45	--	--
Mesh (screening)	No. 16 16 x 16/sq in.	Al	20 (diam)	55		36	--	--
	No. 22	Cu		65 (14 kHz - 60 MHz)				
	No. 12	Cu	20 (diam)	50		50	--	--
	No. 16	Bronze		45 (14 kHz - 60 MHz)				
	No. 10	Monel	18 (diam)	40				
	No. 4	Galva-ized steel	30 (diam)	35		76	--	--
				28 (14 kHz - MHz)				
	No. 2			24		88	--	--

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*Source: R. B. Schultz, et al., "Shielding Theory and Practice," Proceedings of the Tri-Service Conference on Electromagnetic Compatibility (IITRI, October 1973).

Table 5-16. Comparison of measured and calculated values of shielding effectiveness for No. 22, 15-mil copper screens*

Test type	Frequency, MHz	Measured effectiveness, dB	Calculated effectiveness, dB
Magnetic field (r = 1.75 in.)	0.085	31	29
	1.000	43	46
	10.000	43	49
Plane wave	0.200	118	124
	1.000	106	110
	5.000	100	95
	100.000	80	70
Electric field	0.014	65	65

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*Source: W. Jarva, "Shielding Efficiency Calculation Methods for Screening, Waveguide Ventilation Panels, and Other Perforated Electromagnetic Shields," Proceedings of the Seventh Conference on Radio Interference Reduction and Electromagnetic Compatibility (IITRI, November 1961).

Table 5-17. Attenuation factors for reinforcement steel construction*

Bar diameter, cm	Bar spacing, cm	Type of construction	Attenuation decrement, ΔdB
5.8	30	Single-course	+5
4.3	35	Single-course	0
2.5	45	Single-course	-6
5.8	50	Double-course	+8.5
4.3	35	Double-course	+13
2.5	40	Double-course	+5

*Source: EMP Engineering Practices Handbook, NATO File No. 1460-2 (October 1977).

Table 5-18. Application factors for welded wire fabric*

Wire diameter, mm	Spacing, cm	Number of courses	Attenuation increment, dB
3	20	1	-3
3	20	2	+4

*Source: EMP Engineering Practices Handbook, NATO File No. 1460-2 (October 1977).

Table 5-19. Typical values of conductivity for soils and rock*

	Geological period and rock type				
Electrical conductivity, mho/meter	Quaternary	Quaternary tertiary cretaceous	Jurassic triassic carboniferous	Devonian silurian ordovician cambrian	Cambrian precambrian
$1x10^{-1}$	Shallow playa deposits	Loam, clay	--	--	--
$3x10^{-2}$		Chalk	Chalk, trap	--	--
$1x10^{-2}$		Alluvium	Alt. basalt, shale	--	--
$3x10^{-3}$			Limestone, sandstone	Shale, limestone	--
$1x10^{-3}$				Sandstone, dolemite	Sandstone
$3x10^{-4}$ to $1x10^{-4}$	Coarse sand and gravel in surface layers	--	--	--	Quartzite, slate, granite, gneiss

*Source: EMP Engineering Practices Handbook, NATO File No. 1460-2 (October 1977).

Table 5-20. Skin depth (d) and absorption loss (A) for nonmetal materials*

	Water content (%)					
Frequency	1		10		50	
	δ(m)	A(dB/m)	δ(m)	A(dB/m)	δ(m)	A(dB/m)
1 kHz	950	0	172	0.1	50	0.2
10 kHz	280	0	53	0.2	16	0.5
100 kHz	80	0.1	16	0.5	5	1.7
300 kHz	40	0.2	9	0.9	2.8	3.0
1 MHz	18	0.5	4.9	1.8	1.5	5.6
3 MHz	8.7	1.0	2.7	3.2	0.87	9.9
10 MHz	3.5	2.5	1.3	6.7	0.46	18.7
100 MHz	0.56	15.6	0.28	31.2	0.12	68.5

*Source: EMP Engineering Practices Handbook, NATO File No. 1460-2 (October 1977). Calculated using infinite-plane geometry.

Table 5-21. Electromotive series

Element	Volts	Ion	Element	Volts	Ion
Lithium	2.9595		Tin	0.136	
Rubidium	2.9259		Lead	0.122	Pb^{++}
Potassium	2.9241		Iron	0.045	Fe^{+++}
Strontium	2.92		Hydrogen	0.000	
Barium	2.90		Antimony	-0.10	
Calcium	2.87		Bismuth	-0.226	
Sodium	2.7146		Arsenic	-0.30	
Magnesium	2.40		Copper	-0.344	Cu^{++}
Aluminum	1.70		Oxygen	-0.397	
Beryllium	1.69		Polonium	-0.40	
Uranium	1.40		Copper	-0.470	Cu^{+}
Manganese	1.10		Iodine	-0.5345	
Tellurium	0.827		Tellurium	-0.558	Te^{++++}
Zinc	0.7618		Silver	-0.7978	
Chromium	0.557		Mercury	-0.7986	
Sulfur	0.51		Lead	-0.80	Pb^{++++}
Gallium	0.50		Palladium	-0.820	
Iron	0.441	Fe^{++}	Platinum	-0.863	
Cadmium	0.401		Bromine	-1.0648	
Indium	0.336		Chlorine	-1.3583	
Thallium	0.330		Gold	-1.360	Au^{++++}
Cobalt	0.278		Gold	-1.50	Au^{+}
Nickel	0.231		Fluorine	-1.90	

Table 5-22. Characteristics of conductive gasketing materials*

Material	Chief advantages	Chief limitations
Compressed knitted wire	Most resilient all-metal gasket (low flange pressure required). Most points of contact. Available in variety of thicknesses and resiliencies, and in combination with neoprene and silicone.	Not available in sheet (certain intricate shapes difficult to make). Must be 0.040 in. or thicker. Subject to compression set.
Brass or beryllium copper with punctured nail holes	Best breakthrough of corrossion protection films.	Not truly resilient or generally reusable.
Oriented wires in rubber silicone	Combines fluid and RF seal. Can be effective against corrosion films if ends of wires are sharp.	Might require wider or thicker size gasket for same effectiveness. Effectiveness declines with mechanical use.
Aluminum screen impregnated with neoprene	Combines fluid and conductive seal. Thinnest gasket. Can be cut to intricate shapes.	Very low resiliency (high flange pressure required).
Soft metals	Cheapest in small sizes.	Cold flows, low resiliency.
Metal over rubber	Takes advantage of the resiliency of rubber.	Foil cracks or shifts position. Generally low insertion loss yielding poor RF properties.
Conductive rubber (carbon-filled)	Combines fluid and conductive seal.	Provides moderate insertion loss.
Conductive rubber (silver-filled)	Combines fluid and RF seal. Excellent resilience with low compression set. Reusable. Available in any shape or cross section.	Not as effective as metal in magnetic fields. May require salt spray environmental protection.
Contact fingers	Best suited for sliding contact.	Easily damaged. Few points of contact.

*Source: MIL-HDBK-335 (USAF), Management and Design Guidance, Electromagnetic Radiation Hardness for Air Launched Ordnance Systems (DOD, 15 January 1981).

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Table 5-24. Comparison of protection devices

Device type	Clamping (or filtering) thresholds	Operate time, sec	Highest burnout-energy thresholds, J	Shunt capacitance F	Typical circuit applications	Possible disadvantages
Varistors						
MOV	40-1500 V	$<10^{-9}$	$<10^{3}$	10^{-9}	Power, AF	High capacitance
SiC	15-10,000 V	$<10^{-9}$	$<10^{5}$	$<10^{-9}$	Power, term.	Poor clamping
Semiconductors						
Forward diodes (Si Ge)	0.2-0.6 V	$<10^{-9}$	$<10^{1}$	$<10^{-12}$	AF, RF	Low burnout energy
Breakdown diodes (Si, Ge)	2-200 V	$<10^{-9}$	$<10^{2}$	$<10^{-8}$	Power, AF	High capacitance
Selenium-diode packages	30-2000 V	$<10^{-9}$	$<10^{4}$	$<10^{-7}$	Power	High capacitance
Diode thyristors (p-n-p-n)	25-1800 V	$<10^{-6}$	$<10^{1}$	$<10^{-6}$	AF	Latch-up, di/dt burn-out, slow response, high capacitance
Triggered thyristors (SCRs)	25-1800 V	$<10^{-5}$	$<10^{1}$	$<10^{-6}$	AF, alarm	Latch-up, di/dt burn-out, slow response high capacitance
Spark gaps						
Carbon blocks	330-800 V	$<10^{-6}$	$<10^{4}$	$<10^{-11}$	Term., AF, RF	Power-follow, slow response
Ordinary gas tubes	60-30,000	$<10^{-5}$	$<10^{6}$	$<10^{-11}$	Term., AF, RF	Power-follow, slow response, high cost
High-speed gaps	550-20,000	$<10^{-9}$	$<10^{3}$	$<10^{-11}$	Term., AF, RF	Power-follow, high cost
Ordinary arresters	60-30,000 V	$<10^{-5}$	$<10^{3}$	$<10^{-11}$	Power	Slow response, high cost
Arresters using high-speed gaps	550-20,000 V	$<10^{-9}$	$<10^{3}$	$<10^{-11}$	Power	High cost

Table 5-25. Galvanic series for selected metals

Corroded end (anodic,
or least noble)

Magnesium
Magnesium alloys
Zinc
Aluminum 2S
Cadmium
Aluminum 17ST
Steel or iron
Cast iron
Chromium-iron (active)
Ni-Resist
18-8 Stainless (active)
18-8-3 Stainless (active)
Lead-tin solders
Lead
Tin
Nickel (active)
Inconel (active)

Brasses
Copper
Bronzes
Copper-nickel alloys
Monel
Silver solder
Nickel (passive)
Inconel (passive)
Chromium-iron (passive)
18-8 Stainless (passive)
18-8-3 Stainless (passive)
Silver
Graphite
Gold
Platinum

Protected end (cathodic,
or most noble)

Table 5-26. Relative advantages and disadvantages of the principal types of earth electrodes

Type	Advantages	Disadvantages
Vertical rods	Straightforward design. Easiest to install (particularly around an existing facility). Hardware readily available. Can be extended to reach water table.	High impulse impedance. Not useful where large rock formations are near surface. Step voltage on earth surface can be excessive under high fault currents or during direct lightning strike.
Horizontal grid	Minimum surface potential gradient. Straightforward installation if done before construction. Can achieve low resistance contact in areas where rock formations prevent use of vertical rods. Can be combined with vertical rods to stabilize resistance fluctuations.	Subject to resistance fluctuation with soil drying if vertical rods not used.
Plates	Can achieve low resistance contact in limited area.	Most difficult to install.
Horizontal wires	Can achieve low resistance where rock formations prevent use of vertical rods. Low impulse impedance. Good RD counterpoise when laid in star pattern.	Subject to resistance fluctuations with soil drying.
Incidental electrodes (utility pipes, building foundations, buried tanks)	Can exhibit very low resistance if electrically continuous. Generally lowest initial cost (borne by others).	Little or no control over future alterations.

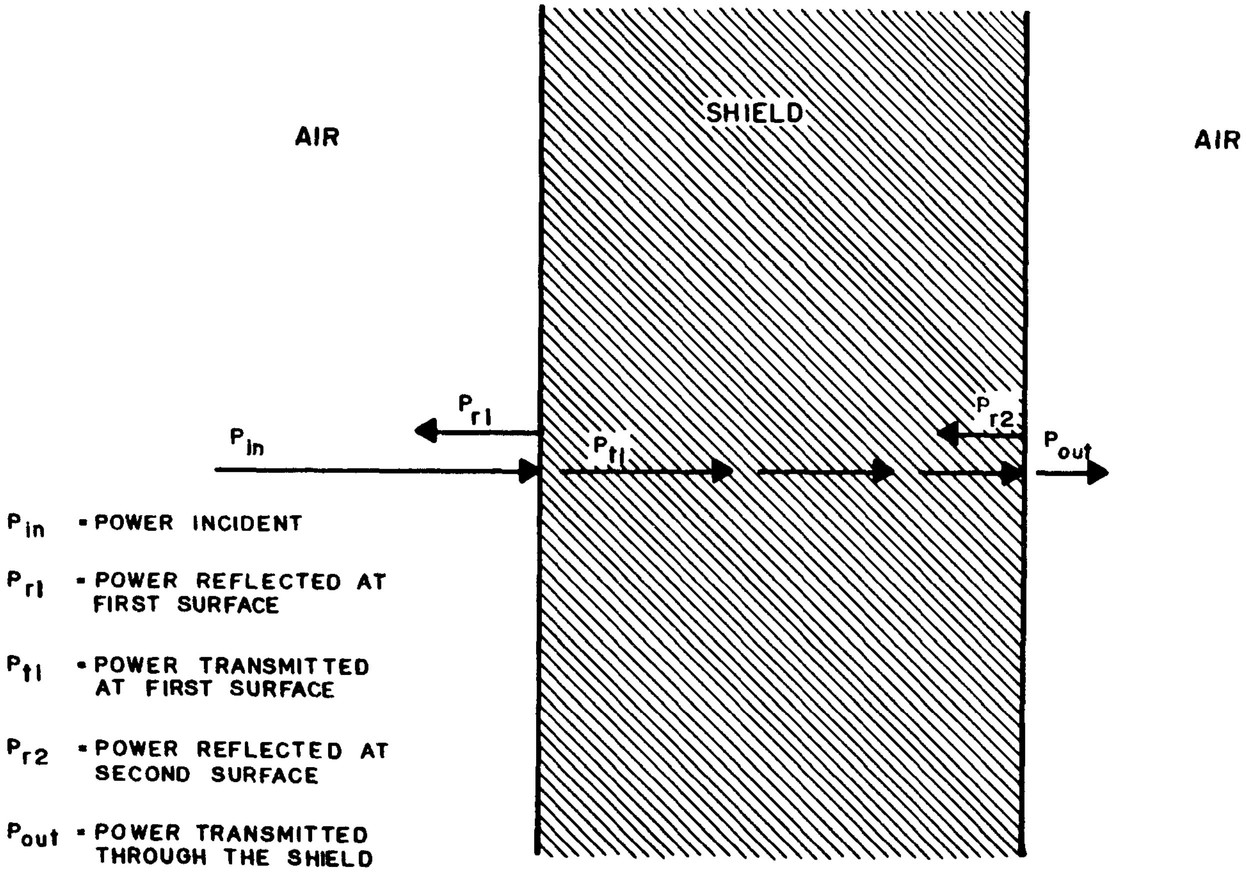

Figure 5-1. Transmission line model of shielding. (Source: ref 5-6)

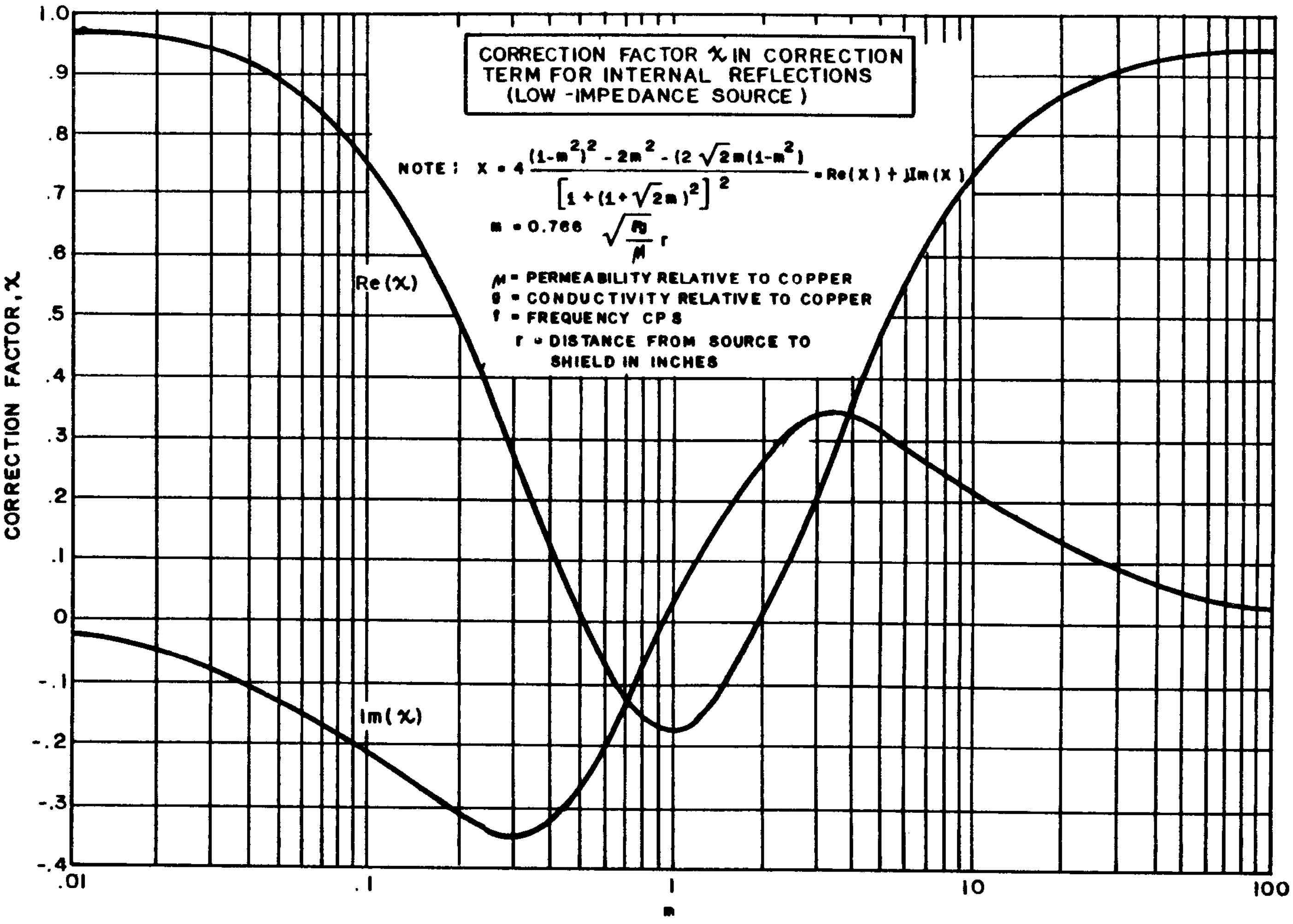

Figure 5-2. Correction factor in correction term for internal reflections. (Source: ref 5-3)

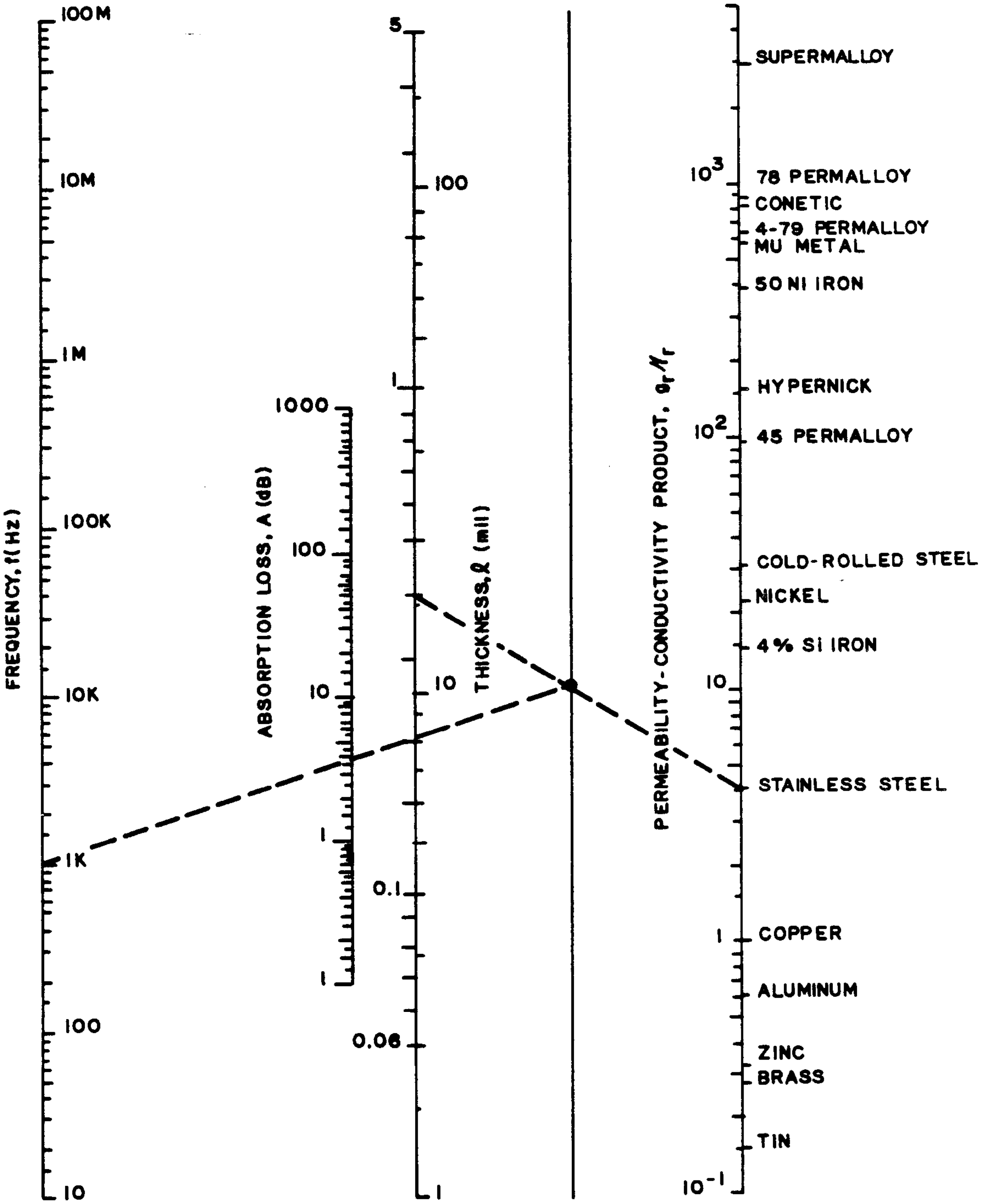

Figure 5-3. Shield absorption loss nomograph. (Source: ref 5-6)

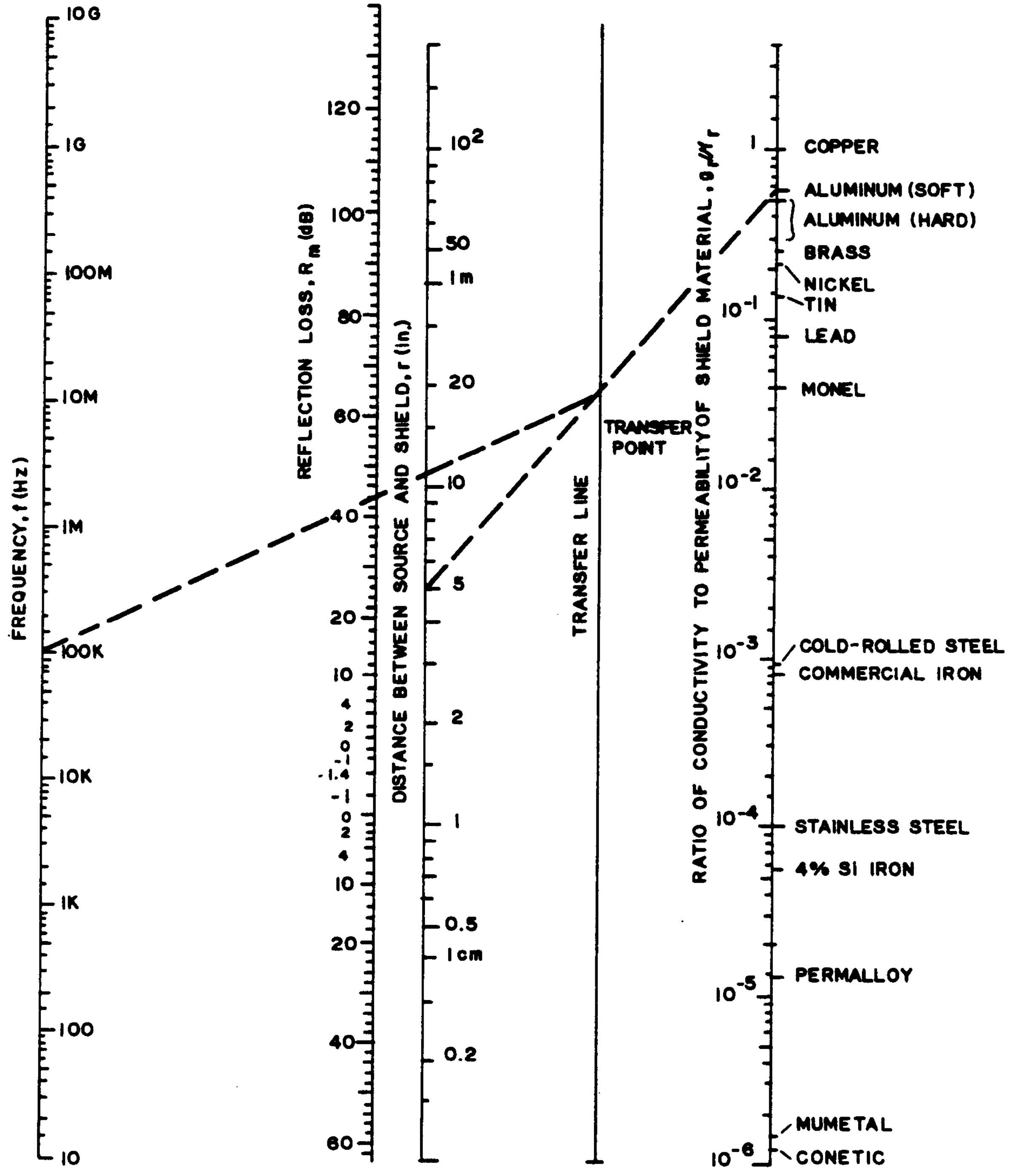

Figure 5-4. Nomograph for determining magnetic field reflection loss. (Source: ref 5-6)