

# ELECTROMAGNETIC SHIELDING

An abstract graphic consisting of several overlapping, translucent blue wave-like shapes that flow horizontally across the middle of the cover. The waves have a soft, ethereal quality, with lighter blue highlights and darker blue shadows, creating a sense of movement and depth.

SALVATORE CELOZZI

•  
RODOLFO ARANEO

•  
GIAMPIERO LOVAT

# Contents

---

<b>Preface</b>	<b>xi</b>
<b>1 Electromagnetics behind Shielding</b>	<b>1</b>
1.1 Definitions	1
1.2 Notation, Symbolology, and Acronyms	3
1.3 Basic Electromagnetics	4
1.3.1 Macroscopic Electromagnetism and Maxwell's Equations	4
1.3.2 Constitutive Relations	6
1.3.3 Discontinuities and Singularities	9
1.3.4 Initial and Boundary Conditions	11
1.3.5 Poynting's Theorem and Energy Considerations	11
1.3.6 Fundamental Theorems	13
1.3.7 Wave Equations, Helmholtz Equations, Electromagnetic Potentials, and Green's Functions	15
1.4 Basic Shielding Mechanisms	18
1.5 Source Inside or Outside the Shielding Structure and Reciprocity	18
References	19
<b>2 Shielding Materials</b>	<b>21</b>
2.1 Standard Metallic and Ferromagnetic Materials	21
2.2 Ferrimagnetic Materials	27
2.3 Ferroelectric Materials	28
2.4 Thin Films and Conductive Coatings	30
2.5 Other Materials Suitable for EM Shielding Applications	32
2.5.1 Structural Materials	32
2.5.2 Conductive Polymers	32

2.5.3	Conductive Glasses and Transparent Materials	33
2.5.4	Conductive (and Ferromagnetic or Ferrimagnetic) Papers	33
2.6	Special Materials	33
2.6.1	Metamaterials and Chiral Materials	33
2.6.2	Composite Materials	36
2.6.3	Nanomaterials	37
2.6.4	High-Temperature Superconductors	37
	References	38
<b>3</b>	<b>Figures of Merit for Shielding Configurations</b>	<b>42</b>
3.1	(Local) Shielding Effectiveness	42
3.2	The Global Point of View	45
3.3	Other Proposals of Figures of Merit	46
3.4	Statistical Methods	50
3.5	Energy-Based, Content-Oriented Definition	52
3.6	Performance of Shielded Cables	53
	References	53
<b>4</b>	<b>Shielding Effectiveness of Stratified Media</b>	<b>55</b>
4.1	Electromagnetic Plane Waves: Definitions and Properties	55
4.2	Uniform Plane Waves Incident on a Planar Shield	58
4.2.1	Transmission-Line Approach	58
4.2.2	The Single Planar Shield	61
4.2.3	Multiple (or Laminated) Shields	66
4.3	Plane Waves Normally Incident on Cylindrical Shielding Surfaces	67
4.4	Plane Waves against Spherical Shields	74
4.5	Limits to the Extension of the TL Analogy to Near-Field Sources	75
	References	84
<b>5</b>	<b>Numerical Methods for Shielding Analyses</b>	<b>87</b>
5.1	Finite-Element Method	89
5.2	Method of Moments	99
5.3	Finite-Difference Time-Domain Method	110
5.4	Finite Integration Technique	119
5.5	Transmission-Line Matrix Method	124
5.6	Partial Element Equivalent Circuit Method	127
5.7	Case Study: Scattering from a Perfectly Conducting Enclosure with a Rectangular Aperture	134
	References	137
<b>6</b>	<b>Apertures in Planar Metal Screens</b>	<b>144</b>
6.1	Historical Background	145
6.2	Statement of the Problem	146
6.3	Low-Frequency Analysis: Transmission through Small Apertures	147

6.4	The Small Circular-Aperture Case	148
6.5	Small Noncircular Apertures	154
6.6	Finite Number of Small Apertures	155
6.7	Rigorous Analysis for Apertures of Arbitrary Shape: Integral Equation Formulation	157
6.8	Rules of Thumb	160
	References	161
<b>7</b>	<b>Enclosures</b>	<b>164</b>
7.1	Modal Expansion of Electromagnetic Fields inside a Metallic Enclosure	165
7.2	Oscillations inside an Ideal Source-Free Enclosure	168
7.3	The Enclosure Dyadic Green Function	169
7.4	Excitation of a Metallic Enclosure	172
7.5	Damped Oscillations inside Enclosures with Lossy Walls and Quality Factor	173
7.6	Apertures in Perfectly Conducting Enclosures	175
	7.6.1 Small-Aperture Approximation	176
	7.6.2 Rigorous Analysis: Integral-Equation Formulation	178
	7.6.3 Aperture-Cavity Resonances	180
7.7	Small Loading Effects	183
7.8	The Rectangular Enclosure	184
	7.8.1 Symmetry Considerations	187
7.9	Shielding Effectiveness of a Rectangular Enclosure with a Circular Hole	188
	7.9.1 External Sources: Plane-Wave Excitation	189
	7.9.2 Internal Sources: Electric and Magnetic Dipole Excitations	192
	References	198
<b>8</b>	<b>Cable Shielding</b>	<b>200</b>
8.1	Transfer Impedance in Tubular Shielded Cables and Aperture Effects	201
8.2	Relationship between Transfer Impedance and Shielding Effectiveness	206
8.3	Actual Cables and Harnesses	207
	References	208
<b>9</b>	<b>Components and Installation Guidelines</b>	<b>210</b>
9.1	Gaskets	210
9.2	Shielded Windows	214
9.3	Electromagnetic Absorbers	215
9.4	Shielded Connectors	216
9.5	Air-Ventilation Systems	216

9.6 Fuses, Switches, and Other Similar Components	217
References	217
<b>10 Frequency Selective Surfaces</b>	<b>219</b>
10.1 Analysis of Periodic Structures	220
10.1.1 Floquet's Theorem and Spatial Harmonics	220
10.1.2 Plane-Wave Incidence on a Planar 1D Periodic Structure	222
10.1.3 Plane-Wave Incidence on a Planar 2D Periodic Structure	223
10.2 High- and Low-Pass FSSs	225
10.3 Band-Pass and Band-Stop FSSs	228
10.3.1 Center-Connected Elements or N-Pole Elements	229
10.3.2 Loop-Type Elements	230
10.3.3 Solid-Interior-Type Elements	230
10.3.4 Combinations and Fractal Elements	231
10.4 Degrees of Freedom in Designing FSSs	231
10.5 Reconfigurable and Active FSSs	232
10.6 FSSs and Circuit Analog Absorbers	234
10.7 Modeling and Design of FSSs	235
References	236
<b>11 Shielding Design Guidelines</b>	<b>241</b>
11.1 Establishment of the Shielding Requirements	242
11.2 Assessment of the Number and Types of Functional Discontinuities	243
11.3 Assessment of Dimensional Constraints and Nonelectromagnetic Characteristics of Materials	244
11.4 Estimation of Shielding Performance	245
References	246
<b>12 Uncommon Ways of Shielding</b>	<b>247</b>
12.1 Active Shielding	247
12.2 Partial Shields	252
12.3 Chiral Shielding	255
12.4 Metamaterial Shielding	256
References	260
<b>Appendix A Electrostatic Shielding</b>	<b>263</b>
A.1 Basics Laws of Electrostatics	264
A.2 Electrostatic Tools: Electrostatic Potential and Green's Function	266
A.3 Electrostatic Shields	270
A.3.1 Conductive Electrostatic Shields	270
A.3.2 Dielectric Electrostatic Shields	274
A.3.3 Aperture Effects in Conductive Shields	279
References	281

<b>Appendix B Magnetic Shielding</b>	<b>282</b>
B.1 Magnetic Shielding Mechanism	283
B.2 Calculation Methods	286
B.3 Boundary-Value Problems	288
B.3.1 Spherical Magnetic Conducting Shield	288
B.3.2 Cylindrical Magnetic Conducting Shield in a Transverse Magnetic Field	293
B.3.3 Cylindrical Magnetic Conducting Shield in a Parallel Magnetic Field	297
B.3.4 Infinite Plane	301
B.4 Ferromagnetic Shields with Hysteresis	314
References	314
<b>Appendix C Standards and Measurement Methods</b>	<b>317</b>
C.1 MIL-STD 285 and IEEE STD-299	319
C.2 NSA 65-6 and NSA 94-106	324
C.3 ASTM E1851	325
C.4 ASTM D4935	326
C.5 MIL-STD 461E	328
C.6 Code of Federal Regulations, Title 47, Part 15	335
C.7 ANSISCTE 48-3	337
C.8 MIL-STD 1377	338
C.9 IEC Standards	339
C.10 ITU-T Recommendations	344
C.11 Automotive Standards	346
References	350
<b>Index</b>	<b>353</b>