

# Contents

<b>Foreword</b>	<b>xiii</b>
<b>Preface</b>	<b>xvii</b>
<b>Chapter 1 Introduction</b>	<b>1</b>
1.1 Scope	1
1.2 Radio Frequency Shielding Definitions and Terminology	2
<b>Chapter 2 The Need for Radio Frequency Shielding</b>	<b>7</b>
2.1 Introduction	7
2.2 The Electromagnetic Environment	7
2.2.1 Introduction, 7	
2.2.2 Electromagnetic interference (EMI), 8	
2.2.3 TEMPEST, 8	
2.2.4 Electromagnetic pulse (EMP), 9	
2.3 Facility versus Equipment Shielding	10
2.4 Shielded Anechoic Test Facilities	10
2.4.1 Introduction, 10	
2.4.2 Shielding of anechoic facilities, 10	
2.5 Conclusions	11
2.6 References	11
<b>Chapter 3 Shielding Theory</b>	<b>13</b>
3.1 Introduction	13
3.2 Shielding Effectiveness	15
3.2.1 Introduction, 15	

3.2.2	Reflection, 16	
3.2.3	Absorption, 18	
3.2.4	Internal reflection, factor $B$ , 18	
3.2.5	Total shielding effectiveness, 20	
3.2.6	Performance degradation, 20	
3.3	Typical Shielding Materials	25
3.4	Seams	26
3.4.1	Introduction, 26	
3.4.2	Welded Seams, 26	
3.4.3	Clamped seams, 26	
3.4.4	Single-shield seams, 30	
3.5	Conclusions	33
3.6	References	34
<b>Chapter 4</b>	<b><i>Modular Shielded Enclosures</i></b>	<b>35</b>
4.1	Introduction	35
4.2	Zinc/Galvanized Steel Modular Shielded Enclosures	36
4.2.1	Introduction, 36	
4.2.2	System description, 36	
4.2.3	Typical performance, 40	
4.2.4	Procurement specifications, 40	
4.3	Double-Isolated Shield System	40
4.3.1	Description, 40	
4.3.2	Procurement specification, 43	
4.4	Double-Isolated Screen Enclosure	43
4.4.1	Description, 43	
4.4.2	Procurement Specification, 44	
4.5	Single-Shield Modular Enclosure	44
4.5.1	Introduction, 44	
4.5.2	Nonferrous NMR enclosures, 44	
4.5.3	The Lindsay system, 46	
4.5.4	Bolt-together wooden frame system, 50	
4.5.5	Low-performance clamp-up shielding System, 50	
4.6	Advantages/Disadvantages of Modular Enclosures	51
4.7	Critical Considerations	51
4.8	Performance Specifications	52
4.9	References	53
<b>Chapter 5</b>	<b><i>Welded Shielded Enclosures</i></b>	<b>55</b>
5.1	Introduction	55
5.1.1	Scope, 55	
5.1.2	Defining the shielded volume, 55	
5.1.3	Shield materials, 56	
5.2	Welded Shield Design and Construction	57
5.2.1	General information, 57	
5.2.2	Shield seam construction, 57	
5.2.3	Corner seams, 64	
5.3	Additional Shield Design Details	64
5.3.1	General discussion, 64	
5.3.2	Shield wall supports, 65	
5.3.3	Interior support columns and walls, 65	

5.3.4	Suspension of ceiling shield from roof joists, 66	
5.3.5	Expansion joints, 66	
5.3.6	Suspended acoustic ceiling, 70	
5.3.7	Other equipment mounting, 70	
5.3.8	Corrosion control, 70	
5.4	Penetrations	72
5.5	Quality Control Recommendations	72
5.6	Shielding Effectiveness Performance	72
5.7	Sample Procurement Specifications	73
5.8	Conclusions and Recommendations	73
5.9	References	73
<b>Chapter 6</b>	<b><i>Architectural Shielding</i></b>	<b>75</b>
6.1	Introduction	75
6.2	Critical Considerations in Architectural Shielding	75
6.3	Aluminum Foil Shielding	76
6.3.1	Introduction, 76	
6.3.2	Shielding material, 77	
6.3.3	Joining methods, 77	
6.3.4	Installation procedures, 77	
6.3.5	Shielded enclosure performance, 78	
6.3.6	Procurement specification, 78	
6.4	Copper Foil Shielded Enclosures	79
6.4.1	Description, 79	
6.4.2	Installation, 79	
6.4.3	Performance, 80	
6.4.4	Recommended Procurement Specifications, 81	
6.5	Copper Alloy Shielded Enclosures	81
6.5.1	Description, 81	
6.5.2	Performance, 82	
6.5.3	Material description, 82	
6.5.4	Installation procedures, 82	
6.5.5	Procurement Specification, 89	
6.6	The Sandwich Seam Shielding System	83
6.6.1	Introduction 83	
6.6.2	Theory of operation, 86	
6.6.3	Installation procedures, 87	
6.6.4	Typical performance, 89	
6.6.5	Procurement Specification, 89	
6.7	Other Shielding Systems,	89
6.7.1	Introduction, 89	
6.7.2	Description of the INSTAR shielding system, 90	
6.7.3	Copper Screen System, 91	
6.8	Other Shielding Materials	91
6.8.1	Introduction, 91	
6.8.2	Aluminum/Polyethylene material, 92	
6.8.3	Nonwoven shielding materials, 92	
6.8.4	Woven shielding materials, 93	
6.8.5	Conductive copper paint, 93	
6.9	Structural Considerations of Architectural Shielding	75

6.9.1	Introduction, 94	
6.9.2	Shielding of existing structure, 94	
6.9.3	Decorative treatment of interior walls, 96	
6.10	References	97
<b>Chapter 7</b>	<b><i>Penetrations and Their Control</i></b>	<b>99</b>
7.1	Introduction	99
7.2	General Design Criteria for Penetration	99
7.3	Doors	100
7.3.1	Introduction, 100	
7.3.2	The important features of an RF door, 101	
7.3.3	The RCM or knife-edge door, 103	
7.3.4	The compression door, 107	
7.3.5	Moderate-performance RF doors, 111	
7.3.6	Vestibule and waveguide tunnel entrances, 111	
7.3.7	Special-purpose shielded door systems 115	
7.4	Heating and Air Conditioning	118
7.4.1	Introduction, 118	
7.4.2	Description and theory of operation, 118	
7.4.3	Performance, 120	
7.4.4	Procurement Specifications, 121	
7.5	Piping	121
7.5.1	Introduction, 121	
7.5.2	Pipe penetrations for welded enclosures, 123	
7.5.3	Piping for modular shielding, 124	
7.5.4	Piping for architectural shielding, 124	
7.5.5	Procurement specification, 125	
7.6	Fiber Optics and Nonmetallic Hoses 126	
7.6.1	Design guides,	126
7.6.2	Procurement specification, 127	
7.7	Shielded Windows 127	
7.7.1	Description, 127	
7.7.2	Shielding effectiveness of windows, 127	
7.7.3	Window installation, 128	
7.8	Fire Protection Systems	130
7.8.1	Introduction, 130	
7.9	References	130
<b>Chapter 8</b>	<b><i>Electrical Filters</i></b>	<b>131</b>
8.1	Introduction	131
8.2	Filter Theory	131
8.2.1	Introduction, 131	
8.2.2	Filter configurations, 132	
8.3	Filter Characteristics	133
8.3.1	Introduction, 133	
8.3.2	Frequency characteristic, 134	
8.3.3	Impedance levels, 134	

8.3.4	Voltage rating, 134	
8.3.5	Current rating, 134	
8.3.6	Insulation resistance, 134	
8.3.7	Size and weight, 134	
8.3.8	Temperature, 134	
8.3.9	Reliability, 135	
8.4	Filter Specifications	135
8.4.1	Introduction, 135	
8.4.2	MIL-F-15733 requirements, 135	
8.4.3	UL 1283 filter requirements, 136	
8.5	Power Line Filters,	137
8.5.1	Introduction, 137	
8.5.2	Description of available configurations, 137	
8.5.3	Duo-shield electromagnetic filters, 137	
8.5.4	Procurement specification, 140	
8.6	Communication Filters	140
8.7	Data Line Filters (Computers)	141
8.8	Control Line Filters	141
8.9	Reference	142
<b>Chapter 9</b>	<b><i>Enclosure Performance Specifications and Testing</i></b>	<b>143</b>
9.1	Introduction	143
9.2	Performance Specification Review	144
9.2.1	Introduction, 144	
9.2.2	MIL-STD-285, 144	
9.2.3	NSA 65-6, 145	
9.2.4	NSA 73-2A, 145	
9.2.5	IEEE 299, 146	
9.2.6	Other specifications, 147	
9.3	How to Select or Prepare a Performance Specification	147
9.3.1	Introduction, 147	
9.3.2	Defining the shielding requirements, 148	
9.4	Enclosure Performance Testing	149
9.4.1	Introduction, 149	
9.4.2	Interpretation of text specifications, 149	
9.4.3	Testing Considerations, 151	
9.4.4	Accuracy of measurements, 154	
9.4.5	Data presentation, 154	
9.4.6	Common testing problems, 155	
9.4.7	Recommended shielding effectiveness test specification, 156	
9.5	Seam Leak Testing (SELDS)	156
9.5.1	Introduction, 156	
9.5.2	Principles of operation, 157	
9.5.3	Recommended use, 157	
9.6	Magnetic Particle Testing	158
9.6.1	Introduction, 158	
9.6.2	Principles of operation, 158	
9.7	Dye Penetrant Testing	159
9.8	References	159

<b>Chapter 10</b>	<b><i>Grounding of Shielded Enclosures</i></b>	<b>161</b>
10.1	Introduction	161
10.2	Grounding Principles	161
	10.2.1 Introduction, 161	
	10.2.2 Fault protection, 161	
	10.2.3 Enclosure isolation, 163	
	10.2.4 Grounding of signal references, 163	
10.3	Selecting the Grounding System	164
10.4	The Earth Ground Test	165
	10.4.1 Introduction, 165	
	10.4.2 The direct method, 167	
	10.4.3 Fall-of-potential method, 167	
10.5	References 167	
<b>Chapter 11</b>	<b><i>Design Checklists</i></b>	<b>169</b>
11.1	Introduction	169
11.2	Checklist for Modular Shielding	169
	11.2.1 Introduction, 169	
	11.2.2 Architectural considerations, 169	
	11.2.3 Electrical considerations, 170	
	11.2.4 Mechanical considerations, 171	
	11.2.5 Shielding considerations, 171	
11.3	Checklist for Welded Enclosures	174
	11.3.1 Introduction, 174	
	11.3.2 Architectural checklist, 174	
	11.3.3 Electrical checklist, 175	
	11.3.4 Mechanical checklist, 175	
	11.3.5 Shielding checklist, 176	
11.4	Checklist for Architectural Shielding	177
	11.4.1 Introduction, 177	
	11.4.2 Architectural checklist, 177	
	11.4.3 Electrical checklist, 178	
	11.4.4 Mechanical checklist, 178	
	11.4.5 Shielding checklist, 178	
<b>Appendix A</b>		<b>179</b>
A-1	Additional Definitions and Terminology	179
A-4	Architects and Engineers Specifications	180
	4.1 Galvanized modular enclosure procurement specifications, 180	
	4.2 Procurement specification for a version of the doubly isolated modular shielded enclosure system, 182	
	4.3 Procurement specifications for a copper screened enclosure, 185	
	4.4 Sample NMR RF shielding specification, 186	
	4.5 Sample procurement specification for the Lindsay single—shield modular enclosure system, 187	
	4.6 Sample procurement specification for a single-shield modular galvanized sheet metal shielding system, 188	
A-5	Sample Specification for a Welded Enclosure	190

<b>A-6</b>	<b>Specifications for Architectural Shielding Systems</b>	<b>198</b>
	6.1 Specifications for aluminum foil shielding systems, 198	
	6.2 Procurement specifications for copper foil shielded enclosures, 199	
	6.3 Specification for copper alloy Shielded Enclosures. 201	
	6.4 Procurement specifications for the sandwich seam shielding system, 202	
<b>A-7</b>	<b>Shielded Penetrations</b>	<b>203</b>
	7.1 Procurement specifications for RCM or knife-edge door, 203	
	7.2 Procurement specifications for doubly isolated shielded door assembly, 204	
	7.3 Procurement specifications for moderate-performance shielded doors, 205	
	7.4 Procurement specifications for electromagnet latched RF shielded doors, 206	
	7.5 Procurement specification for doubly isolated shielded door assembly, 207	
	7.6 Procurement specification for shielded vents, 208	
<b>A-8</b>	<b>Sample Procurement Specifications for RF Filters</b>	<b>209</b>
	8.1 Specification for RF power line filters, 209	
<b>A-9</b>	<b>Sample Test Specification</b>	<b>212</b>
<b><i>Appendix B</i></b>		<b>215</b>
<b><i>Appendix C Selected Bibliography</i></b>		<b>217</b>
<b><i>Index</i></b>		<b>219</b>