Table of Contents

INTRODUCTION: The Electrostatic Shield 1

1 Electrostatics 5

1.1 Charge 5
1.2 Forces Between Charges 5
1.3 Electric Field 6
1.4 Voltage 7
1.5 Voltage Gradient 7
1.6 A Spherical Conductor with a Charge 8
1.7 The Electric Field at a Conductor 9
1.8 The Displacement Field D 10
1.9 Field Representations 10
1.10 Points of Difficulty 12
1.11 MKS System of Units 13
1.12 Charges on Spherical Shells 14
1.13 Typical Charge Distributions 17
1.14 Cylindrical Surfaces 18
1.15 Parallel Plate Capacitors · 19

2 Capacitance and Energy Storage 21

2.1 General Comments 21
2.2 Green's Reciprocation Theorem 21
2.3 Self- and Mutual Elastance 23
2.4 Self- and Mutual Capacitance 24
2.5 Electric Screening (Shielding) 24
2.6 Energy in a Single Capacitor 26
2.7 Energy Stored on a Multiple-Conductor System 26
2.8 Energy in Terms of the Field 27

3 Applying Electrostatics to Practical Processes 29

3.1 General 29
3.2 Current in Capacitors 29
3.3 Voltage Sources 31
3.4 Electrostatic Shielding 32
3.5 The Earth Plane 33
3.6 Typical Capacitances 34
3.7 Room Pickup 34

4 Practical Shielding of Instruments 37

4.1 The Amplifier Shield 37
4.2 Signal Entrances to a Shield Enclosure 39
4.3 Shield Currents 40
4.4 Shield-Drain Direction 41
4.5 Shield Connections—Segments 41
4.6 Power Entrances 42
4.7 Power-Transformer Conventions 42
4.8 Power Transformer with a Single Shield 43
4.9 Coil-to-Shield Capacitance 43
4.10 The Single Transformer Shield and its Connections 45
4.11 The Double Electrostatic Shield 46
4.12 Single-Ended Amplifiers 48
4.13 Segmenting the Amplifier Shield 48
4.14 A Shield-Enclosure Rule 49
4.15 Primary-Shield Ties 50
4.16 A Note on Locating Current Loops 50

5 The Differential Amplifier 53

5.1 General 53
5.2 A Basic Instrumentation Problem 54
5.3 Instrumentation Differential Amplifiers 55
5.4 Common-Mode Voltage 56
5.5 Common-Mode Content 57
5.6 Common-Mode Rejection Ratio or CMR 57
5.7 Solutions to the Differential-Amplifier Problem 58
5.8 The Flux-Coupled Differential DC Amplifier 60
5.9 Input Modulator Techniques with Flux Coupling 61
5.10 Postmodulator Techniques in Flux-Coupled Instruments 62
5.11 Merits of Flux-Coupled Instruments 63
5.12 The Electronically Coupled Differential DC Amplifier 64

5.13 Postamplification in Electronically Coupled Instruments 64
5.14 Preamplification in Electronically Coupled Instruments 65
5.15 Return-Path Requirements in Electronically Coupled Instruments 67
5.16 Merits of Electronically Coupled Instruments 67

6 General Application Problems 69

A Few Explanations 69
6.1 When Single-Ended Amplifiers Should Be Used 69
6.2 Charge Amplifiers 70
6.3 Input Coax Applied to a Single-Ended Amplifier 70
6.4 Coax-to-Twinax Interface 71
6.5 Resistance-Bridge Applications (Strain Gages) 71
6.6 Isolated Resistance Bridge and a Grounded Observation Point 72
6.7 Single-Ended Amplifiers and Thermocouples 73
6.8 When Differential Amplifiers Should be Used 74
6.9 Floating Sources and Differential Amplifiers 75
6.10 A *Misapplied* Shield for Thermocouples 76
6.11 The Double Input Shield for Thermocouples 77
6.12 Grounding vs Floating Signal Lines 78
6.13 Shield-Current Control (The Medical Problem) 79
6.14 The Use of Isolation Transformers 81
6.15 Isolation Transformers for Rack Isolation 83
6.16 Single-Ended to Differential Conversion by Using Buffers 84
6.17 A Calibration Problem 85

7 Shielding in Resistance-bridge Systems 89

7.1 General 89
7.2 The Resistance Bridge and its Signal Environment 89
7.3 The Floating Power Supply 90
7.4 Floating Power-Supply Shielding 91
7.5 Multiconductor Cable 92
7.6 Differential Amplifiers and Resistance Bridges 93
7.7 Common Power-Supply Excitation 94
7.8 Shielding Calibrate Processes 95
7.9 Amplifier Power-Supply Combinations 97

8 Magnetic Processes in Instrumentation 99

8.1 Introduction 99
8.2 Basic Ideas 99

8.3 Lenz's Law 102
8.4 Ampere's Law 103
8.5 Coaxial Current Flow 104
8.6 Magnetic Loop Areas 104
8.7 Magnetic Units 105
8.8 Mutual and Self-Inductance 106
8.9 Signal Circuit Coupling by Magnetic Field 106
8.10 An Electrostatic-Shield Problem 107
8.11 Parallel Cable Runs 108
8.12 Flux Coupling to Shield Connections 108
8.13 Use of Conduit for Field Reduction 109
8.14 Practical Transformer Shields 109
8.15 Ultrashielded Isolation Transformers 110
8.16 Shielding a Toroidal Core 114
8.17 Balanced Transformer Construction 115
8.18 A Special Shielding Technique 115
8.19 Measuring Transformer Mutual Capacitances 116
8.20 Active Measurements of Mutual Capacitance 117

9 Rf Processes in Instrumentation 119

General 119
9.1 Radiation Energy 119
9.2 Controlled Rf Paths 120
9.3 The Transmission Line 121
9.4 Transmission Lines in Instrumentation 122
9.5 Rf Comments 122
9.6 Waveguides 122
9.7 Rf Shielding 123
9.8 Skin Effect 124
9.9 Ground Conductors 124
9.10 Shielded Enclosures 125
9.11 Rf-Pickup Elimination 126
9.12 Rf Common-Mode Signals 126
9.13 The Isolation Transformer 127
9.14 Long Signal Lines 128
9.15 Driven Lines for Capacitance Reduction 129
9.16 Transmission-Line Equations 131
9.17 Signal Cables 131
9.18 Cable Frequency vs Amplitude Response 132
9.19 Cable-Shield Effectiveness 132
9.20 Low-Noise Cable 133

10 The Earth Plane **135**

10.1 General 135
10.2 Units of Resistivity 135
10.3 Typical Soil Resistivities 136
10.4 Resistance and Capacitance Analogy 136
10.5 The Driven Rod 136
10.6 Utility Practice vs Lightning 137
10.7 Utility Practices 137
10.8 A Problem in Earthing Many Conductors 138
10.9 Ground Bus 138
10.10 Flow of Neutral Current 139
10.11 Floating the Instrument Racks 140