
Contents

Preface	xvii
Dedications	xviii
About the Author	xviii
Revisions, Corrections, Updates, Liability	xix
Book Layout and Structure	xix
1 Introduction	1
1.1 The Legacy	1
1.2 Today and the Second Generation of Equipment	1
1.3 The Future	3
1.4 Operational and User Changes	3
1.5 Radio Spectrum Used by Aviation	4
1.5.1 Convergence, Spectrum Sharing	6
1.6 Discussion of the Organizational Structure of Aviation	
Communications Disciplines	6
1.6.1 International Bodies	7
1.6.2 Example National Bodies	7
1.6.3 Industrial Interests	7
1.6.4 Example Standards Bodies and Professional Engineering Bodies	7
1.6.5 Users/Operators	8
2 Theory Governing Aeronautical Radio Systems	9
Summary	9
2.1 Basic Definitions	10
2.1.1 Notations and Units	10
2.2 Propagation Fundamentals	11
2.2.1 Electromagnetic Vectors	11
2.2.2 Polarization	11
2.2.3 Speed of Propagation and Relationship to Wavelength and Frequency	11
2.3 Power, Amplitudes and the Decibel Scale	14
2.4 The Isotropic Power Source and Free Space Path Loss	15
2.4.1 Definition of Isotropic	15
2.4.2 Derivation of Free Space Path Loss Equation	15

2.4.3	Power Flux Density	17
2.4.4	Electric Field Strength	17
2.4.5	Relationship Between Field Strength and Transmitted Power	18
2.5	Radio Geometry	19
2.5.1	Radio Horizon Calculations	19
2.5.2	Earth Bulge Factor – k Factor	22
2.5.3	Nautical Mile	23
2.5.4	Great-circle Distances	24
2.6	Complex Propagation: Refraction, Absorption, Non-LOS Propagation	25
2.6.1	Refraction	26
2.6.1.1	Layer Refraction	26
2.6.1.2	Obstacle Refraction	26
2.6.2	Attenuation from Atmosphere Absorption	28
2.6.2.1	Water Absorption	28
2.6.2.2	Oxygen Absorption and Other Gases	28
2.6.3	Non-LOS Propagation	30
2.6.3.1	Propagation – Ground Wave	30
2.6.3.2	Reflection and Multipath	30
2.6.3.3	Propagation – Sky Wave	32
2.6.4	Propagation to Satellite	36
2.6.4.1	Propagation Distance	36
2.6.4.2	Atmospheric Losses	36
2.7	Other Propagation Effects	37
2.7.1	The Doppler Effect	37
2.7.1.1	Example	37
2.7.1.2	Answer	38
2.8	Modulation	38
2.8.1	The Modulation Conundrum	40
2.8.2	The Analogue and Digital Domains	40
2.8.3	Amplitude Modulation (AM)	41
2.8.3.1	DSB-AM	41
2.8.3.2	The VHF Aeronautical Mobile Communications (Route) Service (AM(R)S)	43
2.8.3.3	Single Sideband (SSB) Modulation	46
2.8.3.4	The Aeronautical HF System and Other SSB Systems	48
2.8.3.5	Suppressed Carrier Double Side Band AM	48
2.8.4	Frequency Modulation	49
2.8.4.1	Capture Effect (Hysteresis)	49
2.8.5	Digital Modulation	50
2.8.5.1	Amplitude Shift Keying (ASK)	50
2.8.5.2	Amplitude Modulated Minimum Shift Keying (AM-MSK)	51
2.8.5.3	Baud/Bit Rate and ‘ M -ary’ ASK	52
2.8.5.4	Bipolar and Differential	52
2.8.5.5	Frequency Shift Keying	53
2.8.5.6	Phase Shift Keying	53
2.8.5.7	Quadrature Amplitude Modulation (QAM) and Trellis Code Modulation (TCM)	58

CONTENTS

vii

2.8.5.8 Trellis Code Modulation	59
2.8.5.9 Gaussian Frequency Shift Keying (GFSK)	60
2.9 Shannon's Theory	62
2.9.1 Non-Errorless Transmission	62
2.10 Multiplexing and Trunking	62
2.10.1 Frequency Division Multiplexing (FDM)	63
2.10.2 Trunking	63
2.10.2.1 Example	63
2.10.3 Time Division Multiplexing (TDM)	65
2.10.4 Orthogonal Frequency Division Multiplexing (OFDM) and Coded OFDM	65
2.11 Access Schemes	66
2.11.1 Frequency Division Multiple Access (FDMA)	66
2.11.2 Time Division Multiple Access (TDMA)	67
2.11.3 Code Division Multiple Access (CDMA)	67
2.11.3.1 CDMA Principles	69
2.11.3.2 Frequency Domain Duplex (FDD) and Time Domain Duplex (TDD)	70
2.11.3.3 CDMA Applications	71
2.12 Mitigation Techniques for Fading and Multipath	71
2.12.1 Equalization	71
2.12.2 Forward Error Correction and Cyclic Redundancy Checking	72
2.12.3 Interleaving	72
2.12.4 Space Diversity	74
2.12.5 Frequency Diversity	75
2.12.6 Passive Receiver Diversity	75
2.13 Bandwidth Normalization	77
2.14 Antenna Gain	80
2.14.1 Ideal Isotropic Antenna	80
2.14.2 Practical Realizations	81
2.14.3 Some Common Antennas Used for Aeronautical Communications	82
2.14.3.1 The Dipole	82
2.14.3.2 The Folded Dipole	82
2.14.3.3 Quarter-Wave Vertical Antenna	82
2.14.3.4 $5/8 \lambda$ Vertical Antenna	83
2.14.3.5 Yagi Antenna	84
2.14.3.6 Log Periodic Antenna	84
2.14.3.7 Parabolic Dish Antennas	86
2.15 The Link Budget	87
2.16 Intermodulation	88
2.16.1 Third-order, Unwanted Harmonics	88
2.16.2 Higher Order Harmonics	92
2.17 Noise in a Communication System	92
2.17.1 Thermal Noise	92
2.17.2 Natural Noise	92
2.17.3 Man-made Noise and Interference	92
2.17.4 Sky Noise	93

2.18	Satellite Theory	93
2.18.1	Extended Noise Equation	93
2.18.2	G/T	93
2.18.3	The Link Budget Equation	94
2.18.4	Noise Temperatures	95
2.18.4.1	Receiver Side of the Reference Point	95
2.18.4.2	Antenna Side of the Reference Point	95
2.19	Availability and Reliability	99
2.19.1	Definitions	99
2.19.2	The Reliability Bathtub Curve	99
2.19.3	Some Reliability Concepts	100
2.19.4	Overall Availability of a Multicomponent System	101
2.19.4.1	Serial Chain	101
2.19.4.2	Parallel Chain	101
2.19.4.3	The Reliability Block Diagram	102
	Further Reading	104
3	VHF Communication	105
	Summary	105
3.1	History	105
3.1.1	The Legacy Pre-1947	105
3.1.2	1947 to Present, Channelization and Band Splitting	106
3.1.2.1	Channel Splitting	108
3.1.3	Today and 8.33 kHz Channelization	108
3.1.4	Into the Future (Circa 2006 Plus)	109
3.2	DSB-AM Transceiver at a System Level	110
3.2.1	System Design Features of AM(R)S DSB-AM System	110
3.2.1.1	Availability and Reliability	113
3.2.1.2	RF Unbalance	113
3.2.1.3	System Specification	113
3.3	Dimensioning a Mobile Communications System—The Three Cs	113
3.3.1	Coverage	115
3.3.1.1	Voting Networks and Extended Coverage	117
3.3.2	Capacity	120
3.3.3	Cwality (Quality)	122
3.4	Regulatory and Licensing Aspects	123
3.4.1	The Three As	123
3.4.1.1	Allocation	123
3.4.1.2	Allotment	124
3.4.1.3	Assignment	124
3.4.1.4	Utilization Profile	124
3.5	VHF ‘Hardening’ and Intermodulation	125
3.5.1	Receiver Swamping	125
3.5.2	Intermodulation	126
3.6	The VHF Datalink	126
3.6.1	Limitations with VHF Voice	126
3.6.2	The History of Datalink	127

CONTENTS

ix

3.6.3	System-Level Technical Description	128
3.6.3.1	ACARS/VDL0/VDLA	128
3.6.3.2	VDL1	129
3.6.3.3	VDL2	130
3.6.3.4	VDL Mode 3	134
3.6.3.5	VDL4	138
3.6.4	Overview of the Modes – A Comparison	140
3.6.5	Services over Datalink	140
3.6.6	Future Data Applications	140
	Further Reading	143
4	Military Communication Systems	145
	Summary	145
4.1	Military VHF Communications – The Legacy	145
4.2	After the Legacy	146
4.3	The Shortfalls of the Military VHF Communication System	147
4.4	The Requirement for a New Tactical Military System	147
4.5	The Birth of JTIDS/MIDS	147
4.6	Technical Definition of JTIDS and MIDS	148
4.6.1	Channelization	148
4.6.2	Link 4A Air Interface	148
4.6.3	Link-11 Air Interface	148
4.6.4	Link 16 – Air Interface	149
4.6.5	Access Methods	151
4.6.6	Link 16 Data Exchange	152
4.6.7	Jitter	152
4.6.8	Synchronization	152
4.6.9	Synchronization Stack	152
4.6.9.1	Header	153
4.6.9.2	Data Packing	153
4.6.9.3	Standard Double Pulse Format	154
4.6.9.4	Packed 2 Single Pulse Format	154
4.6.9.5	Packed 2 Double Pulse Format	155
4.6.9.6	Packed 4 Single Pulse Format	155
4.6.10	Other Salient Features of JTIDS/MIDS	156
4.6.11	Overlay with DME Band	156
5	Long-Distance Mobile Communications	157
	Summary	157
5.1	High-Frequency Radio – The Legacy	157
5.2	Allocation and Allotment	158
5.3	HF System Features	158
5.3.1	Transmitter	159
5.3.2	Receiver	159
5.3.3	System Configuration	159
5.3.4	Selective Calling (SELCAL)	159
5.3.5	Channel Availability	160

x

CONTENTS

5.4	HF Datalink System	162
5.4.1	Protocol	162
5.4.2	Deployment	163
5.5	Applications of Aeronautical HF	163
5.6	Mobile Satellite Communications	165
5.6.1	Introduction	165
5.6.1.1	Geostationary Satellite Systems	165
5.6.1.2	Low-Earth Orbit Satellite Systems	167
5.6.1.3	Medium-Earth Orbit Satellite System	168
5.6.2	Geostationary Services System Detail	168
5.6.2.1	The AMS(R)S Satellite System	168
5.6.3	Antenna System Specifications	171
5.6.3.1	Satellite Antenna Figure of Merit (G/T)	172
5.6.3.2	Antenna Discrimination	172
5.6.3.3	Rx Thresholds	173
5.6.3.4	Tx EIRP Limits	174
5.7	Comparison Between VHF, HF, L Band (JTIDS/MIDS) and Satellite Mobile Communications	175
5.8	Aeronautical Passenger Communications	175
	Further Reading	175
6	Aeronautical Telemetry Systems	177
	Summary	177
6.1	Introduction – The Legacy	177
6.2	Existing Systems	178
6.2.1	A Typical Telemetry System Layout	179
6.2.1.1	Transmitter Side (On-board Aircraft Components)	180
6.2.1.2	Receiver Side (High-performance Ground Station)	181
6.2.1.3	On-board System Duplication and Ground Backhaul Infrastructure	181
6.2.2	Telecontrol	182
6.3	Productivity and Applications	182
6.4	Proposed Airbus Future Telemetry System	183
6.4.1	Channelization Plan	183
6.4.2	System Components	183
6.4.3	Telemetry Downlink	183
6.4.4	Telecommand Uplink	184
6.5	Unmanned Aerial Vehicles	185
7	Terrestrial Backhaul and the Aeronautical Telecommunications Network	187
	Summary	187
7.1	Introduction	187
7.2	Types of Point-to-point Bearers	188
7.2.1	Copper Cables	188
7.2.2	Frequency Division Multiplex Stacks	189
7.2.3	Newer Digital Connections and the Pulse Code Modulation	189
7.2.4	Synchronous Digital Hierarchy, Asynchronous Transfer Mode and Internet Protocol	191

CONTENTS

xi

7.2.5	Fibre Optic	191
7.2.6	Private Networks and the Aeronautical Telecommunications Networks	192
7.2.7	PTT-Offered Services	194
7.2.8	Radio Links	194
7.2.8.1	Fixed Radio Link Design	194
7.2.9	VSAT Networks	197
7.2.9.1	VSAT Radio Link Budget	197
7.2.10	Hybrid Network	199
8	Future Aeronautical Mobile Communication Systems	201
	Summary	201
8.1	Introduction	202
8.2	Near-term Certainties	202
8.2.1	Universal Access Transceiver	202
8.2.1.1	Frame Structure	202
8.2.1.2	UAT Transceiver Specification	203
8.2.1.3	UAT Modes of Operation	204
8.2.1.4	Message Types	204
8.2.1.5	Application and Limitation of UAT	205
8.2.1.6	Further Reading	205
8.2.2	Mode S Extended Squitter	205
8.2.2.1	Mode S Introduction	205
8.2.2.2	Pulse Interrogations and Replies	206
8.2.2.3	Further Reading	207
8.2.3	802.xx Family	207
8.2.3.1	802.16	208
8.2.3.2	Specification	209
8.2.3.3	Application and Limitations	210
8.3	Longer Term Options	210
8.3.1	Analysis	210
8.3.2	Answer	210
8.3.3	The Definition Conundrum	211
8.3.3.1	The Requirements or the Operational Scenario	212
8.3.3.2	Technology Options and Frequency Band	213
8.3.3.3	Spectrum Requirements	214
8.3.4	A Proposal for a CDMA-based Communication System	214
8.3.5	Software Defined Radio	217
	Further Reading	219
9	The Economics of Radio	221
	Summary	221
9.1	Introduction	221
9.2	Basic Rules of Economics	221
9.3	Analysis and the Break-even Point	222
9.4	The Cost of Money	222
9.4.1	Some Basic Financial Concepts	223
9.4.2	Inflation	224

9.5	The Safety Case	225
9.6	Reliability Cost	226
9.7	Macroeconomics	227
10	Ground Installations and Equipment	229
	Summary	229
10.1	Introduction	229
	10.1.1 Environment	229
	10.1.1.1 Indoor Environment	229
	10.1.1.2 Outdoor Environment	230
10.2	Practical Equipment VHF Communication Band (118–137 MHz)	233
	10.2.1 VHF Transmitters	233
	10.2.2 VHF Receivers	233
	10.2.3 VHF Transmitter/Receiver Configurations	235
	10.2.3.1 VHF Single-channel Dual Simplex Station Site Configuration	235
	10.2.3.2 VHF Multichannel, Duplicated Base Station	236
	10.2.4 VHF Cavity Filters	236
	10.2.5 VHF Combiner, Multicouplers, Switches and Splitters	237
	10.2.6 Other Radio Equipment	238
	10.2.6.1 HF	238
	10.2.6.2 Microwave Point-to-point Equipment	240
	10.2.6.3 Satellite Equipment	240
	10.2.6.4 Voice/Data Termination, Multiplex and Other Line-terminating Equipment	241
	10.2.6.5 Future Communication Equipment	241
	10.2.7 Peripheral Equipment	243
	10.2.7.1 Mains/AC Service	243
	10.2.7.2 DC Supplies	244
	10.2.7.3 Heating Ventilation, Air Conditioning	244
	10.2.7.4 Pressurization	244
10.3	Outdoor	245
	10.3.1 Transmission Lines (VHF, L Band and Microwave)	245
	10.3.2 Antenna Engineering	245
	10.3.2.1 Antenna Location and Application	245
	10.3.2.2 Antenna Selection	247
	10.3.2.3 Alignment and Optimization	248
	10.3.2.4 Practical Antennas	248
	10.3.3 Towers or Masts	254
	10.3.4 Equipment Room	255
	10.3.5 Equipment Racks	257
11	Avionics	259
	Summary	259
	11.1 Introduction	259
	11.2 Environment	259

CONTENTS

xiii

11.2.1	Temperature	261
11.2.1.1	Outside	261
11.2.1.2	Interior	262
11.2.2	Pressure	262
11.2.2.1	External Pressure	262
11.2.2.2	Internal Pressure	262
11.2.3	Equipment Testing	262
11.2.4	Apparent Wind Speed	262
11.2.5	Humidity: 0–100 %	264
11.2.5.1	External	264
11.2.5.2	Internal	264
11.2.5.3	General	264
11.2.6	RF Environment, Immunity, EMC	268
11.2.7	Environmental Classification	268
11.3	Types of Aircraft	268
11.3.1	Private Aircraft	269
11.3.2	General Aviation	269
11.3.3	Commercial Aviation	270
11.3.4	Military Aviation	271
11.4	Simple Avionics for Private Aviation	272
11.5	The Distributed Avionics Concept	273
11.5.1	Data Bus Standards	273
11.5.1.1	ARINC 429 Standard	273
11.5.1.2	ARINC 629 Standard	277
11.5.1.3	ARINC 659	278
11.5.1.4	Fibre-distributed Data Interface (FDDI)	278
11.5.2	Power Supply System	279
11.5.2.1	Power Subsystem on an Aircraft	280
11.5.2.2	Example The Boeing 777	280
11.5.2.3	28 V DC	281
11.5.2.4	Flight Management System Monitoring of Circuit Breakers	281
11.6	Avionic Racking Arrangements	282
11.6.1	ATR and MCU	282
11.6.2	Cooling	283
11.6.3	Back Plane Wiring	283
11.6.3.1	Index Pin Code	284
11.6.5	Other Standards	284
11.7	Avionic Boxes	284
11.7.1	VHF Transceivers	284
11.7.1.1	Transmitter Specification	285
11.7.1.2	Receiver Specification	286
11.7.1.3	Navigation Communication Control Panel	287
11.7.2	HF Radios	289
11.7.2.1	Technical Specification	289
11.7.2.2	Transmitter	289
11.7.2.3	HF Physical Specification	290
11.7.2.4	Power	290

11.7.2.5 HF Built-in Test Equipment	291
11.7.2.6 HF Antenna Tuner and Coupler	291
11.7.2.7 Dual System Interlocks	292
11.7.2.8 HF Data Radio	292
11.7.3 Satellite Receiver System Avionics	293
11.7.3.1 Receiver Specification	293
11.7.3.2 Size Specification	293
11.7.4 Other Equipment	294
11.8 Antennas	294
11.8.1 VHF Antennas	294
11.8.1.1 Whip Antennas	295
11.8.1.2 Blade Antennas	297
11.8.1.3 Compound Antennas	298
11.8.2 HF Antennas	298
11.8.2.1 Wireline	298
11.8.2.2 Probe Antennas	299
11.8.2.3 Cap Antennas	300
11.8.2.4 Shunt Antennas	300
11.8.2.5 Notch Antenna	300
11.8.2.6 Antenna Couplers	300
11.8.3 Satellite Antennas	300
11.9 Mastering the Co-site Environment	301
11.10 Data Cables, Power Cables, Special Cables, Coaxial Cables	303
11.11 Certification and Maintaining Airworthiness	303
11.11.1 Certification	303
11.11.2 EUROCAE	304
11.11.3 Master Minimum Equipment List	304
Further Reading	304
12 Interference, Electromagnetic Compatibility, Spectrum Management and Frequency Management	307
Summary	307
12.1 Introduction	308
12.2 Interference	308
12.2.1 Sources of Interference	308
12.2.1.1 Accidental or Inadvertent Interference	309
12.2.1.2 Intended or Purposeful Interference	310
12.2.2 Interference Forms	310
12.2.3 Immunity and Susceptibility	311
12.2.4 Testing for Interference	313
12.3 Electromagnetic Compatibility	314
12.3.1 Analysis	314
12.3.2 Out of Channel, Out of Band, Spurious Emissions	316
12.3.3 EMC Criteria	317
12.3.3.1 Building a Compatibility Matrix	318

CONTENTS	xv
12.4 Spectrum Management Process	318
12.4.1 Co-channel Sharing and Adjacent Channel and Adjacent Band Compatibility	319
12.4.2 Intrasystem and Intersystem Compatibility	319
12.4.3 Intrasystem Criteria	320
12.4.4 Intersystem Criteria	320
12.4.4.1 Two Aviation Systems	320
12.4.4.2 Two Systems: One of Them Not Aviation Safety of Life	320
12.4.5 WRC Process and the Review and Amend Cycles	321
12.5 Frequency Management Process	322
12.5.1 Example	322
12.5.2 Emergency Frequency (Three-channel Guard Band Either Side)	322
12.5.3 SAFIRE (Spectrum frequency information repository)	324
Further Reading	324
Appendix 1 Summary of All Equations (Constants, Variables and Conversions)	325
Appendix 2 List of Symbols and Variables from Equations	333
Appendix 3 List of Constants	335
Appendix 4 Unit Conversions	337
Appendix 5 List of Abbreviations	339
Index	345

