

CONTENTS

Preface	xv
Acknowledgments	xvii
About the Author	xix
1 A Brief History of Microwave Radio Fixed Point-to-Point (Relay) Communication Systems	1
1.1 In the Beginning, 1	
1.2 Microwave Telecommunications Companies, 7	
1.3 Practical Applications, 10	
1.4 The Beat Goes On, 14	
References, 16	
2 Regulation of Microwave Radio Transmissions	20
2.1 Radio Frequency Management, 21	
2.2 Testing for Interference, 28	
2.3 Radio Paths by FCC Frequency Band in the United States, 29	
2.4 Influences in Frequency Allocation and Utilization Policy within the Western Hemisphere, 30	
2.4.1 United States of America (USA), 30	
2.4.2 Canada, 36	
2.5 FCC Fixed Radio Services, 36	
2.6 Site Data Accuracy Requirements, 41	
2.7 FCC Antenna Registration System (ASR) Registration Requirements, 42	
2.8 Engineering Microwave Paths Near Airports and Heliports, 44	
2.8.1 Airport Guidelines, 46	
References, 47	
3 Microwave Radio Overview	48
3.1 Introduction, 48	
3.2 Digital Signaling, 50	
3.3 Noise Figure, Noise Factor, Noise Temperature, and Front End Noise, 50	

3.4	Digital Pulse Amplitude Modulation (PAM),	53
3.5	Radio Transmitters and Receivers,	58
3.6	Modulation Format,	60
3.7	QAM Digital Radios,	65
3.8	Channel Equalization,	68
3.9	Channel Coding,	70
3.10	Trellis Coded Modulation (TCM),	72
3.11	Orthogonal Frequency Division Multiplexing (OFDM),	75
3.12	Radio Configurations,	76
3.12.1	Cross-Polarization Interference Cancellation (XPIC),	78
3.13	Frequency Diversity and Multiline Considerations,	82
3.14	Transmission Latency,	85
3.15	Automatic Transmitter Power Control (ATPC),	87
3.16	Current Trends,	87
3.16.1	TDM (or ATM) over IP,	87
3.16.2	TDM Synchronization over IP,	88
3.16.3	Adaptive Modulation,	89
3.16.4	Quality of Service (QoS) [Grade of Service (GoS) in Europe],	89
	References,	90
4	Radio Network Performance Objectives	96
4.1	Customer Service Objectives,	96
4.2	Maintenance Objectives,	96
4.3	Commissioning Objectives,	98
4.4	Design Objectives,	98
4.4.1	Quality,	98
4.4.2	Availability,	98
4.5	Differences Between North American and European Radio System Objectives,	99
4.5.1	North American Radio Engineering Standards (Historical Bell System Oriented),	99
4.5.2	European Radio Engineering Standards (ITU Oriented),	99
4.6	North American Telecommunications System Design Objectives,	100
4.7	International Telecommunications System Design Objectives,	100
4.7.1	Legacy European Microwave Radio Standards,	102
4.7.2	Modern European Microwave Radio Standards,	102
4.8	Engineering Microwave Paths to Design Objectives,	102
4.9	Accuracy of Path Availability Calculations,	106
4.9.1	Rain Fading,	106
4.9.2	Multipath Fading,	106
4.9.3	Dispersive Fading Outage,	107
4.9.4	Diversity Improvement Factor,	107
4.10	Impact of Flat Multipath Variability,	108
4.11	Impact of Outage Measurement Methodology,	108
4.12	Impact of External Interference,	109
4.13	Conclusion,	109
	References,	110
5	Radio System Components	114
5.1	Microwave Signal Transmission Lines,	115
5.2	Antenna Support Structures,	121
5.2.1	Lattice Towers,	122
5.2.2	Self-Supporting Towers,	122
5.2.3	Guyed Towers,	122

5.2.4	Monopoles,	124
5.2.5	Architecturally Designed Towers,	125
5.2.6	Building-Mounted Antennas,	126
5.2.7	Camouflaged Structures,	126
5.2.8	Temporary Structures,	126
5.3	Tower Rigidity and Integrity,	127
5.4	Transmission Line Management,	127
5.5	Antennas,	127
5.6	Near Field,	137
5.7	Fundamental Antenna Limitations,	143
5.8	Propagation,	143
5.9	Radio System Performance as a Function of Radio Path Propagation,	145
5.9.1	Flat Fading,	146
5.9.2	Dispersive Fading,	148
5.10	Radio System Performance as a Function of Radio Path Terrain,	149
5.11	Antenna Placement,	153
5.12	Frequency Band Characteristics,	155
5.13	Path Distances,	157
5.A	Appendix,	159
5.A.1	Antenna Isotropic Gain and Free Space Loss,	159
5.A.2	Free Space Loss,	163
5.A.3	Antenna Isotropic Gain,	164
5.A.4	Circular (Parabolic) Antennas,	166
5.A.5	Square (Panel) Antennas,	167
5.A.6	11-GHz Two-foot Antennas,	168
5.A.7	Tower Rigidity Requirements,	169
	References,	172
6	Designing and Operating Microwave Systems	175
6.1	Why Microwave Radio?	175
6.2	Radio System Design,	175
6.3	Designing Low Frequency Radio Networks,	179
6.4	Designing High Frequency Radio Networks,	182
6.4.1	Hub and Spoke,	183
6.4.2	Nested Rings,	184
6.5	Field Measurements,	185
6.6	User Data Interfaces,	185
6.7	Operations and Maintenance,	202
6.7.1	Fault Management,	203
6.7.2	Alarms and Status,	206
6.7.3	Performance Management,	207
6.8	Maintaining the Network,	210
	References,	217
7	Hypothetical Reference Circuits	220
7.1	North American (NA) Availability Objectives,	220
7.1.1	NA Bell System Hypothetical Reference Circuit-Availability Objectives,	220
7.1.2	NA Telcordia Hypothetical Reference Circuit-Availability Objectives,	222
7.2	North American Quality Objectives,	225
7.2.1	Residual BER,	225
7.2.2	Burst Errored Seconds,	225
7.2.3	DS1 Errored Seconds,	225
7.2.4	DS3 Errored Seconds,	225

7.3	International Objectives, 225	
7.3.1	International Telecommunication Union Availability Objectives, 228	
7.4	International Telecommunication Union Quality Objectives, 236	
7.4.1	Legacy Quality Objectives, 236	
7.4.2	Current Quality Objectives, 240	
7.5	Error-Performance Relationship Among BER, BBER, and SESs, 245	
	References, 247	
8	Microwave Antenna Theory	249
8.1	Common Parameters, 251	
8.2	Passive Reflectors, 252	
8.2.1	Passive Reflector Far Field Radiation Pattern, 253	
8.2.2	Passive Reflector Near Field Power Density, 255	
8.3	Circular (Parabolic) Antennas, 256	
8.3.1	Circular (Parabolic) Antenna Far Field Radiation Pattern, 256	
8.3.2	Circular (Parabolic) Antenna Efficiency, 260	
8.3.3	Circular (Parabolic) Antenna Beamwidth, 261	
8.3.4	Circular (Parabolic) Antenna Near Field Power Density, 264	
8.3.5	General Near Field Power Density Calculations, 265	
8.3.6	Circular Antenna Near Field Power Density Transitions, 272	
8.3.7	Circular Antenna Far Field Reference Power, 273	
8.4	Square Flat Panel Antennas, 274	
8.4.1	Square Antenna Beamwidth, 276	
8.4.2	Square Near Field Power Density, 279	
8.4.3	Square Antenna Far Field Reference Power, 288	
8.4.4	Square Near Field Power Density Transitions, 289	
8.5	Regulatory Near Field Power Density Limits, 290	
8.6	Practical Near Field Power Calculations, 290	
8.6.1	A Parabolic Antenna Near Field Power Example Calculation, 293	
8.6.2	Safety Limits, 294	
8.7	Near Field Antenna Coupling Loss, 296	
8.7.1	Antenna to Antenna Near Field Coupling Loss, 296	
8.7.2	Coupling Loss between Identical Antennas, 300	
8.7.3	Coupling Loss between Different-Sized Circular Antennas, 300	
8.7.4	Coupling Loss between Different-Sized Square Antennas, 301	
8.7.5	Parabolic Antenna to Passive Reflector Near Field Coupling Loss, 302	
8.7.6	Coupling Loss for Circular Antenna and Square Reflector, 303	
8.7.7	Coupling Loss for Square Antenna and Square Reflector (Both Aligned), 305	
8.7.8	Back-to-Back Square Passive Reflector Near Field Coupling Loss, 306	
8.A	Appendix, 307	
8.A.1	Circular Antenna Numerical Power Calculations, 307	
8.A.2	Square Antenna Numerical Power Calculations, 311	
8.A.3	Bessel Functions, 315	
	References, 318	
9	Multipath Fading	320
9.1	Flat and Dispersive Fading, 329	
9.A	Appendix, 338	
9.A.1	Fading Statistics, 338	
9.A.2	DFM Equation Derivation, 339	
9.A.3	Characteristics of Receiver Signature Curves and DFM, 342	
	References, 344	

10	Microwave Radio Diversity	348
10.1	Space Diversity, 350	
10.2	Dual-Frequency Diversity, 354	
10.3	Quad (Space and Frequency) Diversity, 357	
10.4	Hybrid Diversity, 358	
10.5	Multiline Frequency Diversity, 358	
10.6	Crossband Multiline, 365	
10.7	Angle Diversity, 366	
10.7.1	Angle Diversity Configurations, 368	
10.7.2	Angle Diversity Performance, 371	
10.A	Appendix, 372	
10.A.1	Optimizing Space Diversity Vertical Spacing, 372	
10.A.2	Additional Optimization, 377	
	References, 380	
11	Rain Fading	384
11.1	Point (Single-Location) Rain Loss (Fade) Estimation, 386	
11.2	Path Rain-Fade Estimation, 390	
11.3	Point-to-Path Length Conversion Factor, 398	
11.4	Single-Location Rain Rate R , 398	
11.5	City Rain Rate Data for North America, 407	
11.6	New Rain Zones, 430	
11.7	Worst-Month Rain Rates, 430	
11.8	Point Rain Rate Variability, 439	
11.9	Examples of Rain-Loss-Dominated Path Designs, 441	
11.10	Conclusions, 444	
11.A	Appendix, 446	
11.A.1	North American City Rain Data Index, 446	
	References, 458	
12	Ducting and Obstruction Fading	461
12.1	Introduction, 461	
12.1.1	Power Fading, 463	
12.2	Superrefraction (Ducting), 465	
12.3	Subrefraction (Earth Bulge or Obstruction), 469	
12.4	Minimizing Obstruction Fading, 471	
12.4.1	Path Clearance (Antenna Vertical Placement) Criteria, 471	
12.5	Obstruction Fading Model, 477	
12.6	Obstruction Fading Estimation, 479	
12.7	Bell Labs Seasonal Parameter Charts, 483	
12.8	Refractivity Data Limitations, 484	
12.9	Reviewing the Bell Labs Seasonal Parameter Charts, 485	
12.10	Obstruction Fading Parameter Estimation, 486	
12.11	Evaluating Path Clearance Criteria, 487	
12.A	Appendix: North American Refractivity Index Charts, 490	
12.B	Appendix: Worldwide Obstruction Fading Data, 491	
	References, 511	
13	Reflections and Obstructions	514
13.1	Theoretical Rough Earth Reflection Coefficient, 514	
13.1.1	Gaussian Model, 516	
13.1.2	Uniform Model, 517	

- 13.2 Scattering from Earth Terrain, 517
- 13.3 Practical Earth Reflection Coefficient, 519
- 13.4 Reflection Location, 519
- 13.5 Smooth Earth Divergence Factor, 522
- 13.6 Reflections from Objects Near a Path, 523
- 13.7 Fresnel Zones, 525
- 13.8 Antenna Launch Angle (Transmit or Receive Antenna Takeoff Angle), 527
- 13.9 Grazing Angle, 527
- 13.10 Additional Path Distance, 528
- 13.11 Estimating the Effect of a Signal Reflected from the Earth, 528
- 13.12 Flat Earth Obstruction Path Loss, 529
- 13.13 Smooth Earth Obstruction Loss, 529
- 13.14 Knife-Edge Obstruction Path Gain, 530
- 13.15 Rounded-Edge Obstruction Path Gain, 531
- 13.16 Complex Terrain Obstruction Losses, 532
- 13.A Appendix, 536
 - 13.A.1 Smooth Earth Reflection Coefficient, 536
 - 13.A.2 Procedure for Calculating R_H AND R_V , 536
 - 13.A.3 Earth Parameters for Frequencies Between 100 kHz and 1 GHz, 538
 - 13.A.4 Earth Parameters for Frequencies Between 1 GHz and 100 GHz, 540
 - 13.A.5 Comments on Conductivity and Permittivity, 541
 - 13.A.6 Reflection Coefficients, 541

14 Digital Receiver Interference

559

- 14.1 Composite Interference ($\Delta T/T$) Criterion, 559
- 14.2 Carrier-to-Interference Ratio (C/I) Criterion, 560
- 14.3 Measuring C/I , 560
- 14.4 Estimating C/I , 561
- 14.5 Threshold to Interference (T/I) Criterion, 562
- 14.6 Why Estimate T/I , 563
- 14.7 T/I Estimation—Method One, 564
- 14.8 T/I Estimation—Method Two, 565
- 14.9 Conclusion, 569
- 14.A Appendix, 569
 - 14.A.1 Basic 10^{-6} Threshold for Gaussian (Radio Front End) Noise Only, 569
 - 14.A.2 Using a Spectrum Mask as a Default Spectrum Curve, 570
- 14.B Appendix: Receiver Parameters, 571
 - References, 572

15 Network Reliability Calculations

573

- 15.1 Hardware Reliability, 574
- 15.2 System Reliability, 577
 - 15.2.1 Equipment in Series, 577
 - 15.2.2 Multiple Equipment in Parallel, 578
 - 15.2.3 Nested Equipment, 579
 - 15.2.4 Meshed Duplex Configuration, 579
- 15.3 Communication Systems, 579
- 15.4 Application to Radio Configurations, 580
- 15.5 Spare Unit Requirements, 580
- 15.6 BER Estimation, 583
 - 15.6.1 Time to Transmit N Digits, 585
- References, 585

16 Path Performance Calculations

587

- 16.1 Path Loss, 588
- 16.2 Fade Margin, 589
- 16.3 Path Performance, 589
- 16.4 Allowance for Interference, 590
- 16.5 North American (NA) Path Performance Calculations, 590
 - 16.5.1 Vigants-Barnett Multipath Fading (Barnett, 1972; Vigants, 1975)—NA, 591
 - 16.5.2 Cross-Polarization Discrimination Degradation Outages—NA, 596
 - 16.5.3 Space Diversity: Flat-Fading Improvement—NA, 596
 - 16.5.4 Space Diversity: Dispersive-Fading Improvement—NA, 599
 - 16.5.5 Dual Frequency Diversity: Flat-Fading Improvement—NA, 599
 - 16.5.6 Dual Frequency Diversity: Dispersive-Fading Improvement—NA, 600
 - 16.5.7 Quad (Space and Frequency) Diversity—NA, 601
 - 16.5.8 Hybrid Diversity—NA, 601
 - 16.5.9 Multiline Frequency Diversity—NA, 601
 - 16.5.10 Angle Diversity—NA, 602
 - 16.5.11 Upfading—NA, 603
 - 16.5.12 Shallow Flat Fading—NA, 603
- 16.6 International Telecommunication Union—Radiocommunication Sector (ITU-R) Path Performance Calculations, 604
 - 16.6.1 Flat Fading—ITU-R, 605
 - 16.6.2 Dispersive Fading—ITU-R, 606
 - 16.6.3 Cross-Polarization Discrimination Degradation Outages—ITU-R, 608
 - 16.6.4 Upfading—ITU-R, 609
 - 16.6.5 Shallow Flat Fading—ITU-R, 609
 - 16.6.6 Space Diversity Improvement—ITU-R, 610
 - 16.6.7 Dual-Frequency Diversity Improvement—ITU-R, 611
 - 16.6.8 Quad (Space and Frequency) Diversity—ITU-R, 611
 - 16.6.9 Angle Diversity Improvement—ITU-R, 613
 - 16.6.10 Other Diversity Improvements—ITU-R, 614
- 16.7 Rain Fading and Obstruction Fading (NA and ITU-R), 614
- 16.8 Comparing the North American and the ITU-R Flat-Fading Estimates, 614
 - 16.8.1 Vigants-Barnett Flat-Fading Estimation for Bell Labs Path, 614
 - 16.8.2 ITU-R Flat-Fading Estimation for Bell Labs Path, 615
- 16.9 Diffraction and Vegetation Attenuation, 621
- 16.10 Fog Attenuation, 622
- 16.11 Air Attenuation, 624
- 16.A Appendix, 631
 - References, 649

A Microwave Formulas and Tables

653

- A.1 General, 653
 - Table A.1 General, 653
 - Table A.2 Scientific and Engineering Notation, 654
 - Table A.3 Emission Designator, 655
 - Table A.4 Typical Commercial Parabolic Antenna Gain (dBi), 656
 - Table A.5 Typical Rectangular Waveguide, 656
 - Table A.6 Typical Rectangular Waveguide Data, 657
 - Table A.7 Typical Copper Corrugated Elliptical Waveguide Loss, 657
 - Table A.8 Typical Copper Circular Waveguide Loss, 658
 - Table A.9 Rectangular Waveguide Attenuation Factors, 659
 - Table A.10 CommScope Elliptical Waveguide Attenuation Factors, 659
 - Table A.11 RFS Elliptical Waveguide Attenuation Factors, 660

Table A.12	Elliptical Waveguide Cutoff Frequencies, 660
Table A.13	Circular Waveguide Cutoff Frequencies, 661
Table A.14	Typical Coaxial Microwave Connectors, 663
Table A.15	Coaxial Cable Velocity Factors, 664
Table A.16	50 Ohm Coaxial Cable Attenuation Factors, 664
Table A.17	Frequency Bands, General Users, 665
Table A.18	Frequency Bands, Fixed Point to Point Operators, 665
Table A.19	Frequency Bands, Radar, Space and Satellite Operators, 666
Table A.20	Frequency Bands, Electronic Warfare Operators, 666
Table A.21	Frequency Bands, Great Britain Operators, 666
Table A.22	Signal-to-Noise Ratio for Demodulator 10^{-6} BER, 667
A.2	Radio Transmission, 668
A.2.1	Unit Conversions, 668
A.2.2	Free Space Propagation Absolute Delay, 669
A.2.3	Waveguide Propagation Absolute Delay, 669
A.2.4	Coaxial Cable Propagation Absolute Delay, 669
A.2.5	Free Space Propagation Wavelength, 669
A.2.6	Dielectric Medium Propagation Wavelength, 669
A.2.7	Free Space Loss (dB), 670
A.2.8	Effective Radiated Power (ERP) and Effective Isotropic Radiated Power (EIRP), 670
A.2.9	Voltage Reflection Coefficient, 670
A.2.10	Voltage Standing Wave Ratio Maximum, 670
A.2.11	Voltage Standing Wave Ratio Minimum, 670
A.2.12	Voltage Standing Wave Ratio, 670
A.2.13	Power Reflection Coefficient, 671
A.2.14	Reflection Loss, 671
A.2.15	Return Loss, 671
A.2.16	Q (Quality) Factor (Figure of Merit for Resonant Circuits or Cavities), 671
A.2.17	Q (Quality) Factor (Figure of Merit for Optical Receivers), 672
A.2.18	Typical Long-Term Interference Objectives, 672
A.2.19	Frequency Planning Carrier-to-Interference Ratio (C/I), 672
A.2.20	Noise Figure, Noise Factor, Noise Temperature, and Front End Noise, 672
A.2.21	Shannon's Formula for Theoretical Limit to Transmission Channel Capacity, 674
A.3	Antennas (Far Field), 675
A.3.1	General Microwave Aperture Antenna (Far Field) Gain (dBi), 675
A.3.2	General Microwave Antenna (Far Field) Relative Gain (dBi), 675
A.3.3	Parabolic (Circular) Microwave Antenna (Far Field) Gain (dBi), 675
A.3.4	Parabolic (Circular) Microwave Antenna Illumination Efficiency, 676
A.3.5	Panel (Square) Microwave Antenna (Far Field) Gain (dBi), 676
A.3.6	Panel (Square) Microwave Antenna Illumination Efficiency, 676
A.3.7	Angle Between Incoming and Outgoing Radio Signal Paths, C , for a Passive Reflector, 677
A.3.8	Signal Polarization Rotation Through a Passive Reflector, $\Delta\phi$, 678
A.3.9	Signal Effects of Polarization Rotation, 678
A.3.10	Passive Reflector (Far Field) Two-Way (Reception and Retransmission) Gain (dBi), 678
A.3.11	Rectangular Passive Reflector 3-dB Beamwidth (Degrees, in Horizontal Plane), 678
A.3.12	Elliptical Passive Reflector 3-dB Beamwidth (Degrees), 679
A.3.13	Circular Parabolic Antenna 3-dB Beamwidth (Degrees), 679
A.3.14	Passive Reflector Far Field Radiation Pattern Envelopes, 680
A.3.15	Inner Radius for the Antenna Far-Field Region, 681

A.4	Near-Field Power Density, 682
A.4.1	Circular Antennas, 682
A.4.2	Square Antennas, 682
A.5	Antennas (Close Coupled), 683
A.5.1	Coupling Loss L_{NF} (dB) Between Two Antennas in the Near Field, 683
A.5.2	Coupling Loss L_{NF} (dB) Between Identical Antennas, 683
A.5.3	Coupling Loss L_{NF} (dB) Between Different-Sized Circular Antennas, 684
A.5.4	Coupling Loss L_{NF} (dB) Between Different-Sized Square Antennas (Both Antennas Aligned), 684
A.5.5	Coupling Loss L_{NF} (dB) for Antenna and Square Reflector in the Near Field, 685
A.5.6	Coupling Loss L_{NF} (dB) for Circular Antenna and Square Reflector, 685
A.5.7	Coupling Loss L_{NF} (dB) for Square Antenna and Square Reflector (Both Aligned), 686
A.5.8	Two Back-to-Back Square Reflectors Combined Gain, 687
A.6	Path Geometry, 687
A.6.1	Horizons (Normal Refractivity over Spherical Earth), 687
A.6.2	Earth Curvature (Height Adjustment Used on Path Profiles), 688
A.6.3	Reflection Point, 688
A.6.4	Fresnel Zone Radius (Perpendicular to the Radio Path), 690
A.6.5	Fresnel Zone Projected onto the Earth's Surface, 690
A.6.6	Reflection Path Additional Distance, 691
A.6.7	Reflection Path Additional Delay, 691
A.6.8	Reflection Path Relative Amplitude, 691
A.6.9	Antenna Launch Angle, 691
A.6.10	Antenna Height Difference, 692
A.6.11	K Factor (From Launch Angles), 692
A.6.12	Refractive Index and K Factor (From Atmospheric Values), 693
A.7	Obstruction Loss, 693
A.7.1	Knife-Edge Obstruction Loss, 693
A.7.2	Rounded-Edge Obstruction Path Loss, 694
A.7.3	Smooth-Earth Obstruction Loss, 695
A.7.4	Infinite Flat Reflective Plane Obstruction Loss, 695
A.7.5	Reflection (Earth Roughness Scattering) Coefficient, 695
A.7.6	Divergence Coefficient from Earth, 696
A.7.7	Divergence Factor for a Cylinder, 697
A.7.8	Divergence Factor for a Sphere, 697
A.7.9	Signal Reflected from Flat Earth, 697
A.7.10	Ducting, 697
A.8	Mapping, 698
A.8.1	Path Length and Bearing, 698
A.9	Towers, 700
A.9.1	Three-Point Guyed Towers, 700
A.9.2	Three-Leg Self-Supporting Tower, 701
A.9.3	Four-Leg Self-Supporting Tower, 701
A.10	Interpolation, 702
A.10.1	Two-Dimensional Interpolation, 702
A.10.2	Three-Dimensional Interpolation, 705
B	Personnel and Equipment Safety Considerations
B.1	General Safety Guidelines, 709
B.2	Equipment Protection, 711
B.3	Equipment Considerations, 712
B.4	Personnel Protective Equipment, 713

- B.5 Accident Prevention Signs, 713
- B.6 Tower Climbing, 713
- B.7 Hand Tools, 715
- B.8 Electrical Powered Tools, 715
- B.9 Soldering Irons, 715
- B.10 Ladders, 716
- B.11 Hoisting or Moving Equipment, 716
- B.12 Batteries, 717
- B.13 Laser Safety Guidelines, 717
- B.14 Safe Use of Lasers and LED in Optical Fiber Communication Systems, 718
- B.15 Optical Fiber Communication System (OFCS) Service Groups (SGs), 718
- B.16 Electrostatic Discharge (ESD), 719
- B.17 Maximum Permissible Microwave Radio RF Exposure, 720
- B.18 Protect Other Radio Users [FCC], 720
- B.19 PAUSE (Prevent all Unplanned Service Events) and Ask Yourself (Verizon and AT&T Operations), 721
- B.20 Protect Yourself (Bell System Operations), 721
- B.21 Parting Comment, 721

Index