

Contents

1	Introduction	1
1.1	Evolution of Meteorological Observations	2
1.2	History of Early Radio Communication Systems	5
1.2.1	Evolution of Satellite Communications	10
1.2.2	Experiments with Active Communications Satellites	15
1.2.3	Early Progress in Mobile Satellite Communications and Navigation	17
1.2.4	Early Development in Meteorological Observation Systems	20
1.3	Development of Global Mobile Satellite Systems (GMSS)	21
1.3.1	Global Mobile Satellite Communications (GMSC)	22
1.3.2	Global Navigation Satellite Systems (GNSS)	24
1.3.3	Stratospheric Platform Systems (SPS)	26
1.3.4	Satellite Meteorological Observation Systems (SMOS)	27
1.4	Definition of Fixed Satellite Communications (FSC)	28
1.4.1	Satellite Voice Network	29
1.4.2	Satellite VSAT Network	29
1.5	Definition of Mobile VSAT Service	32
1.5.1	Mobile Broadcast Satellite Service (MBSS)	33
1.5.2	Mobile Satellite Broadband Service (MSBS)	35
1.6	International Coordination Organizations and Regulatory Procedures	36
1.6.1	International Telecommunications Union (ITU) and Radio Regulations	36
1.6.2	World Meteorological Organization (WMO)	37
1.6.3	International Hydrographic Organization (IHO)	38

1.7	Space Systems and Radiocommunication Frequency Assignment	39
1.7.1	Meteorological Space and Ground Segments	39
1.7.2	Meteorological Frequency Designations and Classification of Services	39
1.8	History of Satellite Meteorology	42
1.8.1	Early Meteorological Instrumentation	43
1.8.2	Evolution of PEO Meteorological Satellites	47
1.8.3	Evolution of GEO Meteorological Satellites	55
1.8.4	Evolution of Non-GEO Meteorological Satellites	57
1.9	Mobile Satellite Meteorological Service (MSMS)	59
1.9.1	WEFAX System	61
1.9.2	Automatic Picture Transmission (APT)	62
1.9.3	Applied Weather Technology (AWT)	64
1.9.4	Global Meteorological Technologies (GMT)	65
1.9.5	Maritime Noble Denton Weather Services (NDWS)	66
1.9.6	Global Sea State Information via Internet (GSSII)	66
1.9.7	Aeronautical Weather Applications	67
1.9.7.1	Aviation Routine Weather Report (METAR)	68
1.9.7.2	Aeronautical Weather Forecast	69
2	Space Segment	71
2.1	Platforms and Orbital Mechanics	72
2.1.1	Space Environment	73
2.1.2	History of Motions in Space	73
2.1.3	Laws of Satellite Motion	74
2.1.3.1	Geometry of Elliptical Orbit	78
2.1.3.2	Geometry of Circular Orbit	80
2.1.4	Horizon and Geographic Satellite Coordinates	81
2.1.4.1	Satellite Distance and Coverage Area	81
2.1.4.2	Satellite Look Angles (Elevation and Azimuth)	86
2.1.4.3	Satellite Track and Geometry (Longitude and Latitude)	88
2.1.5	Orientation in Space	90
2.1.6	Satellite Orbit Perturbations	93
2.2	Spacecraft Launching and Station-Keeping Techniques	97
2.2.1	Satellite Installation and Launching Operations	98
2.2.1.1	Direct Ascent Launching	98
2.2.1.2	Indirect Ascent Launching	98
2.2.2	Satellite Launchers and Launching Systems	99
2.2.2.1	Expendable Launching Vehicles	99
2.2.2.2	Reusable Launch Vehicles	100
2.2.2.3	Land-Based Launching Systems	103
2.2.2.4	Sea-Based Launch Systems	104

2.3	Types of Orbits for Meteorological and Other Satellite Systems . .	108
2.3.1	Low Earth Orbits (LEO)	109
2.3.2	Circular Orbits	110
2.3.2.1	Medium Earth Orbits (MEO)	110
2.3.2.2	Geostationary Earth Orbits (GEO)	111
2.3.2.3	Geosynchronous Inclined Orbits (GIO)	112
2.3.3	Highly Elliptical Orbits (HEO)	113
2.3.3.1	Molniya Orbit	115
2.3.3.2	Tundra Orbit	117
2.3.3.3	Loopus Orbit	117
2.3.4	Polar Earth Orbits (PEO)	118
2.4	Main Characteristics of Metrological Satellite Orbits	120
2.4.1	Sunsynchronous Polar Orbits	120
2.4.2	Geostationary Circular Orbits	122
2.4.3	Other Satellite Orbits	124
2.5	Meteorological Satellite Payloads and Antenna Systems	125
2.5.1	Transparent or Bent-pipe Communication Transponder . . .	126
2.5.2	Regenerative Communication Transponder	127
2.5.3	Satellite Meteorological e Communication Transponder . .	128
2.5.4	Diagram of VSAT GEO Satellite Communication Repeater	130
2.5.5	Antenna System onboard Metrological Satellites	131
2.5.5.1	Reflector Antennas	132
2.5.5.2	Aperture Antennas (Horn Antennas)	133
2.5.5.3	Array Antennas	133
2.5.6	Characteristics of Spacecraft Antenna System	134
2.6	Satellite Bus	136
2.6.1	Structure Platform (SP)	137
2.6.2	Electric Power (EP)	137
2.6.3	Thermal Control (TC)	139
2.6.4	Attitude and Orbit Control (AOC)	140
2.6.5	Telemetry, Tracking and Command (TT&C)	141
2.6.6	Propulsion Engine (PE)	143
3	Baseband and Transmission Systems	145
3.1	Baseband Signals	146
3.1.1	Voice Signals	147
3.1.2	Data and Multimedia Signals	148
3.1.3	Sound (Audio) Signals	149
3.1.4	Video and Television Signals	150
3.1.5	Basic Concept of Modulation	151
3.1.6	Analog and Digital Domains	152
3.2	Analog Transmission	153
3.2.1	Baseband Processing	154
3.2.2	Analog Modulation and Multiplexing	155

3.2.2.1	Amplitude Modulation (AM)	156
3.2.2.2	Frequency Modulation (FM)	157
3.2.2.3	Phase Modulation (PM)	158
3.2.3	Double Side Band-Amplitude Modulation (DSB-AM)	158
3.2.4	Single Side Band-Amplitude Modulation (SSB-AM)	160
3.2.5	Frequency Division Multiplexing (FDM)	161
3.3	Digital Transmission	162
3.3.1	Delta Modulation (DM)	164
3.3.2	Coded Modulation (CM)	166
3.3.2.1	Trellis Coded Modulation (TCM)	166
3.3.2.2	Block Coded Modulation (BCM)	167
3.3.3	Pulse Code Modulation (PCM)	167
3.3.4	Quadrature Amplitude Modulation (QAM)	169
3.3.5	Time Division Multiplexing (TDM)	170
3.3.6	Types of Digital Shift Keying	171
3.3.6.1	Amplitude Shift Keying (ASK)	171
3.3.6.2	Frequency Shift Keying (FSK)	172
3.3.6.3	Minimum Shift Keying (MSK)	172
3.3.6.4	Phase Shift Keying (PSK)	173
3.3.7	Combinations of PSK Digital Carriers	173
3.3.7.1	Binary PSK (BPSK)	174
3.3.7.2	Quadrature PSK (QPSK)	174
3.3.7.3	Offset QPSK (O-QPSK)	176
3.3.7.4	Differential PSK (DPSK)	177
3.3.7.5	$\pi/4$ -QPSK	178
3.4	Channel Coding and Decoding	179
3.4.1	Channel Processing	179
3.4.1.1	Channel Encoding	179
3.4.1.2	Digital Compression	181
3.4.2	Coding	182
3.4.2.1	Block Codes	182
3.4.2.2	Cyclic Codes	183
3.4.2.3	Convolutional Codes	185
3.4.2.4	Concatenated Codes	187
3.4.2.5	Turbo Codes	188
3.4.3	Decoding	189
3.4.3.1	Block Decoding	189
3.4.3.2	Convolutional Decoding	189
3.4.3.3	Turbo Decoding	190
3.4.3.4	Sequential Decoding	190
3.4.3.5	Viterbi Decoding	190
3.4.4	Error Correction	191
3.4.4.1	Forward Error Correction (FEC)	192
3.4.4.2	Automatic Request Repeat (ARQ)	193

3.4.4.3	Pseudo Noise (PN)	194
3.4.4.4	Interleaving	195
3.5	Multiple Access Technique	196
3.5.1	Frequency Division Multiple Access (FDMA)	199
3.5.1.1	Multiple Channels Per Carrier (MCPC)	200
3.5.1.2	Single Channel Per Carrier (SCPC)	201
3.5.2	Forms of FDMA Operations	202
3.5.2.1	SCPC/FM/FDMA	202
3.5.2.2	SCPC/PSK/FDMA	202
3.5.2.3	TDM/FDMA	203
3.5.2.4	TDMA/FDMA	203
3.5.3	Time Division Multiple Access (TDMA)	203
3.5.3.1	TDM/TDMA	204
3.5.3.2	FDMA/TDMA	205
3.5.4	Code Division Multiple Access (CDMA)	205
3.5.4.1	Direct Sequence CDMA (DS-CDMA)	207
3.5.4.2	Frequency Hopping CDMA (FH-CDMA)	208
3.5.5	Space Division Multiple Access (SDMA)	209
3.5.5.1	Special Effects of SDMA in Satellite Systems	210
3.5.5.2	Switched Spot Beam Antenna	212
3.5.5.3	Adaptive Array Antenna Systems	213
3.5.5.4	SDMA/FDMA	214
3.5.5.5	SDMA/TDMA	214
3.5.5.6	SDMA/CDMA	215
3.5.6	Random Division Multiple Access (RDMA)	215
3.5.6.1	Aloha	216
3.5.6.2	Slotted Aloha	217
3.5.6.3	Slot Reservation Aloha	218
3.6	Satellite Broadband and Internet Protocols	219
3.6.1	Satellite Internet Protocol (IP)	220
3.6.1.1	IP Security Protocol (IPSec)	221
3.6.1.2	Mobile Transmissions Over IP (MToIP)	221
3.6.1.3	Mobile IP Version 6 (MIPv6)	222
3.6.2	Transmission Control Protocol (TCP)	223
3.6.2.1	TCP/IP Over Satellite	224
3.6.2.2	TCP Intertwined Algorithms	225
3.6.3	Mobile Asynchronous Transfer Mode (ATM)	226
3.6.3.1	IP/ATM Over Satellite	228
3.6.3.2	UBR Over Satellite	231
3.6.3.3	ABR Over Satellite	232
3.6.4	Fixed Digital Video Broadcasting-Return Channel Via Satellite (DVB-RCS)	233
3.6.5	Mobile Digital Video Broadcasting-Return Channel Over Satellite (DVB-RCS)	235

3.7	MPEG Multimedia Standards	237
3.7.1	Audio Broadcasting	237
3.7.1.1	MPEG-2 Audio Layer II (MP2) Encoding	237
3.7.1.2	MPEG-2 Audio Layer III (MP3) Encoding	238
3.7.2	Video Broadcasting	238
3.7.2.1	MPEG-2 Video Encoding	238
3.7.2.2	High-Definition TV and MPEG-4	239
3.7.2.3	Multiplexing and Transporting	239
3.8	Direct-to-Home Broadcast System	240
3.8.1	Transmission System Architecture	241
3.8.2	Generic Reference Integrated Receiver Decoder (IRD) Model	242
3.9	Transmission Standards	242
3.9.1	Digital Video Broadcast-Second Generation (DVB-S2) Standard	243
3.9.2	DVB-S2 Architecture	244
3.9.3	Digital Video Broadcast-Third Generation (DVB-S3) Standard	246
4	Atmospheric Electromagnetic Radiation	249
4.1	Fundamentals of Atmospheric Radiative Transfer	249
4.1.1	Nature of Radiation	251
4.1.1.1	Basic of Radiation	252
4.1.1.2	Solid Angle	253
4.1.1.3	Radiance and Irradiance	256
4.1.1.4	Energy Transitions	257
4.2	Energy Emissions	258
4.2.1	Blackbody Emission	259
4.2.2	Surface Emission	261
4.2.3	Medium Emissivity	261
4.2.4	Earth and Sun Applications	262
4.3	Radiative Properties of Matter	263
4.3.1	Electromagnetic Spectrum and Waves	264
4.3.2	Absorption and Emission of Radiation	265
4.3.3	Atmospheric Scattering of Radiation	268
4.3.4	Surface Reflection	271
4.3.5	Solar and Terrestrial Radiation	271
4.3.6	Conservation of Energy	273
4.3.7	Selective Absorption and Emission	275
4.3.8	Composition of the Earth's Atmosphere	275
4.3.9	Different Atmospheric Absorptions and Emissions	276
4.4	Additional Applications to the Earth's Atmosphere	279
4.4.1	Transfer of the Heat Energy	279
4.4.2	Feedbacks in the Atmosphere	280
4.4.3	Specific Facts for Aerosols	282
4.4.4	Earth and Atmosphere Albedo	283

4.5	Radiative Transfer Equations (RTE)	284
4.5.1	Primers of Radiations	286
4.5.1.1	Infrared Radiation	286
4.5.1.2	Visible Radiation	287
4.5.2	Radiative Budget for the Earth Atmosphere System	288
4.5.2.1	Solar Constant and Emission Effective Temperature	288
4.5.2.2	Energy Budget for the Earth/Atmosphere System	290
5	Satellite Meteorological Parameters	293
5.1	Introduction to Satellite Weather Observation	294
5.1.1	Satellite Meteorological Instruments for Observation and Monitoring	295
5.1.2	Satellite Weather Imagery	297
5.1.3	Characteristics of Satellite Imagery	298
5.1.3.1	Visible Channel Imagery	299
5.1.3.2	Infra Red Channel Imagery	299
5.1.3.3	Water Vapour Channel Imagery	300
5.1.3.4	True Colour RGB Channel Imagery	303
5.1.4	Weather and Atmospheric Properties	304
5.1.4.1	Atmospheric Temperature Measurements	304
5.1.4.2	Atmospheric Density Measurements	306
5.1.4.3	Atmospheric Pressure Measurements	307
5.1.4.4	Atmospheric Humidity Measurements	307
5.2	Temperature and Trace Gases	308
5.2.1	Sounding Theory	308
5.2.1.1	Vertical Sounding Theory	308
5.2.1.2	Limb Sounding Theory	311
5.2.2	Retrieval Methods	312
5.2.2.1	Physical Retrievals	312
5.2.2.2	Statistical Retrievals	314
5.2.2.3	Hybrid Retrievals	315
5.2.3	Operational Retrievals	317
5.2.3.1	TIROS Operational Vertical Sounder	317
5.2.3.2	VISSR Atmospheric Sounder (VAS)	319
5.2.4	Limb Sounding Retrievals	321
5.2.5	Ozone and Other Gases	322
5.2.6	Split-Window Technique	323
5.3	Winds Flow	325
5.3.1	Cloud and Vapour Tracking	325
5.3.2	Winds from Soundings	326
5.3.3	Ocean Surface Winds	327
5.3.4	Doppler Wind Measurements	330

5.4	Clouds and Aerosols	330
5.4.1	Clouds from Sounders	330
5.4.2	Clouds from Imagers	331
5.4.3	Clouds from Microwave Radiometry	335
5.4.4	Stratospheric Aerosols	336
5.4.5	Tropospheric Aerosols	337
5.5	Precipitation Measuring	339
5.5.1	Passive Visible and Infrared Techniques	341
5.5.2	Passive Microwave Techniques	342
5.5.3	Active Ground and Satellite Radar Technique	343
5.5.4	Severe Thunderstorms and Lighting	345
5.5.5	Advanced Global Distribution of Precipitation	346
5.6	Earth Radiation Budget	348
5.6.1	Solar Constant	348
5.6.2	Top of the Atmosphere Radiation Budget	349
5.6.3	Surface Radiation Budget	351
5.7	Measurements and Monitoring of Other Earth Observation Parameters	353
5.7.1	Hydrology Analyzes and Measuring	353
5.7.2	Sea Waves and Ocean Dynamic Measuring	354
5.7.3	Sea Surface Temperature Measuring	356
5.7.4	Sea Pollution and Ecosystem Monitoring	357
5.7.5	Cryosphere Detection and Monitoring	357
5.7.6	Agricultural and Forestry Landscape Monitoring	359
5.7.7	Global Land Cover Mapping	360
5.7.8	Desertification Monitoring and Mapping	361
6	Satellite Meteorological Instruments	363
6.1	Introduction to PEO Satellite Meteorological System	363
6.2	Meteorological Instruments Onboard POES Satellites	366
6.2.1	Advanced Very High Resolution Radiometer	367
6.2.2	High Resolution Infrared Radiation Sounder	371
6.2.3	Advanced Microwave Sounding Unit	375
6.2.4	Solar Backscatter Ultraviolet Radiometer	378
6.2.5	Space Environment Monitor	380
6.2.6	Search and Rescue Satellite Repeater and Processor	380
6.2.7	Digital Tape Recorder and Solid State Recorder	381
6.3	Meteorological Instruments Onboard European PEO Satellites	382
6.3.1	Microwave Humidity Sounder	384
6.3.2	Infrared Atmospheric Sounding Interferometer	386
6.3.3	Global Ozone Monitoring Experiment-2	390
6.3.4	Global Navigation Satellite System Receiver for Atmospheric Sounding	392
6.3.5	Advanced Scatterometer	396

6.4	Introduction to GEO Satellite Meteorological System	400
6.5	Meteorological Instruments Onboard GOES Satellites	401
6.5.1	GOES 4-7 (D-H) Instruments	402
6.5.2	GOES 8-12 (I-M) Instruments	406
6.5.2.1	GOES 8-12 (I-M) Imager Instrument	406
6.5.2.2	GOES 8-12 (I-M) Sounder Instrument	408
6.5.3	GOES 13-15 (N-P) Instruments	409
6.5.4	GOES 16-19 (R-U) Instruments	415
6.5.4.1	Earth Facing Instruments (EFI)	417
6.5.4.2	Sun Facing Instruments (SFI)	422
6.5.4.3	Space Environment Instruments (SEI)	424
6.5.4.4	Unique Payload Services (UPS)	426
6.6	Other GEO Satellite Instruments	429
6.6.1	European Meteosat Instruments	430
6.6.2	Russian Electro Instruments	435
6.6.3	Chinese Feng-Yun Instruments	438
6.6.4	Indian INSAT Instruments	439
6.6.5	Japanese GMS Instruments	439
7	Antenna Systems and Propagation	441
7.1	Evolution of Antenna Systems for Radio Communications	442
7.1.1	Overview of Antennas for Radio and Satellite Communications	442
7.1.2	Satellite Antennas Geometry	443
7.1.3	Antennas Requirements and Technical Characteristics	445
7.2	Basic Relations of Antennas	445
7.2.1	Frequency and Bandwidth in Meteorological Satellite Communications	446
7.2.2	Gain and Directivity	447
7.2.3	Radiation Pattern, Beamwidth and Sidelobes	449
7.2.4	Polarization and Axial Ratio	452
7.2.5	Figure of Merit (G/T) and EIRP	453
7.2.6	Classification of Satellite Antennas	455
7.3	Omnidirectional Low-Gain Antennas (LGA)	455
7.3.1	Quadrifilar Helix Antenna (QHA)	456
7.3.2	Crossed-Drooping Dipole Antenna (CDDA)	457
7.3.3	Microstrip Patch Antenna (MPA)	457
7.4	Directional Medium-Gain Antennas (MGA)	458
7.4.1	Aperture Reflector Antennas	458
7.4.1.1	Short Backfire (SBF) Plane Reflector Antenna	458
7.4.1.2	Modified SBF Plane Reflector Antenna	460
7.4.1.3	Improved SBF Conical Reflector Antenna	460
7.4.2	Wire Antennas	461
7.4.2.1	Helical Wire Antennas	461
7.4.2.2	Inverted V-Form Cross Dipole Antenna	462

7.4.2.3	Crossed-Slot Antenna	463
7.4.2.4	Conical Spiral Antenna	463
7.4.2.5	Planar Spiral Antennas	464
7.4.3	Array Antennas	466
7.4.3.1	Microstrip Array Antenna	466
7.4.3.2	Cross-Slot Array Antenna	466
7.4.3.3	Cross-Dipole Array Antenna	467
7.4.3.4	Four-Element Array Antennas	467
7.4.3.5	Spiral Array Antenna	468
7.4.3.6	Patch Array Antennas	469
7.5	High-Gain Directional Aperture Antennas	470
7.5.1	Parabolic Dish Antenna	471
7.5.2	Parabolic Dish Antenna in Radome	472
7.5.3	Parabolic Umbrella Antenna	472
7.5.4	Horn Antennas	473
7.5.4.1	Pyramidal Horn Antenna	473
7.5.4.2	E-Plane Horn Antenna	474
7.5.4.3	H-Plane Horn Antenna	474
7.5.4.4	Conical Horn Antenna	475
7.6	Ground Antennas for Particular Satellite Meteorological Systems	475
7.6.1	Direct Readout PEO Directional Ground Antenna Systems (GAS)	476
7.6.1.1	Tracking PEO Satellite L-Band GES Receiving Antenna	476
7.6.1.2	Tracking PEO Satellite Multi-Band GES Receiving Antenna	478
7.6.1.3	Tracking PEO X/Y Satellite L/S/X-Band GES Receiving Antenna	479
7.6.1.4	Tracking PEO MEOS Satellite GES Receiving L/S/X-Band Antenna	480
7.6.1.5	Tracking PEO Satellite GES Receiving L/S-Band Antenna	481
7.6.2	Direct Readout PEO Multidirectional Ground Antenna Systems (GAS)	483
7.6.2.1	Omnidirectional Direct Readout PEO Satellite Antennas	484
7.6.2.2	Directional Direct Readout PEO Satellite Antennas	486
7.6.3	Direct Readout GEO Directional Ground Antenna Systems (GAS)	488
7.6.3.1	Tracking GEO Satellite GES Receiving L/C/Ku-Band Antenna	489

7.6.3.2	Tracking GEO Satellite GES Receiving L/S/X-Band Antenna	490
7.6.3.3	Tracking GEO Satellite GES Receiving LRIT/HRIT L-Band Antenna	491
7.6.3.4	Tracking GEO Satellite GES Receiving LRIT/HRIT C-Band Antenna	492
7.6.3.5	Tracking GEO Satellite GES Receiving LRIT/HRIT Ku-Band Antenna	493
7.6.4	Meteocast Direct Readout GEO DVB-RCS GES Antenna Systems	494
7.6.4.1	Meteocast Forward DVB-RCS Uplink Antenna Systems	496
7.6.4.2	Meteocast Return DVB-RCS Downlink Antenna Systems	500
7.6.5	Meteocast Receiving Broadcasting GEO DVB-RCS Antennas	502
7.6.6	User Earth Stations (UES) Antennas Onboard Mobiles . . .	503
7.6.6.1	Shipboard Satellite WDS Receiving 0.61 m L/S-Band Antenna	504
7.6.6.2	Shipboard Satellite Weather Receiving 1.5 m L/S-Band Antenna	505
7.6.6.3	Shipboard Satellite Weather Receiving 2.4 m L/S/X-Band Antenna	507
7.6.6.4	Antennas for TeraScan Satellite Acquisition System (TacSAS)	509
7.6.6.5	Land HRPT/AHRPT Antenna System	510
7.6.6.6	Marine HRPT/AHRPT Antenna System	511
7.6.6.7	GEO Data Collection Platform (DCP) with Antenna	512
7.7	Propagation and Interference Consideration	513
7.7.1	Radiowave Propagation	514
7.7.2	Propagation Loss in Free Space	515
7.7.3	Atmospheric Effects on Propagation	516
7.7.4	Propagation Effects of the Troposphere	517
7.7.4.1	Attenuation due to Atmospheric Gases	517
7.7.4.2	Attenuation by Precipitation and Hydrometeors	518
7.7.4.3	Site Diversity Factors	521
7.7.5	Clear-Sky Effects on Atmospheric Propagation	522
7.7.6	Transionospheric Propagation	523
7.7.6.1	Faraday Rotation and Group Delay	523
7.7.6.2	Ionospheric Scintillation	525
7.7.6.3	Other Ionospheric Effects	526
7.7.6.4	Sky Noise Temperature Contributions	526

7.7.6.5	Environmental Noise Temperature Sources	527
7.7.6.6	Atmospheric Noise Temperature Elements	528
7.7.6.7	Galactic and Other Interplanetary Noise Effects	528
7.7.7	Path Depolarization Causes	529
7.7.7.1	Depolarization and Polarization Components	529
7.7.7.2	Relation between Depolarization and Attenuation	531
7.7.8	Surface Reflection and Local Environmental Effects	532
7.7.9	Reflection from the Earth's Surface	532
Bibliography	535

Global Satellite Meteorological Observation (GSMO)

Theory

Volume 1

Ilcev, S.D.

2018, XXVI, 546 p. 220 illus., 148 illus. in color.,

Hardcover

ISBN: 978-3-319-67118-5