

The Fading of Signals Propagating in the Ionosphere for Wide Bandwidth High-Frequency Radio Systems

by

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Contents

Contents	iii
Abstract	ix
Statement of Originality	xiii
Acknowledgements	xv
List of Figures	xvii
List of Tables	xxix
List of Abbreviations	xxxii
Chapter 1. Introduction	1
1.1 Background and Motivation	1
1.1.1 Ionospheric Propagation	1
1.1.2 Fading of Radio Signals	2
1.2 Literature Review	4
1.2.1 Ionospheric Propagation	4
1.2.2 Geometric Optics	4
1.2.3 Faraday Rotation and Polarisation Fading	5

Contents

1.2.4	Amplitude Fading	6
1.2.5	Propagation Models	6
1.2.6	Experimental Apparatus and Data Collection	7
1.3	Research Objectives and Approach	8
1.4	Overview of Thesis	10
1.5	Major Research Contributions	11
Chapter 2. The Theory of High-Frequency Signal Fading		13
2.1	Propagation of High-Frequency Radio-waves in the Ionosphere	14
2.2	Fading of High-Frequency Signals	19
2.3	Modelling Motivations and Objectives	23
2.4	Model of Polarisation Fading	23
2.4.1	Mode Polarisation	25
2.4.2	Development of the Model	28
2.4.3	Discussion	36
2.5	Model of Amplitude Fading	36
2.5.1	Complex Amplitude	37
2.5.2	Taylor Series Expansion on Complex Amplitude	41
2.5.3	The Diffraction Phase-Screen Model	47
2.5.4	Discussion	48
2.6	Effects of Multi-path Fading	48
2.6.1	Antenna terminal voltage	49
2.6.2	Multi-path interference	51
Chapter 3. Ionospheric Propagation Simulator		53
3.1	Features	54

3.2	Implementation	55
3.2.1	Ionospheric and Magnetic Field Models	55
3.2.2	Ray Tracing Engine	56
3.2.3	Fading Data Generation and Display	58
3.3	Simulation Results	59
3.3.1	Travelling Ionospheric Disturbance	60
3.3.2	Harts Range to Lake Bennett	61
3.3.3	Laverton to Lake Bennett	68
3.3.4	Results summary	71
3.4	Discussion	76
Chapter 4. The Experimental System		79
4.1	Motivations and Objectives	80
4.2	Compact Channel Probe	81
4.2.1	Crossed-dipole active antenna	82
4.2.2	Anti-aliasing filter	95
4.2.3	Digital receiver	101
4.2.4	Software interface	109
4.3	System Performance Testing	112
4.3.1	Laboratory testing	114
4.3.2	Field testing	116
4.4	Applications	130
4.4.1	Monitoring of short-wave broadcasting	130
4.4.2	Monitoring of FMCW signals	131
Chapter 5. Jindalee Radar Experimental Campaign		133

Contents

5.1	Rationale	134
5.2	Jindalee Over-The-Horizon Radar	135
5.3	Experimental Parameters	136
5.4	Ionospheric Conditions	138
5.4.1	Ionosonde Data	140
5.5	Signal Characteristics	142
5.6	Data Processing and Analysis	143
5.6.1	FMCW Processing	144
5.6.2	Amplitude-Phase Fading Separation	148
Chapter 6. Experimental Results		151
6.1	Processing Parameters	152
6.2	Signal Fading Results	154
6.2.1	Observations from 30 March 2005	154
6.2.2	Observations from 31 March 2005	171
6.3	Discussion	184
6.3.1	Comparisons with Simulation Results	185
6.3.2	Important Observations	185
6.4	Potential Further Analysis	186
6.4.1	Samples of Channel Scattering Function in Dual-Polarisations	187
Chapter 7. Conclusion and Future Work		193
7.1	Summary of the Theoretical Investigation of Signal Fading	193
7.1.1	Theoretical Model of Signal Fading	193
7.1.2	Ionospheric Propagation Simulator	194
7.2	Summary of the Experimental Investigation of Signal Fading	195

7.2.1 Compact Channel Probe in Dual-Polarisations	195
7.2.2 Jindalee OTHR Experimental Campaign	195
7.2.3 The Anatomy of Signal Fading	196
7.3 Contributions to the Body of Work	196
7.4 Future Work	197
Appendix A. Derivation of the Models	199
A.1 Ray Path Formulations	199
A.1.1 Value of g at the end of ray path	202
A.1.2 Total ground range	203
A.2 Phase Path Formulations	203
A.3 Perturbed Phase Path Formulations	204
A.4 Complex Amplitude Formulations	206
A.4.1 Second Integral with respect to dz' in (2.77)	206
A.4.2 U_1 for Taylor series expansion on the coefficients	207
Appendix B. Additional IPS Results	209
B.1 Harts Range to Lake Bennett	209
B.2 Laverton to Lake Bennett	214
Appendix C. Elliptic-function low-pass filter	219
C.1 Calculations of the elliptic-function filter	221
C.2 High Q Toroidal Inductors	223
Appendix D. Captured data file format	225
Appendix E. Antenna Equivalent Circuit	227

Contents

E.1	Calculation of Component Values	228
E.2	Circuit Simulations	229
E.3	Circuit Construction	230
E.4	Measurement Results	231

Appendix F. Additional Experimental Results **233**

F.1	30 March 2005 Observations	233
F.1.1	Late Afternoon - 10.858 MHz	233
F.1.2	Sunset period - 10.858 MHz	237
F.2	31 March 2005 Observations	241
F.2.1	Sunset Period - 14.591 MHz	241

Bibliography **245**

Abstract

The use of High-Frequency (HF) radio-wave propagation in the ionosphere remains prevalent for applications such as long-range communication, target detection and commercial broadcasting. The ionosphere presents a challenging channel for radio-wave propagation as it is a varying medium dependent on a number of external factors. Of the many adverse effects of ionospheric propagation, signal fading is one of the most difficult to eliminate due to its unpredictable nature. Increase in the knowledge of how the ionospheric channel affects the propagating signals, in particular fading of the signals, will drive the continual improvements in the reliability and performance of modern wide-bandwidth HF systems. This is the underlying motivation for the study of signal fading of HF radio-waves propagating through the ionosphere, from both the theoretical and experimental perspectives, with the focus of application to modern wide bandwidth HF systems. Furthermore, it is the main objective of this investigation to address the lacking in the current literature of a simple analytical signal fading model for wideband HF systems that relates the physics of the ionospheric irregularities to the observable propagation effects due to the irregularities, and one that is verified by experimental observations.

An original approach was taken in the theoretical investigation to develop an analytical model that combines the effects of signal fading and directly relating them to the ionospheric irregularities that are causing the fading. The polarisation fading model (PFM) is a combination of geometric optics, perturbation techniques and frequency offset techniques to derive expressions for the Faraday rotation of the radio-wave propagating in the ionosphere. Using the same notation as the PFM, the amplitude fading model (AFM) extends the Complex Amplitude concept using perturbation techniques and Green's functions solution to arrive at a set of expressions that describes the focussing and defocussing effects of the wave. The PFM and AFM, together with expressions for combining the effects of multiple propagation paths, provide a simple analytic model that completely

describes the fading of the signal propagating in the ionosphere. This theoretical model was implemented into an efficient ionospheric propagation simulator (IPS) from which simulations of wide bandwidth HF signals propagating through the ionosphere can be undertaken. As an example of the type of results produced by the IPS, for a typical 1200km path in the north-south direction with the ionospheric channel under the influence of a travelling ionospheric disturbance (TID), a 10 MHz radio-wave signal in one-hop path is shown to be affected by polarisation fading with fading periods in the order of minutes, and a fading bandwidth in the order of 100 kHz. Further results generated by the IPS have shown to be consistent with the results reported elsewhere in the literature.

The experimental investigation involves the study of signal fading from observations of real signals propagating in the ionosphere, a major part of which is the development of a digital compact channel probe (CCP) capable of operating in dual-polarisation mode, and the characterisation of such systems to ensure that data collected are not compromised by the non-idealities of the individual devices contained within the system. The CCP was deployed in experiments to collect transmissions of HF frequency-modulated continuous-wave (FMCW) radio signals from the Jindalee Over-the-Horizon radar (OTHR) in dual-polarisation. Analyses of the collected data showed the full anatomy of fading of signals propagating in the ionosphere for both horizontal and vertical polarisations, the results of which are consistent with that from the IPS and thus verifying the validity of the theoretical model of fading. Further experimental results showed that in majority of the observations polarisation fading is present but can be masked by multi-path fading, and confirming that periods of rapid signal fading are associated with rapid changes in the ionospheric channel.

From the theoretical and experimental investigations, the major achievement is the successful development of an efficient propagation simulator IPS based on the simple analytical expressions derived in the PFM and AFM theoretical models of signal fading, which has produced sensible signal fading results that are verified by experimental observations. One of the many outcomes of this investigation is that polarisation diversity has the potential to bring improvements to the quality of wide-bandwidth HF signals in a fading susceptible propagation channel. The combination of an efficient propagation simulator IPS based on theoretical signal fading model and the experimental data collection by the dual-polarisation CCP is a major step in allowing one to fully understand the different aspects of fading of signals propagating in the ionosphere, which sets a solid

foundation for further research into the design of wide bandwidth HF systems and the possible fading mitigation techniques.

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Statement of Originality

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List of Figures

1.1	Structure of the thesis.	12
2.1	The structure of the ionosphere with the different layers of ionisation and their respective heights.	15
2.2	Magnetic field orientation showing the Transverse (T) and Longitudinal (L) component of \mathbf{B}_0 relative to the wave normal vector \mathbf{k}	17
2.3	A ray tube where the bundle of rays intersects area S_1 on a constant phase surface ϕ_1 , and the same bundle later intersects area S_2 on a constant phase surface ϕ_2	19
2.4	The fading of the received signal on orthogonal antennas for a AM carrier signal at 9660 kHz.	20
2.5	Interference fading due to multiple propagation paths.	21
2.6	The effects of medium-scale travelling ionospheric disturbance (TID) on the radio-wave propagation.	22
2.7	The different phase paths and phase speeds of the Ordinary (O) and Extraordinary (X) characteristic waves.	24
2.8	The polarisation ellipses of the Ordinary (O) and Extraordinary (X) characteristic waves.	26
2.9	The limiting polarisation ellipses of the O and X wave.	27
2.10	Geometry of the ray path of a wave propagating through the ionosphere.	29
2.11	Complex Amplitude U as the TID moves through the ionosphere in time.	42

List of Figures

2.12	The ray central coordinate system showing the longitudinal coordinate g and the transverse coordinate τ	43
2.13	The diffraction phase-screen model.	48
2.14	The possible propagation modes that can combine at the receiver and contribute to cause multipath fading.	49
2.15	Phase definition for the O and X wave with the direction of propagation going into the page.	50
3.1	The block diagram of the Ionospheric Propagation Simulator.	56
3.2	Homing of the high ray at 10 MHz.	59
3.3	Simulations were done on the two paths: (1) Harts Range to Lake Bennett, and (2) Laverton to Lake Bennett.	60
3.4	Propagation modes for the transmission path between Harts Range and Lake Bennett.	62
3.5	Signal fading behaviour of the separate propagation modes in the Harts Range to Lake Bennett path.	65
3.6	Polarisation fading behaviour of the 1-hop low-ray propagation mode in the Harts Range to Lake Bennett path.	66
3.7	Spectrogram showing temporal-spectral fading behaviour of the 1-hop low-ray propagation mode in the Harts Range to Lake Bennett path.	67
3.8	Signal fading behaviour of the total combined signal in the Harts Range to Lake Bennett path.	69
3.9	Propagation modes for the transmission path between Laverton and Lake Bennett.	70
3.10	Signal fading behaviour of the separate propagation modes in the Laverton to Lake Bennett path.	72
3.11	Polarisation fading behaviour of the 1-hop low-ray propagation mode in the Laverton to Lake Bennett path.	73

3.12	Spectrograms showing temporal-spectral fading behaviour of the 1-hop low-ray propagation mode in the Laverton to Lake Bennett path.	74
3.13	Signal fading behaviour of the total combined signal in the Laverton to Lake Bennett path.	75
4.1	Block diagram of the Compact Channel Probe	83
4.2	Reference diagram for short dipole	84
4.3	Current distribution on a short dipole antenna.	85
4.4	3-D Gain pattern of an ideal short dipole.	86
4.5	Radiation pattern of an ideal short dipole across the $\phi = 0^\circ$ plane.	86
4.6	FEKO model of the crossed-dipole antenna.	87
4.7	3-D Gain pattern of the vertical short dipole at $f = 10\text{MHz}$	88
4.8	Radiation pattern of the vertical short dipole at $f = 10\text{MHz}$ across the $\phi = 0^\circ$ plane.	88
4.9	3-D Gain pattern of the horizontal short dipole at $f = 10\text{MHz}$	89
4.10	Radiation pattern of the horizontal short dipole at $f = 10\text{MHz}$ across the $\phi = 0^\circ$ plane.	89
4.11	Cross polarisation performance of the vertical short dipole at $f = 10\text{MHz}$ across the azimuthal plane.	91
4.12	Cross polarisation performance of the horizontal short dipole at $f = 10\text{MHz}$ across the azimuthal plane.	91
4.13	Circuit diagram of the active antenna.	93
4.14	5 th order Chebyshev low-pass filter.	93
4.15	Measured gain of the active antenna circuit.	94
4.16	Measured characteristics of the preamplifier and the HF band selection filter.	95
4.17	The S_{11} characteristics of the active short dipole antenna in the HF band.	96
4.18	Circuit diagram of the 11 th order Elliptic low-pass filter.	97

List of Figures

4.19	Response of the 11 th order Elliptic low-pass filter.	98
4.20	High-frequency equivalent circuits of real components showing parasitic elements.	99
4.21	Two elliptic filters residing in a metal enclosure for protective purpose. . .	99
4.22	Measured S_{11} characteristics of the anti-aliasing filters between the frequencies of 1 MHz to 100 MHz.	100
4.23	Measured response of the anti-aliasing filters.	101
4.24	ICS-652 ADC motherboard.	102
4.25	DC-50-MN multi-channel digital down-converter daughtercard.	103
4.26	Block diagram of the individual digital down-converters.	103
4.27	Test set-up for SNR and dynamic range measurements.	106
4.28	Test set-up for IP3 measurements.	106
4.29	ICS-652 ADC response with no input signal present except for noise from the 50 Ω termination.	107
4.30	ICS-652 ADC response to a single tone input at 10 MHz.	108
4.31	DDC response to a single tone input at 10 MHz with demodulator bandwidth set to 10 kHz.	108
4.32	DDC response to a single tone input at 10 MHz with demodulator bandwidth set to 100 kHz.	109
4.33	Digital receiver intermodulation performance measurement using two 0 dBm tones separated by 10 kHz.	110
4.34	Software interface of the digital radio receiver.	111
4.35	Graphical user interface of the monitoring software developed in MATLAB.	112
4.36	Graphical user interface of the capturing software developed in MATLAB.	113
4.37	Noise performance of the overall digital receiver system with no input present, over the entire ADC bandwidth.	115

4.38	Noise performance of the overall digital receiver system with a single 10 MHz tone present, over a 100 kHz bandwidth digitally down-converted to base-band.	117
4.39	Digital receiver system intermodulation performance measurement using two tones separated by 20 kHz ($f_1 = 10$ MHz, demodulator bandwidth = 100 kHz).	118
4.40	Reference received HF spectrum generated by the antenna equivalent circuit.	120
4.41	Day-time received HF spectrum from the (a) vertical, and (b) horizontal antenna.	121
4.42	Day-time HF spectrum received by the horizontal antenna, with (a) active antenna only, and (b) active antenna plus 20 dB gain block.	121
4.43	Day-time reference spectrum of 4 100 kHz-wide channels.	123
4.44	Day-time spectrum of 4 100 kHz-wide channels received by the horizontal active antenna only.	124
4.45	Day-time spectrum of 4 100 kHz wide channels received by the horizontal active antenna with 20 dB gain block.	125
4.46	Night-time HF spectrum received by the horizontal antenna, with (a) active antenna only, and (b) active antenna plus 20 dB gain block.	126
4.47	Night-time reference spectrum of 4 100 kHz-wide channels.	127
4.48	Night-time spectrum of 4 100 kHz-wide channels received by the horizontal active antenna only.	128
4.49	Night-time spectrum of 4 100 kHz wide channels received by the horizontal active antenna with 20 dB gain block.	129
5.1	Map showing the three radar locations and their area of coverage.	136
5.2	The location of the JFAS radar transmitter and the CCP in Darwin.	137
5.3	The global daily sunspot number over the period of 28 March 2005 to 1 April 2005.	139

List of Figures

5.4	The global three-hour magnetic activity index, $10 \times K_p$, over the period of 28 March 2005 to 1 April 2005.	140
5.5	The critical frequencies of the three layers - E, F1 and F2, over the time period of the experiment.	141
5.6	Peak heights of the three layers - E, F1 and F2, over the time period of the experiment.	142
5.7	Frequency-Time characteristics of a FMCW signal, showing the centre frequency f_0 , bandwidth B and sweep period T_r	143
5.8	Spectrogram of the received FMCW signal at $f_0 = 10.677$ MHz and bandwidth of 46 kHz.	144
5.9	Frequency-Time characteristics of the transmitted and received FMCW signal.	145
5.10	Processing stages of the Data Analysis Module (DAM).	147
6.1	Received propagation modes and their relative received time delays for the 46 kHz band at 10.677 MHz over the different time periods on 30th March 2005.	159
6.2	Signal fading behaviour of the separate propagation modes for the 46 kHz band at 10.677 MHz during the late afternoon period.	160
6.3	Spectrograms showing temporal-spectral fading behaviour of the separate propagation modes for the 46 kHz band at 10.677 MHz during the late afternoon period.	161
6.4	Signal multi-path fading behaviour for the 46 kHz band at 10.677 MHz during the late afternoon period.	162
6.5	Spectrograms showing temporal-spectral multi-path fading behaviour for the 46 kHz band at 10.677 MHz during the late afternoon period.	162
6.6	Signal fading behaviour of the separate propagation modes for the 46 kHz band at 10.677 MHz during the sunset period.	163

6.7	Spectrograms showing temporal-spectral fading behaviour of the separate propagation modes for the 46 kHz band at 10.677 MHz during the sunset period.	164
6.8	Signal multi-path fading behaviour for the 46 kHz band at 10.677 MHz during the sunset period.	165
6.9	Spectrograms showing temporal-spectral multi-path fading behaviour for the 46 kHz band at 10.677 MHz during the sunset period.	165
6.10	Signal fading behaviour of the dominant mode for the 46 kHz band at 10.677 MHz during the post-sunset period.	166
6.11	Signal fading behaviour of the dominant mode for the 44 kHz band at 10.858 MHz during the post-sunset period.	166
6.12	Spectrograms showing temporal-spectral fading behaviour of the dominant mode for the 46 kHz band at 10.677 MHz during the post-sunset period.	167
6.13	Fading separation of the dominant mode for the 46 kHz band at 10.677 MHz during the post-sunset period.	167
6.14	Signal fading behaviour of the separate propagation modes for the 46 kHz band at 10.677 MHz starting at 21:09 LT.	168
6.15	Spectrograms showing temporal-spectral fading behaviour of the separate propagation modes for the 46 kHz band at 10.677 MHz starting at 21:09 LT.	169
6.16	Signal multi-path fading behaviour for the 46 kHz band at 10.677 MHz starting at 21:09 LT.	170
6.17	Spectrograms showing temporal-spectral multi-path fading behaviour for the 46 kHz band at 10.677 MHz starting at 21:09 LT.	170
6.18	Received propagation modes and their relative received time delays for the 90 kHz band at 13.125 MHz at 16:58 LT on 31st March 2005.	173
6.19	Signal fading behaviour of the separate propagation modes for the 90 kHz band at 13.125 MHz at 16:58 LT on 31st March 2005.	174

List of Figures

6.20	Spectrograms showing temporal-spectral fading behaviour of the separate propagation modes for the 90 kHz band at 13.125 MHz at 16:58 LT on 31st March 2005.	175
6.21	Signal multi-path fading behaviour for the 90 kHz band at 13.125 MHz at 16:58 LT on 31st March 2005.	176
6.22	Spectrograms showing temporal-spectral multi-path fading behaviour for the 90 kHz band at 13.125 MHz at 16:58 LT on 31st March 2005.	176
6.23	Received propagation modes and their relative received time delays for the 46 kHz band at 14.951 MHz at 16:58 LT on 31st March 2005.	177
6.24	Signal fading behaviour of the separate propagation modes for the 46 kHz band at 14.951 MHz at 16:58 LT on 31st March 2005, in both vertical and horizontal polarisations.	178
6.25	Spectrograms showing temporal-spectral fading behaviour of the separate propagation modes for the 46 kHz band at 14.951 MHz at 16:58 LT on 31st March 2005.	179
6.26	Received propagation modes and their relative received time delays for the 90 kHz band at 13.125 MHz at 18:18 LT on 31st March 2005.	180
6.27	Signal fading behaviour of the separate propagation modes for the 90 kHz band at 13.125 MHz at 18:18 LT on 31st March 2005.	181
6.28	Spectrograms showing temporal-spectral fading behaviour of the separate propagation modes for the 90 kHz band at 13.125 MHz at 18:18 LT on 31st March 2005.	182
6.29	Signal multi-path fading behaviour for the 90 kHz band at 13.125 MHz at 18:18 LT on 31st March 2005.	183
6.30	Spectrograms showing temporal-spectral multi-path fading behaviour for the 90 kHz band at 13.125 MHz at 18:18 LT on 31st March 2005.	183
6.31	Ionospheric parameters on 30 March 2005.	189
6.32	Ionospheric parameters on 31 March 2005.	189

6.33	Channel scattering function for the 46 kHz band at 10.677 MHz starting at 16:51 LT.	190
6.34	Channel scattering function for the 46 kHz band at 10.677 MHz starting at 18:54 LT.	191
6.35	Channel scattering function for the 46 kHz band at 10.677 MHz starting at 19:34 LT.	192
A.1	Geometry of the ray path of a wave propagating through the ionosphere. .	200
B.1	Signal fading behaviour of the separate propagation modes in the Harts Range to Lake Bennett path for $\Delta N = 10\%$	210
B.2	Polarisation fading behaviour of the 1-hop low-ray propagation mode in the Harts Range to Lake Bennett path for $\Delta N = 10\%$	211
B.3	Spectrogram showing temporal-spectral fading behaviour of the 1-hop low-ray propagation mode in the Harts Range to Lake Bennett path for $\Delta N = 10\%$	212
B.4	Signal fading behaviour of the total combined signal in the Harts Range to Lake Bennett path for $\Delta N = 10\%$	213
B.5	Signal fading behaviour of the separate propagation modes in the Laverton to Lake Bennett path for $\Delta N = 10\%$	215
B.6	Polarisation fading behaviour of the 1-hop low-ray propagation mode in the Laverton to Lake Bennett path for $\Delta N = 10\%$	216
B.7	Spectrograms showing temporal-spectral fading behaviour of the 1-hop low-ray propagation mode in the Laverton to Lake Bennett path for $\Delta N = 10\%$.	217
B.8	Signal fading behaviour of the total combined signal in the Laverton to Lake Bennett path for $\Delta N = 10\%$	218
C.1	Normalised elliptic-function low-pass filter response.	220
C.2	Minimum elliptic-function filter order for the required attenuation.	222
C.3	Prototype 11 th order Elliptic low-pass filter.	222

List of Figures

E.1	Antenna equivalent circuit.	228
E.2	Calculation of component values based on the optimisation algorithm.	229
E.3	Antenna simulation circuit as simulated in ADS.	230
E.4	Simulation results for the antenna simulation circuit over the frequency band of 5 to 20 MHz.	230
E.5	Simulated S11 result of the antenna simulation circuit over the frequency of 5 to 20 MHz.	231
E.6	Test S11 result of the antenna simulation circuit over the frequency of 5 to 20 MHz.	232
F.1	Received propagation modes and their relative received time delays for the 44 kHz band at 10.858 MHz at 16:51 local time on 30 March 2005.	233
F.2	Signal fading behaviour of the separate propagation modes for the 44 kHz band at 10.858 MHz during the late afternoon period.	234
F.3	Spectrograms showing temporal-spectral fading behaviour of the separate propagation modes for the 44 kHz band at 10.858 MHz during the late afternoon period.	235
F.4	Signal multipath fading behaviour for the 44 kHz band at 10.858 MHz during the late afternoon period.	236
F.5	Spectrograms showing temporal-spectral multipath fading behaviour for the 44 kHz band at 10.858 MHz during the late afternoon period.	236
F.6	Received propagation modes and their relative received time delays for the 44 kHz band at 10.858 MHz at 16:51 local time on 30 March 2005.	237
F.7	Signal fading behaviour of the separate propagation modes for the 46 kHz band at 10.677 MHz during the sunset period.	238
F.8	Spectrograms showing temporal-spectral fading behaviour of the separate propagation modes for the 46 kHz band at 10.677 MHz during the sunset period.	239

F.9	Signal multipath fading behaviour for the 46 kHz band at 10.677 MHz during the sunset period.	240
F.10	Spectrograms showing temporal-spectral multipath fading behaviour for the 46 kHz band at 10.677 MHz during the sunset period.	240
F.11	Received propagation modes and their relative received time delays for the 46 kHz band at 14.951 MHz at 18:18 local time on 31st March 2005.	241
F.12	Signal fading behaviour of the separate propagation modes for the 46 kHz band at 14.951 MHz at 18:18 local time on 31st March 2005.	242
F.13	Spectrograms showing temporal-spectral fading behaviour of the separate propagation modes for the 90 kHz band at 13.125 MHz at 18:18 local time on 31st March 2005.	243
F.14	Signal multipath fading behaviour for the 90 kHz band at 13.125 MHz at 18:18 local time on 31st March 2005.	244
F.15	Spectrograms showing temporal-spectral multipath fading behaviour for the 90 kHz band at 13.125 MHz at 18:18 local time on 31st March 2005.	244

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List of Tables

3.1	Summary of the fading period for all propagation modes.	76
3.2	Summary of the fading bandwidth for all propagation modes.	77
4.1	Radiation resistance and antenna reactance of the short dipole at various frequencies.	92
4.2	Stopband resonances for normalised and actual 11 th -order Elliptic filter. . .	97
4.3	Full specifications of the ADC motherboard and DDC daughter card. . . .	104
4.4	Summary of the average noise floor recorded for all 100 kHz channels during the day-time field tests.	130
4.5	Summary of the average noise floor recorded for all 100 kHz channels during the night-time field tests.	130
5.1	Centre frequencies and bandwidths of the linear FMCW signals that were transmitted during the 3-day experimental campaign.	138
6.1	STFT data processing parameters used for the generation of fading data of different propagation modes.	153
6.2	STFT data processing parameters used for the generation of fading data of multi-path propagation.	153
6.3	Mode separation and multi-path STFT data processing time and frequency resolutions for a number of input data source.	153
C.1	Design parameters for the elliptic low-pass filter.	220

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List of Abbreviations

ADC	Analog-to-Digital Converter
AFM	Amplitude Fading Model
AM	Amplitude-Modulated
CCP	Compact Channel Probe
CIC	Cascaded Integrator-Comb
CPR	Cross-Polarisation Ratio
DAM	Data Analysis Module
DDC	Digital Down-Converter
DRM	Digital Radio Mondiale
DSP	Digital Signal Processor
DSTO	Defence Science and Technology Organisation
EM	Electro-Magnetic
FIR	Finite Impulse Response
FMCW	Frequency-Modulated Continuous-Wave
FMS	Frequency Management System
FT	Fourier Transform
GO	Geometric Optics
GUI	Graphical User Interface
HF	High-Frequency
HFSS	High-Frequency Structure Simulator
IPS	Ionospheric Propagation Simulator
IRI	International Reference Ionosphere
JFAS	Jindalee Facility Alice Springs
JORN	Jindalee Operational Radar Network
LT	Local Time

List of Abbreviations

MIMO	Multiple-Input Multiple-Output
MUF	Maximum Usable Frequency
O	Ordinary
OTHR	Over-The-Horizon Radar
PFM	Polarisation Fading Model
RTE	Ray Tracing Engine
SNR	Signal-to-Noise Ratio
SSN	Sunspot Number
STFT	Short-Time Fourier Transform
TID	Travelling Ionospheric Disturbance
WRF	Waveform Repetition Frequency
WWM	World Magnetic Model
X	Extraordinary