

Contents

Abbreviations and symbols	V
List of Figures	IX
List of Tables	XIII
1 Introduction	1
1.1 Motivation	1
1.2 State of the art	2
1.3 Approach	3
2 Generation and measurement of arbitrary light fields for multimode fibre applications	7
2.1 Maxwell's classical electromagnetism and the derivation of the wave equation	7
2.2 Optical Fibres	9
2.3 Generating tailored light fields using adaptive optics and computer-generated holograms	13
2.3.1 Computer-generated holograms for complex wavefront shaping	14
2.3.2 Performance of computer-generated hologram algorithms on spatial frequency variation	16
2.3.3 Comparative analysis on simulation results	18
2.3.4 Experimental implementation of superpixel	20
2.4 Complex field measurement for mode decomposition	24
2.4.1 Light field measurement using off-axis digital holography . . .	27
2.4.1.1 Digital hologram acquisition	28
2.4.1.2 Digital hologram reconstruction using the angular spectrum approach	30
2.4.2 Mode decomposition using artificial neural networks and deep learning	32
2.4.2.1 Neural network architectures for mode decomposition	34
2.4.2.2 Generation of training data and training procedure .	41
2.4.3 Comparing analysis on mode decomposition performance . . .	47
2.5 Discussion and conclusion	51

3	Transmission matrix measurement of multimode fibres	57
3.1	The optical transmission matrix	57
3.2	Optical setup	61
3.3	Measurement of the optical transmission matrix	63
3.3.1	Search algorithm for assignment of the fibre facet area	64
3.3.2	Drift correction	66
3.3.3	Measurement results on MMFs with different lengths	68
3.3.4	Transmission matrix measurement of long multi-mode fibres using an adaptive pinhole	70
3.4	Discussion and conclusion	73
4	Unscrambling modal crosstalk for secure data transmission in multimode fibres	79
4.1	Controlling light propagation through multimode fibre using optical precoding	79
4.2	Transmission matrix inversion using Tikhonov regularisation	82
4.3	Channel diagonalisation using singular value decomposition	84
4.4	Achievable selectivity using SVD diagonalisation	87
4.5	Discussion and conclusion	90
5	Implementation of physical layer security in multimode fibres	93
5.1	Realisation aspects of physical layer security in multimode fibres	93
5.2	Communication model for physical layer security in multimode fibres . . .	95
5.3	Exploiting channel asymmetries using transmitter-side optical precoding and artificial noise	98
5.4	Experimental demonstration of secure data streams	102
5.5	Implementation of wiretap codes and secrecy analysis	104
5.6	Discussion and conclusion	108
6	Conclusion	113
6.1	Summary	113
6.2	Future work and concluding remarks	116
A	Derivation of mode fields in multi-mode fibres	121
A.1	Wave equation solved for step-index fibres	121
A.2	Wave equation solved for parabolic gradient index fibres	124
B	Implementation of selected computer-generated hologram algorithms	129
B.1	Double constraint Gerchberg-Saxton	130
B.2	Direct search	131
B.3	Superpixel	133
B.4	Phase encoding	134

C Alignment techniques	139
D 3D illustration of the optical setup	143
Bibliography	145
List of publications	