

SMART ANTENNA DESIGN TECHNIQUES FOR ULTRA-WIDEBAND COMMUNICATIONS

by

V. V. MANI

Department Of Electrical Engineering

Submitted in fulfillment of the requirements
for the degree of Doctor of Philosophy

to the

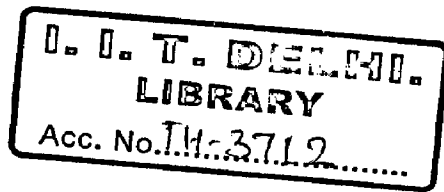


INDIAN INSTITUTE OF TECHNOLOGY, DELHI

HAUZ KHAS, NEW DELHI-110016, INDIA

AUGUST 2008

ra - Design and construction



TH

621.396.67

MAN-S

Certificate

This is to certify that the thesis titled “**Smart Antenna Design Techniques for Ultra-Wideband Communications**” being submitted by **Mrs. V. V. Mani** for the award of Doctor of Philosophy is a record of bona-fide work carried out by her under my guidance and supervision at the Department of Electrical Engineering, Indian Institute of Technology, Delhi. The work presented in this thesis has not been submitted elsewhere either in part or full, for the award of any other degree or diploma.



Dr. Ranjan Bose

Professor

Department of Electrical Engineering

Indian Institute of Technology

New Delhi - 110 016

Acknowledgements

This work has been made possible by the generous support from many people. First of all, I would like to express my thanks to the Lord for providing me with the spiritual support to complete this project. I am greatly thankful to my advisor **Prof. Ranjan Bose** for his invaluable advice, encouragement, and financial support throughout my doctoral studies. His insight, kindness, and genuine concern for his students made working with him a memorable experience. His profound technical insight and vision has helped to give the proper shape to this dissertation.

I am very grateful to my committee members Prof. Devi Chadha, Dr. Ananjan Basu, Dr. Shankar Prakriya for their help and suggestions. I thank Dr. Monica Aggarwal for her support in understanding the literature of the wideband beamforming. I acknowledge the help and support of Ravindra who helped me in the early stage by valuable discussions on a variety of technical issues with regard to my research.

I acquired tremendous knowledge in the course work I undertook and would like to thank all faculty members of IIT Delhi. I am thankful to staff members of Electrical Engineering department and Bharti School for their cooperation in resolving the problems faced during the day-to-day work. My heartfelt thanks are for my father V.A.Naidu, my mother V.K.Veni, my husband Bhaskar, brothers DR.Ramana and Ramesh. My sincere thanks to my sons Dhiran and Tarun who cooperated me through all these years to reach my goals.

New Delhi



V. V. Mani

Abstract

Ultra-wideband (UWB) technology, based on transmission of short duration pulses, has gained much interest for its application to wireless communications. Because of the extremely large bandwidth, UWB is currently considered as a physical layer solution for high data rate, short range wireless networks. However, high user density, multipath fading and interference lead to serious issues, resulting in the degradation of bit error rates (BER). To combat these problems and to achieve higher capacity, smart antenna systems with adaptive beamforming capability are very effective.

In this thesis, we have studied the feasibility of using smart antennas at the receiver for UWB communication. We present several novel ways of looking at the problem of UWB Direction of Arrival estimation (DOA) and beamforming via Uniform Linear Array (ULA).

We begin with the preliminary study of UWB communication system and the performance of Rake-Receivers of DS-UWB for the different IEEE channel models. We next examine the problem of UWB impulse beamforming using smart antennas, when the desired signal and several interferences from different directions are received by the antenna array. The proposed UWB smart antenna points its main beam towards presteered direction of the array and suppresses interference and noise coming from other than the look direction of the array. We also analyze the signal to interference noise ratio (SINR) of the array for different interference directions.

We, next look at the problem of the estimation of DOA's of multiple superimposed UWB signals with multipath arrivals in additive white gaussian noise when arrived at ULA. In order to generalize narrowband DOA algorithms to UWB, signals are first decomposed into narrowband signals by using discrete Fourier transform. Then this spatial- temporal data at the output of a ULA is formulated to obtain the exact expression for the Maximum Likelihood (ML) criteria in terms of the prediction polynomial. This polynomial has embedded DOA information. Methods like Iterative Quadratic Maximum Likelihood (IQML) and its modification are suitably applied for obtaining

the coefficients of this polynomial. Rooting of this polynomial yields DOA estimates of coherent UWB signals. Performance of the proposed method is evaluated via computer simulations.

In the remainder of the work we look at the optimum beamforming for the coherent UWB signals. It is shown that ULA space-time data provides an appropriate framework for formulating three different types of optimum beamformers for the UWB sources viz., the optimum combiner beamformer, the optimum notch or null steering beamformer, and the optimum interference-plus-noise rejector beamformer, all based on IQML estimation of the generating polynomial. Simulation results shows that they are able to handle correlated sources and interferences, without the need for pre-processing techniques like spatial smoothing.

Contents

Acknowledgements	v
Abstract	vii
Contents	ix
List of Figures	xiii
List of Tables	xvii
List of Abbreviations	xix
1 Introduction	1
1.1 Overview of Ultra-Wideband Communication	1
1.2 UWB Channel Model	2
1.3 UWB Transceiver	4
1.3.1 Single-band vs. Multi-band UWB	4
1.3.2 Gaussian Pulse	5
1.3.3 Modulation Schemes	6
1.3.4 UWB Receivers	7
1.4 Overview of Smart Antenna Systems	8
1.5 Smart Antenna for Beamforming of UWB signals	9
1.5.1 Time-domain Beamforming	12
1.5.2 Frequency-domain Beamforming	13
1.6 Genetic Algorithm for Smart Antenna Design	14

1.7	Direction of Arrival (DOA) estimation of UWB Signals	14
1.7.1	Narrowband DOA Estimation	16
1.7.2	Wideband DOA Estimation	19
1.8	Problem Definition and Scope of the Thesis	21
1.9	Organization of the Thesis	24
2	Receivers for UWB Communications	27
2.1	Introduction	27
2.2	System Model	28
2.2.1	Transmit Signal	28
2.2.2	Channel Model	29
2.2.3	Received Signal	30
2.3	Channel Estimation	31
2.4	Weight Estimation	33
2.5	Simulation Results	34
2.6	Conclusions	39
3	Smart Antenna Design for UWB Beamforming	41
3.1	Introduction	41
3.2	UWB Signal Model	42
3.3	Smart Antenna Architecture	42
3.4	Optimal Weights Using Genetic Algorithm	47
3.4.1	Chromosome Representation	48
3.4.2	Fitness Function Definition	49
3.4.3	Genetic Operators	49
3.5	Simulation Results	51
3.6	Conclusions	57
4	SINR analysis of Smart Antenna for UWB communications	59
4.1	Introduction	59
4.2	UWB Smart Antenna Architecture	60
4.3	UWB Smart Antenna SINR Analysis	64

4.4	Simulation Results	67
4.5	Conclusions	73
5	DOA Estimation of Coherent UWB Signals	75
5.1	Introduction	75
5.2	UWB Data Model	77
5.3	UWB Direction Finding	78
5.3.1	Time Domain	78
5.3.2	Frequency Domain	79
5.4	The Maximum Likelihood Criterion	81
5.5	UWB ML Estimation Algorithm	85
5.5.1	Some remarks on the Implementation of the constraint set	86
5.6	Simulation Results	87
5.7	Conclusions	90
6	Optimum Beamforming for UWB	93
6.1	Introduction	93
6.2	UWB Smart Antenna Signal Model	95
6.3	Beamformer Optimization Criteria	99
6.3.1	Optimum Combiner	100
6.3.2	Optimum Interference plus Noise Rejector	100
6.3.3	Optimum Interference Notch	101
6.4	Subspace Characterization for Optimum Beamforming for UWB	102
6.5	Optimum Beamforming	105
6.5.1	Optimum Combiner	105
6.5.2	Optimum Interference plus Noise Rejector	106
6.5.3	Optimum Interference Notch	109
6.6	Beamformer Output	110
6.7	Simulation Results	111
6.8	Conclusions	114

7 Conclusion 117

7.1 Introduction 117

7.2 Summary of Results 118

7.3 Directions for Future Work 120

Bibliography 122

Publications 129