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FOUR-DIMENSIONAL Q²PSK MODULATION AND CODING FOR MOBILE DIGITAL COMMUNICATION

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FOUR-DIMENSIONAL Q^2PSK MODULATION AND CODING FOR MOBILE DIGITAL COMMUNICATION

by

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To my wife, Daleen

For all her support and love.
Without her, this study would
not have been possible.

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Phase-Shift Keying, Mobile Digital Communication, Multidimensional Signalling, Synchronisation and Forward Error Correction.

SUMMARY

In this dissertation an indepth research into the design, implementation and evaluation of a digital four-dimensional modem for application to high speed mobile communication on the V/UHF channel has been carried out. The four-dimensional digital signalling employs Quadrature-Quadrature Phase-Shift Keying (Q^2PSK) as modulation scheme, which was claimed to outperform two-dimensional modulation schemes in terms of spectral efficiency. Q^2PSK constitutes a relatively new modulation technique, and for this reason considerations of digital modulation and demodulation, synchronisation and error correction coding for this signalling scheme, are of utmost importance.

A conventional DSP based implementation of a Q^2PSK modulator/demodulator is considered in this thesis. Furthermore, key synchronisation strategies are considered, including new carrier phase and frequency tracking loops. A novel frame synchronisation strategy for Q^2PSK, employing complex correlation sequences, is presented. The excellent bandwidth efficiency of the Q^2PSK signalling strategy and elegant signal structure, facilitates the incorporation of sophisticated forward error correction strategies. For this reason the dissertation introduces new trellis codes for Q^2PSK, including classical, TCM and MTCM, for transmission over both the AWGN and mobile fading channels. Performance evaluations of the developed Q^2PSK digital modem are given from results obtained from computer simulations when operating on the static AWGN channel and mobile Rician or Rayleigh fading channels.

The research work can be summarised as follows:

- Realisation of a digital Q^2PSK mobile communication system simulation test facility, facilitating burst mode communication scenarios;
- Design and implementation of a novel frame synchronisation strategy employing complex correlation sequences, for the Q^2PSK system;
- Design and implementation of a Q^2PSK dual carrier phase and frequency Kalman estimator for carrier phase and frequency tracking;
- Novel application of classical convolutional error correction codes to Q^2PSK. In addition, the derivation of theoretical upper bounds to bit error probability are presented;
- Design and application of trellis codes for transmission over the AWGN channel are presented;
- Design and application of multiple trellis codes for transmission over the Rician fading channel are presented with some new results;
- Not only are the extensive evaluations presented, but the performance bounds derived, are benchmarked against actual simulation curves.

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CONTENTS

GLOSSARY OF ABBREVIATIONS

1D	— One-Dimensional
2D	— Two-Dimensional
4D	— Four-Dimensional
ACI	— Adjacent Channel Interference
AFC	— Automatic Frequency Control
ASK	— Amplitude-Shift Keying
AWGN	— Additive White Gaussian Noise
B-E	— Bandwidth-Efficiency
BEP	— Bit Error Probability
BER	— Bit Error Rate
BPF	— Bandpass Filter
BSC	— Binary Symmetric Channel
CC	— Cross-Correlation
CCI	— Co-Channel Interference
CCRM8	— Convolutional Codes over Ring Modulo-8
CDMA	— Code-Division Multiple-Access
CE-Q^2PSK	— Constant Envelope Q^2PSK
C/N	— Carrier-to-Noise Ratio
CSI	— Channel State Information
DPFKE	— Dual Phase-Frequency Kalman Estimator
DMC	— Discrete Memoryless Channel
DS	— Distance Spectrum
DSP	— Digital Signal Processing
EEP	— Error Event Path
ED	— Euclidean Distance
EKF	— Extended Kalman Filter
EM	— Electromagnetic
E-E	— Energy-Efficiency
FDMA	— Frequency-Division Multiple-Access
FEC	— Forward Error Correction
FH	— Frequency Hopped
FPM	— Frequency Phase Modulation
FIR	— Finite Impulse Response
FSK	— Frequency-Shift Keying
GMSK	— Gauss Minimum-Shift Keying
HT	— Hilbert Transform(er)
IF	— Intermediate Frequency
ISI	— Intersymbol Interference

LCR	— Level Crossing Rate
LMC	— Land Mobile Channel
LMSC	— Land Mobile Satellite Channel
LO	— Local Oscillator
LOS	— Line-of-Sight
LPF	— Lowpass Filter
M-PSK	— M-ary Phase-Shift Keying
MED	— Minimum Euclidean Distance
MFD	— Mean Fade Duration
ML	— Maximum Likelihood
MSE	— Minimum Square Error
MSED	— Minimum Squared Euclidean Distance
MSK	— Minimum Shift-Keying
MTCM	— Multiple Trellis-Coded Modulation
NEP	— Negative Equally Probable
PCS	— Personal Communication Services
PDF	— Probability Density Function
PLL	— Phase-Locked Loop
PSK	— Phase-Shift Keying
PSD	— Power Spectral Density
QASK	— Quadrature Amplitude-Shift Keying
QPSK	— Quadrature Phase-Shift Keying
$\pi/4$-QPSK	— $\pi/4$ Quadrature Phase-Shift Keying
Q^2PSK	— Quadrature-Quadrature Phase-Shift Keying
Q^2PSK/TCM	— Trellis Coded Q^2PSK
Q^2PSK/MTCM	— Multiple-Trellis Coded Q^2PSK
RHS	— Right Hand Side
RI	— Rotational Invariant
RF	— Radio Frequency
SEP	— Symbol Error Probability
SFH	— Slow Frequency Hopping
SKF	— Scalar Kalman Filter
SNR	— Signal-to-Noise Ratio
S/P	— Serial-to-Parallel
TCM	— Trellis-Coded Modulation
TDMA	— Time-Division Multiple-Access
VA	— Viterbi Algorithm
V/UHF	— Very- and Ultra-High Frequency

LIST OF SYMBOLS

C	— Channel capacity
D	— Dimensions per second
d_{free}	— Minimum Euclidean Distance
d^2_{free}	— Minimum Squared Euclidean Distance
η_f	— Bandwidth Efficiency (*bits/s/Hz*)
E_b/N_o	— Ratio of Energy per bit to Noise spectral density
f	— Frequency
f_c	— Carrier frequency (*Hz*)
f_d	— Deviation frequency (*Hz*)
f_D	— Doppler frequency (*Hz*)
f_e	— Frequency error
G_c	— Coding gain
γ_c	— Assymptotic coding gain
h	— Deviation ratio
k	— MTCM multiplicity
K	— Rician factor
L_c	— Constraint length
M	— Number of symbols per signal set
N	— Dimensionality
N_s	— Number of trellis coder states
P_b	— Bit Error Probability
P_s	— Symbol Error Probability
ψ_i	— i-th Orthonormal basis
Q	— Number of quantisation bits
R_b	— Bit Rate (*bits/s*)
R_c	— Code rate (k/n)
R_s	— Symbol Rate (*Symbols/s*)
$s(t)$	— Function of time
$S(f)$	— Function of frequency
t	— Time (*seconds*)
T_b	— Bit Duration (*seconds*)
T_s	— Symbol Duration (*seconds*)
$T(D)$	— Transfer function
θ_e	— Phase error (*radians*)
θ_D	— Doppler angle (*radians*)
θ_o	— Phase offset (*radians*)
W	— Bandwidth (*Hz*)

LIST OF FIGURES

LIST OF TABLES