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UWB

Theory and Applications

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Preface

The work covered in this book has been undertaken at the Centre for Wireless Communication (CWC) at the University of Oulu, Finland. The authors have been involved with ultra-wideband (UWB) projects for several years, which have included fundamental studies as well as design–build–test projects. A substantial number of propagation measurements have been undertaken as well as work developing simulators, antenna components and prototypes.

The book focuses very much on impulse radio UWB techniques rather than multi-band systems. The reasons for this are both practical and historical. The promise of UWB was low complexity, low power and low cost. Impulse radio, being a baseband technology, holds the most promise to achieve these three benefits. The newer multi-band proposals may potentially offer the most spectrally efficient solutions, but they are substantially more complex and it is potentially more difficult to ensure compliance with Federal Communications Commission (FCC) requirements.

The historical reason for the focus on impulse radio techniques is that CWC has been working on UWB devices based on impulse radio techniques since 1999. Much of the work in this book has been performed as part of projects carried out at CWC.

At the time of writing, the European regulatory bodies are still to decide on the spectrum allocation mask for Europe. It is expected to be very similar to the FCC mask, but with more stringent protection for bands below 3.1 GHz. Europe's decision on UWB will have a dramatic impact on the size and shape of the market for UWB devices worldwide. Europe is definitely aware of the historical battles of wireless Local Area Network systems (Hiperlan versus IEEE 802.11) and is seeking a harmonized, global approach to standardization and regulation. The race for UWB consumer devices is moving quickly but is definitely not over yet.

Ian Oppermann
Matti Hämäläinen
Jari Iinatti
Oulu, July 2004

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The work in this book has predominantly been carried out in projects at CWC in the last several years. The contributing projects include FUBS (future UWB systems), IGLU (indoor geo-location solutions), ULTRAWAVES (UWB audio visual entertainment systems) and URFA (UWB RF ASIC). More information about each of these projects may be found on the CWC WWW site http://www.cwc.oulu.fi/home.

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Abbreviations

A	Gain
A_{peak}	Peak amplitude
a_o	first signal component
a	power scaling constant
$a_n^{(t)}$	amplitude gain for n^{th} multipath component
B	Bandwidth
B_e	Bandwidth expansion factor
B_f	Fractional bandwidth
$c_j^{(k)}$	Pseudo random time-hopping code
C	Capacitance, capacitor
C_{gd}	Gate to drain capacitance
C_{gs}	Gate to source capacitance
C_{int}	Integrating capacitor
C_L	Load capacitance
C_{ox}	Gate capacitance
C_n	Node capacitance
$c(t)$, $C(t)$	Spreading code
C_i	Chip (bit of the spreading code)
C_u	number of cells in uncertainty region
D_{opt}	Optimum number of rake branches
D	number of rake fingers
d	distance
d_{o}	reference distance
d_{j}	data bit
E_{w}	Energy
f	Frequency
Δf	Frequency shift
f_c	Centre frequency
f_0	Nominal centre frequency
f_H	Upper frequency
f_i	Carrier frequency
f_L	Lower frequency
f_{max}	Maximum frequency
f_n	Node frequency
f_{PRF}	Pulse repetition frequency

f_T	Transit frequency
g_i	Chip (bit of the spreading code)
g_m	Transconductance, small signal
G_m	Transconductance, large signal
h_{RX}	receiver antenna height
h_{TX}	transmitter antenna height
$h(t)$	Impulse response
i_{dj}	Small signal drain current
i_{out}	Small signal output current
i_{sj}	Small signal source current
I	Current
I_{bias}	Bias current
$I_{D1}, I_{D2}\ldots$	Drain currents of transistor M1, M2...
I_0	The zeroth order modified Bessel function of the first kind
I_{out}	Output current
I_{SS}	Current of tail current source
j	Number of current monocycle
k	User
k	Transconductance parameter
k	k-factor of Ricean faded signal
K	SNR value for Ricean fading channel
L	Number of multipath
L	Length of a MOS transistor, Number of multipath
L_r	Number of rake branches
L_c	number of clusters
M	number of simultaneous users
$M1$, $M2$,..	MOS transistor 1, 2, ...
n	Number of bits, body effect factor, attenuation factor
N	Noise power
NP_{10dB}	Number of paths within 10dB of the peak
NP (85%)	Number of paths capturing 85% of the energy
N_{smp}	Number of sample points
NF	Noise figure
$Nfft$	Length of IFFT
N	Number of pulses per data symbol
N_U	Number of users
P_d	probability of detection
P_{fa}	probability of false alarm
P_d^{ov}	overall probability of detection
P_m^{ov}	overall probability of missing a code
PG_4	Processing gain from the pulse repetition
PG_2	Processing gain due to the low duty cycle
PG	Processing gain
$P_{TX,av}$	Average single pulse power
$P_{TX,fr}$	Average power over time hopping frame
PL	Attenuation factor

r	Distance
r_n	Node resistance
r_{s1}	Source resistance of M1
$r(t)$	Transmitted signal
R	Resistance, data rate
R_S	Symbol rate
$s(k)$	Laplace operator, non-centrality parameter of Ricean distribution function
$s\ (t)$	information signal
S_{tr}	Received waveform
S	Signal power
S_{RX}	Received power spectral density
S_{TX}	Transmitted power spectral density
t	Time
t_{coh}	coherence time
$t^{(k)}$	Clock for user k
t_{tr}	Time of flight
t_{sw}	Sweeping time
ΔT	Time delay used in PPM, modulation index
T_c	Time hopping interval inside a frame (thus, chip length)
T_f	Time hopping frame
T_l^i	Delays of the lth cluster
T_p	Pulse width
T_{PRF}	Pulse repetition interval, length of a time frame
T_s	Symbol time
T_i	time to evaluate a decision variable
T_{acq}	acquisition time
T_{fa}	penalty time
T_h	threshold
T_{MA}	mean acquisition time
T_s	time limit
T_w	time delay between the pulses in doublet
$y(t)$	Received signal
$V(t)$	pulse waveform
$V(f)$	pulse spectrum
V_{in}	Small signal input voltage
V_i^+	Positive single-ended, small signal input voltage
V_i^-	Negative single-ended, small signal input voltage
V	Voltage
V_{bias}	Bias voltage
V_{eff}	Effective gate to source voltage
V_{GS}	Gate to source voltage
V_i	Input voltage
V_{int}	Voltage across integrating capacitor
V_{out}	Output voltage
V_{RF}	RF input voltage
V_T	Threshold voltage of a MOS transistor

V_X	Upper input voltage for Gilbert cell
V_Y	Lower input voltage for Gilbert cell
w_{gi}	i^{th} derivative of the Gaussian pulse
w_{tr}	Transmitted waveform
W	Width of a MOS transistor
X_i	Shadowing effect
α	Exponential decay coefficient
$\alpha_{k,l}^{i}$	Multipath gain coefficients
β	Exponential decay constant
$\delta d_{\lfloor j/N_s \rfloor}^{(k)}$	Early/late data modulation
δ_{opt}	optimal modulation index
δ	modulation index
γ	Ray decay factor
Γ	Cluster decay factor
λ	Ray arrival rate
Λ	Cluster arrival rate
Ω_0	The mean energy of the first path of the first cluster
σ	Standard deviation
σ_1	standard deviation for cluster lognormal fading
σ_2	standard deviation for ray lognormal fading
σ_{Tacq}	Variance of the acquisition time
σ_x	standard deviation for lognormal shadowing
$\tau_{k,l}^{i}$	Delays for the kth multipath component
τ_{max}	Maximum detectable delay
$\tau_n^{(t)}$	excess delay
τ_e	code phase
μ_n	Electron mobility near silicon surface
ω_{ti}	Unity-gain frequency of integrator
ξ_l	Fading term
ξ	signal-to-noise ratio
a.c.	Alternating Current
AC	Absolute Combining
ACF	Autocorrelation Function
ACK	Acknowledgement
ADSL	Asymmetric Digital Subscriber Line
ALT PHY	Alternative Physical
AOA	Angle of arrival
A-rake	all rake receiver
ARQ	Automatic Repeat reQuest
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BiCMOS	Bipolar Complementary Metal-Oxide-Semiconductor process
BJT	Bipolar Junction Transistor
BPAM	Binary Pulse Amplitude Modulation
CAP	Contention Access Period
CLPDI	chip level post detection integration algorithm

CTA	Channel Time Allocation
CTAP	Channel Time Allocation Period
CTS	clear to send
CDMA	Code Division Multiple Access
CEPT	European Conference of Postal and Telecommunications
CIR	Channel Impulse Response
CMOS	Complementary Metal-Oxide-Semiconductor
CFAR	constant false alarm rate
CMF	Code Matched Filter
CSMA/CA	Carrier sense multiple access with collision avoidance
DAB	Digital Audio Broadcasting
DARPA	Defense Advanced Research Projects Agency, USA
DC	Direct Current
DCOP	Direct Current Operation Point
DEV	Device
DM	Deterministic Model
DME	Device Management Entity
DS	Direct Sequence
DSO	Digital Sampling Oscilloscope
DSSS	Direct Sequence Spread Spectrum
DUT	Device Under Test
DVB	Digital Video Broadcasting
EGC	Equal GainCombining
ETSI	European Telecommunications Standards Institute
FCC	US Federal Communications Commission
FAA	Federal Aviation Administration, USA
FCC	Federal Communications Commission, USA
FD	Frequency Domain
FEM	Finite element method
FDTD	Finite difference time domain
FET	Field Effect Transistor
FFT	Fast Fourier Transform
FIR	Finite Impulse Response,
GaAs	Gallium Arsenide
GaN	Gallium Nitride
GaP	Gallium Phosphide
Gm-C	Transconductor-Capacitor
GPR	Ground Penetrating Radar
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HBT	Hetero-junction Bipolar Transistor
HDR	high data rate
HEMT	High Electron Mobility Transistor
IC	Integrated Circuit
IEEE	The Institute of Electrical and Electronics Engineers
IF	Intermediate Frequency

IFFT	Inverse fast Fourier transform
I/H	Integrate and Hold
InP	Indium Phosphide
InSb	Indium Antimonide
IR	Impulse Radio
IRA	Impulse radiating antenna
I-Rake	Ideal rake receiver
ISI	Inter Symbol Interference
ISM	Industrial, Scientific and Medical
ISO	International Standards Organization
ITU	International Telecommunications Union
LDR	Low data rate
LLC	Logical Link Control
LLNL	Lawrence Livermore National Laboratory
LNA	Low Noise Amplifier
LO	Local Oscillator (frequency)
LOS	Line-of-Sight
LPD	Low Probability of Detection
LPDA	Log-periodig dipole array
LPI	Low Probability of Interception
MAC	Medium Access Control
MBT	Modified Bowtie
MC	Multi-Carrier
MCTA	Management Channel Time Allocations
MESFET	Metal Semiconductor Field Effect Transistor
MF	Matched Filter
ML	Maximum Likelihood
MLME	MAC Layer Management Entity
MMIC	Microwave/Millimetre-wave Integrated Circuit
MoM	Methods of moments
MRC	Maximum Ratio Combining
MT	Multi-tone
NLOS	Non-Line-of-Sight
NMOS	N-channel Metal-Oxide-Semiconductor FET
NOI	Notice of Inquiry
OOK	On-off Keying
OSI	Open System Interconnection
PA	Power Amplifier
PAM	Pulse Amplitude Modulation
PCB	Printed circuit board
PE	Power Estimation
PER	Packet Error Rate
PG	Processing Gain
PHY	Physical layer
PLL	Phase Locked Loop
PMOS	P-channel Metal-Oxide-Semiconductor

PN	Pseudo-random Noise
PNC	PicoNet Coordinator
PPM	Pulse Position Modulation
PR	Pseudo Random
P-rake	Partial rake receiver
PRI	Pulse Repetition Interval
PRF	Pulse Repetition Frequency
PSD	Power Spectral Density
PSM	Pulse Shape Modulation
PTD	Programmable Time Delay
PVT	Process, power supply Voltage and Temperature
PPM	Pulse Position Modulation
QoS	Quality of Service
RC	Resistor-Capacitor (circuit)
RF	Radio Frequency
RFIC	Radio Frequency Integrated Circuit
RMS	Root Mean Square
RTS	Request to send
RX	Receiver, Receiver port
S1, S2	Short Pulses 1, 2
SC	Switched Capacitor
S/H	Sample and Hold (circuit)
SIFS	Short Inter-frame spacing
SiGe	Silicon Germanium semiconductor process
SINR	Signal-to-Interference-plus-Noise Ratio
SIR	Signal-to-Interference Ratio
SM	Statistical Model
SNR	Signal-to-Noise Ratio
S-rake	Selective rake receiver
SRD	Step Recovery Diode
SS	Spread Spectrum
SV	Saleh-Valenzuela Channel Model
TD	Time Domain
TDMA	Time division multiple access
TDOA	Time difference of arrival
TH	Time-Hopping
TH-PPM	Time-Hopping Pulse Position Modulation
TM	Time Modulated
TOA	Time of Arrival
TR	Transistor
TSA	Tapered slot antenna
TX	Transmitter, Transmitter port
UMTS	Universal Mobile Telecommunications System
UMB	Ultra-WideBand
UWBWG	Ultra-Wideband Working Group
VCO	Voltage Controlled Oscillator

VHF	Very high frequency
VNA	Vector Network Analyser
VSWR	Voltage standing wave ratio
WLAN	Wireless Local area network
WO	Worst case One
WP	Worst case Power
WPAN	Wireless Personal Area Networks
WS	Worst case Speed
WZ	Worst case Zero

Contents