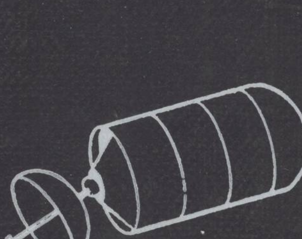
DIGITAL SATELLITE COMMUNICATIONS

TRI T. HA



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To Minh-Hien

for love and support

in difficult times

Preface

This book addresses the fundamental principles of satellite communications. Although most materials deal with digital systems, analog systems are also treated in detail. The book is written at a level suitable for use by seniors and first-year graduate students in electrical engineering. Examples are used throughout the text to help students develop a good understanding of the subject. Because the material in each chapter is independent or nearly independent of each other, the book provides full flexibility for the instructor. For a senior course I suggest Chapters 1–5 (one quarter) or Chapters 1–6 with selected materials in Chapter 7 (one semester). For a first-year graduate course, Chapters 6–9 are appropriate for one quarter, and Chapters 6–11 for one semester. The end-of-chapter problems are an important and integral part of the book. They are intended not only to help students test their comprehension of the subject but also to extend the discussion sometimes made brief because of the page constraint. A list of symbols and a list of acronyms are provided to make reading more pleasant.

Because satellite technology is a big picture, it is impossible to cover all topics in a book of this length. Therefore, I have focused only on fundamental principles, and I have tried to keep the mathematics to a minimum level. Advanced concepts of satellite communications are referred to in appropriate references. I hope that this book on satellite communications will serve students and satellite engineers well.

It would not have been possible for me to complete this book without the direct and indirect help of many persons, whom I wish to acknowledge. Professor D. B. Hodge (EE Department Head) provided a light teaching load in my first year at VPI&SU. Professor C. W. Bostian (Clayton Ayre Professor and Head of Satellite Communication Group) has given me the opportunity to work in satellite projects. Professor S. Haykin (McMaster University) and Professor L. Couch II (University of Florida) reviewed the book and offered many valuable comments. T. Battle, A. Bennani, N. Miles, and W. Wattaul provided supporting materials; Tuan Ha helped on TDMA. I also wish to thank Professor R. W. Newcomb for being an academic mentor during my graduate career at the University of Maryland. Finally, I wish to thank my wife Hien, to whom this book is dedicated, for typing and retyping the manuscript. Her support and encouragement during the past three years made this project possible.

List of Acronyms

ACU:	antenna control unit
ARFA:	assisted receive frame acquisition
AWGN:	additive white Gaussian noise
BPF:	bandpass filter
CCIR:	International Radio Consultative Committee
CCITT:	International Telegraph and Telephone Consultative Committee
CCR:	carrier and clock recovery
CDMA:	code division multiple access
CONUS:	Continental United States
CSC:	common signaling channel
DA-FDMA:	demand assignment–frequency division multiple access
DA-TDMA:	demand assignment–time division multiple access
DAMA:	demand assignment multiple access
DAU:	data acquisition unit
DBS:	direct broadcasting satellite
DC:	downconverter
DS:	direct sequence
DS-CDMA:	direct sequence–code division multiple access
DSI:	digital speech interpolation
EIRP:	effective isotropic radiated power

EQL: equalizer
FCC: Federal Communication Commission
FDM: frequency division multiplexing
FDMA: frequency division multiple access
FH: frequency hop
FH-CDMA: frequency hop–code division multiple access
FM: frequency modulation
FSK: frequency-shift keying
HPA: high-power amplifier
IF: intermediate frequency
INTELSAT: International Telecommunications Satellite Organization
ITU: International Telecommunication Union
LNA: low-noise amplifier
LO: local oscillator
LPF: low-pass filter
M&C: monitoring and control
M-ary FSK: *M*-ary frequency-shift keying
M-ary PSK: *M*-ary phase-shift keying
MSK: minimum shift keying
MTTF: mean time to failure
MTTR: mean time to repair
NCC: network control center
OMT: orthogonal mode transducer
OQPSK: off-set quaternary phase shift keying
PCM: pulse code modulation
PLL: phase-locked loop
PN: pseudo-noise
PRB: primary reference burst
PRS: primary reference station
PSK: phase-shift keying
QPSK: quaternary phase-shift keying
RBT: receive burst timing
RF: radio frequency
RFA: receive frame acquisition
RFS: receive frame synchronization
RFT: receive frame timing
SB: short burst
SCPB: single channel per burst
SCPB-DAMA: single channel per burst–demand assignment multiple access
SCPC: single channel per carrier
SCPC-DAMA: single channel per carrier–demand assignment multiple access

SRB:	secondary reference burst
SRS:	secondary reference station
SS-TDMA:	satellite-switched TDMA
SSB:	superframe short burst
SSB:	single sideband
SSB-AM-FDMA:	single sideband-amplitude modulation-frequency division multiple access
TA:	transmit acquisition
TB:	traffic burst
TBT:	transmit burst timing
TDM:	time division multiplexing
TDMA:	time division multiple access
TFA:	transmit frame acquisition
TFS:	transmit frame synchronization
TFT:	transmit frame timing
TIM:	terrestrial interface module
TRT:	timing and reference transponder
TS:	transmit synchronization
TV:	television
TWTA:	traveling wave tube amplifier
UC:	upconverter
VCO:	voltage-controlled oscillator
WARC:	World Administrative Radio Conference

List of Symbols

a:	orbital radius (42,164.2 km), traffic intensity
A:	amplitude, area, azimuth angle
$b(t)$:	baseband signal
B:	bandwidth
$B(n,a)$:	blocking probability
B_3:	3-dB bandwidth
B_{rms}:	rms bandwidth (10.95)
BO_{i}:	input back-off
BO_{o}:	output back-off
c:	light velocity (2.997925×10^5 km/s)
C:	carrier power
$\mathscr{C}$:	channel capacity
d:	Hamming distance
d_{d}:	downlink slant range
d_N:	distance from satellite to station N
d_{u}:	uplink slant range
D:	antenna diameter
D_N:	transmit frame delay
E:	elevation angle
E_{b}:	energy per bit
E_{c}:	energy per coded bit
E_{s}:	energy per symbol

$E\{x\}$:	expected value of x
Erfc(x):	complementary error function (9.31)
f:	frequency
F:	force, noise figure
g:	gravitational constant, rectangular pulse
G:	antenna gain, channel traffic
$h(t)$:	impulse response
H:	orbital altitude (35786.045 km), transfer function
i:	inclination angle
I:	interference power
$I_n(x)$:	modified Bessel function of order n of the first kind
j:	imaginary number, summation index, product index
J:	jamming power
J_0:	jamming density
$J_n(x)$:	Bessel function of order n of the first kind
k:	Boltzmann constant (1.38×10^{-23} J/K), information block length in a codeword, number of users in DS-CDMA
K:	degree Kelvin, randomized interval
ln:	natural logarithm
log:	logarithm of base 10
$\log_2$:	logarithm of base 2
L:	length, power loss
L_a:	atmospheric attenuation
L_d:	downlink free-space attenuation
L_r:	rain attenuation
L_u:	uplink free space attenuation
m:	mass
M:	$M = 2^k$ in M-ary signaling
n:	length of a code word
N:	noise power, processing gain
$\mathcal{N}$:	effective noise power
$N_0/2$:	noise power spectral density
$\mathcal{N}_0/2$:	effective noise power spectral density
p:	transition probability
$p(x)$:	probability density function of x
P:	power
P_A:	availability probability
P_b:	probability of bit error
P_d:	detection probability
P_F:	false alarm probability
P_s:	probability of symbol error
$\Pr\{x\}$:	probability of x
q:	successful probability of a packet
$Q(x)$:	Gaussian integral (9.29)

r: distance
R: reliability, resistance, channel capacity
R_b: bit rate
R_e: earth radius (6378.155 km)
R_p: chip rate
R_s: symbol rate
$s(t)$: signal
S: channel throughput
$S(f)$: power spectral density
t: error-correcting capability, time
T: noise temperature
T_b: bit duration
T_0: ambient temperature (290 K)
T_e: equivalent noise temperature
T_f: frame length
T_R: satellite propagation delay
T_s: symbol duration, system noise temperature
$u(t)$: unit step function
v: true anomaly
V: orbital velocity, voltage
W: aperture window
X: cross-polarization discrimination, x coordinate
$y(t)$: envelope of a burst
Y: y coordinate
z: a random variable
Z: z coordinate
α: coupling coefficient
β: coupling coefficient
β_{max}: maximum root mean square of partial cross-correlations
γ: partial cross-correlation
Γ: reflection coefficient
δ: duty cycle
ΔA: differential attenuation
$\Delta\psi$: differential phase
ϵ: rms surface error of antenna, threshold of unique word detection
η: antenna efficiency
θ: carrier phase, antenna off-axis angle
θ_l: earth station latitude
θ_L: earth station longitude
λ: wavelength, a constant in Chernoff bound, latitude, arrival rate
μ: mean value, mean hang-up rate
π: 3.1416

ρ:	failure rate, traffic intensity
$\rho(\tau)$:	autocorrelation
ρ_{nm}:	cross-correlation
σ^2:	variance
τ:	time delay
ϕ:	carrier phase
ω:	angular frequency
Ω:	carrier power flux density
Ω_{sat}:	saturation carrier flux density
x^*:	conjugate of x
$\lvert x \rvert$:	absolute value of x
$\overline{f(t)}$:	time average of $f(t)$
$f(t) \circledast g(t)$:	convolution of $f(t)$ and $g(t)$
$\mathrm{Re}(x)$:	real part of x

Contents