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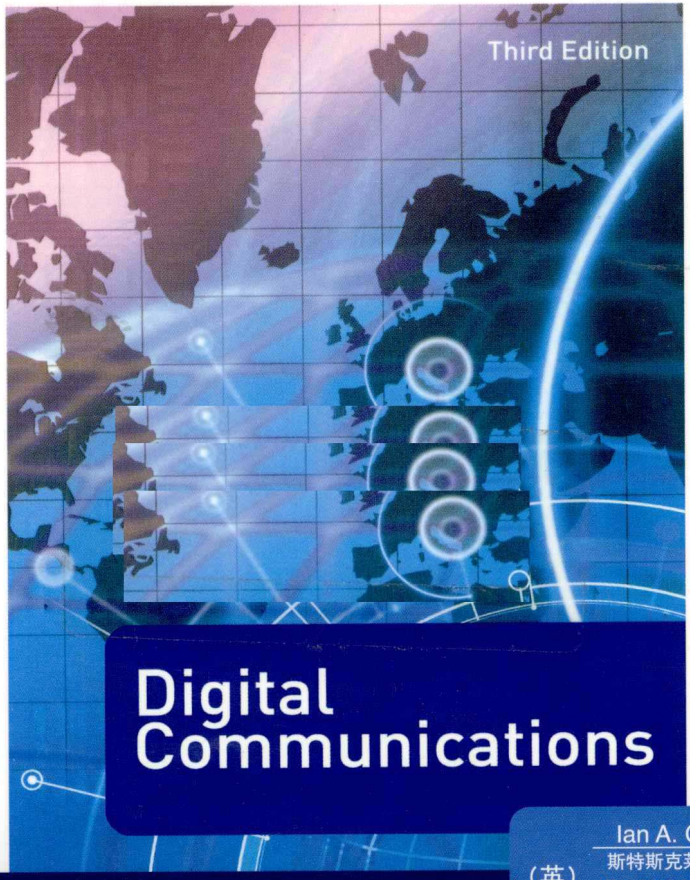


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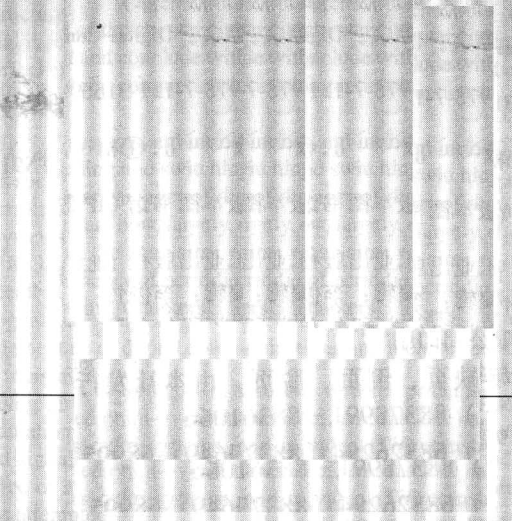
# 数字通信

（英文版 · 第3版）

# Digital Communications

(Third Edition)



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# Preface

Digital communications is a rapidly advancing applications area. Significant current activities are in the development of mobile communications equipment for personal use, in the expansion of the available bandwidth (and hence information carrying capacity) of the backbone transmission structure through developments in optical fibre, and in the ubiquitous use of networks for data communications.

The aim of this book is fourfold: (1) to present the mathematical theory of signals and systems as required to understand modern digital communications equipment and techniques, (2) to apply and extend these concepts to information transmission links which are robust in the presence of noise and other impairment mechanisms, (3) to show how such transmission links are used in fixed and mobile data communication systems for voice and video transmission, and (4) to introduce the operating principles of modern communications networks formed by the interconnection of many transmission links using a variety of topological structures.

The material is set in an appropriate historical context. Most of the chapters include substantive numerical examples to illustrate the material developed and conclude with problem questions which have been designed to help readers assess their comprehension of this material.

In Chapter 1, we summarise the history of communication systems and introduce some basic concepts such as accessing, modulation, multiplexing, coding and switching, for line and radio transmission. Chapter 1 also includes a review of the advantages of digital communications systems over the older analogue systems which they are now, largely, replacing.

The next 18 chapters are organised in four parts reflecting the four aims referred to above. Specifically Chapters 2 through 4 are devoted to a basic theory of periodic, transient and random signals and the concept of linear transmission systems. Chapters 5 through 13 cover the fundamentals of digital communications and include sampling and multiplexing, baseband line transmission, decision and information theory, cryptography and error control coding, including turbo coding. This second part also includes a description of the many bandpass modulation schemes used in modern systems, the calculation of received power and associated signal-to-noise ratio for a communications link, and an indication of how the performance of a system can be assessed by simulation, before any actual hardware construction is attempted.

Part Three, Chapters 14 through 16, describes how the principles of digital communications are applied in fixed point-to-point terrestrial, and satellite based, microwave systems, in mobile and cellular radio systems, and in video (TV) transmission and storage systems. The fourth part, Chapters 17 through 21, is devoted to communication networks. This starts with a discussion of network topologies, access techniques and their signalling and

routing protocols and architectures before moving on to queueing theory. It then progresses naturally to public networks, SDH and ISDN, the internationally agreed standard for the worldwide digital telecommunications network, before finally concluding with broadcast networks, both wired and wireless local area networks. This completely revised and extended networks section in the second edition introduces the reader to a range of rapidly evolving wireless networking techniques.

To assist the reader, the book includes a list of abbreviations and also a list of notations and conventions used for the mathematical material.

An extensive reference list including key WWW addresses, standards and a bibliography is provided at the end of the book, before the index. All publications referred to in the text are compiled in this list. Each reference is identified in the text by the name(s) of the author(s) and, where necessary, the year of publication in square brackets.

The book is aimed at readers who are completing a graduate level BEng/MEng degree, or starting a postgraduate level MSc degree in Communications, Electronics or Electrical Engineering. It is assumed that these readers will have competence in the mathematical concepts required to handle comfortably the material in Part One.

The book has been compiled from lecture notes associated with final year BEng/MEng/MSc core, and optional, courses in signal theory and digital communications as provided at the Universities of Bath, Bradford and Edinburgh from 1990 to date. We have deliberately extended our coverage, however, to include some practical aspects of the implementation of digital PCM, SDH, packet speech systems, and the capability of optical and microwave long haul communication systems. With this balance between theory, applications and systems implementation we hope that this text will be useful both in academia and in the rapidly growing communications industry.

To aid the instructor and the student we provide a current erratum plus outline solutions to the majority of the end of chapter problems on the World Wide Web at the Edinburgh server address: http://www.see.ed.ac.uk/~pmg/DIGICOMMS/index.html or via the Pearson Education website at www.pearsoned.co.uk/glover.

In addition, we have some further software examples in the areas of filtering, transforms and adaptive processors which are available via the above server address.

Ian Glover and Peter Grant

# Author's acknowledgements

## First edition

Parts of this book have been developed from BEng, MEng and MSc courses provided at the Universities of Edinburgh and Bradford. Three of these courses were first taught by Dr James Dripps at Edinburgh, and Professor Peter Watson and Dr Neil McEwan at Bradford, and we acknowlegde their initial shaping of these courses, which is reflected in the book's content and structure. We are grateful to Dr Dripps for having provided draft versions of Chapters 7 and 9 and also for giving us access to material which now forms parts of Chapters 6, 10, 17 and 18. We are grateful to Dr McEwan for providing the original versions of sections 2.5.1, 4.3.1, 4.3.2 and 4.3.3 in the form of his teaching notes. Some of the material in Chapters 2, 3, 4, 8 and 11 had its origins in notes taken during lectures delivered at Bradford by Professor Watson and Dr McEwan. We also acknowledge Dr Brian Flynn for assistance with parts of Chapter 19, Dr Angus McLachlan for providing initial thoughts on Chapter 12, Dr Tom Crawford (of Hewlett Packard, Telecomms Division, South Queensferry) for giving us access to further material for Chapter 19 and providing some initial insights into Chapter 6. We are grateful to Dr David Parish of Loughborough University of Technology, for providing an initial draft of Chapter 16, Professor Paddy Farrell (of Victoria University, Manchester) for helpful comments on Chapter 10 and Dr David Cruickshank at Edinburgh for assistance with the problem solutions which are provided on the WWW.

We would like to thank all those colleagues at the Universities of Bradford and Edinburgh who have provided detailed comments on sections of this text. Thanks must also go to the many students who have read and commented on earlier versions of this material, helped to refine the end of chapter problems and particularly Yoo-Sok Saw and Paul Antoszczyszn who generously provided figure material for Chapter 16.

Special thanks are due to Joan Burton, Liz Paterson, Diane Armstrong and Beverley Thomas for their perseverance over several years in typing the many versions of the individual chapters, as they have evolved from initial thoughts into their current form. We also acknowledge Bruce Hassall's generous assistance with the preparation of the final version of the text in the appropriate typefont and text format.

Finally we must thank our respective families, Nandini and Sonia, and Marjory, Lindsay and Jenny for the considerable time that we required to write this book.

Ian Glover and Peter Grant, 1998

## Second edition

This second edition has been further developed from BEng, MEng and MSc courses provided at the Universities of Edinburgh, Bath and Bradford. We acknowledge Professor Keith Blow from the University of Birmingham for updates to Chapter 12, Professor Mike Woodward of Bradford University for preparing the revised Chapter 17 (now Chapter 19), Professor Simon Shepherd also of Bradford University for reading and commenting on the new material on encryption in Chapter 9, Dr Robert Watson at Bath for preparing the new section in Chapter 10 on turbo coding and the Bluetooth section in Chapter 21, the generous assistance of both John Martin and Steve Pennock, also from Bath, for providing access to all their material on networks for enhancing Part Four of this revised text, and Dr David Cruickshank at Edinburgh for continued assistance with the problem solutions which are provided on the WWW.

We would like to thank all those colleagues at the Universities of Bath and Edinburgh who have again provided detailed comments on sections of this text. Thanks must also go to the many students who continue to read, comment and suggest improvements to the chapter contents and also the solutions to the problem questions. Thanks are also due to the many instructors worldwide who have emailed us with positive comments and suggestions.

Special thanks are due to Diane Armstrong, Caroline Saunders and Kim Orsi for their perseverance in typing the revised chapters and tables. We also acknowledge again Bruce Hassall, the IT Services Manager in the School of Engineering and Electronics at the University of Edinburgh and his staff, in particularly Michael Gordon, for their generous assistance with the typsetting, formatting, and figure editing to achieve the professional layout of the final text.

Finally, we must thank our respective families, Nandini and Sonia, and Marjory for our time spent writing and revising this book.

Ian Glover and Peter Grant, 2003

## Third edition

This third edition has been further developed to reflect recent advances in the five years since we prepared the second edition to ensure that the text remains current and up to date. We have thus extended particularly Chapter 21 on networks to include MIMO and UWB as well as increasing the coverage of FDDI and DQDB networks.

This edition is dedicated to Nandini (1952–2007).

Ian Glover and Peter Grant, 2009

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## Figures

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# Abbreviations

| | |
|---|---|
| 2G | Second generation |
| 3G | Third generation |
| AAL | ATM adaption layer |
| ABM | Asynchronous balanced mode |
| ABR | Available bit rate |
| AC | Alternating current (i.e. sinusoidal signal), access control, area code |
| ACF | Autocorrelation function, access control field |
| ACK | Acknowledgement |
| ACL | Asynchronous connectionless |
| ACSE | Association control service element |
| A/D or ADC | Analogue to digital converter |
| ADCCP | Advanced data communications control procedure |
| ADM | Add and drop multiplexer, adaptive delta modulation |
| ADPCM | Adaptive differential pulse code modulation |
| ADSL | Asymmetric digital subscriber line (transmissions) |
| AFI | Authority and format identifier |
| AGC | Automatic gain control |
| AI | Adaption interface |
| AIA | Active interference avoidance |
| AK-TPDU | Acknowledgement TPDU |
| ALOHA | (not an abbreviation but Hawaiian for 'hello') |
| AM | Amplitude modulation |
| AMI | Alternate mark inversion |
| AMPS | Advanced mobile phone system (USA) |
| AN | Access network |
| ANS | Abstract syntax notation |
| ANSI | American National Standards Institute |
| AOA | Angle of arrival |
| AP | Access point |
| APCO | (US) associated public safety comminications office |
| APD | Avalanche photodiode |
| APK | Amplitude/phase keying |
| ARM | Asynchronous response mode |
| ARPANET | Advanced Research Projects Agency Network |
| ARQ | Automatic repeat request |
| ASCII | American Standard Code for Information Interchange |

| | |
|---|---|
| ASIC | Application specific integrated circuit |
| ASK | Amplitude shift keying |
| ASN | Abstract syntax notation |
| ATM | Asynchronous transfer mode, automatic teller machine |
| AU | Administrative unit |
| AUG | AU group |
| AUI | Attachment unit interface |
| AWG | American wire gauge |
| | |
| BA | Basic (rate) access (in ISDN) |
| BASK | Binary amplitude shift keying |
| BCH | Bose–Chaudhuri–Hocquenghem |
| BCJR | Bahl, Cocke, Jelinek, Raviv (algorithm) |
| BER | Bit error ratio/rate |
| BFSK | Binary frequency shift keying |
| BFWA | Broadband fixed wireless access |
| BICI | Broadband (or B-ISDN) intercarrier interface |
| BIM | Broadcast interface module |
| BIS | Boundary/border IS |
| B-ISDN | Broadband ISDN |
| BL | Baseband layer |
| BMV | Branch metric value |
| BNA | Broadcast network adaptor |
| $BO_{i/o}$ | Back-off (input/output) |
| BPI | Baseline privacy interface |
| B-PON | Broadband passive optical network |
| BPSK | Binary phase shift keying |
| BRAN | Broadband radio access network |
| BRL | Bluetooth radio layer |
| BRZ | Bipolar return to zero |
| BS | Base station |
| BSS | Broadcast satellite service, basic service set |
| BT | British Telecom |
| | |
| CAC | Connection admission control, channel access control |
| CAP | Carrierless amplitude and phase (modulation) |
| CASE | Common application service element |
| CATV | Community antenna TV |
| CBR | Constant bit rate |
| CC | Central controller |
| CCIR | Comité Consultatif International des Radiocommunications |
| CCITT | Comité Consultatif International Télégraphique et Téléphonique |
| CCK | Complementary code keying |
| CCRE | Commitment, concurrency and recovery element |
| CCS7 | Common channel signalling system No. 7 |
| CC-TPDU | Connection confirm TPDU |
| CD | Cumulative distribution, compact disc, collision detection, carrier detection |

| | |
|---|---|
| CDDI | Copper distributed data interface |
| CDMA | Code division multiple access |
| CD-ROM | Compact disc read-only memory |
| CDT | Credit (flow control) |
| CDV | Cell delay variation |
| CELP | Codebook of excited linear prediction |
| CEPT | Confederation of European PTT Administrations |
| CFMSK | Continuous frequency minimum shift keying |
| CIR | Carrier to interference ratio |
| CLNP | Connectionless network layer (IP) protocol |
| CLNS | Connectionless network layer service |
| CLR | Cell loss ratio |
| CM | Cable modem |
| CMCI | Cable modem computer interface |
| CMI | Coded mark inversion |
| CMIP | Common management information protocol |
| CMIR | Carrier modulated IR |
| CMOS | Complementary metal oxide silicon (transistor) |
| CMRI | Cable modem return path interface |
| CMTRI | Cable modem telephone return path interface |
| CMTS | Cable modem termination system |
| CN | Core network |
| CNR | Carrier-to-noise ratio |
| CODEC | Coder/decoder |
| COFDM | Coded orthogonal frequency division multiplex |
| CONP | Connection-oriented network protocol |
| CONS | Connection-oriented network service |
| CPD | Centre point detection |
| CPN | Customer premises network |
| CP(S)M | Continuous phase (shift) modulation |
| CR | Call request |
| CRC | Cyclic redundancy check |
| CRT | Cathode-ray tube |
| CR-TPDU | Connection request TPDU |
| CS | Carrier sense, circuit switched, convergence sub-layer |
| CSDN | Circuit switched data network |
| CSMA/CD | Carrier sense multiple access/collision detection |
| CSPDN | Circuit switched packet data network |
| CTD | Cell transfer delay |
| CTS | Clear to send |
| CW | Continuous wave |
| | |
| D | Data |
| DA | Demand assigned |
| DAC | Digital to analogue converter |
| DASS | Digital access signalling system |
| DAT | Digital audio tape |

| | |
|---|---|
| DAVIC | Digital Audio Video Council |
| DBS | Direct broadcast satellite |
| DC | Direct current |
| D/C | Downconverter |
| DCCE | Digital cell centre exchange |
| DCE | Data communication equipment |
| DCF | Distributed coordination function |
| DCT | Discrete cosine transform |
| DDSSC | Digital delivered services switching centre |
| DECT | Initially Digital European cordless telecommunications<br>now Digital enhanced cordless telecommunications |
| DEPSK | Differentially encoded phase shift keying |
| DES | Data encryption standard |
| DFB | Distributed feedback (laser) |
| DFS | Discrete Fourier series, dynamic frequency selection |
| DFT | Discrete Fourier transform |
| DHCP | Dynamic host configuration protocol |
| DI | Distribution interface |
| DIUC | Downlink interval usage code |
| DLC | Data-link controller |
| DL-MAP | Downlink map |
| DM | Delta modulation |
| DMIR | Direct modulation IR |
| DMPSK | Differential $M$-symbol phase shift keying |
| DMSU | Digital main switching unit |
| DMT | Discrete multitone |
| DNS | Domain name system |
| DOA | Direction of arrival |
| DOCSIS | Data over cable service interface specification |
| DPCM | Differential pulse code modulation |
| DPNSS | Digital private network signalling system |
| DPRS | DECT packet radio service |
| DPSK | Differential phase shift keying |
| DQDB | Distributed queue dual bus |
| DQPSK | Differential quadrature phase shift keying |
| DRFSI | Downstream RF site interface |
| DSB | Double sideband |
| DS-CDMA | Direct sequence CDMA |
| DSI | Digital speech interpolation |
| DSL | Digital subscriber line |
| DSMX | Digital system multiplexer |
| DSP | Digital signal processing, domain specific part |
| DSR | Data set ready |
| DSS1 | Digital subscriber signalling No. 1 |
| DSSS | Digital subscriber signalling system,<br>direct sequence spread spectrum |

| | |
|---|---|
| DTE | Data terminal equipment |
| DTI | Department of Trade and Industry (UK) |
| DTP | Distributed transaction processing |
| DTR | Data terminal ready |
| DT-TPDU | Data TPDU |
| DUP | Data user part |
| DV | Data/voice (packet) |
| DVB | Digital video broadcast |
| DVB-C | Digital video broadcast – cable |
| DVD | Digital video disc |
| DVR | Digital video recorder |
| | |
| ECMA | European Computer Manufacturers Association |
| ED | End delimiter |
| EDFA | Erbium doped fibre amplifier |
| EDGE | Enhanced data rate for GPRS evolution |
| EFT | Electronic funds transfer |
| EFTPOS | Electronic funds transfer at point of sale |
| EIA | Electronic Industries Association |
| EIRP | Effective isotropic radiated power |
| EM | Encrypted message |
| EMI | Electromagnetic interference |
| ENQ | Enquiry |
| EOT | End of transmission |
| EOW | Engineering order wire |
| ER | Error reporting (flag) |
| ERD | End routing domain |
| ERF | Error function |
| ERFC | Complementary error function |
| ERMES | European Radio Message System |
| ES | End system, elimination signal |
| ESD | Energy spectral density |
| ES-IS | End system to intermediate system |
| ETS(I) | European Telecommunications Standards Institute (formerly CEPT) |
| ESS | Extended service set |
| EY-NPMA | Elimination yield non pre-emptive priority multiple access |
| | |
| FCC | Federal Communications Commission |
| FCFS | First come first served |
| FCS | Frame check sequence |
| FDD | Frequency division duplex |
| FDDI | Fibre distributed data interface |
| FDM | Frequency division multiplex |
| FDMA | Frequency division multiple access |
| FEC | Forward error correction |
| FECC | Forward error correction coding |
| FET | Field effect transistor |

| | |
|---|---|
| FEXT | Far end crosstalk |
| FFSK | Fast frequency shift keying |
| FFT | Fast Fourier transform |
| FH | Frequency hopped (transmission) |
| FHS | Frequency hop synchronisation |
| FH(SS) | Frequency hopped (spread spectrum) |
| FIFO | First in first out |
| FILO | First in last out |
| FIR | Finite impulse response |
| FIRO | First in random out |
| FM | Frequency modulation |
| FP | Final permutation |
| FPGA | Field programmable gate array |
| FPLMTS | Future public land mobile telecommunications system |
| FS | Fourier series |
| FSK | Frequency shift keying |
| FSPL | Free space path loss |
| FT | Fourier transform |
| FTAM | File transfer access and management |
| FTTB | Fibre to the building/business |
| FTTC | Fibre to the kerb |
| FTTCab | Fibre to the cabinet |
| FTTH | Fibre to the home |
| FWA | Fixed wireless access |
| FZ | Fresnel zone |
| | |
| G3G | Global third generation |
| GAN | Global area network |
| GFI | General format identity |
| GMSK | Gaussian (filtered) minimum shift keying |
| GoS | Grade of service |
| GPRS | General packet radio system |
| GPS | Global positioning system |
| GSC | Group switching centre |
| GSM | originally Groupe Spéciale Mobile<br>now Global System for Mobile communications |
| | |
| HACE | Higher order automatic cross-connect equipment |
| HALO | High altitude long operation |
| HAP | High altitude platform |
| HCI | Host controller interface |
| HDB | High density bipolar |
| HDLC | High level DLC |
| HDSL | High speed digital subscriber loop |
| HDTV | High definition television |
| HEO | High earth orbit |
| HF | High frequency |

| | |
|---|---|
| HFC | Hybrid fibre coax |
| HIHE | Highly inclined highly elliptical (orbit) |
| HIPERACCESS | ETSI HIPERLAN variant |
| HIPERLAN | High performance local area network |
| HomePNA | Home Phoneline Network Alliance |
| HPA | High power amplifier |
| HSCSD | High speed circuit switched data |
| HSDPA | High speed downlink packet access |
| HSLAN | High speed LAN |
| HUMAN | High rate unlicensed MAN |
| | |
| I | Inphase (signal component), information |
| IC | Incoming call |
| ICSDS | Interactive channel satellite distribution system |
| I+D | Integrate and dump |
| ID | Identity |
| IDEA | International data encryption algorithm |
| IDI | Initial domain identifier |
| IDN | Integrated digital network |
| IDP | Initial domain port |
| IDRP | Interdomain routing protocol |
| IDSL | ISDN DSL |
| IEEE | Institute of Electrical and Electronics Engineers |
| IF | Intermediate frequency |
| IFA | Intermediate frequency amplifier |
| IFS | Inter-frame space |
| IFFT | Inverse fast Fourier transform |
| IIM | Interactive network module |
| IIR | Infinite impluse response |
| ILD | Injection laser diode |
| INA | Interaction network adaptor |
| INMARSAT | International Maritime Satellite Consortium |
| INTELSAT | International Telecommunications Satellite Consortium |
| IP | Intermodulation product, internet protocol, initial permutation |
| IPSS | International packet switched service |
| IR | Infrared, interdomain routing |
| IS | Intermediate system |
| ISC | International switching centre |
| ISDN | Integrated services digital network |
| ISI | Intersymbol interference |
| IS-IS | Intermediate system to intermediate system |
| ISM | Industrial, scientific and medical (frequency band) |
| ISO | International Organization for Standardization |
| ISO-PP | ISO presentation protocol |
| ISO-SP | ISO session (layer) protocol |
| ISP | Internet service provider, intermediate services part |
| ISUP | ISDN user part |