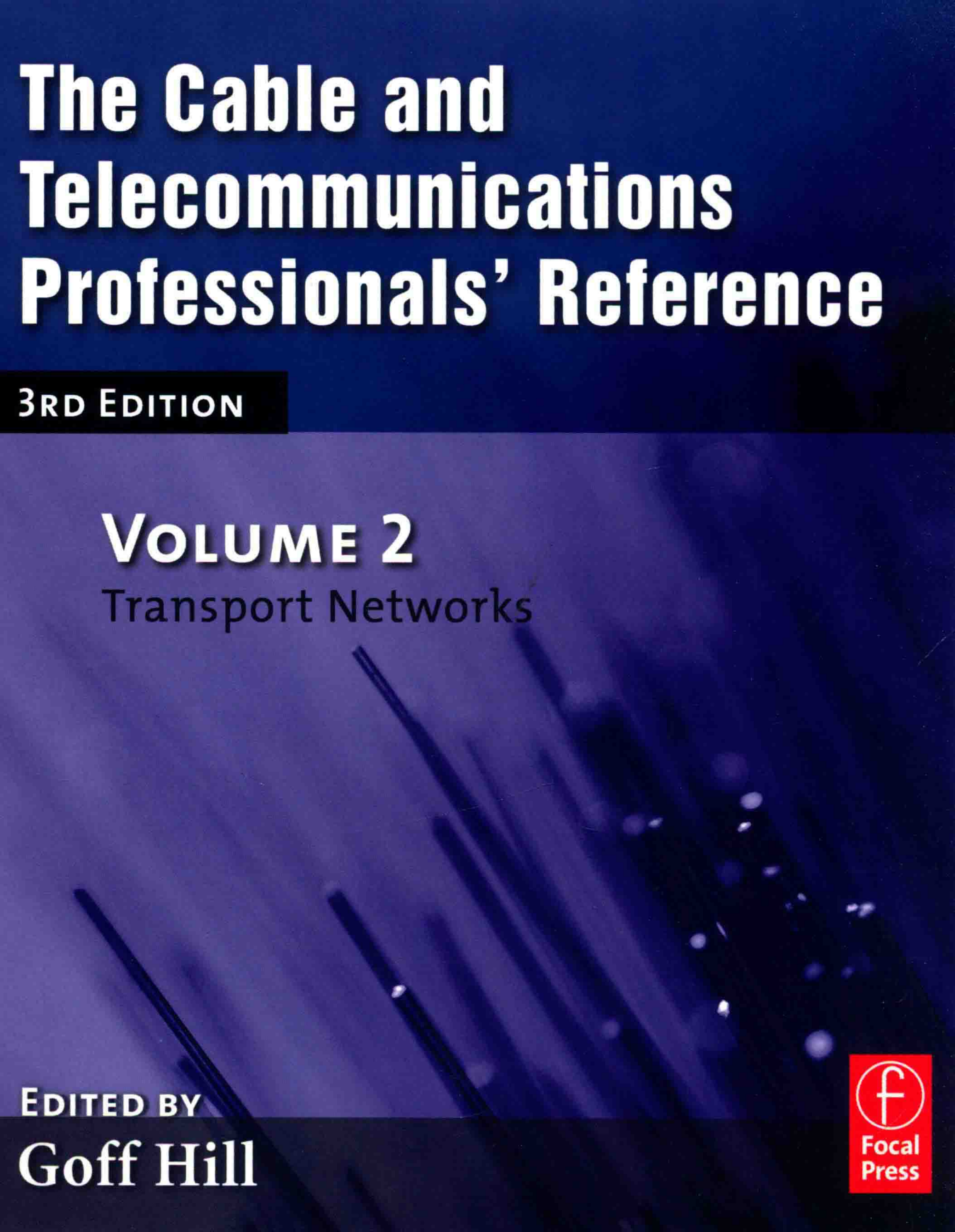
The Cable and Telecommunications Professionals' Reference

3RD EDITION

VOLUME 2

Transport Networks



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Goff Hill

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The Cable and Telecommunications Professionals' Reference

To my family

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Preface

The past decade has seen massive change in the telecomunications industry. Industry structure, regulation, technology, and services have all seen or caused substantial development. New technologies and services are displacing long established ones, and the convergence of different networks, technologies, and services compound the change. The predecessor to this reference was called the *Telecommunication Engineer's Reference Book*. Recent trends toward convergence of voice, data, and video technologies and services have suggested that the title, scope, and content of the book should reflect these changes. For this reason the new reference is entitled *The Cable and Telecommunications Professionals' Reference*. Some of the content in the earlier edition has become dated, and a substantial amount of new material is now included so that it remains an authoritative reference book. However, some of the earlier content remains fundamentally relevant and is retained in this volume. Inevitably this means that some of the earlier material relating to the displaced technologies should, in some cases, be downsized and in other cases removed.

Even so, the huge amount of new material entering the scene means that the full scope would lead to a significant increase in the length of the book. The current edition is therefore divided into three volumes, and I have attempted to associate related material in each. Because of the many relationships between different topics, however, it is not possible to split them into three completely independent volumes.

The first volume dealt with the telecommunications industry and with voice and data and their convergence in both landline and mobile cellular networks. This seemed a logical grouping because of the historical influence of telephone networks on today's communications systems. This volume deals with core transport network technologies and the changes that are enabling them to deal with converged voice, data, and video traffic. The third volume will deal with the broadband access network technologies and the way in which they are used to support new services.

Volume 2 of *The Cable and Telecommunications Professionals' Reference* is arranged into three parts. The parts deal firstly with the digitization and coding of source information, secondly with the properties of the transmission paths across which the signals are carried, and thirdly with the networking techniques that are used to ensure that the signals reach their destination.

Because of the growth in demand for data services and the way in which voice, data, and video services have converged, core transport networks have needed to adapt to become more "data friendly." Transport networks and the services they carry are therefore adopting packet principles to a far greater extent than they did 10 years ago.

Part 1 examines the way voice, data, and video sources are digitized and coded in preparation for transmission over telecommunications networks. This provides a solid introduction to the way signals are carried over transport networks.

Part 2 deals with the physical media commonly used in core transport networks—namely optical fiber and radio. Optical fiber carries the vast majority of telecommunications traffic at regional, national, and international levels. The basic properties of optical fiber itself are discussed, and the principle characteristics and limiting factors of high-capacity, long-range optical systems are explained. Radio systems are used to a lesser extent in core networks. Very good discussions of these were included in the earlier *Telecommunication Engineer's Reference Book*, and selected chapters are reproduced here, with only minor additions, on the grounds that the principles of radio propagation have not changed.

Part 3 presents the main network technologies used today in core transport networks. While the trend is toward data-networking technologies, such as IP/MPLS and carrier-grade Ethernet, the concept of "next-generation networks" is not specific about which technologies should predominate, other than that a packet-networking technology should act as a convergence layer. Indeed, a key principle is that converged traffic can be carried over any underlying transport technology. For example, while SDH is generally considered to be a legacy technology now, its installed base is so huge that it will continue to be a key transport technology for many years to come. Moreover, its life is effectively extended with the application of Next Generation SDH. Other "legacy" technologies are also described, including ISDN, leased lines, Frame Relay, and ATM. In conclusion, IP/MPLS, which is now favored by many operators as a core transport network for data traffic, and the emerging carrier-grade Ethernet, are described.

Where appropriate, chapters that were included in the Second Edition of *Telecommunications Engineer's Reference Book* are reproduced in this volume with changes and updates as needed. I was unfortunately unable to contact four of the previous contributors for their updates. In Part 2 this applies to Chapters 7, 8, and 9 and in Part 3 to Chapter 10. An assessment was that these chapters contained a lot of information that is still very important, relevant, and clearly presented. In most cases the changes to the original text are minor. As for Chapter 10, the previous edition's chapter focused on SDH; for this book, I have rearranged the original text slightly and made some additions to highlight the similarities and differences between SONET and SDH.

I am greatly indebted to the authors who have contributed to this volume of the *Cable and Telecommunications Professionals' Reference*. They are all experts in their fields and working at the forefront of technology. I should like to express my thanks to them and to their respective organizations for all the support they have given.

Goff Hill
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Tahmina Ajmal received her Ph.D. from Essex University in 2007, having earlier earned her B.Eng. in 1990 and her M.Eng. in 1993 from Aligarh Muslim University in India. Before starting her doctoral studies at the University of Essex, she was a lecturer at Aligarh Muslim University and was upgraded to the post of reader there in August 2000. Since June 2007, Tahmina has worked as a part-time research officer at the University of Essex on the MUSE (Multi-Service Access Everywhere) project for the development of a low-cost multi-access network. Her research interests include fiber sensors, physical-layer cryptography, and different modulation formats for transmission.

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John Causebrook graduated in physics from the University of London in 1970 and obtained his doctorate for research into radio wave propagation in 1974. He worked for the BBC research department on broadcast coverage and frequency planning and later for the IBA, directing the work of several teams of propagation and broadcast-planning engineers. Dr. Causebrook participated in engineering the mobile phone network at Vodafone, the main product of which was a computer system for showing the coverage of networks that is used in the broadcasting-planning process. He also worked on the parameters for base stations and radio health of the mobile phone industry, was chairman of an international group that studied the subject, and lectured to University M.Sc. students in this area. Dr. Causebrook has published many technical papers and books and has presented several papers at international conferences. In 1978 he received the Oliver Lodge Premium Award from the IEE for his paper on propagation.

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Ken Guild is currently a senior lecturer within the Department of Computing and Electronic Systems Engineering at the University of Essex, U.K. He received an M.Eng. degree in electronic and electrical engineering from the University of Surrey in 1993. Between 1993 and 1997, he was with Alcatel Submarine Networks, and worked on a variety of projects related to advanced optical transport networks and systems. In 1997, Ken joined the University of

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Anagnostis Hadjifotiou graduated from Southampton University in 1969 with a B.Sc. degree in electronic science with final-year options on communications, semiconductor physics, electronic devices, microwaves, and quantum electronics. He received his M.Sc. in 1970 from Manchester University in control systems, specializing in optimal control, stochastic processes, stochastic control, and space control systems. In 1974 he was awarded a Ph.D. from Southampton University for work on digital-signal processing for target extraction in radars. Anagnostis joined the Nortel Research Laboratories in Harlow, England (then Standard Telecommunications Laboratories) in 1984 and worked on nonlinear electronic circuits, computer-aided circuit design, optical systems (submarine, terrestrial, and free space), optical technologies, device and system simulation, and nonlinear optics. From 2000 until his retirement from Nortel in 2004, he was responsible for research on optical communications and optical technologies. He has also been a visiting professor at Essex University and University College London and a lecturer at a number of U.K. universities. Anagnostis is a fellow of the Royal Academy of Engineering, a fellow of the IET, a chartered engineer, and a member of the IEEE and the OSA. He has 104 publications to his credit.

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Goff Hill is the managing director of GTel Consultancy, which provides advice on broadband and core transport networks and is active in supporting Europe's Framework Program research. Globally recognized as a pioneer of "optical network" technology, Goff has more than 40 years' experience in telecommunications, including 17 years in optical telecommunications as a technical group leader and project manager with BT and 2 years as a chief network architect with ilotron and later with Altamar Networks. He has been a special editor for both *IEEE Communications Magazine* and *IEEE Journal of Lightwave Technology* and has published more than 70 technical papers. He also delivers lectures for university and professional short courses. Goff obtained an honors degree in electrical engineering from the University of Newcastle upon Tyne in 1969 and is a member of the IET.

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David Hunter, now a reader in the Department of Computing and Electronic Systems at the University of Essex, received a first-class honors B.Eng. in electronics and microprocessor engineering from the University of Strathclyde in 1987, and a Ph.D. from the same university in 1991 for research on optical TDM switch architectures. He then researched optical networking and optical packet switching at Strathclyde. In August 2002, he began teaching at the University of Essex, concentrating on TCP/IP, network performance modeling, and

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Malcolm Macleod graduated from the University of Cambridge with a B.A. in electronic engineering and a Ph.D. for his work on the discrete optimization of DSP systems. From 1978 to 1988, he worked for Cambridge Consultants Ltd. on a wide range of research and development projects. In 1988 he joined the engineering department of Cambridge University as a lecturer in signal processing and communications and was subsequently the department's director of research. Malcolm joined QinetiQ Ltd in Malvern as a senior research scientist and technical manager in November 2002. In 2007 he was appointed a visiting professor at the University of Strathclyde. A fellow of the IEE, Malcolm is a chartered engineer and an associate editor of *IEEE Signal Processing Letters*. He has published nearly 100 papers on nonlinear and adaptive filtering, efficient implementation of DSP systems, detection, estimation, beamforming, and wireless communications and image processing and their applications.

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Alan McGuire is a principal engineer at BT, leading a multidisciplinary team working on next-generation transport networks. He is also active in the standards arena, where he has made numerous contributions and has acted as editor on a variety of ITU-T Recommendations concerning network architecture, control and management, optical networking, and Ethernet. Alan graduated from the University of St. Andrews in 1987 with a first in physics and earned his M.Sc. in medical physics one year later from the University of Aberdeen. He is a chartered engineer and chartered physicist, as well as a member of the Institute of Physics, a member of the IET, and a senior member of the IEEE.

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Rouzbeh Razavi received his master's degree with distinction in telecommunications and information systems from the University of Essex in 2005. He is currently pursuing his research toward a Ph.D. at that university and since June 2006 has been a research officer on the IST European Project, MUSE. Rouzbeh has been a reviewer for various journals and has published more than 30 papers in scholarly journals and conference proceedings. He is the recipient of both a best-paper award and an outstanding-paper award from two international conferences.

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Martin Reed is a lecturer at the University of Essex. He is also an active researcher in the fields of transmitting media over packet networks and traffic engineering in IP networks and has published more than 25 papers in the fields of network control and audio signal

processing. Martin was an early experimenter in spatialized (multichannel) voice for multiparty conferencing transmitted over ATM and IP networks, having worked on a 1998 project funded in the United Kingdom by BT. This earlier work has inspired projects investigating a number of issues with transmission of the next generation of voice applications over packet networks ranging from network-level traffic control to signal-processing requirements such as echo cancelation.

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Emilio Salas received his master's degree in telecommunications and information systems from the University of Essex in 2002. He is currently pursuing his Ph.D. degree at that university. Since June 2006, Emilio has been a research officer on the IST European Project, MUSE, and has worked for ALCATEL Mexico as a product and network design engineer in the transmission networks area. Emilio has been a reviewer for various journals and has published more than 15 papers in scholarly journals and conference proceedings.

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Stuart Walker received a B.Sc. (Hons.) in physics from Manchester University in 1973, following that with an M.Sc. in telecommunications systems in 1975 and a Ph.D. in electronics from Essex University in 1981. In 1982 he joined BT Research Laboratories in Martlesham Heath, U.K., where he helped pioneer unrepeatered submarine optical system technologies. Stuart became a senior lecturer at Essex University in 1988 and then, in 2003 and 2004, reader and full professor, respectively. His group is extensively involved in U.K. government and European Union projects. Stuart has published more than 200 journal and refereed conference papers and has 10 patents granted.

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Contents

Part 1

For most of the past century, the main purpose of telecommunications networks has been to enable voice communications between people at a distance. To a lesser extent it has included communications between people and voice recording or playback devices, such as automatic voice response systems. In more recent decades, there has also been a steady growth in the use of telecommunications networks to provide data connections for applications such as remote sensing, transfering data between data centers, or carrying TV signals in digital format. However, more recently, the emphasis has shifted very much toward the provision of connections between information systems or between people and information systems capable of carrying voice, video, or data signals.

Voice and video signals are analogue at their source and in early systems were transported over telecommunications networks in analogue form. With the relentless development of digital technology, however, analogue systems have progressively given way to digital transmission, with signals remaining in analogue format for only a short distance before being converted to digital. Data signals, on the other hand, often start out in digital format—for example, from a file or data storage device.

Digital signals generally need more bandwidth for their transmission than analogue ones, but they offer the advantage (with careful systems design) of being highly resistant to noise and other impairments and of being highly extendable. In recent years considerable emphasis has been placed on ways to reduce the bit-rate (and therefore bandwidth) needed to carry analogue signals that have been digitized without significant loss of quality.

Part 1 of Volume 2 of *The Cable and Telecommunications Professionals' Reference* looks at the process of digitizing analogue signals and at the properties of the

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