DECLARATION OF JUNE ANN MUNFORD

1. My name is June Ann Munford. I am over the age of 18, have personal knowledge of the facts set forth herein, and am competent to testify to the same.

2. I earned a Master of Library and Information Science (MLIS) from the University of Wisconsin-Milwaukee in 2009. I have over ten years of experience in the library/information science field. Beginning in 2004, I have served in various positions in the public library sector including Assistant Librarian, Youth Services Librarian and Library Director. I have attached my Curriculum Vitae as Appendix CV.

3. During my career in the library profession, I have been responsible for materials acquisition for multiple libraries. In that position, I have cataloged, purchased and processed incoming library works. That includes purchasing materials directly from vendors, recording publishing data from the material in question, creating detailed material records for library catalogs and physically preparing that material for circulation. In addition to my experience in acquisitions, I was also responsible for analyzing large collections of library materials, tailoring library records for optimal catalog

search performance and creating lending agreements between libraries during my time as a Library Director.

4. I am fully familiar with the catalog record creation process in the library sector. In preparing a material for public availability, a library catalog record describing that material would be created. These records are typically written in Machine Readable Catalog (herein referred to as "MARC") code and contain information such as a physical description of the material, metadata from the material's publisher, and date of library acquisition. In particular, the 008 field of the MARC record is reserved for denoting the date of creation of the library record itself. As this typically occurs during the process of preparing materials for public access, it is my experience that an item's MARC record indicates the date of an item's public availability.

5. Typically, in creating a MARC record, a librarian would gather various bits of metadata such as book title, publisher and subject headings among others and assign each value to a relevant numerical field. For example, a book's physical description is tracked in field 300 while title/attribution is tracked in field 245. The 008 field of the MARC record is reserved for denoting the creation of the library record itself. As this is the only date reflecting the inclusion of said materials within the library's collection, it is my experience

that an item's 008 field accurately indicates the date of an item's public availability.

6. I have reviewed Exhibit DISH-1016, "An Efficient Digital Modulation Scheme for Multimedia Transmission on the Cable Television Network" by Krista S. Jacobsen and John M. Cioffi as published in *National Cable Television Association 1994 Technical Papers*.

7. Attached hereto as Appendix JACOBSEN01 is a true and correct copy of the MARC record for *National Cable Television Association Technical Papers* as held by the Linda Hall Library. I secured this record myself from the library's public catalog. The 'Location Items' field visible on page 2 of Appendix JACOBSEN01 indicates that this collection includes the 1994 edition of *National Cable Television Association Technical Papers* containing "An Efficient Digital Modulation Scheme for Multimedia Transmission on the Cable Television Network". The MARC record contained within Appendix JACOBSEN01 accurately describes the title, author and publisher of *National Cable Television Association Technical Papers.*

8. Attached hereto as Appendix JACOBSEN02 is a true and correct copy of "An Efficient Digital Modulation Scheme for Multimedia Transmission on the Cable Television Network" as published in *National Cable Television Association 1994 Technical Papers* as held by the Linda Hall Library. These scans were secured from the library's collection by counsel. In comparing Exhibit DISH-1016 to Appendix JACOBSEN01, it is my determination that Exhibit DISH-1016 is a true and correct copy of "An Efficient Digital Modulation Scheme for Multimedia Transmission on the Cable Television Network" by Krista S. Jacobsen and John M. Cioffi.

9. The 008 field of the MARC record in Appendix JACOBSEN01 indicates the date of record creation. The 008 field of Appendix JACOBSEN01 indicates the Linda Hall Library first acquired this book as of September 19, 1995. Considering this information, it is my determination that *National Cable Television Association 1994 Technical Papers* and therefor "An Efficient Digital Modulation Scheme for Multimedia Transmission on the Cable Television Network" was made available to the public shortly after its initial acquisition in September 1995.

10. I have reviewed Exhibit DISH-1017, *Introduction to Communications Engineering* by Robert M. Gagliardi, 2nd Edition.

11. Attached hereto as Appendix GAGLIARDI01 is a true and correct copy of the MARC record for *Introduction to Communications Engineering* as held by the University of Pittsburgh library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix GAGLIARDI01 accurately describes the title, author, publisher, and ISBN number of *Introduction to Communications Engineering*.

12. Attached hereto as Appendix GAGLIARDI02 is a true and correct copy of selections from *Introduction to Communications Engineering* as held by the University of Pittsburgh library. I secured these scans myself from the library's collection. In comparing Exhibit DISH-1017 to Appendix GAGLIARDI02, it is my determination that Exhibit DISH-1017 is a true and correct copy of *Introduction to Communications Engineering* by Robert M. Gagliardi.

13. The 008 field of the MARC record in Appendix GAGLIARDI01 indicates the date of record creation. The 008 field of Appendix GAGLIARDI01 indicates University of Pittsburgh library first acquired this book as of March 4, 1988. Considering this information, it is my determination that

Introduction to Communications Engineering was made available to the public shortly after its initial acquisition in March 1988.

14. I have reviewed Exhibit DISH-1019, *Broadband Cable TV Access Networks: From Technologies to Applications* by Shlomo Ovadia.

15. Attached hereto as Appendix OVADIA01 is a true and correct copy of the MARC record for *Broadband Cable TV Access Networks: From Technologies to Applications* as held by the Penn State University library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix OVADIA01 accurately describes the title, author, publisher, and ISBN number of *Broadband Cable TV Access Networks: From Technologies to Applications.*

16. Attached hereto as Appendix OVADIA02 is a true and correct copy of selections from *Broadband Cable TV Access Networks: From Technologies to Applications* as held by the Penn State University library. I secured these scans myself from the library's collection. In comparing Exhibit DISH-1019 to Appendix OVADIA02, it is my determination that Exhibit DISH-1019 is a true and correct copy of *Broadband Cable TV Access Networks: From Technologies to Applications* by Shlomo Ovadia.

17. The 008 field of the MARC record in Appendix OVADIA01 indicates the date of record creation. The 008 field of Appendix OVADIA01 indicates Penn State University library first acquired this book as of May 10, 2001. Considering this information, it is my determination that *Broadband Cable TV Access Networks: From Technologies to Applications* was made available to the public shortly after its initial acquisition in May 2001.

18. I have reviewed Exhibit DISH-1021, *DSL: Simulation Techniques and Standards Development for Digital Subscriber Line Systems* by Walter Y. Chen.

19. Attached hereto as Appendix CHEN01 is a true and correct copy of the MARC record for *DSL: Simulation Techniques and Standards Development for Digital Subscriber Line Systems* as held by the Penn State University library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix CHEN01 accurately describes the title, author, publisher, and ISBN number of *DSL: Simulation Techniques and Standards Development for Digital Subscriber Line Systems.*

20. Attached hereto as Appendix CHEN02 is a true and correct copy of selections from *DSL: Simulation Techniques and Standards Development*

for Digital Subscriber Line Systems as held by the Penn State University library. I secured these scans myself from the library's collection. In comparing Exhibit DISH-1021 to Appendix CHEN02, it is my determination that Exhibit DISH-1021 is a true and correct copy of *DSL: Simulation Techniques and Standards Development for Digital Subscriber Line Systems* by Walter Y. Chen.

21. The 008 field of the MARC record in Appendix CHEN01 indicates the date of record creation. The 008 field of Appendix CHEN01 indicates Penn State University library first acquired this book as of May 26, 1998. Considering this information, it is my determination that *DSL: Simulation Techniques and Standards Development for Digital Subscriber Line Systems* was made available to the public shortly after its initial acquisition in May 1998.

22. I have reviewed Exhibit DISH-1022, *ASDL/VDSL Principles: A Practical and Precise Study of Asymmetric Digital Subscriber Lines and Very High Speed Digital Subscriber Lines* by Dennis J. Rauschmayer.

23. Attached hereto as Appendix RAUSCHMAYER01 is a true and correct copy of the MARC record for *ASDL/VDSL Principles: A Practical and Precise Study of Asymmetric Digital Subscriber Lines and Very High Speed*

Digital Subscriber Lines as held by the Penn State University library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix RAUSCHMAYER01 accurately describes the title, author, publisher, and ISBN number of *ASDL/VDSL Principles: A Practical and Precise Study of Asymmetric Digital Subscriber Lines and Very High Speed Digital Subscriber Lines.*

24. Attached hereto as Appendix RAUSCHMAYER02 is a true and correct copy of *ASDL/VDSL Principles: A Practical and Precise Study of Asymmetric Digital Subscriber Lines and Very High Speed Digital Subscriber Lines* as held by the Penn State University library. I secured these scans myself from the library's collection. In comparing Exhibit DISH-1022 to Appendix RAUSCHMAYER02, it is my determination that Exhibit DISH-1022 is a true and correct copy of *ASDL/VDSL Principles: A Practical and Precise Study of Asymmetric Digital Subscriber Lines and Very High Speed Digital Subscriber Lines* by Dennis J. Rauschmayer.

25. The 008 field of the MARC record in Appendix RAUSCHMAYER01 indicates the date of record creation. The 008 field of Appendix RAUSCHMAYER01 indicates Penn State University library first acquired this book as of February 25, 1999. Considering this information, it is my

determination that *ASDL/VDSL Principles: A Practical and Precise Study of Asymmetric Digital Subscriber Lines and Very High Speed Digital Subscriber Lines* was made available to the public shortly after its initial acquisition in February 1999.

26. I have reviewed Exhibit DISH-1023, "Synchronized Discrete Multi-Tone (SDMT) Modulation for Cable Modems: Making the Most of the Scarce Reverse Channel Bandwidth" by Krista S. Jacobsen as published in *Proceedings of WESCON 97*.

27. Attached hereto as Appendix JACOBSEN03 is a true and correct copy of the MARC record for *Proceedings of WESCON 97* as held by the University of Pittsburgh library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix JACOBSEN03 accurately describes the title, author, publisher, and ISBN number of *Proceedings of WESCON 97*. In comparing Exhibit DISH-1023 to Appendix JACOBSEN03, it is my determination that Exhibit DISH-1023 is a true and correct copy of "Synchronized Discrete Multi-Tone (SDMT) Modulation for Cable Modems: Making the Most of the Scarce Reverse Channel Bandwidth" by Krista S. Jacobsen.

28. The 008 field of the MARC record in Appendix JACOBSEN03 indicates the date of record creation. The 008 field of Appendix JACOBSEN03 indicates the University of Pittsburgh library first acquired these proceedings as of February 13, 1998. Considering this information, it is my determination that *Proceedings of WESCON 97* and therefore "Synchronized Discrete Multi-Tone (SDMT) Modulation for Cable Modems: Making the Most of the Scarce Reverse Channel Bandwidth" was made available to the public shortly after its initial acquisition as of February 13, 1998, if not earlier via the conference itself.

[remainder of page intentionally left blank]

29. I have been retained on behalf of the Petitioner to provide assistance in the in establishing the authenticity and public availability of the documents discussed in this declaration. I understand that my declaration will be submitted as an exhibit to a petition for inter partes review. I am being compensated for my services in this matter at the rate of $200.00 per hour plus reasonable expenses. My statements are objective, and my compensation does not depend on the outcome of this matter.

30. I declare under penalty of perjury that the foregoing is true and correct. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: 1/7/2024



June Ann Munford

APPENDIX CV

June A. Munford
Curriculum Vitae

Education

University of Wisconsin-Milwaukee - MS, Library & Information Science, 2009
Milwaukee, WI

- Coursework included cataloging, metadata, data analysis, library systems, management strategies and collection development.
- Specialized in library advocacy, cataloging and public administration.

Grand Valley State University - BA, English Language & Literature, 2008
Allendale, MI

- Coursework included linguistics, documentation and literary analysis.
- Minor in political science with a focus in local-level economics and government.

Professional Experience

Researcher / Expert Witness, October 2017 – present
Freelance ● Pittsburgh, Pennsylvania & Grand Rapids, Michigan

- Material authentication and public accessibility determination. Declarations of authenticity and/or public accessibility provided upon research completion. Experienced with appeals and deposition process.

- Research provided on topics of public library operations, material publication history, digital database services and legacy web resources.

- Past clients include Alston & Bird, Arnold & Porter, Baker Botts, Fish & Richardson, Erise IP, Irell & Manella, O'Melveny & Myers, Perkins-Coie, Pillsbury Winthrop Shaw Pittman and Slayden Grubert Beard.

Library Director, February 2013 - March 2015
Dowagiac District Library ● Dowagiac, Michigan

- Executive administrator of the Dowagiac District Library. Located in

Southwest Michigan, this library has a service area of 13,000, an annual operating budget of over $400,000 and total assets of approximately $1,300,000.

● Developed careful budgeting guidelines to produce a 15% surplus during the 2013-2014 & 2014-2015 fiscal years while being audited.

● Using this budget surplus, oversaw significant library investments including the purchase of property for a future building site, demolition of existing buildings and building renovation projects on the current facility.

● Led the organization and digitization of the library's archival records.

● Served as the public representative for the library, developing business relationships with local school, museum and tribal government entities.

● Developed an objective-based analysis system for measuring library services - including a full collection analysis of the library's 50,000+ circulating items and their records.

November 2010 - January 2013
Librarian & Branch Manager, Anchorage Public Library ● Anchorage, Alaska

● Headed the 2013 Anchorage Reads community reading campaign including event planning, staging public performances and creating marketing materials for mass distribution.

● Co-led the social media department of the library's marketing team, drafting social media guidelines, creating original content and instituting long-term planning via content calendars.

● Developed business relationships with The Boys & Girls Club, Anchorage School District and the US Army to establish summer reading programs for children.

June 2004 - September 2005, September 2006 - October 2013
Library Assistant, Hart Area Public Library
Hart, MI

● Responsible for verifying imported MARC records and original MARC

cataloging for the local-level collection as well as the Michigan Electronic Library.

● Handled OCLC Worldcat interlibrary loan requests & fulfillment via ongoing communication with lending libraries.

Professional Involvement

Alaska Library Association - Anchorage Chapter
- Treasurer, 2012

Library Of Michigan
- Level VII Certification, 2008
- Level II Certification, 2013

Michigan Library Association Annual Conference 2014
- New Directors Conference Panel Member

Southwest Michigan Library Cooperative
- Represented the Dowagiac District Library, 2013-2015

Professional Development

Library Of Michigan Beginning Workshop, May 2008
Petoskey, MI
- Received training in cataloging, local history, collection management, children's literacy and reference service.

Public Library Association Intensive Library Management Training, October 2011
Nashville, TN
- Attended a five-day workshop focused on strategic planning, staff management, statistical analysis, collections and cataloging theory.

Alaska Library Association Annual Conference 2012 - Fairbanks, February 2012
Fairbanks, AK
- Attended seminars on EBSCO advanced search methods, budgeting, cataloging, database usage and marketing.

Depositions

2019 ● Fish & Richardson

Apple v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282 and 39521-00421IP2)

2019 ● Erise IP

Implicit, LLC v. Netscout Systems, Inc (Civil Action No. 2:18-cv-53-JRG)

2019 ● Perkins-Coie

Adobe Inc. v. RAH Color Technologies LLC (Cases IPR2019-00627, IPR2019-00628, IPR2019-00629 and IPR2019-00646)

2020 ● O'Melveny & Myers

Maxell, Ltd. v. Apple Inc. (Case No. 5:19-cv-00036-RWS)

2021 ● Pillsbury Winthrop Shaw Pittman LLP

Intel v. SRC (IPR2020-1449)

2022 ● Perkins-Coie

Realtek v. Future Link (IPR2021-01182)

2023 ● Fish & Richardson

Neuroderm Ltd. v. Abbvie, Inc (Case No. PGR2022-00040)

2023 ● Fish & Richardson

Nearmap US Inc. v. Pictometry International Corp. (IPR2022-00735)

2023 ● Fish & Richardson

Samsung Electronics v. MemoryWeb LLC (Case No. 39843-0136PS1)

Limited Case History & Potential Conflicts

Alston & Bird

- Ericsson
  - v. Collision Communications (IPR2022-01233)
- Nokia
  - v. Neptune Subsea, Xtera (Case No. 1:17-cv-01876)
- Universal Electronics Inc
  - v. Roku Inc (IPR2022-00818)

Arnold & Porter

- Ivantis
  - v. Glaukos (Case No. 8:18-cv-00620)
- Samsung
  - v. Jawbone (Case No. 2:21-cv-00186)

Benesch Friedlander Coplan & Aronoff

- Voyis
  - v. Cathx (Case No. 5:21-cv-00077-RWS)

Erise I.P.

- Apple
  - v. Ericsson Inc. (IPR2022-00715)

v. Future Link Systems (IPRs 6317804, 6622108, 6807505, and 7917680)

v. INVT (Case No. 20-1881)

v. Navblazer LLC (IPR2020-01253)

v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)

v. Quest Nettech Corp (Case No. 2:19-cv-00118-JRG)

v. Telefonaktiebolaget LM Ericsson (IPR2022-00275)

- Fanduel

v. CGT (Case No. 19-1393)

- Garmin

v. Phillips North America LLC (Case No. 2:19-cv-6301-AB-KS)

- Netscout

v. Longhorn HD LLC (Case No. 2:20-cv-00349)

v. Implicit, LLC (Civil Action No. 2:18-cv-53-JRG)

- Sony Interactive Entertainment LLC

v. Bot M8 LLC (IPR2020-01288)

v. Infernal Technology LLC (Case No. 2:19-CV-00248-JRG)

- Unified Patents

v. GE Video Compression (Civil Action No. 2:19-cv-248)

Fish & Richardson

- Apple

v. AliveCor (3:21-cv-03958)

v. LBS Innovations (Case No. 2:19-cv-00119-JRG-RSP)

v. Koss Corporation (IPR2021-00305)

v. Masimo (IPR 50095-0012IP1, 50095-0012IP2, 50095-0013IP1, 50095-0013IP2, 50095-0006IP1, 50095-0135IP1)

v. Neonode (Case No. 21-cv-08872-EMC)

v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)

- Dell

v. Neo Wireless (IPR2022-00616)

- Dish Network

v. Realtime Adaptive Streaming (Case No. 1:17-CV-02097-RBJ)

v. TQ Delta LLC (Case No. 18-1798)

- Evapco Dry Cooling

v. SPG Dry Cooling (IPR2021-00688)

- Genetec

v. Sensormatic Electronics (Case No. 1:20-CV-00760)

- Huawei

v. Bell Northern Research LLC (IPR2019-01174)

- Kianxis

v. Blue Yonder (Case No. 3:20-cv-03636)

- LG Electronics
  - v. Bell Northern Research LLC (Case No. 3:18-cv-2864-CAB-BLM)

- Metaswitch
  - v. Sonus Networks (IPR2018-01719)

- Microsoft
  - v. Throughputer Inc (IPR2022-00757)

- MLC Intellectual Property
  - v. MicronTech (Case No. 3:14-cv-03657-SI)

- Nearmap Inc
  - v. EagleView Technologies (IPR2022-01009)

- Neuroderm Ltd.
  - v. Abbvie, Inc (Case No. PGR2022-00040)

- Realtek Semiconductor
  - v. Future Link (IPR2021-01182)

- Quectel
  - v. Koninklijke Philips (Case No. 1:20-cv-01710)

- Samsung
  - v. Aire Technology (IPR2022-00877)
  - v. Bell Northern Research (Case No. 2:19-cv-00286-JRG)
  - v. Communication Technologies Inc (IPR2022-01221)

v. Jawbone Innovations (IPR2022-00865)

v. MemoryWeb LLC (IPR2022-00885)

v. Telefonaktiebolaget LM Ericsson (IPR2021-00615)

- Texas Instruments

  v. Vantage Micro LLC (IPR2020-01261)

- Xilinx

  v. Sentient Sensors LCC (Case No. 1:22-cv-00173)

Irell & Manella

- Curium

O'Melveny & Myers

- Apple

  v. Maxell (Case No. 5:19-cv-00036-RWS)

- Samsung

  v. Daedalus Prime LLC (1335 Investigation)

Perkins-Coie

- Heru Industries

  v. The UAB Research Foundation (IPR2022-01148)

- Intel Corporation

  v. BitMICRO (Case No. 5:23-cv-00625)

- Realtek Semiconductor

  v. Future Link (IPR2021-01182)

- Twitter Inc

  v. VOIP-Pal.com (Case No. 3:20-cv-02397-JD)

- TCL Industries

  v. Koninklijke Philips NV (IPR2021-00495, IPR2021-00496 and IPR2021-00497)

Pillsbury Winthrop Shaw Pittman

- Intel

  v. FG SRC LLC (Case No. 6:20-cv-00315)

- Gravel Rating Systems

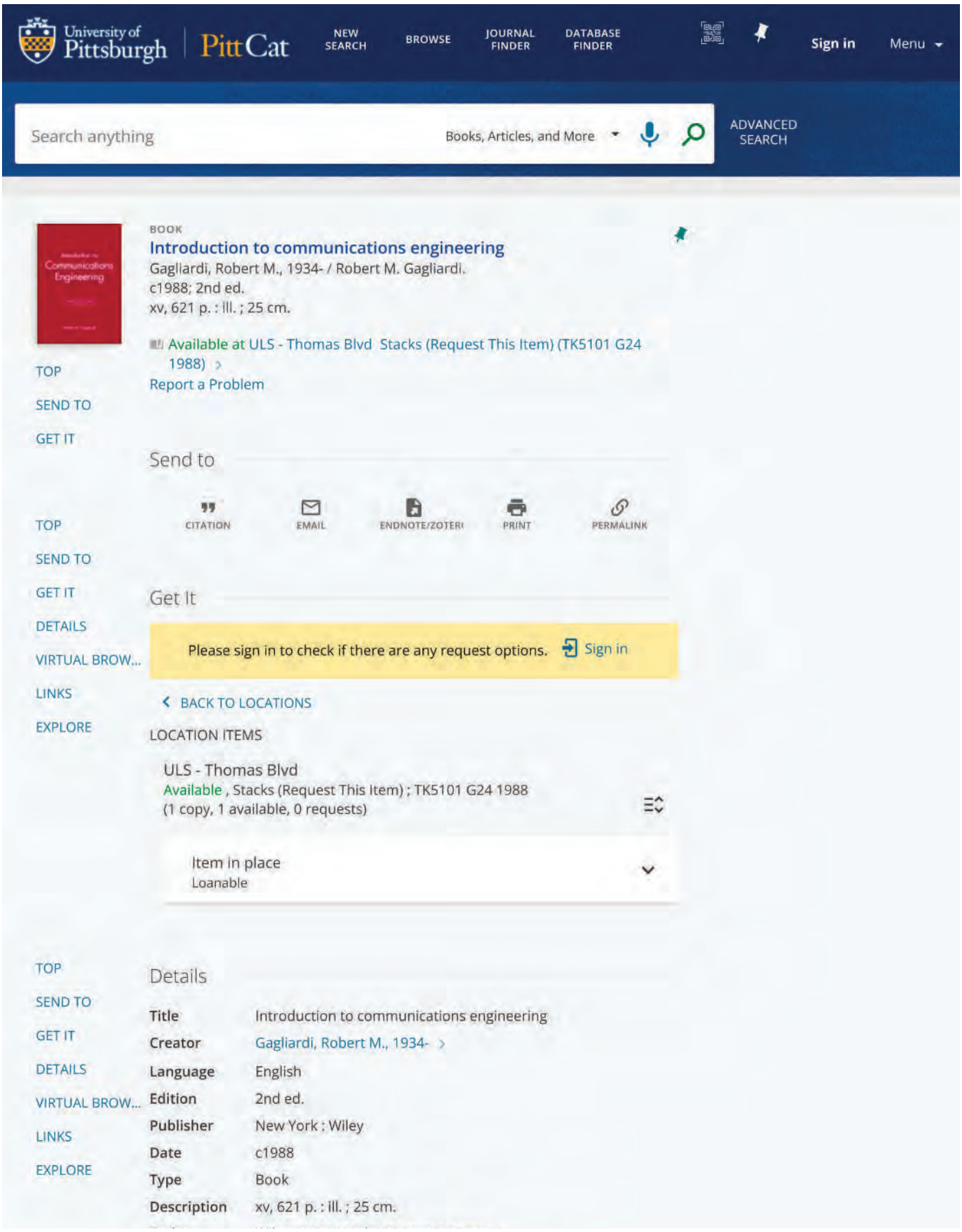
  v. Costco (Case No. 4:21-cv-149)
  v. Lowe's Home Centers (Case No. 4:21-cv-150)
  v. T-Mobile USA (Case No. 4:21-cv-152)
  v. Kohl's Inc. (Case No. 4:21-cv-258)
  v. Under Armor (Case No. 4:21-cv-356)

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082     0#$a621.38 $219
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245     10$aIntroduction to communications engineering / $cRobert M. Gagliardi.
250     ##$a2nd ed.
260     ##$aNew York : $bWiley, $cc1988.
300     ##$axv, 621 p. : $bill. ; $c25 cm.
440     #0$aWiley series in telecommunications
500     ##$a"A Wiley-Interscience publication."
504     ##$aIncludes bibliographies and index.
650     #0$aTelecommunication.
948     ##$alc:um;cm:kb
906     ##$aULS
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SUMMARY

Presents thorough coverage of the engineering aspects of modern communication systems, paying particular attention to the practical system considerations in the end-to-end construction of a typical communication link. The text is designed to provide readers with a solid background in current terminology, methodology, and procedures. This updated edition places greater emphasis on modern (read more)

ABOUT THE AUTHOR

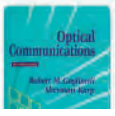


Robert M. Gagliardi

Robert M. Gagliardi is the author of *Introduction to Communications Engineering*, 2nd Edition, published by Wiley.

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Introduction to Communications Engineering

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Introduction to Communications Engineering

Second Edition

Robert M. Gagliardi
Department of Electrical Engineering
University of Southern California



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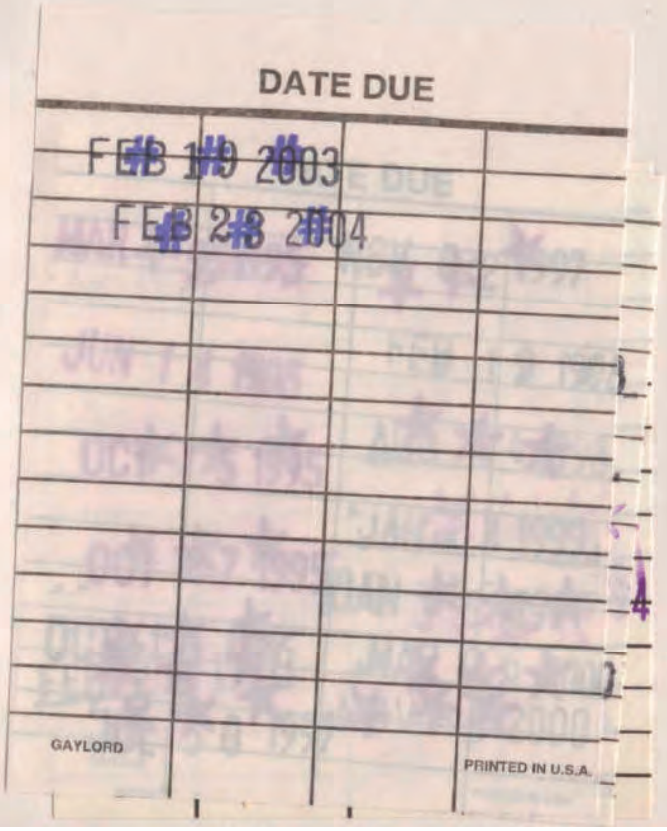
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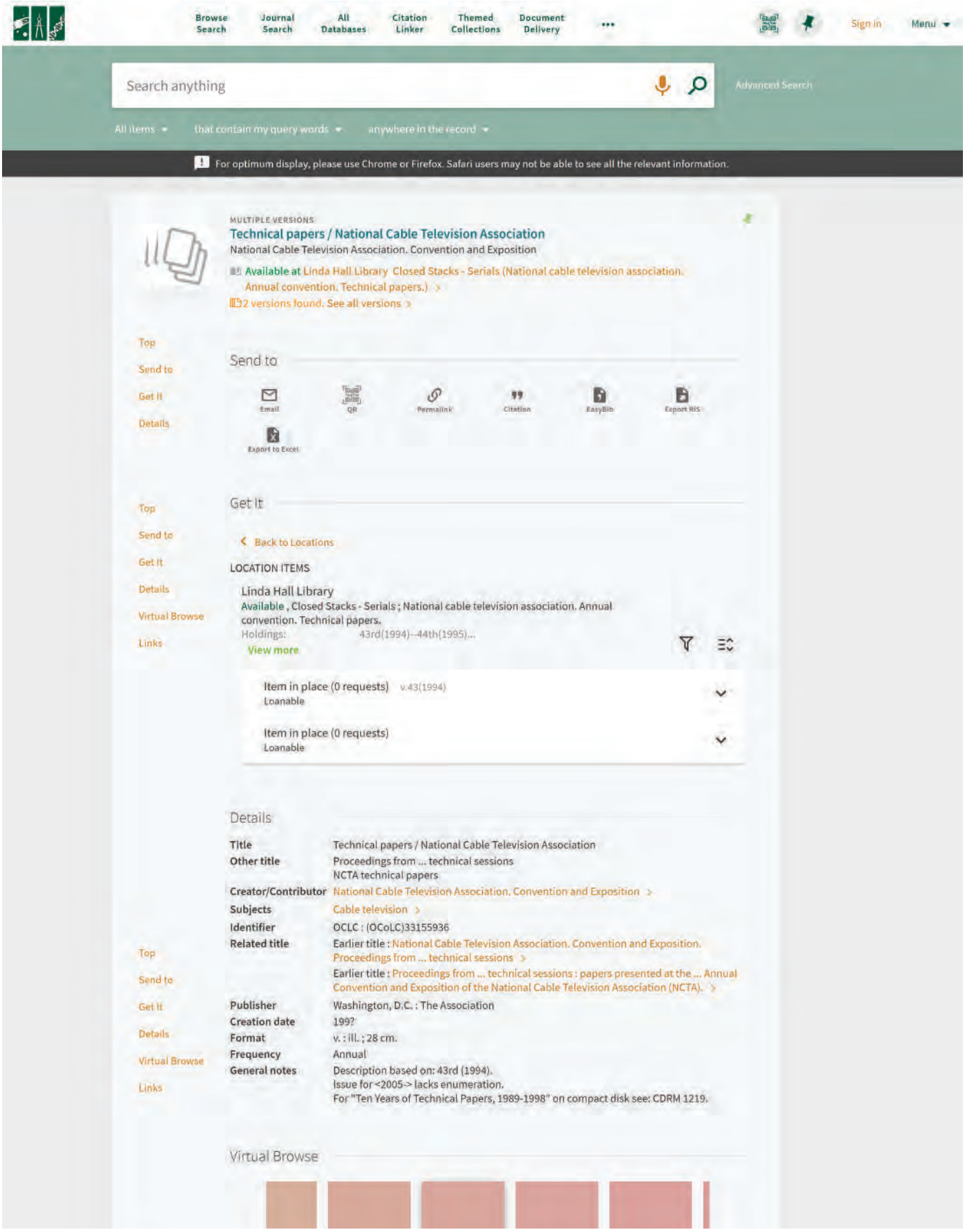


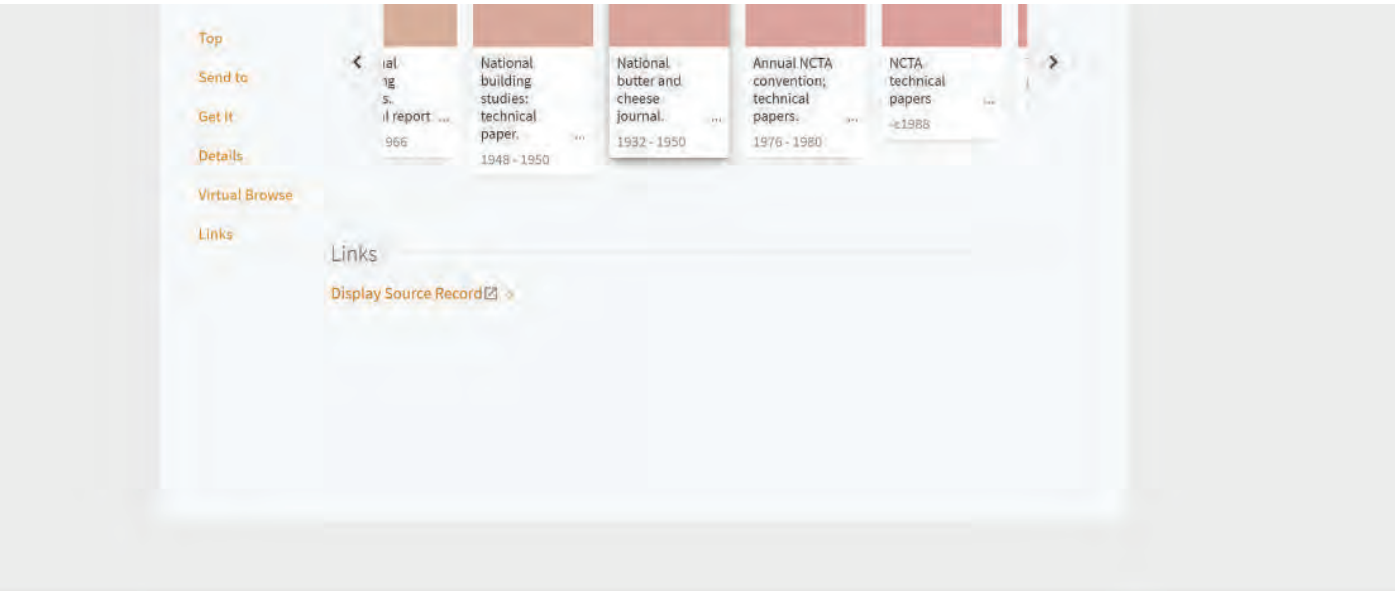
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An Efficient Digital Modulation Scheme for Multimedia Transmission on the Cable Television Network

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Information Systems Laboratory
Stanford University
Stanford, California 94305-4055

Abstract

We present a comparison between the performances of single-carrier modulation with equalization and multicarrier modulation on simulated cable television (CATV) channels. Simulations indicate that for a given data rate, the complexity of multicarrier is significantly lower than that of a single-carrier system. Furthermore, multicarrier is able to reduce the effects of various distortions on a CATV network, including microreflections and interference from external signals such as amateur radio, with a reasonable computational complexity while achieving information bit rates on the order of 80 Mbits/s.

Introduction

The feasibility of offering high-speed interactive data services to customers on CATV networks or similar broadband coaxial networks is currently being investigated by a number of service providers. With over 92% of the homes in the United States passed by cable, the CATV network is a potential supplier of these interactive data services. However, there are several electrical transmission problems that must be overcome before these services can be supplied reliably over CATV networks.

Presently, CATV networks are generally simplex broadcast tree- or star-structured networks. However, these networks can be converted for duplex service, as some already have been, by replacing amplifier/repeater segments with so-called "diplex" filters and amplifiers that separate the downstream frequencies (50-550 MHz) from upstream frequencies (5-40 MHz) for interactive transmission. Some CATV networks can also have high-frequency attenuation reduced by the installation of equalizing diplex amplifiers that can boost the usable spectrum to 1 GHz. Even after such installation, however, the network operator finds that only some channels are available for new digital services. Consequently, the deployment of digital services is likely to be incremental and to demand high spectral efficiency in those channels allocated for the new services.

The transmission of digital signals over the CATV network is complicated by two general effects. First, the hardware in CATV networks is not ideal. Taps, amplifiers, and splitters can all cause signals to be reflected at their insertion points. In particular, splitters in subscriber homes are known to have poor isolation characteristics. The effect of reflected signals on the frequency transfer characteristic of a CATV channel is passband ripple, which is known to cause "ghosting" in received analog signals. The effects of rippling on digital signals, however, are more severe. Variations in a channel's frequency response cause successively transmitted symbols to interfere with one another, an effect known as intersymbol interference (ISI). Depending on the absolute deviations of the channel magnitude response (which are determined by the magnitudes of impedance mismatches on a CATV system) and the frequency with which those deviations occur in the frequency response (which depends on the length of coaxial cable between mismatches), a given symbol could interfere significantly with a large number of adjacent symbols. Without some scheme to combat ISI, a receiver would make detection errors. In turn, the detection errors could disable, for example, a digital video

*This work was supported by NSF contract number NCR-9203131, JSEP contract number NCR-9203131, NASA contract number NAG2-842, and an NSF Graduate Fellowship.

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decoder, resulting in a loss of the signal. Consequently, a robust digital transmission technique for multimedia signals must alleviate the ISI caused by CATV channels if reliable transmission is to be achieved.

A second source of signal degradation in CATV networks is interference from other signals. For example, leaks in a CATV network caused by poorly shielded consumer devices or system hardware allow amateur radio (ham) signals to enter the CATV system. Because the frequency spectrum allocations for CATV and ham overlap, receivers on leaky CATV networks can tune interfering ham signals along with the desired signals. As a result, the received signal is degraded. Furthermore, the bandwidth of ham signals can vary from fewer than 100 Hz to several megahertz.[1] In addition, the duration, spectral location, and severity of ham interferers can vary. As a result, an effective digital transmission scheme must be able to maintain a desired performance level in the presence of interfering signals.

In the next section, we discuss two candidate techniques for multimedia transmission on the CATV network: single-carrier quadrature amplitude modulation (QAM) with equalization and multicarrier modulation. Subsequently, we present a simulated channel, and we compare the performances of the single-carrier and multicarrier systems on this channel. Our results indicate that for a fixed system throughput, the computational complexity of the multicarrier system is significantly less than that of the single-carrier system. Next, we simulate a ham interfering signal and investigate its effect on the achievable data rates and system complexities. Simulations show that a slightly more complex multicarrier system achieves bit rates and data rates only slightly lower than those achievable on the "clean" channel. In contrast, the single-carrier system requires an enormous increase in complexity to achieve a data throughput comparable to the multicarrier system's.

Background

Although numerous digital transmission techniques exist for transmitting digital signals on bandlimited channels, given a finite-complexity constraint and the desire to achieve high throughput with little latency, there are two practical options: single-carrier quadrature amplitude modulation (QAM) with equalization and multicarrier modulation. In QAM, symbols are decoded one by one in the receiver. Because practical channels cause ISI, an equalizer is used to reduce the ISI, thereby improving the performance of the system with a fixed complexity. Equalization is, however, an inherently suboptimal detection method for practical channels. Furthermore, equalizers do not perform well on channels with significant deviations in their frequency response magnitudes. As a result, we investigate multicarrier modulation for digital transmission over CATV networks.

In multicarrier modulation, a channel is divided into N equal-bandwidth subchannels, each with its own carrier, such that the frequency response is roughly constant across each subchannel. The resulting subchannels are approximately memoryless if N is large enough. *Discrete multitone modulation (DMT)*, a common form of multicarrier modulation, makes the subchannels exactly independent and memoryless in the white Gaussian noise case by using the basis vectors of the inverse fast Fourier transform (IFFT) as the subchannel carriers and adding a *cyclic prefix* to each symbol. The cyclic prefix is a block of deterministic data that is used to "clear" each subchannel after every symbol period, and it is discarded at the receiver prior to reconstructing the data stream using an FFT. The length of the cyclic prefix must be sufficient to ensure that blocks of data from one symbol period to the next do not interfere with each other. Specifically, if the length of the channel impulse response is $\nu + 1$, then the length of the cyclic prefix must be ν. Because each transmitted block must have a cyclic prefix to be transmitted over any non-ideal channel, a portion of every block is wasted by the inclusion of the cyclic prefix. Therefore, one goal in the design of a multicarrier system is to minimize the percentage of each block wasted by transmitting the cyclic prefix. For any fixed channel impulse response, the percentage of each block lost to the cyclic prefix decreases as the FFT/IFFT size (which is $2N$)[1] is increased. The penalty for the increased FFT/IFFT size is an increase in system complexity. This relationship will be demonstrated in detail in the next section.

In contrast to traditional frequency-division multiplexing (FDM) techniques, multicarrier modulation does not constrain the number of bits per subchannel

[1] A $2N$-point complex-to-real IFFT is required in the transmitter to ensure that the signal applied to the channel is real.

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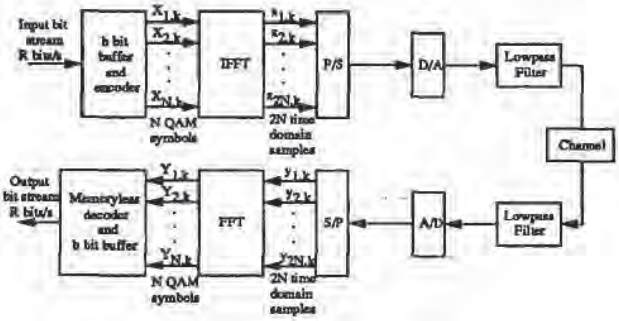


Figure 1: DMT block diagram

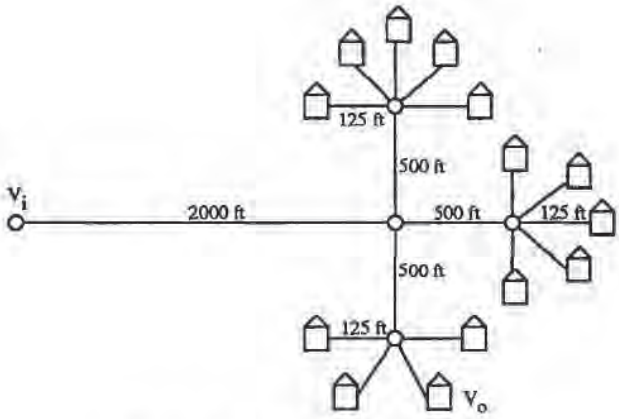


Figure 2: CATV system diagram

to be equal for all subchannels. Instead, bits are originally assigned to subchannels just after training during system initialization in direct proportion to the subchannel signal-to-noise ratios. As a result, subchannels that suffer from little attenuation and/or little noise carry the most bits, while subchannels that are severely attenuated and/or very noisy might not carry any bits. This property can be used to alleviate the problems caused by both frequency-domain ripple and interferers such as ham radio signals. Because the bit distribution is continuously updated during transmission as the receiver sends the required information to the transmitter on secure overhead channels, even severe and unpredictable interference like ham can be tolerated by a multicarrier system. If the noise on a subchannel becomes severe while the system is in use, the transmitter simply assigns fewer or no bits to that subchannel while the noise persists. Each subchannel then supports its own QAM constellation, and, because the subchannels are essentially independent and memoryless, a memoryless detector is used for each in the receiver. As a result, no equalizer is required in the multicarrier receiver. Figure 1 shows a block diagram of the DMT transmitter and receiver. For more information on multicarrier modulation and DMT, see [2], [3], [4], [5], and [6].

Simulations

In this section, we describe our simulated channel model and discuss how well our model approximates actual CATV channels. We then use our simulated channel to compare the performances, in terms of the computational complexity required to support a given throughput, of multicarrier systems and single-carrier systems with equalization. Finally, we modify our simulated channel to determine the effects of interference from amateur radio signals or other comparatively narrowband signals on the two transmission systems.

CATV Channel Model

To enable us to quantify the performances of both single-carrier and multicarrier modulation on CATV channels, we computed a "typical" channel frequency response using the system configuration shown in Figure 2.[2] Because most of the degradations to CATV signals are caused by "leaky" hardware in subscriber drops, we have only modeled the portion of the cable system that is nearest to subscriber homes. The system is modeled as 1/2" copperclad coaxial cable delivering signals through bridge taps to fourteen homes. We have assumed that both source and termination impedances are 75Ω. Since the upstream frequency allocation in most CATV systems is from 5-40 MHz, and we are trying to determine the viability of transmitting bidirectionally on the CATV network, we selected the 6-MHz slot from 30-36 MHz as our simulated channel. The frequency response magnitude of this channel is shown in Figure 3. In computing the frequency response magnitude of the channel, we have assumed the presence of a gain element that brings the maximum magnitude to 0 dB. We note that our channel meets the FCC's technical specifications for the frequency response of CATV channels.[7] Furthermore, our channel exhibits the frequency-domain rippling that is common

[2]Thanks to Professor D. G. Messerschmitt of the University of California at Berkeley for making his transmission line modeling program available to our research group.

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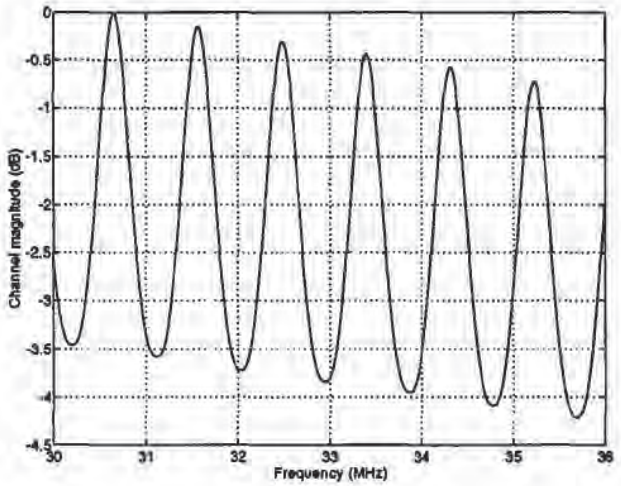


Figure 3: Frequency response magnitude of simulated channel

in actual CATV channels due to leaky consumer hardware such as splitters. Consequently, this channel will help us to illustrate the ability of multicarrier modulation to combat ISI. In addition, by modeling interfering signals as flat nulls in the channel's frequency response, we will be able to illustrate the effect of interferers on the performances of both single-carrier and multicarrier transmission systems.

System Comparison on Simulated Channel

In this section, we investigate the achievable data rates and complexities of both DMT and single-carrier systems for various signal power and channel noise levels. We assume here that no interfering signals, either from within the CATV system or from external sources, degrade the channel.

First, we simulated the DMT system described previously using $2N = 4096$ (2048 subchannels) with our simulated channel and symbol error probabilities of 10^{-7} and 10^{-9}. We assumed a flat noise power spectral density over the 6 MHz bandwidth and a flat power distribution over the subchannels. With these assumptions, we have defined the overall DMT signal-to-noise ratio (SNR) as the ratio of the signal power to the noise power for the subchannels that have 0 dB attenuation. Allocating fractional numbers of bits to subchannels was allowed in the simulation, and a 5.0 dB coding gain was assumed. Table 1 details the

Table 1: Achievable bit rates on simulated channel

DMT SNR (dB)	Bit rate (Mbps)	
	$P_e = 10^{-7}$	$P_e = 10^{-9}$
40	65.256	57.493
43	71.251	63.485
46	77.246	69.479
49	83.243	75.474
52	89.240	81.471
55	95.237	87.467
58	101.23	93.464
61	107.23	99.461

achievable bit rates for various DMT SNRs and the two error probabilities.[3] We see from the data in the table that, for any SNR, the throughput of the system operating with a symbol error probability of 10^{-9} is decreased by approximately 7.8 Mbits/s with respect to the $P_e = 10^{-7}$ system. For either symbol error probability, however, the throughput of the multicarrier system is adequate to support a number of multimedia services. For example, with 49 dB SNR and $P_e = 10^{-7}$, a bit rate of 83.243 Mbits/s is high enough to support 4 20-Mbit/s HDTV signals or 16 5-Mbit/s digitized NTSC signals. We note that a 6-MHz slot on the CATV network could easily be used to transmit a variety of multimedia signals with different bandwidth requirements simply by assigning an appropriate number of subchannels to each signal. Furthermore, because of the flexibility in bandwidth allocation that multicarrier affords, a given 6-MHz slot could serve several users at the same time.

To illustrate the relationship between the channel frequency response magnitude and the number of bits supported by each DMT subchannel, Figure 4 shows the bit allocation for the 49 dB SNR case with a symbol error probability of 10^{-9}. Because both the power distribution and noise power spectral density are assumed to be flat, each subchannel supports a number of bits directly proportional to its frequency response magnitude.

Because the complexity of DMT systems is proportional to the FFT/IFFT size used in the implementation (or, equivalently, the number of subchannels into which the channel is divided), we varied the FFT size to determine the effect of a reduced number of subchannels on the achievable bit rate. With $P_e = 10^{-9}$, the results are given in Table 2. In addition to the achievable bit rates, Table 2 gives the

[3] These data were first presented in [8].

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Table 2: Achievable bit rates with $P_e = 10^{-9}$ as a function of FFT size

DMT SNR (dB)	FFT size ($M = 2N$)					
	4096	2048	1024	512	256	128
40	57.493	57.468	57.420	57.323	57.131	56.752
43	63.485	63.457	63.402	63.294	63.078	62.653
46	69.479	69.448	69.388	69.267	69.028	68.556
49	75.474	75.441	75.374	75.243	74.980	74.461
52	81.471	81.434	81.362	81.218	80.933	80.366
55	87.467	87.428	87.350	87.195	86.885	86.272
58	93.464	93.422	93.338	93.171	92.838	92.178
61	99.464	99.416	99.326	99.147	98.791	98.084
% data	98.6	97.2	94.3	88.7	77.3	54.7
Complexity (MIPS) (assumes $2M \log_2 M$ instructions/FFT)	264	240	216	192	168	144

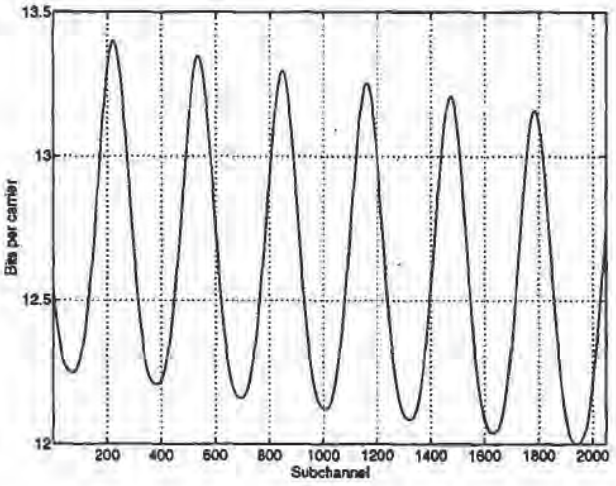


Figure 4: Bit allocation for multicarrier system with 49 dB SNR and $P_e = 10^{-9}$

percentage of each block that is actually data given that the length of our channel's impulse response is approximately $\nu + 1 = 59$ symbol periods. Finally, the complexity, in millions of instructions per second (MIPS), of the multicarrier transmitter and receiver combination is given for each FFT size. The number of instructions required to compute the M-point FFT of a real input sequence is commonly approximated as $2M \log_2 M$, where M is a power of 2. Because we must compute $\frac{2}{MT}$ FFTs per second for a passband multicarrier system operating in a bandwidth of $1/T$ Hz, we find that the complexity in MIPS for a multicarrier system is roughly equal to $\frac{4 \log_2 M}{T}$, where $M = 2N$ in our notation. We have assumed in computing the complexity values in the table that the multicarrier system uses the entire 6 MHz of allocated bandwidth.

The data in Table 2 show that for a given DMT SNR, the maximum achievable bit rate decreases only slightly as the FFT size (or, equivalently, the system complexity) is decreased. However, the percentage of each block that is data decreases more dramatically as the cyclic prefix consumes a larger percentage of each size-$2N$ block. Because we wish to maximize the amount of data transmitted, we cannot arbitrarily decrease the size of our FFT simply because the system throughput remains approximately constant.[4] Consequently, we will constrain the minimum FFT size to be 512, allowing a maximum 11.3% of each transmitted block to be lost to the cyclic prefix. In addition, because the achievable bit rates for $P_e = 10^{-9}$ with $2N = 4096$, 2048, and 1024 are nearly equal, and the data percentages per block are also similar, we have used only the FFT sizes 1024 and 512 with $P_e = 10^{-9}$ in the following analysis.

To compute the complexity of single-carrier systems yielding the same throughputs as the DMT systems, we first computed the data rates and the numbers of bits per symbol that must be supported by each single-carrier QAM system. After adjusting the throughput values according to the data percentages given in Table 2, we find that single-carrier QAM systems must support the bit rates and approximate numbers of bits given in Table 3. To make the comparison between the single-carrier and multicarrier systems more tractable for the reader, we have maintained a column of DMT

[4] In actuality, we could use the smaller FFT sizes (for example, $2N \leq 256$) by implementing a time-domain equalizer (TEQ), the purpose of which is to reduce the required length of the cyclic prefix in exchange for an increase in system complexity. A detailed discussion of the TEQ is beyond the scope of this paper, but interested readers should consult [5] or [9] for details.

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Table 3: Data for single-carrier systems assuming 5.0 dB coding gain

DMT SNR (dB)	Corresponding to $N = 1024$ DMT			Corresponding to $N = 512$ DMT		
	Data (Mbps)	QAM bits	SNR_{rcv}	Data (Mbps)	QAM bits	SNR_{rcv}
40	54.170	9	32.5	50.828	8	29.5
43	59.813	10	35.5	56.123	9	32.5
46	65.461	11	38.5	61.419	10	35.5
49	71.108	12	41.5	66.718	11	38.5
52	76.757	13	44.5	72.016	12	41.5
55	82.406	14	47.5	77.316	13	44.5
58	88.055	15	50.5	82.615	14	47.5
61	93.704	16	53.5	87.914	15	50.5

SNR values. Table 3 also contains the SNRs that must be achieved by single-carrier receivers to support the required numbers of bits. In computing the required receiver SNRs, we have used the rule of thumb that, for $P_e = 10^{-9}$, the first 2 QAM bits require 16.5 dB, and each additional bit requires 3.0 dB. Additionally, we have assumed, as we did for the multicarrier system, a 5.0 dB coding gain.

Finally, we simulated a series of minimum mean-square-error linear equalizers (MMSE-LEs) to compare the single-carrier computational complexities at the various data throughput rates to the complexities of the corresponding DMT systems. Since the complexity of an MMSE-LE is proportional to the number of taps, N_f, in the equalizer, we have computed the approximate numbers of taps required for the MMSE-LEs to achieve the required SNRs given in Table 3. The results are given in Table 4. In Table 4, γ is the "complexity increase factor," and it is the ratio of MMSE-LE complexity to DMT complexity for each DMT SNR and FFT size given in the table. In computing the complexities for the MMSE-LE systems, we have assumed $T/2$ spacing and a transmit symbol rate of 6 Msymbols/s. Therefore, the bandwidths of the single-carrier and multicarrier systems are equal. In addition, the increases in complexity for both the DMT system and the single-carrier system due to the 5.0 dB code are approximately equal. Thus, we have neglected the code in our complexity calculations in both cases. The data in Table 4 show that the complexity of the MMSE-LE system increases with SNR in contrast to the DMT system, the complexity of which is constant for any SNR once the FFT size is selected. Furthermore, the complexity increase factors given in Table 4 show that, for this channel, the complexity of a single-carrier QAM system with an MMSE-LE receiver is at least 2.5 times the complexity of a DMT system operating at the same data rate.

We note that by using a decision feedback equalizer (DFE) instead of a linear equalizer, the complexity of the single-carrier system might be reduced slightly with respect to the MMSE-LE case because only the feedforward filter would need to run at the $T/2$ rate. However, our preliminary results from DFE simulations show that the complexity of a DFE receiver is still at least twice that of the multicarrier system.

System Comparison on Degraded Channel

In this section, we explore the effect of interfering signals on the performances of single-carrier and multicarrier systems. For this simulation, we have simulated a ham interferer of bandwidth 30-kHz located near the middle of our 6-MHz simulated channel. We have assumed that the ham signal causes a -20 dB null in our channel's frequency response magnitude, as shown in Figure 5.

In order to select an appropriate FFT size for the multicarrier system, we computed the channel's impulse response to determine the required cyclic prefix length. Since the impulse response length is roughly 281 samples, we chose $2N = 2048$, implying that approximately 86% of each transmitted block is data. Assuming $P_e = 10^{-9}$ and 5.0 dB coding gain, we then simulated another multicarrier system and found the achievable bit rates on this channel for the same DMT SNRs we used previously. The results are given in Table 5. Comparing the bit rates given in Table 5 with those in Table 2 for the case $2N = 2048$, we see that the effect of the interferer is a minimal decrease in the overall bit rate for each value of DMT SNR. A plot of the bit distribution, shown in Figure 6 for the 49 dB SNR case, indicates that only the subchannels overlap-

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Table 4: MMSE-LE complexity data assuming $T/2$-spaced equalizer

DMT SNR (dB)	Corresponding to $2N = 1024$ DMT			Corresponding to $2N = 512$ DMT		
	N_f	Complexity (MIPS)	γ	N_f	Complexity (MIPS)	γ
40	45	540	2.50	40	480	2.50
43	45	540	2.50	45	540	2.81
46	50	600	2.75	45	540	2.81
49	50	600	2.75	45	540	2.81
52	55	660	3.00	50	600	3.13
55	60	720	3.33	50	600	3.13
58	70	840	3.88	55	660	3.44
61	75	900	4.17	65	780	4.06

Table 5: Achievable bit rates and data rates for $2N = 2048$ DMT system on channel with 30-kHz interfering signal

DMT SNR (dB)	Bit rate (Mbps)	Data rate (Mbps)
40	57.314	49.479
43	63.600	54.647
46	69.291	59.819
49	75.283	64.992
52	81.276	70.166
55	87.270	75.340
58	93.264	80.515
61	99.258	85.689

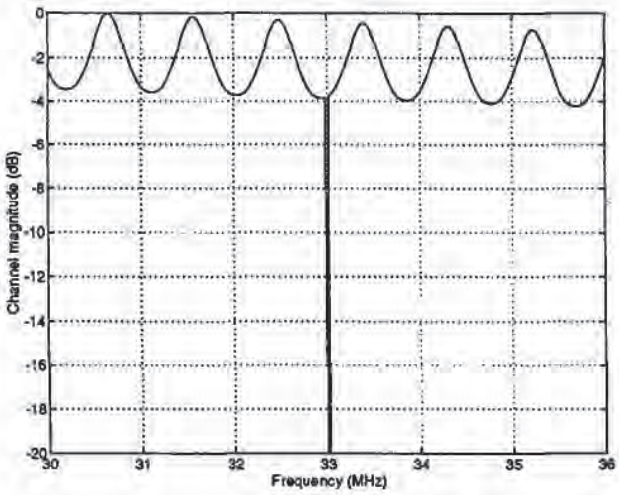


Figure 5: Frequency response magnitude of simulated channel with 30-kHz interferer

ping the interfering signal's bandwidth carry fewer bits than they did in the previous simulations. However, since the channel's impulse response length has increased significantly, the data percentage per block has decreased, yielding lower data rates. Specifically, for each DMT SNR value, the percent decrease in data throughput with respect to the data rates achievable with $2N = 2048$ on the "clean" channel of the previous section is about 11%.

Finally, we computed the required numbers of QAM bits and receiver SNRs and simulated another set of MMSE-LEs that achieve the same data rates as the DMT systems on the degraded channel. The pertinent values are given in Table 6. In computing the data in Table 6, we have again assumed a 5.0 dB coding gain and $T/2$ equalizer spacing. The values of γ in Table 6 clearly illustrate the dramatic increase in complexity required by the MMSE-LE to achieve the same data rates as the multicarrier system. We note again that the complexity of the single-carrier system increases with SNR, while that of the multicarrier system remains 240 MIPS. Furthermore, if the bandwidth of the interfering ham signal were even wider than the 30 kHz we assumed, then the complexity comparison would further favor multicarrier. Equalizers with reasonable numbers of taps are simply not effective on channels with so-called "dead-zones" caused by strong interfering signals. Thus, to achieve data rates on the order of those attainable with a multicarrier system on a channel with a dead-zone, a receiver would need an equalizer with a prohibitive number of taps.

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Table 6: MMSE-LE data for degraded channel

DMT SNR (dB)	Data rate (Mbps)	QAM bits	SNR_{rcv}	N_f	Complexity (MIPS)	γ
40	49.479	8	29.5	160	1920	8.00
43	54.647	9	32.5	165	1980	8.25
46	59.819	10	35.5	170	2040	8.50
49	64.992	11	38.5	195	2340	9.75
52	70.166	12	41.5	225	2700	11.25
55	75.340	13	44.5	250	3000	12.50
58	80.515	13	44.5	250	3000	12.50
61	85.689	14	47.5	260	3120	13.00

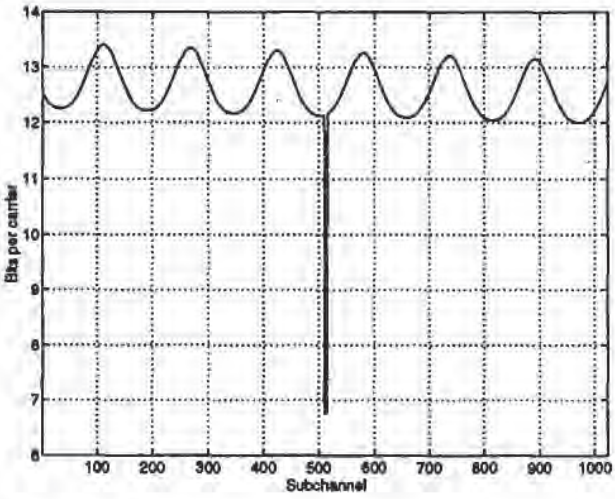


Figure 6: Bit allocation for multicarrier system on degraded channel with 49 dB SNR and $P_e = 10^{-9}$

Conclusion

The results of our simulations indicate that discrete multitone modulation is more computationally efficient than single-carrier modulation with equalization for the transmission of digital data over CATV channels with rippled passbands. Furthermore, DMT can easily adapt to a variety of channel degradations, optimizing the system bit rate for a given channel and complexity. Because system reliability is important for any consumer service, a digital transmission system must maintain a certain level of performance under a wide variety of circumstances. Given our simulation results, multicarrier modulation appears to be better equipped than single-carrier modulation to accomplish this objective.

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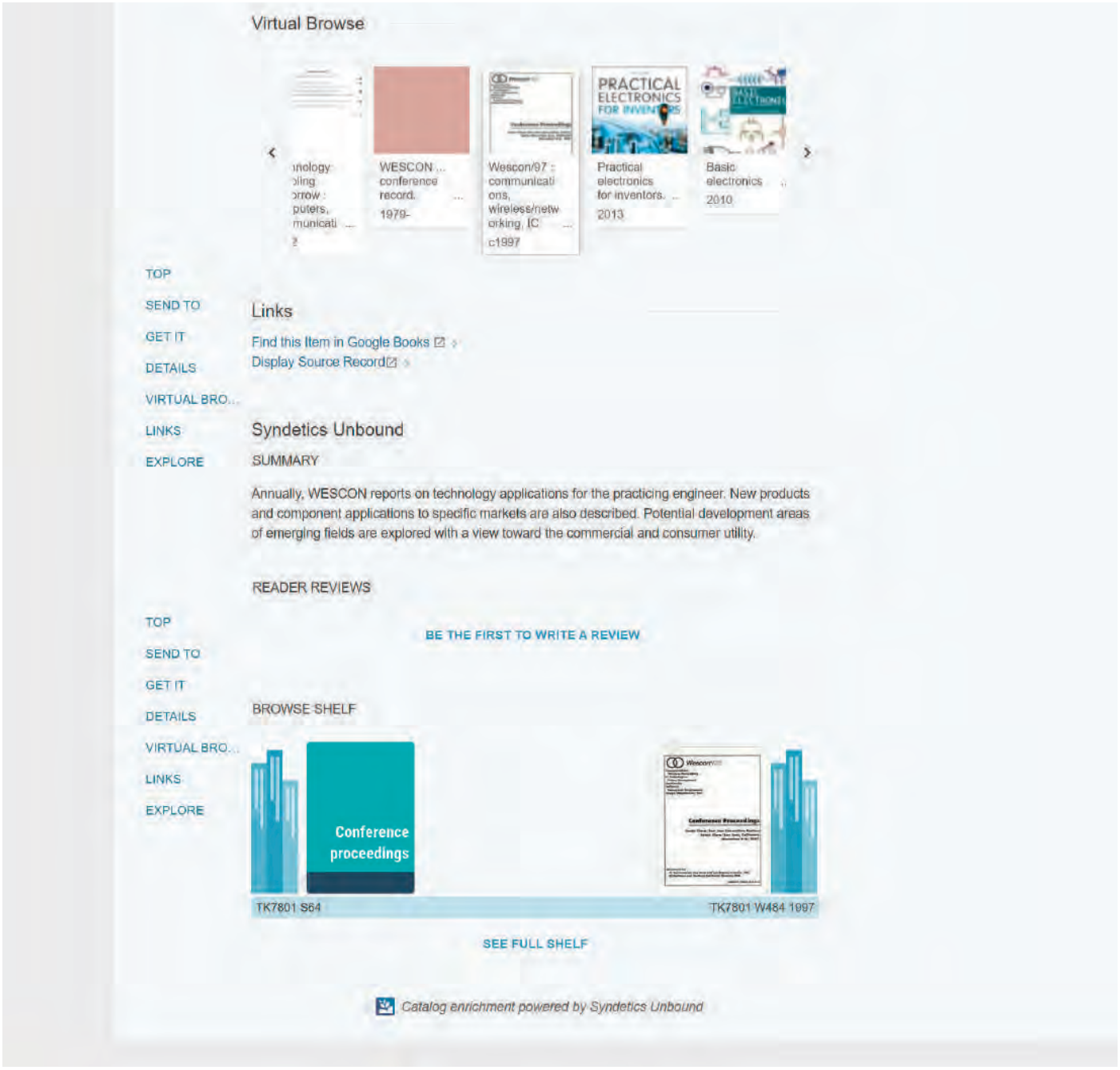
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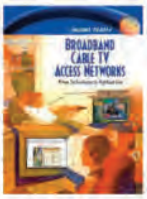
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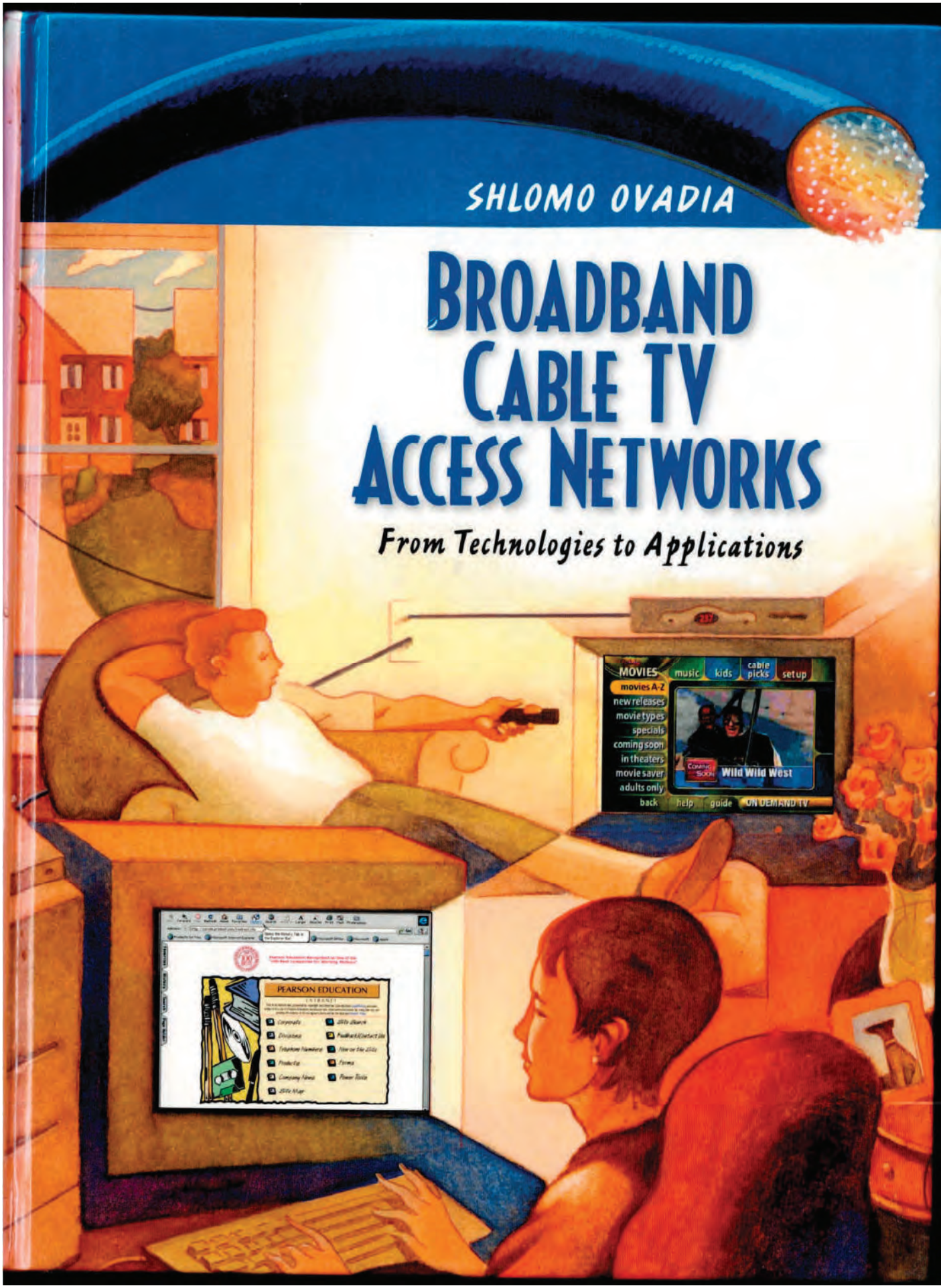
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Ovadia offers in-depth analyses of single-and multiple-wavelength fiber-optics transmission impairments over HFC and DWDM networks, and presents the emerging two-way DWDM network architecture. Finally, he discusses the DOCSIS cable modem protocol, as well as key set-top box applications such as electronic program guides (EPGs), video-on-demand (VOD), Internet-based applications such as e-mail, and e-commerce.

Whether you're an engineer, scientist, cable professional, manager, or investor, if you want to understand where cable is headed, you need *Broadband Cable TV Access Networks: From Technologies to Applications.*

About the Author

SHLOMO OVADIA is a Principal System Architect in the Cable Network Operation business unit at Intel. Prior to joining Intel, he was involved in the development of digital set-top boxes and cable modems as a Principal Scientist at Digital Network Systems, General Instrument/ Motorola. He is a Senior Member of IEEE and has written more than 60 technical publications and as eight patents pending, and his personal biog on of *Who's Who in America: Science and Engi*

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To my parents, Mazal and Moshe,
My wife, Nina, and our children,
Yafit, Shlomit, Binyamin, and Leora

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CHAPTER 7

RF DIGITAL QAM MODEMS

The purpose of this chapter is to explain the design and operation principles of RF cable modulators and demodulators (modems) for transporting digital video and data signals over the HFC network using the quadrature amplitude modulation (QAM) format based on a well-known standard. The principles of design and operation of QAM modems are essential for the understanding of cable modems and digital set-top boxes, which are discussed in Chapter 8. We shall start with a brief review of all the building blocks of QAM modems. In Section 7.2, the MPEG transport framing is discussed, which enables the transmission of MPEG packets. The next four sections will explain each of the four layers in the forward-error-correction (FEC) coding scheme. The FEC layers include Reed-Solomon coding, Trellis coded modulation, interleaving, and randomization. The building blocks, operation, and design of M-ary QAM modulators are discussed in Sections 7.7 and 7.8. Three key building blocks of the QAM receiver, namely, adaptive equalizer, carrier, and timing recovery are explained in Sections 7.9 and 7.10. Two important parameters to test the fidelity of the QAM transmitter are introduced in Section 7.11. Finally, the BER of M-ary QAM signals in a Gaussian channel are derived in Section 7.12.

7.1 RF QAM Modem Building Blocks

Radio frequency (RF) digital transmitters and receivers constitute one of the most important systems in HFC networks to transport digital video and/or data signals from the cable TV headend to the subscriber and back to the headend. In particular, the QAM modulation format was selected as the standard format for cable TV access networks by well-known standard organizations DOCSIS [1], DAVIC [2], and ITU-T J.83 Annex B [3]. Figure 7.1 shows a simplified block diagram of a QAM transmitter and receiver operating over an HFC network. The QAM transmitter portion of the modem consists of a Reed-Solomon (R-S) encoder, a convolutional interleaver, a randomizer or scrambler, a Trellis encoder (TCM), a symbol mapper, an M-ary QAM modulator with differential encoder, and an RF up-converter. The QAM receiver portion of the modem consists of an RF tuner, a QAM demodulator, a symbol demapper, a TCM decoder, a convolutional deinterleaver, an R-S decoder, and a derandomizer (descrambler). All these QAM modem building blocks are explained in the following sections based on the DOCSIS 1.1 protocol [1], which is the primary standard used in the U.S. Figure 7.2 illustrates the FEC section of the QAM modem.

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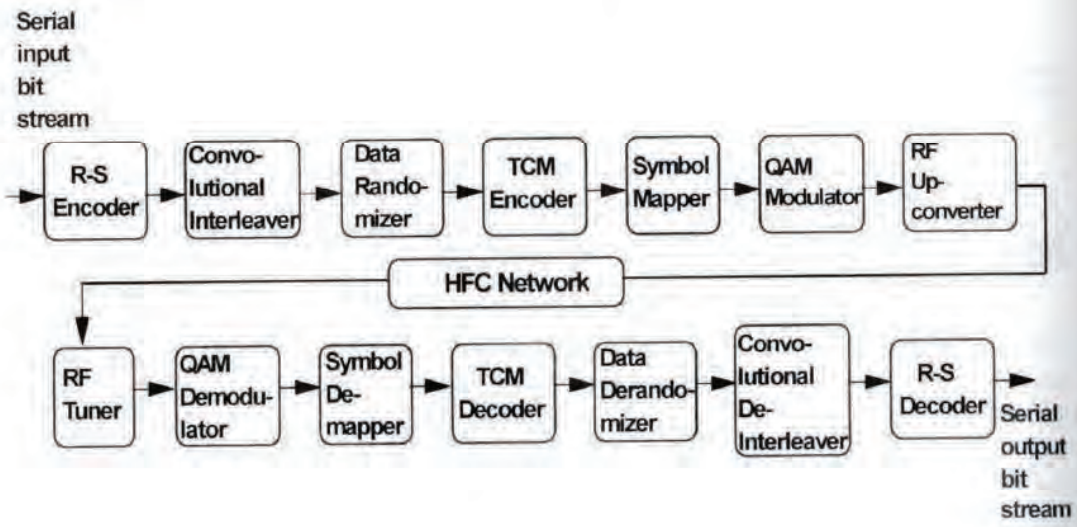


Figure 7.1 A simplified block diagram of RF QAM modem operating over HFC network.

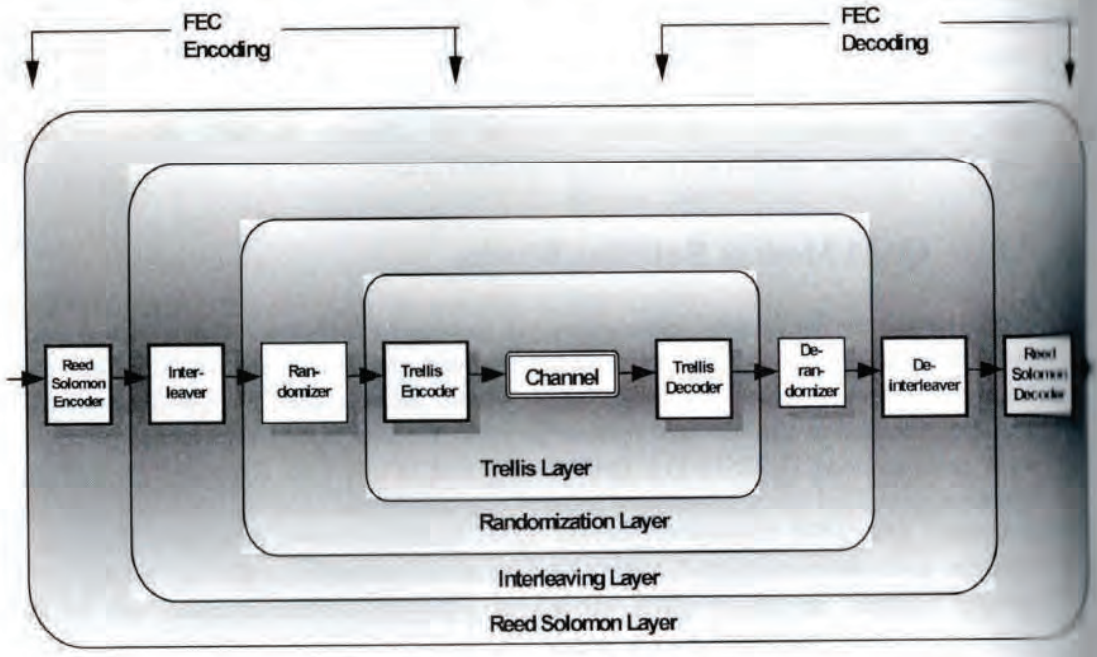


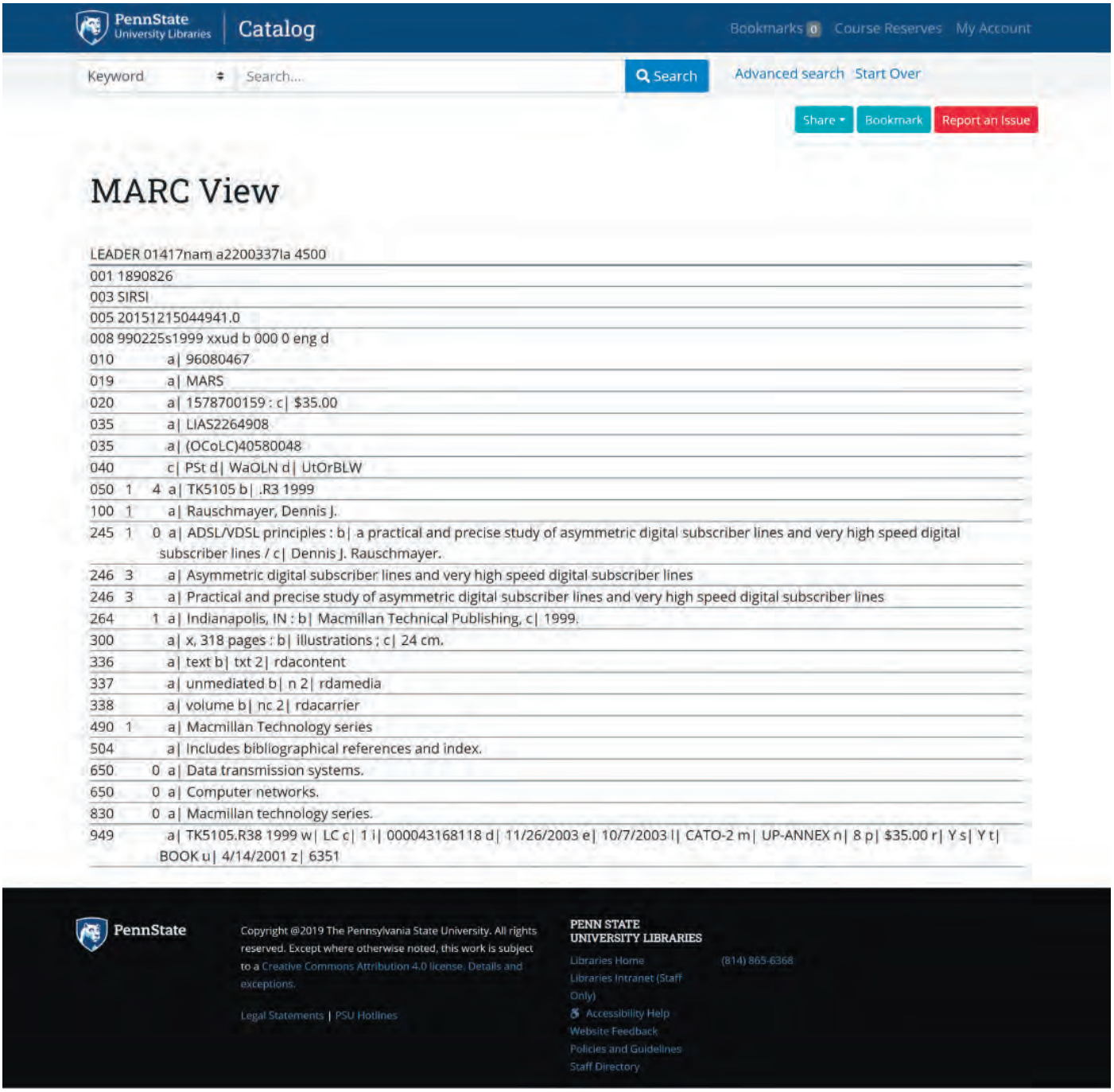
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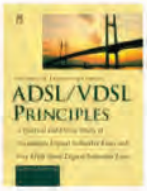
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- Explanations of network aspects involved in implementing networks with subscribers using DSL access techniques, including protocol issues for ATM networks, Ethernet and LAN networks, and PPP and tunneling techniques.

With the detailed and comprehensive information provided by a noted expert in ADSL/VDSL technologies, the communication and networking engineer will be able to understand and successfully implement ADSL/VDSL technologies. *ADSL/VDSL Principles* provides practical explanations and discussions for the casual reader as well as technical details for the more advanced reader in the following areas:

- The outside plant
- Crosstalk analysis
- ADSL and VDSL modulation
- Protocol schemes for access networks

Dr. Dennis J. Rauschmayer received a B.S. degree (summa cum laude) in electrical engineering from Wilkes University, an M.S.E.E. degree from George Washington University, and a Ph.D. in electrical engineering from Temple University.

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Dr. Rauschmayer is an active member of ANSI Working Group T1E1.4, ITU-T, and the ADSL Forum, making numerous contributions assisting in the effort to standardize ADSL and VDSL technologies.

Dedication

To Jen

—for every single smile—

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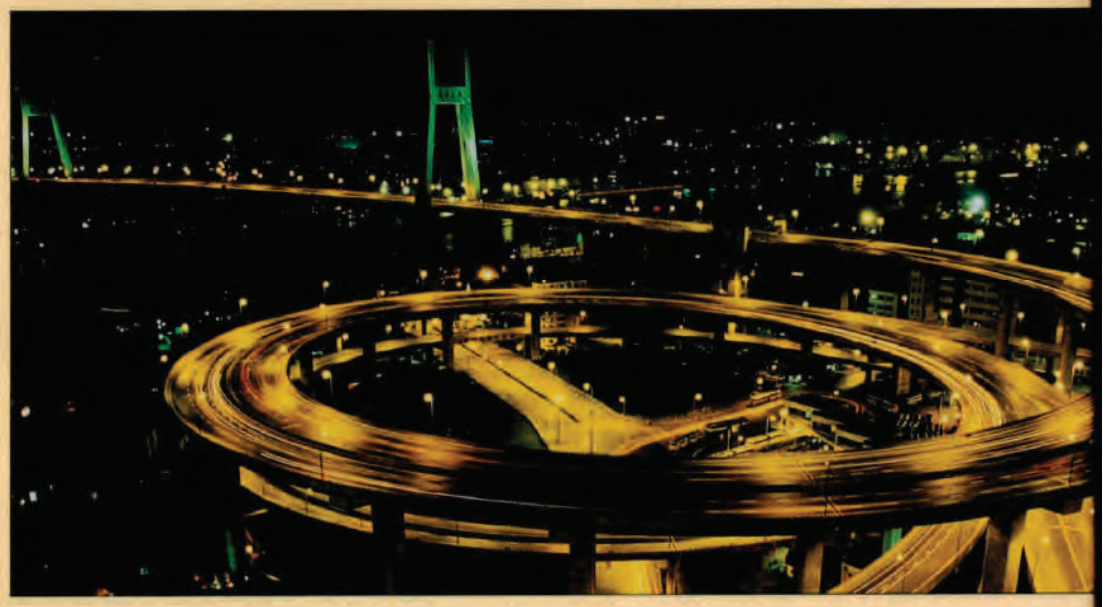
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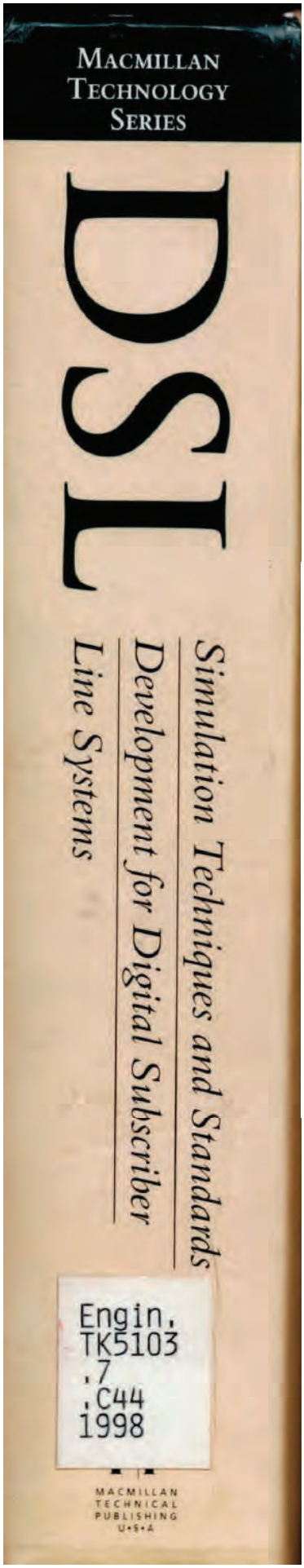
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Digital Subscriber Line technology heralds the age of digital communication, providing a faster, more efficient method of transmitting data over regular telephone lines. The widespread adoption of DSL technology increases the demand for subject-specific, in-depth knowledge of this breakthrough in digital communication. *DSL: Simulation Techniques and Standards Development for Digital Subscriber Line Systems* arms the communications and networking engineer with the quintessential information for implementing DSL systems, including:

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