

**M
TP**
MACMILLAN
TECHNOLOGY
PUBLICATION
DIVISION



MACMILLAN TECHNOLOGY SERIES

ADSL/VDSL PRINCIPLES

A Practical and Precise Study of

Asymmetric Digital Subscriber Lines and

Very High Speed Digital Subscriber Lines

Dr. Dennis J. Rauschmayer



ADSL/VDSL PRINCIPLES

*A Practical and Precise Study of
Asymmetric Digital Subscriber Lines and
Very High Speed Digital Subscriber Lines*

WITHDRAWN



Copyright 1998
YOKOHAMA BAY BRIDGE
Yokohama, Japan
The Stock Market

Opened in 1989 as the gateway of the Port of Yokohama, the Yokohama Bay Bridge plays important roles in both waterfront development of the Bay of Tokyo and relaxation of the traffic situation of Yokohama City. A cable braced bridge of double girders with a 460 meter span between towers (total length of 860 meters), the Yokohama Bay Bridge is the second largest of its type in the world. The bridge is accented with a pedestrian walkway on the underbelly, which extends to an observation deck, called the Sky Walk, that offers breathtaking views of the harbor.

ADSL/VDSL PRINCIPLES:

*A Practical and Precise Study of Asymmetric Digital Subscriber
Lines and Very High Speed Digital Subscriber Lines*

Dr. Dennis J. Rauschmayer

**M
TP**
MACMILLAN
TECHNICAL
PUBLICATIONS
1999

ENGR.
004.6
R193a
1999

ADSL/VDSL Principles

By Dr. Dennis J. Rauschmayer

Published by:
Macmillan Technical Publishing
201 West 103rd Street
Indianapolis, IN 46290 USA

All rights reserved. No part of this book may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or by any information storage and retrieval system, without written permission from the publisher, except for the inclusion of brief quotations in a review.

Copyright © 1999 by Macmillan Technical Publishing
Printed in the United States of America 1 2 3 4 5 6 7 8 9 0
02 01 00 99 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Library of Congress Cataloging Number: 96-80467

ISBN: 1-57670-015-9

Universal Product Code: 619472001592

Warning and Disclaimer

This book is designed to provide information about Digital Subscriber Line technology. Every effort has been made to make this book as complete and as accurate as possible, but no warranty or fitness is implied.

The information is provided on an "as is" basis. The authors and Macmillan Technical Publishing shall have neither liability nor responsibility to any person or entity with respect to any loss or damages arising from the information contained in this book or from the use of the disks or programs that may accompany it.

Trademark Acknowledgments

All terms mentioned in this book that are known to be trademarks or service marks have been appropriately capitalized. Macmillan Technical Publishing cannot attest to the accuracy of this information. Use of a term in this book should not be regarded as affecting the validity of any trademark or service mark.

DEVELOPMENT EDITOR

Brad Miser
Christopher Cleveland

PROJECT EDITOR

Dayna Isley

COPY EDITORS

Geneil Brezza
June Waldman

TECHNICAL REVIEWER

Jacky Chow

TEAM COORDINATOR

Amy Lewis

MANUFACTURING COORDINATOR

Brook Farling

BOOK DESIGNER

Anne Jones

COVER DESIGNER

Sandra Schneider

COVER PRODUCTION

Aren Horvill

DIRECTOR OF PRODUCTION

Larry Klein

PRODUCTION MANAGER

Laurie Casey

GRAPHICS IMAGE SPECIALIST

Oliver Jackson

PRODUCTION TEAM

Louis Porten, Jr.

INDEXER

Brent Davis

PROOFREADER

Mary Ellen Stephenson

Acknowledgments

Writing this book was a great experience. Along the way, interactions with many of the people working on the standardization, design, and development of high-speed communications over copper increased my knowledge of the subject matter tenfold. I tip my hat to these engineers. This field truly has a bright future.

I must extend my thanks to the many folks who reviewed and contributed creative ideas to this text, including Chuck Stanski, Jeremy Nightingale, Debbie Wisniewski, and Jack Waller. A special thanks also goes out to Technical Editor Jacky Chow and Development Editor Brad Miser for playing an integral part in the development of this manuscript, as well as to the crew at Macmillan: Chris Cleveland, David Gibson, Tracy Hughes, and Dayna Isley.

Personally, I am indebted to many for the support I've received over the past year, including the fine folks at Pubscum, especially Gerhard Pilcher, and my family—my sisters Eileen, Kathy, Joan, Nancy, Mary, Carol, and Linda; my brothers Joe and Rich; and most especially my mother.

About the Author

Dr. Dennis J. Rauschmayer received a B.S. (summa cum laude) degree in electrical engineering in 1992 from Wilkes University, an M.S.E.E. degree from The George Washington University in 1994, and a Ph.D. in electrical engineering from Temple University in 1997.

From 1992 to 1996, Dr. Rauschmayer was a design engineer with Pulsecum, where he designed voice-band line cards with automatic gain control and adaptive hybrid equalization to optimize performance against voice-band data modems and on-hook data transmission devices. Since 1996 he has been employed as principle scientist, broadband copper access, at Pulsecum. His work includes research, design, and development of high-speed copper access devices as well as network design of systems utilizing xDSL access devices.

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—

OVERVIEW

- 1 Introduction and Motivation, 1
 - 2 Twisted Pair Environment, 23
 - 3 Loop Analysis, 63
 - 4 Power Spectral Densities and Crosstalk Models, 89
 - 5 DSL Theoretical Capacity in Crosstalk Environments, 131
 - 6 DSL Modulation Basics, 157
 - 7 ADSL Modulation Specifics, 207
 - 8 ADSL in WAN Networks, 253
 - 9 VDSL Overview, 283
- Index, 307

TABLE OF CONTENTS

1 Introduction and Motivation	1
<i>Telephone and Data Systems</i>	2
Coexistence	2
Subscriber Lines	4
<i>Motivation for Higher Bit Rates</i>	5
Growth of the PC	5
Bulletin Board Services	6
Internet	6
World Wide Web	6
Internet Service Providers	7
Video on Demand	8
Small Office/Home Office	8
<i>Modem Evolution</i>	9
<i>Why DSL Technology?</i>	10
<i>The Market Demand</i>	11
<i>The DSLs</i>	12
ADSL	13
HDSL	13
HDSL2	14
IDSL	14
MDSL	14
RDSL and RADSL	14
SDSL	15
VDSL	15
<i>Other High-Speed Data Options</i>	15
Cable Modems	15
Wireless Technologies	16
<i>End-to-End System Diagram</i>	16
Customer Interface	16
The POTS Splitter	17
The Twisted Pair	17
xTU-R	17
xTU-C	17
DSLAM	18
NSP Network	18
Line Codes	18
Data Link Framing and Encapsulation	19
Backbone/ATM Cloud	19

<i>ADSL and VDSL Standardization</i>	19
ADSL Standardization	19
VDSL Standardization	22
<i>Summary</i>	22
2 Twisted Pair Environment	23
<i>A Brief History of Twisted Pairs</i>	23
<i>Introduction to Twisted Pairs</i>	25
<i>Differential Mode and Common Mode Signals</i>	25
<i>Two-Wire Full-Duplex Systems</i>	27
<i>Physical Characteristics</i>	28
Cable Bundles	28
Gauges and Line Characteristics	29
<i>Electrical Characteristics of Twisted Pairs</i>	30
Analytic RLCG Models	30
Numeric RLCG Models	31
<i>Transmission Line Parameters</i>	35
Propagation Constant	36
Characteristic Impedance	41
<i>Crosstalk</i>	42
Crosstalk Types	43
Unbalance Models	44
General Unbalance Expression	53
Near-end Crosstalk (NEXT)	53
Far-end Crosstalk (FEXT)	57
<i>Summary</i>	59
<i>Exercises</i>	60
<i>Endnotes</i>	60
3 Loop Analysis	63
<i>ABCD Parameters</i>	63
ABCD Parameters of a Lumped Impedance	65
ABCD Parameters of a Uniform Twisted Pair	66
<i>Bridged Taps</i>	70
<i>Loop Analysis</i>	71
<i>Input Impedance, Transfer Functions, and Insertion Loss</i>	72
<i>Basic Loop Configurations</i>	76
ADSL Loops	76
VDSL Loops	82

<i>Summary</i>	86
<i>Exercises</i>	86
<i>Endnotes</i>	87
4 Power Spectral Densities and Crosstalk Models	89
<i>Introduction</i>	90
<i>Crosstalk Equations</i>	91
<i>Number of Crosstalkers</i>	92
<i>Types of Disturbers</i>	92
ISDN and HDSL	94
T1 Lines	99
DMT ADSL (Downstream)	104
DMT ADSL (Upstream)	109
CAP/QAM ADSL	112
VDSL PSDs	121
Summary of PSDs	123
<i>NEXT and FEXT Expressions</i>	123
NEXT Disturbers	124
FEXT Disturbers	127
<i>Summary</i>	128
<i>Exercises</i>	129
5 DSL Theoretical Capacity in Crosstalk Environments	131
<i>A Review of Capacity</i>	132
Entropy and Information	132
Gaussian Channels	135
Channels with Memory and Interference	136
<i>Framework for Capacity Calculations for ADSL and VDSL</i>	141
<i>ADSL Capacities</i>	142
Loop Capacities with Identical Crosstalk	142
Comparison of Different Types of Crosstalk	143
Industry Standard Loop and Crosstalk Configurations	145
<i>VDSL Capacities</i>	145
<i>Usable Frequencies on Crosstalk Channels</i>	147
<i>Summary</i>	150
<i>Exercises</i>	150
<i>Endnotes</i>	151
<i>Appendix 5A</i>	152

6 DSL Modulation Basics	157
<i>Modulation/Demodulation Blocks</i>	158
QAM Modulation	158
CAP Modulation	164
Multitone Modulation	166
<i>Forward Error Correction</i>	172
Reed-Solomon Coding	173
Convolution Codes	174
<i>Interleaving</i>	182
Block Interleaving	182
Convolutional Interleaving	184
<i>Scrambling</i>	185
<i>Equalization</i>	187
Folded Spectrums	189
Linear Equalization	191
Decision Feedback Equalization	194
Tomlinson-Harashima Precoding	199
Frequency-Domain Equalization	201
<i>Shaping</i>	203
<i>Summary</i>	203
<i>Exercises</i>	203
<i>Endnotes</i>	204
7 ADSL Modulation Specifics	207
<i>DMT ADSL Systems</i>	207
Transmitter and Receiver Blocks	209
DMT ADSL Overhead	228
ADSL Reduced Overhead Modes	233
Physical Layer Training	235
ATM over ADSL	240
<i>CAP/QAM ADSL Systems</i>	240
<i>Summary</i>	249
<i>Exercises</i>	249
<i>Endnotes</i>	250
8 ADSL in WAN Networks	253
<i>Protocol Basics</i>	254
Ethernet	255

IP	256
TCP	263
ATM	263
PPP	265
Tunneling	266
<i>End-to-End Players</i>	268
Users	269
Network Access Providers	269
Network Transport Providers	269
Network Service Providers	270
ILECs and CLECs	270
<i>Architectures for DSL Networks</i>	270
Bridging Architectures	270
ATM End-to-End Architectures	273
Tunneling Architectures	276
Premise Network Considerations	278
<i>Summary</i>	280
<i>Exercises</i>	280
<i>Endnotes</i>	280
9 VDSL Overview	283
<i>VDSL Deployment Locations</i>	283
Crosstalk Issues	286
RFI Issues	288
<i>VDSL Requirements</i>	291
Rate and Reach Goals	291
Frequency Allocation	292
<i>Modulation Methods for VDSL</i>	295
TDD Approaches	295
FDD Approaches	302
<i>VDSL in WAN Networks</i>	304
Video Services	304
Data Services	305
The Full-Service Network	305
<i>Summary</i>	305
<i>Endnotes</i>	305
Index	307

Introduction and Motivation

In this chapter:

- Overview of this book
- Basic discussion of the outside plant
- Motivation for higher bit rates
- Introduction to DSL technologies

This book discusses networks capable of delivering high-speed data to all end users. Specifically, the book discusses having widespread users connected to the network using traditional telephone lines with access rates in excess of 1 Mbps. Digital Subscriber Line (DSL) technologies, a family of relatively new and exciting high-speed access technologies using ordinary telephone lines, are especially well suited for the access portion or "on ramp" of such a network.

The principles of two specific DSL technologies, *Asymmetric Digital Subscriber Line* (ADSL) technology and *Very High Speed Digital Subscriber Line* (VDSL) technology, are the primary focus of this book, along with networks to which they allow access. ADSL provides an end user with data rates up to 8 Mbps in one direction and up to 800 Kbps in the other. VDSL provides even higher speeds as well as asymmetric or symmetric operation. This book presents in-depth discussions of ADSL and VDSL as well as how networks are designed to use them. Background discussion and theory are given for the issues faced by DSL technologies and the fundamental performance limits that can be achieved. Most of the discussions in this book are explained in terms suitable for both technical and nontechnical readers. In addition, detailed theory and extensive equations are provided for those who want to dive more deeply into the subject matter.

The book is logically divided into three main sections. The first section deals with the background necessary to understand the challenges and limits of DSL technologies. This section includes Chapter 1 through Chapter 5. Chapter 1 provides a basic introduction and motivation explaining why DSL technologies are important to widespread network access. Chapter 2 discusses physical and electrical characteristics of *twisted pairs* (telephone wires), including electrical and physical properties, and it discusses the basics of *crosstalk*. Chapter 3 continues this discussion by presenting tools used to analyze any type of twisted pair. Chapter 4 focuses on several different types of DSL technologies and the *Power Spectral Densities* (PSDs) used by each. From this, the crosstalk results of Chapter 2 are expanded to show mathematical models of how different technologies interact with one another. Chapter 5 takes this one step farther by combining these effects with the tools from Chapter 3 to predict the theoretical limits of performance of ADSL and VDSL.

The second part of the book deals with ADSL and consists of Chapter 6 through Chapter 8. Chapter 6 discusses, in general terms, the different blocks often present in DSL transmitters and receivers; the material in Chapter 6 is applicable to ADSL and VDSL as well as many other types of communications systems. Chapter 7 is dedicated to different types of ADSL transmitter and receiver systems. The specific implementations of the blocks discussed in Chapter 6 are explained. Real-world insight and issues are provided. Finally, Chapter 8 discusses how ADSL is integrated into *wide area networks* (WANs). Higher layer protocol issues are discussed as well as several network implementations.

The final part of the book deals with VDSL and consists of Chapter 9. There, candidate VDSL implementations (which are still under development) are discussed as well as some issues above and beyond ADSL. Finally, a brief discussion of possible VDSL WAN networks is provided.

Telephone and Data Systems

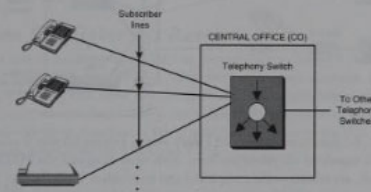
In the modern world, a telephone in every home and every building—and sometimes in every room—is the norm. This is relevant to DSL technology in that in each instance the telephone is connected to a pair of wires (or copper pair) that run out of the building and somewhere within the next 20,000 feet or so connect into telephone switching equipment. (This copper pair is also known as the *subscriber line*.) Thus, every home and building already has a physical means through which data can pass.

Coexistence

Figure 1.1 shows a typical section of the telephone system. The copper loops, or subscriber lines, could be serving a group of homes, an apartment building, an office building, or more generically, a subscriber. Common devices at the subscriber end of the subscriber line

include telephones, fax machines, and voice band modems. Generically, these will be referred to as *Plain Old Telephone Service* (POTS) devices.

Figure 1.1 A typical example of subscriber lines and a Central Office (CO) housing a telephone switch.



The telephone switching equipment allows one end user to call another end user. Although the links between the telephone switches are typically high-bandwidth optical fibers, the links must be capable of serving many users simultaneously, and so each end user can only use a small portion of the data bandwidth. Furthermore, the switching equipment is designed to handle only small amounts of bandwidth per end user. Typically, the bandwidth available for POTS spans from about 200 Hz to around 3200 Hz and has a capability of carrying a maximum of 64 Kbps.

Now consider switching devices and terminal devices designed and optimized to handle large amounts of data rather than only voice signals for each end user. Further, consider that this new equipment should use the same subscriber lines that the telephone system previously used. Finally, add the criteria that this new system and the original telephone system both use the same subscriber line simultaneously without interfering with one another. This is the basis of DSL technology and is shown in Figure 1.2.

DMT ADSL (Downstream)

For ADSL separate models are necessary for the upstream and downstream directions as a result of different data rates and modulation parameters for each direction. Several methods can be used to find the downstream PSD of a DMT-based ADSL system. One reasonable method is to simply find the theoretical PSD for DMT modulation. A second method is to make an assumption about how the transmitter is implemented and create a mathematical model similar to those for 2B1Q and T1. Both of these methods have some shortcomings. The former is not always applicable to practical implementations. The latter assumes a type of implementation that can vary depending on the actual design. Neither method adequately addresses out-of-band energy. The value, however, of these models is that they form a good basis on which to specify a generic PSD mask. An implementation can then be engineered to keep the actual output power spectrum within the PSD mask. This section looks at and compares these two methods and then compares the standard DMT PSD mask for the downstream direction to the models.

Later chapters show that an ADSL DMT symbol is merely a number of sign and cosine waves at different frequencies being sent at a baud rate of 4.3125 kHz. The lowest frequency usable is 34.5 kHz, and the highest is 1.104 MHz. All frequency multiples of 4.3125 kHz between these limits are also used. Mathematically, it is correct to say that a sine and cosine wave are sent having a frequency of $n \times 4.3125$ kHz with $n=8,9,\dots,256$. A theoretical way to create a DMT symbol is to create the cosine and sine waves at all the necessary frequencies and then sum them. Eqtn. 4.31 gives the summation for $f_s=4.3125$ kHz.

Eqtn. 4.31

$$s(t) = \sum_{n=8}^{256} (a_n \cos(2\pi n f_s t) + b_n \sin(2\pi n f_s t)) \quad \text{for } 0 \leq t < \frac{1}{f_s} \quad (4.31)$$

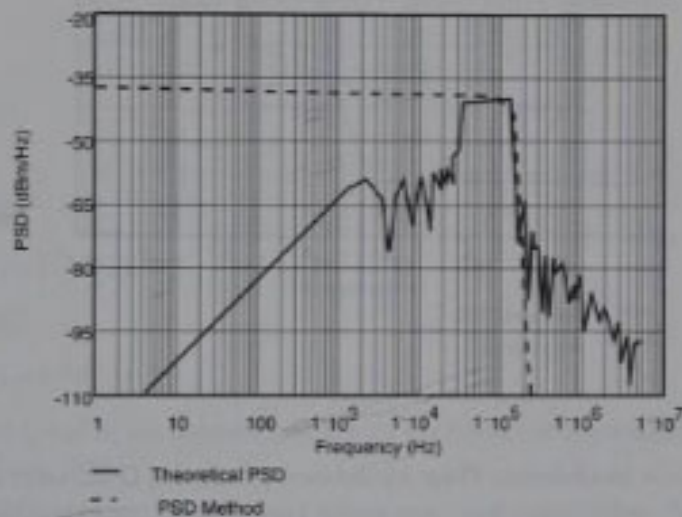
For a single cosine and sine summation in Eqtn. 4.31 (say, for $n=m$), the expression for the power spectrum is derived later in the chapter in detail. Eqtn. 4.32 gives a generalized version of this PSD, representing the PSD due to term m of Eqtn. 4.31.

Eqtn. 4.32

$$\begin{aligned} PSD_m &= \frac{4V^2 \sin^2(\pi T(f - mf_s))}{\pi^2 ZT(f - mf_s)^2} \\ &= K_m \frac{\sin^2(\pi T(f - mf_s))}{\pi^2 (f - mf_s)^2} \end{aligned}$$

The resulting PSD due to the implementation along with the mask defined in Eqtn. 4.42 is shown in Figure 4.16. Overlaid on this figure is the theoretical expression from Eqtn. 4.40.

Figure 4.16 Theoretical and implementation ADSL upstream PSDs with a linear frequency scale and a log frequency scale.



To more fully specify the upstream ADSL PSD, a piecewise continuous mask was created. This mask is based on the masks shown in Figure 4.16 and adds more complete out-of-band specifications. The piecewise continuous mask is shown in Figure 4.17.

One caution about the ADSL upstream and downstream masks is that they continue to evolve. As new services are studied, requests made for the out-of-band PSD regions may be tightened. In some cases, because of implementation problems, loosening of the requirements is proposed. These activities may continue for many years to come.

In Eqtn. 4.59, the terminating impedance Z is 100 ohms, and T is purposely left unspecified. The center frequency f_c is also not specified. The CAP/QAM modem developers have not yet finalized the exact parameters for ADSL lines.

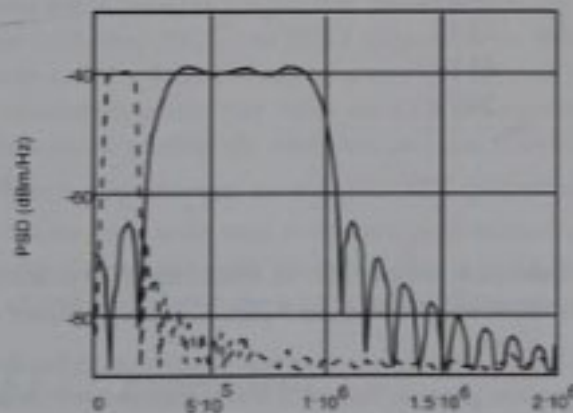
Some candidate values are shown in Table 4.2.

Table 4.2 Candidate Symbol Rates and Bandwidths for CAP/QAM ADSL Signals

Symbol Rate 1/T (ksymbols/s)	Excess Bandwidth (α)	Center Frequency (kHz)	Low-End 3 dB Point (kHz)	High-End dB Point (kHz)
84	0.20	84.0	42.0	126.0
136	0.15	113.2	45.2	181.2
340	0.15	435.5	265.5	605.5
680	0.15	631.0	291.0	971.0
952	0.15	787.4	311.4	1263.4

The first two entries in Table 4.2 are for upstream ADSL, and the rest are for downstream. The PSDs for two of the CAP/QAM implementations shown are given in Figure 4.23.

Figure 4.23 PSDs for various CAP/QAM signals.



VDSL PSDs

Standards for VDSL are still under development; although a PSD requirement has been agreed upon, it is likely to evolve as times goes on. The mask may change drastically depending on the modulation type chosen for VDSL (several modulation candidates exist, including a variation of DMT called "synchronous DMT(SDMT)," a variation of DMT called "zipper," and also CAP- and QAM-based techniques).

One major difference between ADSL and VDSL is that VDSL signals overlap the amateur radio bands as well as several other allocated frequency regions. Even though a VDSL signal is confined to a twisted pair and not radiated from an antenna, at high frequencies the emissions from the twisted pair can be large enough to interfere with receivers of these other services.

This type of emission is commonly referred to as radio frequency interference (RFI) egress. Depending on the region and type of VDSL installation, the RFI egress may or may not be a problem. When it is a problem, to reduce RFI egress, the VDSL PSD will have notches at identified frequency bands. A list of the frequency bands at which the VDSL PSD will need reduction appears in Table 4.3.

Table 4.3 Internationally Recognized Bands That Require PSD Reduction for VDSL

Start Frequency (MHz)	Stop Frequency (MHz)
1.8	2.0
3.4	4.0
7.0	7.3
10.1	10.15
14.0	14.35
18.068	18.168
21	21.45
24.890	24.990
28.0	29.7

Other possible bands needing PSD reduction are under study and may be added to those listed in Table 4.3.

Any type of VDSL modulation must be able to reduce the PSD to acceptable levels in these bands. The PSD mask requirement for VDSL is shown in Figure 4.24.

Similar to the ADSL masks, this mask is piecewise continuous. A requirement to reduce the PSD in the RFI regions given in Table 4.3 is also imposed (but not shown in Figure 4.24). The PSD in these regions must be reduced to -80 dBm/Hz (or lower if desired). Note that the VDSL band is much wider than the bands of any other DSL technology and that the starting point of the passband is above the highest frequency used in ADSL. This arrangement would allow ADSL and VDSL to coexist in a binder group without major interference. An option to allow the VDSL band's lower limit to extend down into the ADSL band is being discussed for situations in which VDSL is deployed, but ADSL is not.

For ideal calculations, the number of subchannels would approach infinity, and the summation in Eqtn. 5.23 would become an integration. For practical performance calculations, however, the summation is adequate. For ADSL, capacity is found with the following variations:

- Different loops with the same noise and interference
- A single loop with different types of crosstalk
- Loop and noise called out in the ADSL standard

For VDSL, a slightly less vigorous examination will be carried out, focusing on the capacity of different VDSL loops under some limited crosstalk noises.

Also, a case study on a loop shows the SNR as a function of frequency and the information-carrying ability at different points in the frequency band of the channel. Note that capacity is independent of the type of modulation scheme used on the twisted pair. How close each modulation method comes to operating at the maximum theoretical rate (capacity) is investigated in later chapters.

ADSL Capacities

For ADSL, the signal power at the input to the channel is simply given by the PSD derived for ADSL. The capacity will be found for both the upstream and the downstream directions of data transmission. For the downstream direction, the capacity summation uses 1,000 points evenly spaced between 30 kHz and 1.106 MHz. These frequencies correspond to the actual usable band of an ADSL signal. Frequencies below 30 kHz are typically not used because of the Plain Old Telephone Service (POTS) underlay, and above 1.106 MHz the PSD for a downstream ADSL signal drops off quickly.

For the upstream direction, the capacity summation uses 1,000 points between 30 kHz and 138 kHz. The PSD of the upstream signal is specified to fall off above 138 kHz, and most usable signal energy is within this frequency range.

Loop Capacities with Identical Crosstalk

To compare the different types of loops, a single crosstalk will be applied to a variety of different loops, and the capacities calculated. In general, the crosstalk will consist of 24 HDSL disturbers and a background AWGN of -140 dBm/Hz. The capacity for each case will be found as well as the theoretical maximum rate of each line with a 6 SNR margin. The SNR margin, or simply margin, is similar to a cushion given for performance. With a 6 dB margin specified, the maximum achievable rate is equivalent to the capacity of a line having noise 6 dB greater than the actual noise (or equivalently, multiplying the SNR by

Industry Standard Loop and Crosstalk Configurations

Some of the standard test loops and test noise configurations appear in Table 5.4. Upstream and downstream theoretical maximum rates with a 6 dB margin are also shown. For the HDSL, ISDN, and T1 NEXT, the crosstalk was injected at the near end for both the upstream and downstream measurements.

Table 5.4 Performance over Different Standard Specified Loops

Loop	Type and Number of Disturbances				Achievable Rates with 6 dB Margin (except where noted)	
	ADSL NEXT And FEXT	HDSL NEXT	ISDN NEXT	T1 NEXT	Upstream (kbit/s)	Downstream (Mbit/s)
T1 601 #7	0	0	24	0	767	4.46
T1 601 #13	0	0	24	0	730	5.39
CSA #4	24	0	24	0	887	10.6
CSA #6	0	20	0	0	889	10.2
Mid CSA (3 dB margin only)	0	0	0	10	2325	12.2
T1 601 #13	0	0	24	0	629	5.80
CSA #4	10	10	24	0	852	9.59
CSA #6	10	10	24	0	824	9.45
CSA #8	10	10	24	0	892	8.85
CSA #6 ¹	0	0	0	4	1821	6.88
Mid CSA	0	0	10	24	1981	9.45

¹ 0 dB margin. Originally, if T1 disturbances were detected, a 6 dB power boost to the downstream PSD was recommended to boost the rate of this configuration. The power boost was dropped because of the added complexity it gave to the analog portion of the ADSL modem. The result shown assumes no power boost.

VDSL Capacities

For VDSL, the capacity of different lines will be found with no crosstalk and then with several different types of disturbers. The loops investigated are the VDSL loops discussed in Chapter 3, and the reduction of capacity due to RFI is disregarded for the time being. The PSD used for the VDSL transmitter is that given in Chapter 4. From 1.1 MHz to 20 MHz, 1,000 equally spaced points approximate Eqn. 5.23. In contrast to the ADSL performance calculations, a single result, rather than an upstream and a downstream capacity, is shown. If VDSL systems employed echo cancellation, one might argue that the calculated rates would be achievable bidirectionally. This discussion assumes, however, that the systems are not echo canceled and that the resultant bit rate must be split between an