EAST Search History

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
S1	53	modem adj diagnost$6	USPAT	OR	OFF	2006/10/12 13:36
S2	8	375/222.ccls. and (modem adj diagnost$6)	USPAT	OR	OFF	2006/10/16 15:23
S3	1	"4385384".pn.	USPAT	OR	OFF	2006/10/12 15:44
S4	2	bilinear adj multiplier	USPAT	OR	OFF	2006/10/12 15:44
S5	9022	375/222.ccls. and (modem adj diagnost$6) amd multicarrier	USPAT	OR	OFF	2006/10/16 15:23
S6	103	375/222.ccls. and ((modem adj diagnost$6) amd (multi adj carrier))	USPAT	OR	OFF	2006/10/16 15:24
S7	2	375/222.ccls. and ((modem adj diagnost$6) and (multi adj carrier))	USPAT	OR	OFF	2006/10/16 15:25
S8	5	"375"/$.ccls. and ((modem adj diagnost$6) and (multi adj carrier))	USPAT	OR	OFF	2006/10/16 15:26
S9	0	"375"/222.ccls. and ((initiat$4 near diagnostic adj mode) and (multi adj carrier))	USPAT	OR	OFF	2006/10/16 15:27
S10	0	"375"/222.ccls. and ((initiat$4 near (diagnostic adj mode)) and (multi adj carrier))	USPAT	OR	OFF	2006/10/16 15:27
S11	0	"375"/$.ccls. and ((initiat$4 near (diagnostic adj mode)) and (multi adj carrier))	USPAT	OR	OFF	2006/10/16 15:27
S12	2	"375"/$.ccls. and ((initiat$4 near (diagnostic adj mode)))	USPAT	OR	OFF	2006/10/16 15:31
S13	1	("6566889").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2006/10/16 15:28
S14	12	("4566100" | "5128619" | "5608643" | "5864602" | "5964891" | "6075821" | "6188717" | "6219378" | "6404774" | "6411678" | "6449307" | "6512789"). PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2006/10/16 15:29
S15	2	"375"/$.ccls. and ((initiat$4 near (diagnostic adj mode)) and modem)	USPAT	OR	OFF	2006/10/16 15:31
S16	0	"375"/227.ccls. and ((initiat$4 near (diagnostic adj mode)) same modem)	USPAT	OR	OFF	2006/10/16 15:32
S17	0	"375"/227.ccls. and ((initiat$4 with (diagnostic adj mode)) same modem)	USPAT	OR	OFF	2006/10/16 15:32
S18	1	"375"/227.ccls. and (((diagnostic adj mode)) same modem)	USPAT	OR	OFF	2006/10/16 15:33
S19	1	"375"/222.ccls. and ((diagnostic adj mode) with trigger)	USPAT	OR	OFF	2006/10/16 15:34

EAST Search History

S20	1	"375"/222.ccls. and ((diagnostic adj mode) same trigger)	USPAT	OR	OFF	2006/10/16 15:50
S21	2	"375"/222.ccls. and (initiat$8 with (diagnostic adj mode))	USPAT	OR	OFF	2006/10/16 15:42
S22	0	"370"/222.ccls. and ((initiat$8 with (diagnostic adj mode)) same modem)	USPAT	OR	OFF	2006/10/16 15:42
S23	1	((initiat$8 with (diagnostic adj mode)) same modem)	USPAT	OR	OFF	2006/10/16 15:43
S24	77	((initiat$8 with (diagnostic adj mode)))	USPAT	OR	OFF	2006/10/16 15:46
S25	15	(initiat$8 with (diagnostic adj mode)) and modem	USPAT	OR	OFF	2006/10/16 15:46
S26	6	"375"/222.ccls. and ((diagnostic adj mode))	USPAT	OR	OFF	2006/10/16 16:16
S27	25	"379"/$.ccls. and ((diagnostic adj mode))	USPAT	OR	OFF	2006/10/16 16:16
S28	1	"379"/$.ccls. and (initiate near2 (diagnostic adj mode))	USPAT	OR	OFF	2006/10/16 16:18
S29	1	"379"/$.ccls. and ((diagnostic adj mode) same CRC)	USPAT	OR	OFF	2006/10/16 16:16
S30	4	"375"/222.ccls. and (initiat$6 near2 (diagnostic))	USPAT	OR	OFF	2006/10/16 16:17
S31	0	"379"/$.ccls. and (initiate near2 (diagnostic) same (transmission adj power))	USPAT	OR	OFF	2006/10/16 16:18
S32	0	"379"/$.ccls. and (initiate near2 (diagnost$6) same (transmission adj power))	USPAT	OR	OFF	2006/10/16 16:18
S33	1	"375"/222.ccls. and (link adj diagnostic)	USPAT	OR	OFF	2006/10/25 10:41
S34	1	("6566889").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2006/10/25 10:41
S35	6	"375"/222.ccls. and (link near diagnos$5)	USPAT	OR	OFF	2006/10/25 10:42
S36	8	"375"/$.ccls. and ((link near diagnos$5) same modem)	USPAT	OR	OFF	2006/10/25 10:44
S37	1	"6636603".pn.	USPAT	OR	OFF	2006/10/25 10:44
S38	0	"10619691"	USPAT	OR	OFF	2006/10/27 06:48
S39	1	"6636603".pn.	USPAT	OR	OFF	2006/10/27 06:48

Day : Friday
Date: 10/27/2006

PALM INTRANET

Time: 07:01:14

Inventor Name Search Result

Your Search was:

Last Name = KRINSKY
First Name = DAVID

Application#	Patent#	Status	Date Filed	Title	Inventor Name
60309630	Not Issued	159	08/02/2001	Multicarrier modulation method using multiple frame synchronization points	KRINSKY, DAVID
60410339	Not Issued	159	09/12/2002	Clipping in multicarrier modulation systems during initialization	KRINSKY, DAVID
60411134	Not Issued	159	09/16/2002	Clipping in multicarrier modulation systems during initialization	KRINSKY, DAVID
60424119	Not Issued	159	11/05/2002	Selecting the MEDLEY PRBS during initialization	KRINSKY, DAVID
09485614	6266348	150	02/11/2000	SPLITTERLESS MULTICARRIER MODEM	KRINSKY, DAVID M.
09573816	6549520	150	05/17/2000	METHOD AND APPARATUS FOR VARYING POWER LEVELS IN A MULTICARRIER MODEM	KRINSKY, DAVID M.
09755173	6658052	150	01/08/2001	SYSTEMS AND METHODS FOR ESTABLISHING A DIAGNOSTIC TRANSMISSION MODE AND COMMUNICATING OVER THE SAME	KRINSKY, DAVID M.
10189212	Not Issued	161	07/05/2002	Splitterless multicarrier modem	KRINSKY, DAVID M.
10613052	Not Issued	30	07/07/2003	Splitterless multicarrier modem	KRINSKY, DAVID M.
10619691	Not Issued	30	07/16/2003	Systems and methods for establishing a diagnostic transmission mode and communicating over the same	KRINSKY, DAVID M.
10635449	Not Issued	30	08/07/2003	Splitterless multicarrier modem	KRINSKY, DAVID M.

09597926	Not Issued	161	06/19/2000	METHOD AND APPARATUS FOR COMMUNICATING WITH MULTIPLE REMOTE TRANSCEIVERS	KRINSKY, DAVID M.
60061689	Not Issued	159	10/10/1997	SPLITTERLESS MULTICARRIER MODULATION FOR HIGH SPEED DATA TRANSPORT OVER TELEPHONE WIRES	KRINSKY, DAVID M.
60174865	Not Issued	159	01/07/2000	MULTICARRIER MODULATION SYSTEM WITH REMOTE DIAGNOSTIC TRANSMISSION MODE	KRINSKY, DAVID M.

Inventor Search Completed: No Records to Display.

Search Another: Inventor **Last Name** KRINSKY **First Name** DAVID Search

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Day : Friday
Date: 10/27/2006
Time: 07:01:29

PALM INTRANET

Inventor Name Search Result

Your Search was:

Last Name = PIZZANO
First Name = ROBERT

Application#	Patent#	Status	Date Filed	Title	Inventor Name
60174865	Not Issued	159	01/07/2000	MULTICARRIER MODULATION SYSTEM WITH REMOTE DIAGNOSTIC TRANSMISSION MODE	PIZZANO, JR, ROBERT E.
09755173	6658052	150	01/08/2001	SYSTEMS AND METHODS FOR ESTABLISHING A DIAGNOSTIC TRANSMISSION MODE AND COMMUNICATING OVER THE SAME	PIZZANO, ROBERT EDMUND
10619691	Not Issued	30	07/16/2003	Systems and methods for establishing a diagnostic transmission mode and communicating over the same	PIZZANO, ROBERT EDMUND

Inventor Search Completed: No Records to Display.

Search Another: Inventor **Last Name** PIZZANO **First Name** ROBERT Search

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Alexandria, Virginia 22313-1450
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APPLICATION NUMBER	PATENT NUMBER	GROUP ART UNIT	FILE WRAPPER LOCATION
10/619,691		2611	0500

Correspondence Address / Fee Address Change

The following fields have been set to Customer Number 62574 on 09/01/2006

- Correspondence Address
- Maintenance Fee Address

The address of record for Customer Number 62574 is:
SHERIDAN ROSS P C
SUITE 1200
1560 BROADWAY
DENVER,CO 80202

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APPLICATION NUMBER	PATENT NUMBER	GROUP ART UNIT	FILE WRAPPER LOCATION
10/619,691		2611	0500

Correspondence Address / Fee Address Change

The following fields have been set to Customer Number 62574 on 08/10/2006

- Correspondence Address
- Maintenance Fee Address

The address of record for Customer Number 62574 is:
JASON H. VICK
SUITE 500
1751 PINNACLE DRIVE
MCLEAN,VA 22102-3833

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10/619,691		2611	0500

Correspondence Address / Fee Address Change

The following fields have been set to Customer Number 62574 on 08/02/2006

- Correspondence Address
- Maintenance Fee Address

The address of record for Customer Number 62574 is:
JASON H. VICK
SUITE 500
1751 PINNACLE DRIVE
MCLEAN,VA 22102-3833

Attorney Docket No. T3653-8765US02

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:

First Named Inventor: KRINSKY, DAVID M. | Art Unit: 2631

Application No.: 10/619,691 | Examiner:

Filed: July 16, 2003 | Confirmation No.: 7134

For: SYSTEMS AND METHODS FOR ESTABLISHING A DIAGNOSTIC TRANSMISSION MODE AND COMMUNICATING OVER THE SAME

* * *

INFORMATION DISCLOSURE STATEMENT

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

Pursuant to 37 C.F.R. § 1.56, and without any assertion as to materiality or prior art effect, the documents listed on the attached Form PTO/SB/08A are hereby cited.

The Commissioner is hereby authorized to charge to Deposit Account No. 50-1165 (T3653-8765US02) any fees under 37 C.F.R. §§ 1.16 and 1.17 that may be required by this paper and to credit any overpayment to that Account. If any extension of time is required in connection with the filing of this paper and has not been separately requested, such extension is hereby requested.

Respectfully submitted,

Date: August 1, 2006

By: ______________________
Jason H. Vick
Reg. No. 45,285

Miles & Stockbridge, P.C.
1751 Pinnacle Drive
Suite 500
McLean, Virginia 22102-3833
(703) 903-9000

#9309436

Please type a plus sign (+) inside this box → +

PTO/SB/08A (08-03)

Approved for use through 07/31/2006. OMB 0651-0031

U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

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Substitute for form 1449A/PTO

INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(use as many sheets as necessary)

Sheet 1 of 1

Complete it Known	
Application Number	10/619,691
Filing Date	July 16, 2003
First Named Inventor	KRINSKY, DAVID M.
Art Unit	2631
Examiner Name	
Attorney Docket Number	T3653-8765US02

OTHER PRIOR ART – NON PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No. [1]	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T[2]
		Cioffi, John M., ADSL Maintenance with DMT, T1E1.4 ADSL Project, Amati Communications Corporation, December 1, 1992, pages 1-14	

Examiner Signature		Date Considered	

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

[1] Unique citation designation number. [2] See attached Kinds of U.S. Patent Documents. [3] Enter Office that issued the document, by the two-letter code (WIPO Standard St.3). [4] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document. [5] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST. 16 if possible. [6] Applicant is to place a check mark here if English language Translation is attached. This collection of information is required by 37 CFR 1.97 and 1.98. This information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 2 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

Electronic Acknowledgement Receipt

EFS ID:	1135854
Application Number:	10619691
Confirmation Number:	7134
Title of Invention:	Systems and methods for establishing a diagnostic transmission mode and communicating over the same
First Named Inventor:	David M. Krinsky
Customer Number:	181
Filer:	Jason Vick/Cherrise Texidor
Filer Authorized By:	Jason Vick
Attorney Docket Number:	081513-334
Receipt Date:	01-AUG-2006
Filing Date:	16-JUL-2003
Time Stamp:	14:17:33
Application Type:	Utility
International Application Number:	

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)	Multi Part	Pages
1	Information Disclosure Statement (IDS) Filed	T3653-8765US02_ids.pdf	78050	no	2

Warnings:					
Information:					
This is not an USPTO supplied IDS fillable form					
2	NPL Documents	NPL_T1E1.pdf	773790	no	14
Warnings:					
Information:					
			Total Files Size (in bytes):	851840	

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If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

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APPLICATION NUMBER	PATENT NUMBER	GROUP ART UNIT	FILE WRAPPER LOCATION
10/619,691		2634	0500

Change of Address/Power of Attorney

The following fields have been set to Customer Number 181 on 01/31/2005

- Correspondence Address
- Power of Attorney
- Maintenance Fee Address

The address of record for Customer Number 181 is:
MILES & STOCKBRIDGE PC
1751 PINNACLE DRIVE
SUITE 500
MCLEAN, VA 22102-3833

The Practitioners of record for Customer Number 181 are:

PTO INSTRUCTIONS:

Please take the following action when the correspondence address has been changed to a customer number:
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TRANSMITTAL FORM *(to be used for all correspondence after initial filing)*		**Application Number**	10/619,691
		Filing Date	July 16, 2003
		First Named Inventor	David M. Krinsky et al.
		Group Art Unit	2634
		Examiner Name	Kevin Kim
Total Number of Pages in This Submission		Attorney Docket Number	T3653-8765US02

ENCLOSURES *(check all that apply)*

- ☐ Fee Transmittal Form
  - ☐ Fee Attached
- ☐ Amendment / Reply
  - ☐ After Final
  - ☐ Affidavits/declaration(s)
- ☐ Extension of Time Request
- ☐ Express Abandonment Request
- ☐ Information Disclosure Statement
- ☐ Certified Copy of Priority Document(s)
- ☐ Response to Missing Parts/ Incomplete Application
  - ☐ Response to Missing Parts under 37 CFR 1.52 or 1.53
- ☐ Assignment Papers *(for an Application)*
- ☐ Drawing(s)
- ☐ Declaration and Power of Attorney
- ☐ Licensing-related Papers
- ☐ Petition
- ☐ Petition to Convert to a Provisional Application
- ☒ Power of Attorney, Revocation Change of Correspondence Address
- ☐ Terminal Disclaimer
- ☐ Request for Refund
- ☐ CD, Number of CD(s) ________
- ☐ After Allowance Communication to Group
- ☐ Appeal Communication to Board of Appeals and Interferences
- ☐ Appeal Communication to Group (Appeal Notice, Brief, Reply Brief)
- ☐ Proprietary Information
- ☐ Status Letter
- ☐ Application Data Sheet
- ☐ Other Enclosure(s) *(please identify below)*:

Remarks: ☒ The Commissioner is hereby authorized to charge any additional fees required or credit any overpayments to Deposit Account No. 50-1165 (081513-334) for the above identified docket number.

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm *or* Individual name	Jason H. Vick, Reg. No. 45,285 Miles & Stockbridge P.C. 1751 Pinnacle Drive Suite 500 McLean, VA 22102
Signature	
Date	December 1, 2003

CERTIFICATE OF MAILING OR TRANSMISSION
[37 CFR 1.8(a)]

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Application

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Application Number	10/619,691
Filing Date	July 16, 2003
First Named Inventor	David M. Krinsky et al.
Art Unit	2634
Examiner Name	Kevin Kim
Attorney Docket Number	T3653-8765US02

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OR

☑ **Firm or Individual Name**	Miles & Stockbridge P.C.				
Address	1751 Pennacle Drive				
Address	Suite 500				
City	McLean	**State**	VA	**Zip**	22102-3833
Country	USA				
Telephone	703-903-9000	**Fax**	703-610-8686		

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I am the:

☐ Applicant/Inventor

☐ Assignee of record of the entire interest.
Statement under 37 CFR 3.73(b) is enclosed. (Form PTO/SB/96).

☑ Attorney or Agent of record. Registration Number 45,285

☐ Registered practitioner named in the application transmittal letter in an application without an executed oath or declaration. See 37 CFR 1.33(a)(1) Registration Number__________.

Typed or Printed Name	Jason H. Vick		
Signature	[signature]		
Date	December 1, 2003	Telephone	703-903-9000

NOTE: Signatures of all the inventors or assignees of record of the entire interest or their representative(s) are required. Submit multiple forms if more than one signature is required, see below*.

☐ *Total of ________ forms are submitted.

This collection of information is required by 37 CFR 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: **Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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17513 U.S. PTO 10/619691 07/16/03

UTILITY PATENT APPLICATION TRANSMITTAL *(Only for new nonprovisional applications under 37 CFR 1.53(b))*	Attorney Docket No.	081513-334
	First Inventor	David M. Krinsky et al.
	Title	SYSTEMS AND METHODS FOR ESTABLISHING A DIAGNOSTIC TRANSMISSION MODE AND COMMUNICATING OVER THE SAME
	Express Mail Label No.	

APPLICATION ELEMENTS See *MPEP chapter 600 concerning utility patent application contents.*	ADDRESS TO: Mail Stop Patent Application, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450

1. ☒ Fee Transmittal Form (e.g., PTO/SB/17) *(Submit an original and a duplicate for fee processing)*
2. ☐ Applicant claims small entity status. See 37 CFR 1.27.
3. ☒ Specification [Total Pages *18*] (preferred arrangement set forth below)
   - Descriptive title of the invention
   - Cross Reference to Related Applications *(if applicable)*
   - Statement Regarding Fed sponsored R & D *(if applicable)*
   - Reference to sequence listing, a table, or a computer program listing appendix *(if applicable)*
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings *(if filed)*
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
4. ☒ Drawing(s) *(35 U.S.C. 113)* *[Total Sheets 02]*
5. Oath or Declaration *[Total Pages 02]*
   a. ☐ Newly executed (original or copy)
   b. ☐ Unsigned
   c. ☒ Copy from a prior application (37 CFR 1.63(d)) *(for continuation/divisional with Box 18 completed)*
      i. ☐ DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b)
6. ☒ Application Data Sheet. See 37 CFR 1.76
7. ☐ CD-ROM or CD-R in duplicate, large table or Computer Program (Appendix)
8. Nucleotide and/or Amino Acid Sequence Submission *(if applicable, all necessary)*
   a. ☐ Computer Readable Form (CRF)
   b. Specification Sequence Listing on:
      i. ☐ CD-ROM or CD-R (2 copies; or
      ii. ☐ paper
   c. ☐ Statements verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

9. ☐ Assignment Papers (cover sheet & document(s))
10. ☐ 37 CFR 3.73(b) Statement *(when there is an assignee)* ☐ Power of Attorney
11. ☐ English Translation Document *(if applicable)*
12. ☒ Information Disclosure Statement (IDS)/PTO-1449 ☒ Copies of IDS Citations
13. ☐ Preliminary Amendment
14. ☒ Return Receipt Postcard (MPEP 503) *(Should be specifically itemized)*
15. ☐ Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
16. ☐ Nonpublication request under 35 U.S.C. 122(b)(2)(B)(i). Applicant must attach form PTO/SB/35 or its equivalent.
17. ☐ Other: ____________

18. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in a preliminary amendment, or in an Application Data Sheet under 37 CFR 1.76:*

☐ Continuation ☒ Divisional ☐ Continuation-in-part (CIP) of prior application No.: 09/755,173

Prior application information: Examiner Kevin Kim Group / Art Unit: 2634

For CONTINUATION OR DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

19. CORRESPONDENCE ADDRESS

☒ *Customer Number or Bar Code Label* 22204 or ☐ *Correspondence address below*

Name					
Address					
City		State		Zip Code	
Country		Telephone		Fax	

Name (Print/Type)	Jason H. Vick	Registration No. (Attorney/Agent)	45,285
Signature	[signature]	Date	July 16, 2003

NVA270930.1

07/16/03 18334 U.S. PTO

FEE TRANSMITTAL FOR FY 2003

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☐ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT	$1,668.00

Complete if Known	
Application Number	New Divisional Application based on USSN: 09/755,173
Filing Date	July 16, 2003
First Named Inventor	David M. Krinsky et al.
Examiner Name	Kevin Kim
Art Unit	2634
Attorney Docket No.	081513-334

METHOD OF PAYMENT *(check all that apply)*

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FEE CALCULATION

1. BASIC FILING FEE

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1001	750	2001	375	Utility filing fee	750.00
1002	330	2002	165	Design filing fee	
1003	520	2003	260	Plant filing fee	
1004	750	2004	375	Reissue filing fee	
1005	160	2005	80	Provisional filing fee	

SUBTOTAL (1) $750.00

2. EXTRA CLAIM FEES FOR UTILITY AND REISSUE

	Claims		Extra Claims		Fee from below		Fee Paid
Total Claims	43	-20** =	23	X	18.00	=	414.00
Independent Claims	9	-3** =	6	X	84.00	=	504.00
Multiple Dependent				X		=	0

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
1202	18	2202	9	Claims in excess of 20
1201	84	2201	42	Independent claims in excess of 3
1203	280	2203	140	Multiple dependent claim, if not paid
1204	84	2204	42	** Reissue independent claims over original patent
1205	18	2205	9	** Reissue claims in excess of 20 and over original patent

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FEE CALCULATION (continued)

3. ADDITIONAL FEES

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1051	130	2051	65	Surcharge – late filing fee or oath	
1052	50	2052	25	Surcharge - late provisional filing fee or cover sheet	
1053	130	1053	130	Non-English specification	
1812	2,520	1812	2,520	For filing a request for *ex parte* reexamination	
1804	920*	1804	920*	Requesting publication of SIR prior to Examiner action	
1805	1,840*	1805	1,840*	Requesting publication of SIR after Examiner action	
1251	110	2251	55	Extension for reply within first month	
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1254	1,450	2254	725	Extension for reply within fourth month	
1255	1,970	2255	985	Extension for reply within fifth month	
1401	320	2401	160	Notice of Appeal	
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1403	280	2403	140	Request for oral hearing	
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1503	630	2503	315	Plant issue fee	
1460	130	1460	130	Petitions to the Commissioner	
1807	50	1807	50	Processing fee under 37 CFR 1.17(q)	
1806	180	1806	180	Submission of Information Disclosure Stmt	
8021	40	8021	40	Recording each patent assignment per property (times number of properties)	
1809	750	2809	375	Filing a submission after final rejection (37 CFR 1.129(a))	
1810	750	2810	375	For each additional invention to be examined (37 CFR 1.129(b))	
1801	750	2801	375	Request for Continued Examination (RCE)	
1802	900	1802	900	Request for expedited examination of a design application	

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SUBMITTED BY				Complete *(if applicable)*	
Name *(Print/Type)*	Jason H. Vick	Registration No. *(Attorney/Agent)*	45,285	Telephone	(703) 770-9300
Signature				Date	July 16, 2003

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NVA270980.1

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	081513-334
First Inventor	David M. Krinsky et al.
Title	SYSTEMS AND METHODS FOR ESTABLISHING A DIAGNOSTIC TRANSMISSION MODE AND COMMUNICATING OVER THE SAME
Express Mail Label No.	

17513 U.S. PTO 10/619691 07/16/03

APPLICATION ELEMENTS

See *MPEP chapter 600 concerning utility patent application contents.*

ADDRESS TO: Mail Stop Patent Application
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1. ☒ Fee Transmittal Form (e.g., PTO/SB/17)
   (Submit an original and a duplicate for fee processing)
2. ☐ Applicant claims small entity status. See 37 CFR 1.27.
3. ☒ Specification [Total Pages *18*]
   (preferred arrangement set forth below)
   - Descriptive title of the invention
   - Cross Reference to Related Applications *(if applicable)*
   - Statement Regarding Fed sponsored R & D *(if applicable)*
   - Reference to sequence listing, a table, or a computer program listing appendix *(if applicable)*
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings *(if filed)*
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
4. ☒ Drawing(s) *(35 U.S.C. 113)* *[Total Sheets 02]*
5. Oath or Declaration *[Total Pages 02]*
   a. ☐ Newly executed (original or copy)
   b. ☐ Unsigned
   c. ☒ Copy from a prior application (37 CFR 1.63(d))
   (for continuation/divisional with Box 18 completed)
      i. ☐ DELETION OF INVENTOR(S)
      Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b)
6. ☒ Application Data Sheet. See 37 CFR 1.76
7. ☐ CD-ROM or CD-R in duplicate, large table or Computer Program (Appendix)
8. Nucleotide and/or Amino Acid Sequence Submission *(if applicable, all necessary)*
   a. ☐ Computer Readable Form (CRF)
   b. Specification Sequence Listing on:
      i. ☐ CD-ROM or CD-R (2 copies; or
      ii. ☐ paper
   c. ☐ Statements verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

9. ☐ Assignment Papers (cover sheet & document(s))
10. ☐ 37 CFR 3.73(b) Statement *(when there is an assignee)* ☐ Power of Attorney
11. ☐ English Translation Document *(if applicable)*
12. ☒ Information Disclosure Statement (IDS)/PTO-1449 ☒ Copies of IDS Citations
13. ☐ Preliminary Amendment
14. ☒ Return Receipt Postcard (MPEP 503) *(Should be specifically itemized)*
15. ☐ Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
16. ☐ Nonpublication request under 35 U.S.C. 122(b)(2)(B)(i). Applicant must attach form PTO/SB/35 or its equivalent.
17. ☐ Other: ____________

18. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in a preliminary amendment, or in an Application Data Sheet under 37 CFR 1.76:*

☐ Continuation ☒ Divisional ☐ Continuation-in-part (CIP) of prior application No.: 09/755,173

Prior application information: Examiner Kevin Kim Group / Art Unit: 2634

For CONTINUATION OR DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

19. CORRESPONDENCE ADDRESS

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Address					
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Country		Telephone		Fax	

Name (Print/Type)	Jason H. Vick	Registration No. (Attorney/Agent)	45,285
Signature		Date	July 16, 2003

NVA270930.1

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Name *(Print/Type)*	Jason H. Vick	Registration No. *(Attorney/Agent)*	45,285	Telephone	(703) 770-9300
Signature				Date	July 16, 2003

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NVA270980.1

SYSTEMS AND METHODS FOR ESTABLISHING A DIAGNOSTIC TRANSMISSION MODE AND COMMUNICATING OVER THE SAME

Related Application Data

[0001] This application is a Divisional Application of U.S. Utility Application Serial No. 09/755,173 entitled "Systems and Methods For Establishing A Diagnostic Transmission Mode And Communicating Over the Same" filed January 8, 2001, which claims benefit of Provisional Application Nos. 60/224,308 filed August 10, 2000 and 60/174,865 filed January 7, 2000 and incorporated herein by reference in their entirety.

Field of the Invention

[0002] This invention relates to test and diagnostic information. In particular, this invention relates to a robust system and method for communicating diagnostic information.

Background of the Invention

[0003] The exchange of diagnostic and test information between transceivers in a telecommunications environment is an important part of a telecommunications, such as an ADSL, deployment. In cases where the transceiver connection is not performing as expected, for example, where the data rate is low, where there are many bit errors, or the like, it is necessary to collect diagnostic and test information from the remote transceiver. This is performed by dispatching a technician to the remote site, e.g., a truck roll, which is time consuming and expensive.

[0004] In DSL technology, communications over a local subscriber loop between a central office and a subscriber premises is accomplished by modulating the data to be transmitted onto a multiplicity of discrete frequency carriers which are summed together and then transmitted over the subscriber loop. Individually, the carriers form discrete, non-overlapping communication subchannels of limited bandwidth. Collectively, the carriers form what is effectively a broadband communications channel. At the receiver end, the carriers are demodulated and the data recovered.

[0005] DSL systems experience disturbances from other data services on adjacent phone lines, such as, for example, ADSL, HDSL, ISDN, T1, or the like. These disturbances may commence after the subject ADSL service is already initiated and, since DSL for internet access is envisioned as an always-on service, the effect of these disturbances must be ameliorated by the subject ADSL transceiver.

SUMMARY OF THE INVENTION

[0006] The systems and methods of this invention are directed toward reliably exchanging diagnostic and test information between transceivers over a digital subscriber line in the presence of voice communications and/or other disturbances. For simplicity of reference, the systems and methods of the invention will hereafter refer to the transceivers generically as modems. One such modem is typically located at a customer premises such as a home or business and is "downstream" from a central office with which it communicates. The other modem is typically located at the central office and is "upstream" from the customer premises. Consistent with industry practice, the modems are often referred to as "ATU-R" ("ADSL transceiver unit, remote," i.e., located at the customer premises) and "ATU-C" ("ADSL transceiver unit, central office" i.e., located at the central office). Each modem includes a transmitter section for transmitting data and a receiver section for receiving data, and is of the discrete multitone type, i.e., the modem transmits data over a multiplicity of subchannels of limited bandwidth. Typically, the upstream or ATU-C modem transmits data to the downstream or ATU-R modem over a first set of subchannels, which are usually the higher-frequency subchannels, and receives data from the downstream or ATU-R modem over a second, usually smaller, set of subchannels, commonly the lower-frequency subchannels. By establishing a diagnostic link mode between the two modems, the systems and methods of this invention are able to exchange diagnostic and test information in a simple and robust manner.

[0007] In the diagnostic link mode, the diagnostic and test information is communicated using a signaling mechanism that has a very high immunity to noise and/or other disturbances and can therefore operate effectively even in the case where the modems could not actually establish an acceptable connection in their normal operational mode.

[0008] For example, if the ATU-C and/or ATU-R modem fail to complete an initialization sequence, and are thus unable to enter a normal steady state communications mode, where the diagnostic and test information would normally be exchanged, the modems according to the systems and methods of this invention enter a robust diagnostic link mode. Alternatively, the diagnostic link mode can be entered automatically or manually, for example, at the direction of a user. In the robust diagnostic link mode, the modems exchange the diagnostic and test information that is, for example, used by a technician to determine the cause of a failure without the technician having to physically visit, i.e., a truckroll to, the remote site to collect data.

[0009] The diagnostic and test information can include, for example, but is not limited to, signal to noise ratio information, equalizer information, programmable gain setting information, bit allocation information, transmitted and received power information, margin information, status and rate information, telephone line condition information, such as the length of the line, the number and location of bridged taps, a wire gauge, or the like, or any other known or later developed diagnostic or test information that may be appropriate for the particular communications environment. For example, the exchanged diagnostic and test information can be directed toward specific limitations of the modems, to information relating to the modem installation and deployment environment, or to other diagnostic and test information that can, for example, be determined as needed which may aid in evaluating the cause of a specific failure or problem. Alternatively, the diagnostic and test information can include the loop length and bridged tap length estimations as discussed in copending Attorney Docket No. 081513-000003, filed herewith and incorporated herein by reference in its entirety.

[0010] For example, an exemplary embodiment of the invention illustrates the use of the diagnostic link mode in the communication of diagnostic information from the remote terminal (RT) transceiver, e.g., ATU-R, to the central office (CO) transceiver, e.g., ATU-C. Transmission of information from the remote terminal to the central office is important since a typical ADSL service provider is located in the central office and would therefore benefit from the ability to determine problems at the remote terminal without a truckroll. However, it is to be appreciated, that the systems and the methods of this invention will work equally well in communications from the central office to the remote terminal.

[0011] These and other features and advantages of this invention are described in or are apparent from the following detailed description of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The embodiments of the invention will be described in detail, with reference to the following figures wherein:

[0013] Fig. 1 is a functional block diagram illustrating an exemplary communications system according to this invention; and

[0014] Fig. 2 is a flowchart outlining an exemplary method for communicating diagnostic and test information according to this invention.

DETAILED DESCRIPTION OF THE INVENTION

[0015] For ease of illustration the following description will be described in relation to the CO receiving diagnostic and test information from the RT. In the exemplary embodiment, the systems and methods of this invention complete a portion of the normal modem initialization before entering into the diagnostic link mode. The systems and methods of this invention can enter the diagnostic link mode manually, for example, at the direction of a technician or a user after completing a portion of initialization. Alternatively, the systems and methods of this invention can enter the diagnostic link mode automatically based on, for example, a bit rate failure, a forward error correction or a CRC error during showtime, e.g., the normal steady state transmission mode, or the like. The transition into the diagnostic link mode is accomplished by transmitting a message from the CO modem to the RT modem indicating that the modems are to enter into the diagnostic link mode, as opposed to transitioning into the normal steady state data transmission mode. Alternatively, the transition into the diagnostic link mode is accomplished by transmitting a message from the RT modem to the CO modem indicating that the modems are to enter into the diagnostic link mode as opposed to transitioning into the normal steady state data transmission mode. For example, the transition signal uses an ADSL state transition to transition from a standard ADSL state to a diagnostic link mode state.

[0016] In the diagnostic link mode, the RT modem sends diagnostic and test information in the form of a collection of information bits to the CO modem that are, for example, modulated by using one bit per DTM symbol modulation, as is used in the C-Rates1 message in the ITU and ANSI ADSL standards, where the symbol may or may not include a cyclic prefix. Other exemplary modulation techniques include Differential Phase Shift

Keying (DPSK) on a subset or all the carriers, as specified in, for example, ITU standard G.994.1, higher order QAM modulation (>1 bit per carrier), or the like.

[0017] In the one bit per DMT symbol modulation message encoding scheme, a bit with value 0 is mapped to the REVERB1 signal and a bit with a value of 1 mapped to a SEGUE1 signal. The REVERB1 and SEGUE1 signals are defined in the ITU and ANSI ADSL standards. The REVERB1 signal is generated by modulating all of the carriers in the multicarrier system with a known pseudo-random sequence thus generating a wideband modulated signal. The SEGUE1 signal is generated from a carrier by 180 degree phase reversal of the REVERB1 signal. Since both signals are wideband and known in advance, the receiver can easily detect the REVERB1 and SEGUE1 signal using a simple matched filter in the presence of large amounts of noise and other disturbances

Exemplary Message Variables
Data Sent in the Diag Link
Train Type
ADSL Standard
Chip Type
Vendor ID
Code Version
Average Reverb Received Signal
Programmable gain amplifier (PGA) Gain – Training
Programmable gain amplifier PGA Gain – Showtime
Filter Present during Idle Channel Calculation
Average Idle Channel Noise
Signal to Noise during Training
Signal to Noise during Showtime
Bits and Gains
Data Rate
Framing Mode
Margin
Reed-Solomon Coding Gain
QAM Usage
Frequency Domain Equalizer (FDQ) Coefficients
Gain Scale
Time domain equalizer (TDQ) Coefficients
Digital Echo Canceller (DEC) Coefficients

Table 1

[0018] Table 1 shows an example of a data message that can be sent by the RT to the CO during the diagnostic link mode. In this example, the RT modem sends 23 different data variables to the CO. Each data variable contains different items of diagnostic and test information that are used to analyze the condition of the link. The variables may contain more than one item of data. For example, the *Average Reverb Signal* contains the power levels per tone, up to, for example, 256 entries, detected during the ADSL Reverb signal. Conversely, the *PGA Gain – Training* is a single entry, denoting the gain in dB at the receiver during the ADSL training.

[0019] Many variables that represent the type of diagnostic and test information that are used to analyze the condition of the link are sent from the RT modem to the CO modem. These variables can be, for example, arrays with different lengths depending on, for example, information in the initiate diagnostic mode message. The systems and methods of this invention can be tailored to contain many different diagnostic and test information variables. Thus, the system is fully configurable, allowing subsets of data to be sent and additional data variables to be added in the future. Therefore, the message length can be increased or decreased, and diagnostic and test information customized, to support more or less variables as, for example, hardware, the environment and/or the telecommunications equipment dictates.

[0020] Therefore, it is to be appreciated, that in general the variables transmitted from the modem being tested to the receiving modem can be any combination of variables which allow for transmission of test and/or diagnostic information.

[0021] Fig. 1 illustrates an exemplary embodiment of the additional modem components associated with the diagnostic link mode. In particular, the diagnostic link system 100 comprises a central office modem 200 and a remote terminal modem 300. The central office modem 200 comprises, in addition to the standard ATU-C components, a CRC checker 210, a diagnostic device 220, and a diagnostic information monitoring device 230. The remote terminal modem 300 comprises, in addition to the standard components associated with an ATU-R, a message determination device 310, a power control device 320, a diagnostic device 330 and a diagnostic information storage device 340. The central office modem 200 and the remote terminal model 300 are also connected, via link 5, to a splitter 10 for a phone switch 20, and a splitter 30 for a phone 40. Alternatively, the ATU-R can operate without a splitter, e.g., splitterless, as specified in ITU standard G.992.2 (G.lite) or with an in-line filter in series with the phone 40. In addition, the remote terminal modem 300, can also be connected to, for example, one or more user terminals 60. Additionally, the central office modem 200 can be connected to one or more distributed networks 50, via link 5, which may or may not also be connected to one or more other distributed networks.

[0022] While the exemplary embodiment illustrated in Fig. 1 shows the diagnostic link system 100 for an embodiment in which the remote terminal modem 300 is communicating test and diagnostic information to the central office 200, it is to be appreciated that the various components of the diagnostic link system can be rearranged such that the diagnostic and test information can be forwarded from the central office 200 to the remote terminal modem 300, or, alternatively, such that both modems can send and receive diagnostic and/or test information. Furthermore, it is to be appreciated, that the components of the diagnostic link system 100 can be located at various locations within a distributed network, such as the POTS network, or other comparable telecommunications network. Thus, it should be appreciated that the components of the diagnostic link system 100 can be combined into one device for respectively transmitting, receiving, or transmitting and receiving diagnostic and/or test information. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the diagnostic link system 100 can be arranged at any location within a telecommunications network and/or modem without affecting the operation of the system.

[0023] The links 5 can be a wired or wireless link or any other known or later developed element(s) that is capable of supplying and communicating electronic data to and from the connected elements. Additionally, the user terminal 60 can be, for example, a personal computer or other device allowing a user to interface with and communicate over a modem, such as a DSL modem. Furthermore, the systems and method of this invention will work equally well with splitterless and low-pass mulitcarrier modem technologies.

[0024] In operation, the remote terminal 300, commences its normal initialization sequence. The diagnostic device 330 monitors the initialization sequence for a failure. If there is a failure, the diagnostic device 330 initiates the diagnostic link mode. Alternatively, a user or, for example, a technician at the CO, can specify that the remote terminal 300 enter into the diagnostic link mode after completing a portion of an initialization. Alternatively still, the diagnostic device 330 can monitor the normal steady state data transmission of the remote terminal, and upon, for example, an error threshold being exceeded, the diagnostic device 330 will initiate the diagnostic link mode.

[0025] Upon initialization of the diagnostic link mode, the diagnostic device 330, in cooperation with the remote terminal 300 will transmit an initiate diagnostic link mode message from the remote terminal to the central office 200 (RT to CO). Alternatively, the central office modem 200 can transmit an initiate diagnostic link mode message to the remote terminal modem 300. If the initiate diagnostic link mode message is received by the central office 200, the diagnostic device 330, in cooperation with the message determination device 310, determines a diagnostic link message to be forwarded to the central office 200. For example, the diagnostic link message can include test information that has been assembled during, for example, the normal ADSL initialization procedure. The diagnostic and/or test information can include, but is not limited to, the version number of the diagnostic link mode, the length of the diagnostic and/or test information, the communications standard, such as the ADSL standard, the chipset type, the vendor identifications, the ATU version number, the time domain received reverb signal, the frequency domain reverb signal, the amplifier settings, the CO transmitter power spectral density, the frequency domain received idle channel, the signal to noise ratio, the bits and gains and the upstream and downstream transmission rates, or the like.

[0026] If the initiate diagnostic link mode message is not received by the central office 200, the initiate diagnostic link mode message can, for example, be re-transmitted a predetermined number of iterations until a determination is made that it is not possible to establish a connection.

[0027] Assuming the initiate diagnostic link mode message is received, then, for a predetermined number of iterations, the diagnostic device 330, in cooperation with the remote terminal modem 300 and the diagnostic information storage device 340, transmits the diagnostic link message with a cyclic redundancy check (CRC) to the central office modem 200. However, it is to be appreciated that in general, any error detection scheme, such as bit error detection, can be used without affecting the operation of the system. The central office 200, in cooperation with the CRC checker 210, determines if the CRC is correct. If the CRC is correct, the diagnostic information stored in the diagnostic information storage device 340 has been, with the cooperation of the diagnostic device 330, and the remote terminal modem 300, forwarded to the central office 200 successfully.

[0028] If, for example, the CRC checker 210 is unable to determine the correct CRC, the diagnostic device 330, in cooperation with power control device 320, increases the transmission power of the remote terminal 300 and repeats the transmission of the diagnostic link message from the remote terminal 300 to the central office 200. This process continues until the correct CRC is determined by the CRC checker 210.

[0029] The maximum power level used for transmission of the diagnostic link message can be specified by, for example, the user or the ADSL service operator. If the CRC checker 210 does not determine a correct CRC at the maximum power level and the diagnostic link mode can not be initiated then other methods for determining diagnostic information are utilized, such as dispatching a technician to the remote site, or the like.

[0030] Alternatively, the remote terminal 300, with or without an increase in the power level, can transmit the diagnostic link message several times, for example, 4 times. By transmitting the diagnostic link message several times, the CO modem 200 can use, for example, a diversity combining scheme to improve the probability of obtaining a correct CRC from the received diagnostic link message(s).

[0031] Alternatively, as previously discussed, the central office 200 comprises a diagnostic information monitoring device 230. The remote terminal 300 can also include a diagnostic information monitoring device. One or more of these diagnostic information monitoring devices can monitor the normal steady state data transmission between the remote terminal 300 and the central office 200. Upon, for example, the normal steady state data transmission exceeded a predetermined error threshold, the diagnostic information monitoring device can initiate the diagnostic link mode with the cooperation of the diagnostic device 300 and/or the diagnostic device 220.

[0032] Fig. 2 illustrates an exemplary method for entering a diagnostic link mode in accordance with this invention. In particular, control begins in step S100 and continues to step S110. In step S110, the initialization sequence is commenced. Next, in step S120, if an initialization failure is detected, control continues to step S170. Otherwise, control jumps to step S130. In step S130, a determination is made whether the diagnostic link mode has been selected. If the diagnostic link mode has been selected, control continues to step S170, otherwise, control jumps to step S140.

[0033] In step S170, the initiate diagnostic link mode message is transmitted from, for example, the remote terminal to the central office. Next, in step S180, a determination is made whether the initiate diagnostic mode message has been received by the CO. If the initiate diagnostic mode message has been received by the CO, control jumps to step S200. Otherwise, control continues to step S190. In step S190, a determination is made whether to re-transmit the initiate diagnostic mode message, for example, based on whether a predetermined number of iterations have already been completed. If the initiate diagnostic mode message is to be re-transmitted, control continues back to step S170. Otherwise, control jumps to step S160.

[0034] In step S200, the diagnostic link message is determined, for example, by assembling test and diagnostic information about one or more of the local loop, the modem itself, the telephone network at the remote terminal, or the like. Next, in step S210, for a predetermined number of iterations, steps S220-S240 are completed. In particular, in step S220 a diagnostic link message comprising a CRC is transmitted to, for example, the CO. Next, in step S230, the CRC is determined. Then, in step S240, a determination is made whether the CRC is correct. If the CRC is correct, the test and/or diagnostic information has been successfully communicated and control continues to step S160.

[0035] Otherwise, if step S210 has completed the predetermined number of iterations, control continues to step S250. In step S250, the transmission power is increased and control continues back to step S210. Alternatively, as previously discussed, the diagnostic link message may be transmitted a predetermined number of times, with our without a change in the transmission power.

[0036] In step S140, the normal steady state data transmission is entered into between two modems, such as the remote terminal and the cental office modems. Next, in step S150, a determination is made whether an error threshold during the normal steady state data transmission has been exceeded. If the error threshold has been exceeded, control continues to step S170. Otherwise, control jumps to step S160. In step S160, the control sequence ends.

[0037] As shown in Fig. 1, the diagnostic link mode system can be implemented either on a single program general purpose computer, a modem, such as a DSL modem, or a separate program general purpose computer having a communications device. However, the diagnostic link system can also be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element, an ASIC or other integrated circuit, a digital signal processor, a hardwired electronic or logic circuit such as a discrete element circuit, a programmed logic device such as a PLD, PLA, FPGA, PAL, or the like, and associated communications equipment. In general, any device capable of implementing a finite state machine that is capable of implementing the flowchart illustrated in Fig. 2 can be used to implement a diagnostic link system according to this invention.

[0038] Furthermore, the disclosed method may be readily implemented in software using object or object-oriented software development environments that provide portable source code that can be used on a variety of computer, workstation, or modem hardware platforms. Alternatively, the disclosed diagnostic link system may be implemented partially or fully in hardware using standard logic circuits or a VLSI design. Other software or hardware can be used to implement the systems in accordance with this invention depending on the speed and/or efficiency requirements of the systems, the particular function, and a particular software or hardware systems or microprocessor or microcomputer systems being utilized. The diagnostic link system and methods illustrated herein however, can be readily implemented in hardware and/or software using any known or later developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

[0039] Moreover, the disclosed methods can be readily implemented as software executed on a programmed general purpose computer, a special purpose computer, a microprocessor, or the like. In these instances, the methods and systems of this invention can be implemented as a program embedded on a modem, such a DSL modem, as a resource residing on a personal computer, as a routine embedded in a dedicated diagnostic link system, a central office, or the like. The diagnostic link system can also be implemented by physically incorporating the system and method into a software and/or hardware system, such as a hardware and software systems of a modem, a general purpose computer, an ADSL line testing device, or the like.

[0040] It is, therefore, apparent that there is provided in accordance with the present invention, systems and methods for transmitting a diagnostic link message. While this invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable arts. Accordingly, applicants intend to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and the scope of this invention.

What is Claimed is:

1. A diagnostic link system for communicating data between modems using multicarrier modulation comprising:

an initiate diagnostic mode trigger that instructs a transmitting modem to forward an initiate diagnostic mode message to a receiving modem;

a message determination device that determines a diagnostic link message; and

a receiving modem diagnostic device that receives the diagnostic link message and determines the accuracy of the diagnostic link message.

2. The system of claim 1, further comprising a power control device that increases a transmission power of the diagnostic link message if the received diagnostic link message is inaccurate.

3. The system of claim 1, wherein the diagnostic link message is re-transmitted at least one time.

4. The system of claim 1, wherein the diagnostic link message comprises at least one of test and diagnostic information.

5. The system of claim 4, wherein the diagnostic link message comprises at least one of a version number of a diagnostic link mode, a length of the diagnostic information, a communications standard, a chipset type, one or more vendor identifications, an ATU version number, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and downstream transmission rates.

6. The system of claim 1, wherein the accuracy is determined based on at least one of an error detecting scheme, a bit error detection and a cyclic redundancy check.

7. The system of claim 1, wherein the trigger is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during a normal steady state transmission mode, a forward error correction error, a user request, a central office modem request and a remote terminal modem request.

8. The system of claim 1, wherein the transmitting modem completes a portion of a modem initialization sequence before forwarding the initiate diagnostic mode message.

9. The system of claim 1, wherein the transmitting modem is at least one of a central office modem and a remote terminal modem.

10. The system of claim 1, wherein the receiving modem is at least one of a central office modem and a remote terminal modem.

11. A method for communicating data between modems using multicarrier modulation comprising:

instructing a transmitting modem to forward an initiate diagnostic mode message to a receiving modem;

determining a diagnostic link message;

transmitting the diagnostic link message; and

determining the accuracy of the transmitted diagnostic link message.

12. The method of claim 11, further comprising increasing a transmission power of the diagnostic link message if a received diagnostic link message is inaccurate.

13. The method of claim 11, further comprising re-transmitting the diagnostic link message at least one time.

14. The method of claim 11, wherein the diagnostic link message comprises at least one of test and diagnostic information.

15. The method of claim 14, wherein the diagnostic link message comprises at least one of a version number of a diagnostic link mode, a length of the diagnostic information, a communications standard, a chipset type, one or more vendor identifications, an ATU version number, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and downstream transmission rates.

16. The method of claim 11, wherein the accuracy is determined based on at least one of an error detecting scheme, a bit error detection and a cyclic redundancy check.

17. The method of claim 11, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request, a central office modem request and a remote terminal modem request.

18. The method of claim 11, further comprising completing a portion of a modem initialization sequence before forwarding the initiate diagnostic mode message.

19. The method of claim 11, wherein the transmitting modem is at least one of a central office modem and a remote terminal modem.

20. The method of claim 11, wherein the receiving modem is at least one of a central office modem and a remote terminal modem.

21. A method for communicating data between modems using multicarrier modulation comprising:

receiving an initiate diagnostic mode message;

determining a diagnostic link message;

transmitting the diagnostic link message; and

at least one of increasing a transmission power of the diagnostic link message if the received diagnostic link message is inaccurate and re-transmitting the diagnostic link message at least one time.

22. The method of claim 21, wherein the diagnostic link message comprises at least one of test and diagnostic information.

23. The method of claim 22, wherein the diagnostic link message comprises at least one of a version number of a diagnostic link mode, a length of the diagnostic information, a communications standard, a chipset type, one or more vendor identifications, an ATU version number, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and downstream transmission rates.

24. The method of claim 21, wherein the accuracy is determined based on at least one of an error detecting scheme, a bit error detection and a cyclic redundancy check.

25. The method of claim 21, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request, a central office modem request and a remote terminal modem request.

26. The method of claim 21, further comprising completing a portion of a modem initialization sequence before forwarding the initiate diagnostic mode message.

27. The method of claim 21, wherein a transmitting modem is at least one of a central office modem and a remote terminal modem.

28. The method of claim 21, wherein a receiving modem is at least one of a central office modem and a remote terminal modem.

29. A method for communicating data between modems using multicarrier modulation comprising:

receiving an initiate diagnostic mode message;

determining the accuracy of a received diagnostic link message; and

receiving at least one of an increased transmission power diagnostic link message if the received diagnostic link message is inaccurate and a re-transmission of at least one of the diagnostic link messages.

30. The method of claim 29, wherein the diagnostic link message comprises at least one of test and diagnostic information.

31. The method of claim 30, wherein the received diagnostic link message comprises at least one of a version number of a diagnostic link mode, a length of the diagnostic information, a communications standard, a chipset type, one or more vendor identifications, an ATU version number, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and downstream transmission rates.

32. The method of claim 29, wherein the accuracy is determined based on at least one of an error detecting scheme, a bit error detection and a cyclic redundancy check.

33. The method of claim 29, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request, a central office modem request and a remote terminal modem request.

34. The method of claim 29, further comprising completing a portion of a modem initialization sequence before receiving the initiate diagnostic mode message.

35. An information storage media comprising information for communicating data between modems using multicarrier modulation comprising:

information that instructs a transmitting modem to forward an initiate diagnostic mode message to a receiving modem;

information that determines a diagnostic link message;

information that transmits the diagnostic link message; and

information that determines the accuracy of the transmitted diagnostic link message.

36. An information storage media comprising information for communicating data between modems using multicarrier modulation comprising:

information that receives an initiate diagnostic mode message;

information that determines a diagnostic link message;

information that transmits the diagnostic link message; and

information that at least one of increases a transmission power of the diagnostic link message if the received diagnostic link message is inaccurate and re-transmits the diagnostic link message at least one time.

37. An information storage media comprising information for communicating data between modems using multicarrier modulation comprising:

information that receives an initiate diagnostic mode message;

information that determines the accuracy of a received diagnostic link message; and

information that receives at least one of an increased transmission power diagnostic link message if the received diagnostic link message is inaccurate and a re-transmission of at least one of the diagnostic link messages.

38. A method for communicating diagnostic information between DSL modems using multicarrier modulation comprising:

completing a portion of a modem initialization sequence;

transmitting an initiate diagnostic communication mode message to a receiving modem;

entering a diagnostic communications mode based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request, a central office modem request and a remote terminal modem request; and

transmitting a diagnostic link message comprising at least one of a version number of a diagnostic link mode, a length of the diagnostic information, a communications standard, a chipset type, one or more vendor identifications, an ATU version number, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and downstream transmission rates.

39. The method of claim 38, further comprising re-transmitting the diagnostic link message at least one time.

40. The method of claim 38, further comprising increasing a transmission power of the diagnostic link message.

41. A method for communicating diagnostic information between DSL modems using multicarrier modulation comprising:

completing a portion of a modem initialization sequence;

receiving an initiate diagnostic communication mode message;

entering a diagnostic communications mode based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request, a central office modem request and a remote terminal modem request;

receiving a diagnostic link message comprising at least one of a version number of a diagnostic link mode, a length of the diagnostic information, a communications standard, a chipset type, one or more vendor identifications, an ATU version number, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and downstream transmission rates.

42. The method of claim 41, further comprising receiving a re-transmitted diagnostic link message at least one time.

43. The method of claim 41, further comprising receiving an increased transmission power diagnostic link message.

ABSTRACT OF THE DISCLOSURE

[0041] Upon detection of a trigger, such as the exceeding of an error threshold or the direction of a user, a diagnostic link system enters a diagnostic information transmission mode. This diagnostic information transmission mode allows for two modems to exchange diagnostic and/or test information that may not otherwise be exchangeable during normal communication. The diagnostic information transmission mode is initiated by transmitting an initiate diagnostic link mode message to a receiving modem accompanied by a cyclic redundancy check (CRC). The receiving modem determines, based on the CRC, if a robust communications channel is present. If a robust communications channel is present, the two modems can initiate exchange of the diagnostic and/or test information. Otherwise, the transmission power of the transmitting modem is increased and the initiate diagnostic link mode message re-transmitted to the receiving modem until the CRC is determined to be correct.

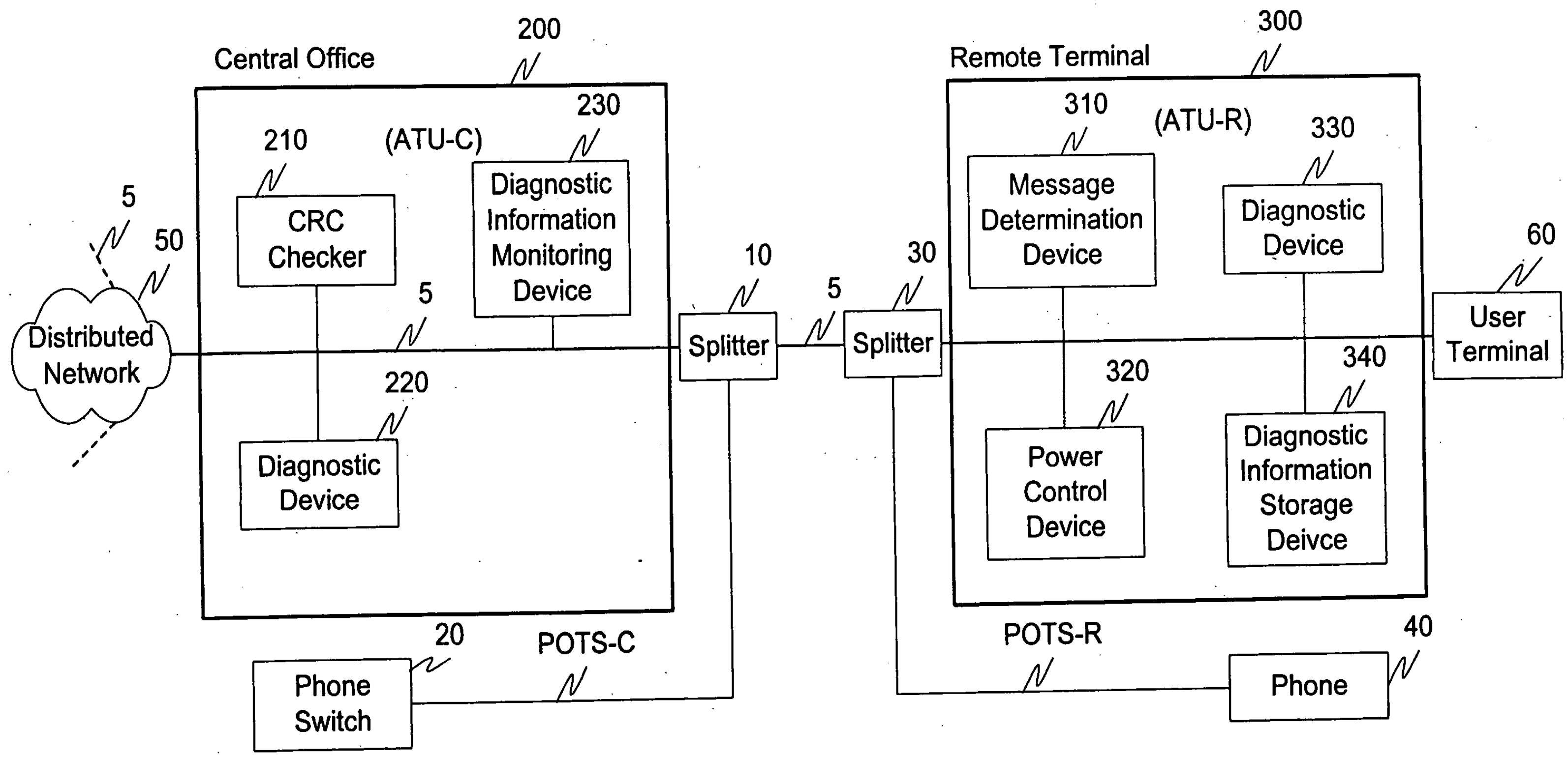
Central Office
200
(ATU-C)
210
CRC Checker
230
Diagnostic Information Monitoring Device
5
220
Diagnostic Device
5
50
Distributed Network
10
Splitter
5
30
Splitter
Remote Terminal
300
(ATU-R)
310
Message Determination Device
330
Diagnostic Device
320
Power Control Device
340
Diagnostic Information Storage Deivce
60
User Terminal
20
Phone Switch
POTS-C
POTS-R
40
Phone

Fig. 1

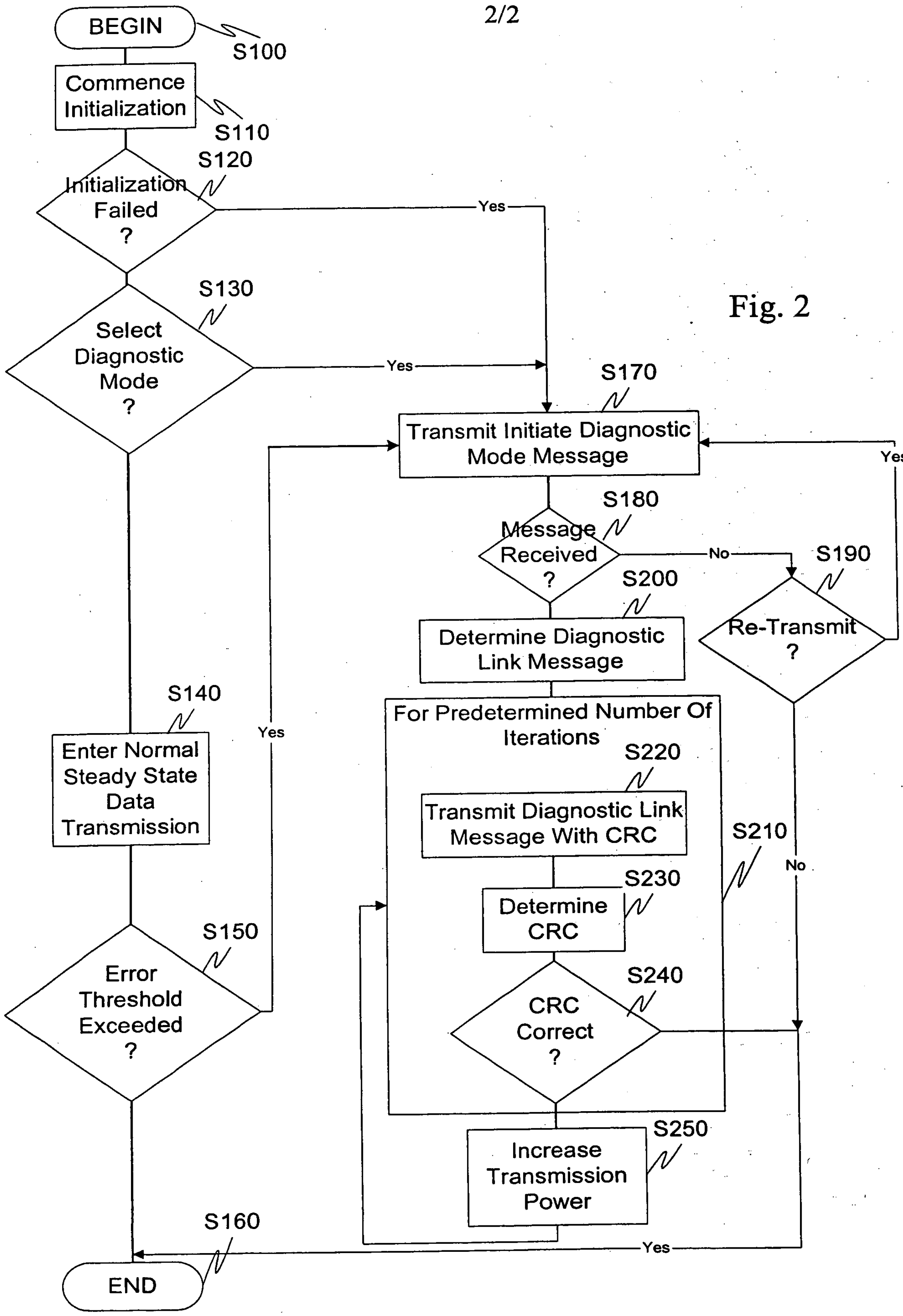
BEGIN
S100
Commence Initialization
S110
S120
Initialization Failed ?
Yes
S130
Select Diagnostic Mode ?
Yes
S170
Transmit Initiate Diagnostic Mode Message
S180
Message Received ?
No
S190
Re-Transmit ?
Yes
S200
Determine Diagnostic Link Message
For Predetermined Number Of Iterations
S220
Transmit Diagnostic Link Message With CRC
S210
S230
Determine CRC
S240
CRC Correct ?
S250
Increase Transmission Power
No
S140
Enter Normal Steady State Data Transmission
Yes
S150
Error Threshold Exceeded ?
S160
Yes
END

Fig. 2

PATENT APPLICATION

Attom y Docket No. 081513.00004

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled: SYSTEMS AND METHODS FOR ESTABLISHING A DIAGNOSTIC TRANSMISSION MODE AND COMMUNICATING OVER THE SAME

the specification and claims of which
☒ are attached hereto OR ☐ was filed on ________ as U.S. Application No. ________

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims.

I acknowledge the duty to disclose information which is material to the patentability as defined in Title 37, Code of Federal Regulations, §1.56.

I hereby claim priority benefits under Title 35, United States Code, §119 of any foreign or U.S. Provisional application(s) for patent listed below, and have also identified below any foreign application(s) or Provisional application(s) for patent having a filing date before that of the application on which priority is claimed:

Prior Foreign or U.S. Provisional Application(s)

(Number)	(Country)	(Day/Month/Year Filed)
60/224,308	U.S.A.	August 10, 2000
60/174,865	U.S.A.	January 7, 2000

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following registered practitioners to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

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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 with the knowledge that willful false statements and th lik so made are punishable by fine or imprisonment, or both, under §1001 of Title 18 of the United States Code and that such willful false statem nts may jeopardize the validity of th application or any patent issuing thereon.

DECLARATION AND POWER OF ATTORNEY, continued

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NVA166186.1

APPLICATION DATA SHEET

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Stylesheet Version: 1.0 — Attorney Docket Number: 081513-334

Publication Filing Type:	**new-utility**
Application Type:	**utility**
Title of Invention:	**SYSTEMS AND METHODS FOR ESTABLISHING A DIAGNOSTIC TRANSMISSION MODE AND COMMUNICATING OVER THE SAME**

Legal Representative:

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22204

Continuity Data:

This application is a division of 09/755,173 2001-01-08 US Pending

which is a non-provisional of provisional 60/224,308 2000-08-10 US Expired

said application 09/755,173 is a non-provisional of provisional 60/174,865 2000-01-07 US Expired

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Docket No. 081513-334

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Divisional Patent Application of:	)	
David M. Krinsky et al.	)	Examiner: **Kevin Kim**
based on U.S. Serial No. 09/755,173	)	Group Art Unit: **2634**
Filed: **July 16, 2003**	)	
For: ***SYSTEMS AND METHODS FOR ESTABLISHING***	)	
A DIAGNOSTIC TRANSMISSION MODE AND	)	
COMMUNICATING OVER THE SAME	)	

INFORMATION DISCLOSURE STATEMENT

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

In accordance with the duty of disclosure as set forth in 37 C.F.R. §1.56, Applicants hereby submit the following information in conformance with 37 C.F.R. §§ 1.97 and 1.98. Pursuant to 37 C.F.R. § 1.98, a copy of each of the documents was cited in a parent application.

The documents are being submitted within three (3) months of the filing of this application or entry into the national stage of this application, or before the first Office Action on the merits, whichever is later, therefore no fee or certification is required under 37 C.F.R. § 1.97(b).

It is requested that the accompanying PTO-1449 be considered and made of record in the above-identified application. To assist the Examiner, the documents are listed on the attached form PTO-1449. It is respectfully requested that an Examiner initial a copy of this form be returned to the undersigned.

The Commissioner is hereby authorized to charge any fees connected with this filing which may be required now, or credit any overpayment to Deposit Account No. 19-2380.

Respectfully submitted,

By: ______________________
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NVA270996.1

Substitute for form 1449A/PTO			Complete if Known	
INFORMATION DISCLOSURE STATEMENT BY APPLICANT *(use as many sheets as necessary)*			Application Number	New Divisional Application based on USSN: 09/755,173
			Filing Date	July 16, 2003
			First Named Inventor	David M. Krinsky et al.
			Art Unit	2634
			Examiner Name	Kevin Kim
Sheet		of	Attorney Docket Number	081513-334

U.S. PATENT DOCUMENTS

Examiner Initials*	Cite No.[1]	U.S. Patent Document Number - Kind Code[2] *(if known)*	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
		US-4,566,100	01-21-1986	Mizuno et al.	
		US-5,128,619	07-07-1992	Bjork et al.	
		US-5,608,643	03-04-1997	Wichter et al.	
		US-5,864,602	01-26-1999	Needle	
		US-5,964,891	01-12-1999	Casewell et al.	
		US-6,075,821	06-13-2000	Kao et al.	
		US-6,219,378	04-17-2001	Wu	
		US-6,404,774	06-11-2002	Jenness	
		US-6,411,678	06-25-2002	Tomlinson, Jr. et al.	
		US-6,449,307	09-10-2002	Ishikawa et al.	
		US-6,512,789	01-28-2003	Mirfakhraei	

FOREIGN PATENT DOCUMENTS

Examiner Initials*	Cite No.[1]	Foreign Patent Document Country Code[3] Number[4] Kind Code[5] *(if known)*	Publication Date MM-DD-YYYY	Name of Patentee or Application of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear	T[6]
		WO 97/01900	01-16-1997	Pfeiffer		
		WO 99/26375	05-27-1999	Hakanson		
		WO 99/63427	12-09-1999	Eichen et al.		
		WO 00/64130	10-26-2000	Rudinski et al.		
		EP 0 889 615	01-07-1999	Liu et al.		
		GB 2 303 032	02-05-1997	Chun		

OTHER PRIOR ART – NON PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No.[1]	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.)., date, page(s), volume-issue number(s), publisher, city and/or country where published.	T[2]
		Boets P. et al.: *"The Modeling Aspect of Transmission Line Networks"* Proceedings Of The Instrumentation And Measurement Technology Conference, US, New York, IEEE, 12 May 1992, pages 137-141, XP000343913 ISBN: 0-7803-0640-6.	
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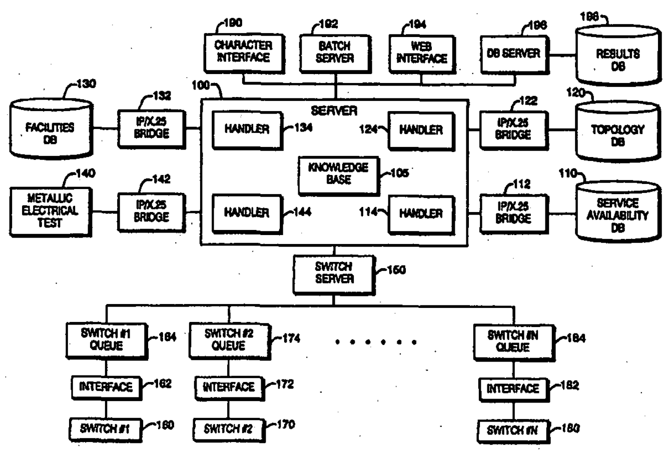

(57) Abstract

A system and methodology for qualifying a twisted pair copper loop for digital subscriber loop services are described. The system automatically queries telecommunications provider database records and/or requests measurements from network switching equipment or testing systems to obtain data regarding the twisted pair copper loop, such as loop length, electrical characteristics, and other loop topology characteristics such as wire gauge, the presence of load coils (88, 90), and the presence of bridge taps (84, 86). The system determines which digital subscriber loop services are available for the copper loop based on the combination of all data obtained. The system may be implemented in part as an expert system with a knowledge base of qualification rules used in the decision-making process.

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METHOD AND APPARATUS FOR DIGITAL SUBSCRIBER LOOP QUALIFICATION

Technical Field

The present invention relates to digital subscriber loop technology and, more specifically, to the qualification of existing twisted pair copper loops for digital subscriber loop service.

Background Art

Digital subscriber loop technology is the digital encoding of all information transmitted on the local loop, *i.e.*, the connection between a customer's premises (home, office, etc.) and a telecommunications provider's central office serving the customer's premises. Most existing local loops in the United States and throughout the world are twisted pair copper loops, originally designed for analog service, or plain old telephone service (POTS). With digital subscriber loop technology, high speed access to the Internet, advanced telephony functions, and multimedia services is possible over the twisted pair copper access network. Digital subscriber systems can provide data from speeds of 64 kb/second in both upstream and downstream directions to over 10 Mb/second in a single direction. Digital subscriber loop technology, often referred to as "xDSL" where x stands for any of a number of letters, includes the following:

ADSL, Asymmetric Digital Subscriber Loop
VDSL, Very High-Speed Digital Subscriber Loop
HDSL, High Data Rate Digital Subscriber Loop
SDSL, Symmetric Digital Subscriber Loop
IDSL, ISDN-based Digital Subscriber Loop
RADSL, Rate Adaptive Digital Subscriber Loop
ISDN, Integrated Digital Service Network

Some of these digital subscriber loop technologies (*e.g.*, HDSL, ISDN, and in particular ADSL) have been standardized by various standards bodies with respect to modulation format, bandwidth, and embedded operations channels, while others have not been standardized and are available from different vendors in a wide variety of modulation formats, upstream/downstream bandwidths, and operation channels.

As illustrated in Figure 1, digital subscriber loop technology consists of two terminal endpoints (TEs) 10 and 20, which provide conversion, modulation, transmission, and reception of data, and copper loop 30 connecting TEs 10 and 20. TE 10 is typically owned and operated by the service provider, while TE 20 is typically at the customer's premises. In the United States, TE 20 is typically owned or rented by the customer, while in most other parts of the world TE 20 is typically owned and operated by the service provider. In addition, the digital subscriber loop topology can include terminal equipment, such as a repeater, between the two terminal endpoints to provide additional network flexibility or to boost signal strength and transmission distances. For example, Figure 2 illustrates network terminal 70 in copper loop 60 between TEs 40 and 50.

Digital subscriber loop services, however, cannot be carried over all twisted pair copper loops that support POTS service. The various digital subscriber loop technologies have complex (real and imaginary) signal attenuation restrictions that depend upon downstream (to the customer) and upstream (from the customer) bandwidth, modulation format, and receiver sensitivity for a particular chip set used by a vendor terminal endpoint equipment. Signal attenuation itself depends on several factors, including the length and gauge of the copper wires contained in the loop, the environment in which the copper wires are placed (including temperature variations), and the quality of connections (*e.g.*, splices and terminal connections) that attach the different sections of wire contained in a given loop. Digital subscriber loop technologies also have restrictions on loop topology, such as the position and number of bridge taps and load coils, and restrictions on services provided in adjacent copper pairs in the same binder group (*i.e.*, a group of twisted pairs bundled together) because of crosstalk between pairs and overlapping frequency spectrums.

Figure 3 illustrates a typical copper loop between central office (CO) 80 and terminal endpoint 82, made up of several different lengths of wire of different gauges spliced together. One leg of the loop terminates at terminal endpoint 82, while two other legs are unterminated, resulting in bridge taps 84 and 86. The loop in Figure 3 also includes two load coils, 88 and 90, as well as cross connect 92.

As an example of loop topology requirements, a loop is restricted to less than approximately 5.25 km of 24 gauge wire when the digital service is provided at the rate of 1.5 Mb/second downstream and 80 kb/second upstream for a commonly available chip sent that uses carrierless amplitude phase (CAP) modulation for ADSL. For this modulation format and bandwidth allocation, if there is an analog carrier POTS service in the same wire binder group, the ADSL modulation will interfere with the analog carrier, effectively destroying the POTS service. Similarly, if there is a T1 carrier system in the same wire binder group, the T1 service will interfere with the ADSL modulation, nullifying the digital subscriber service, but typically not affecting the T1 service. The number of copper pairs and the potential for crosstalk in a binder group depends on the type and manufacturer of the copper cable.

Today, when a customer wishes to order a digital subscriber loop service, the local telecommunications service provider must determine whether the customer's existing twisted pair copper loop can support the requested digital subscriber loop service at the desired bandwidth. This can be a difficult and time-consuming task to perform manually because of the many restrictions on loop topology and services just described. All necessary data may not be available to a person trying to qualify a loop for digital subscriber loop services, particularly because telecommunications providers often have data in many different databases or stored in paper records. Even if data is available, data concerning outside plant information such as loop length and topology is often out of date. Also, certain metallic loop electrical data is not stored in a database and can only be determined by a measurement or test system.

It is desirable, therefore, to provide a system and methodology for determining which digital subscriber loop technologies can be supported by a particular twisted pair copper loop. It is more desirable to qualify a copper loop for digital subscriber loop services on the basis of real-time electrical measurements as well as records stored in telecommunications provider databases. It is even more desirable to provide an automated system for digital subscriber loop qualification that economically determines which digital subscriber loop technologies can be supported by a copper loop. It is also desirable to implement such a system as an expert system containing a knowledge base of rules.

Disclosure of Invention

The present invention satisfies those desires by providing a system and methodology for qualifying a twisted pair copper loop for digital subscriber loop services. The system automatically queries telecommunications provider database records and/or requests measurements from network switching equipment or testing systems to obtain information regarding the twisted pair copper loop in question. The system then determines which digital subscriber loop services are available for the copper loop based on the combination of all information obtained.

A method consistent with the present invention for qualifying a twisted loop pair for a digital subscriber service comprises the steps of receiving as input a unique identifier corresponding to the loop, determining a topology corresponding to the loop, and determining whether the loop meets topology restrictions of the digital subscriber service. Another method consistent with the present invention comprises the steps of receiving data corresponding to physical characteristics of the loop and applying a plurality of rules to the data to determine whether the loop is suitable for the digital subscriber service. Other methods consistent determine whether electrical characteristics of the loop meet restrictions of the digital subscriber service and whether services provided on other cable pairs in the same binder group with the loop are compatible with the digital subscriber service.

Systems are also provided for carrying out the methodologies of the present invention.

The advantages accruing to the present invention are numerous. A loop qualification system and method consistent with the present invention reduce the time for determining which digital subscriber loop services a particular copper loop supports from several hours to a few minutes. A system and method consistent with the present invention also provide a substantially more accurate result, in part because they use real-time electrical measurements to determine many topological characteristics of the copper loop.

The above desires, and other desires, features, and advantages of the present invention will be readily appreciated by one of ordinary skill in the art from the following detailed description of the preferred implementations when taken in connection with the accompanying drawings.

Brief Description of Drawings

Figure 1 illustrates digital subscriber loop technology connecting two terminal endpoints;

Figure 2 illustrates digital subscriber loop technology with network terminal equipment between two terminal endpoints;

Figure 3 illustrates a typical digital subscriber loop topology;

Figure 4 illustrates the architecture of a loop qualification system consistent with the present invention; and

Figure 5 is a flow chart of a method for qualifying loops consistent with the present invention.

Best Mode for Carrying Out the Invention

A system consistent with the present invention automatically qualifies twisted pair copper loops for digital subscriber loop services. Generally, a method for qualifying loops for digital subscriber loop services consistent with the present invention includes at least four types of qualification:

(1) Service Availability: Is the point at which the copper loop terminates equipped to provide the requested digital subscriber service?

(2) Length Qualification: Which digital subscriber loop services at which bandwidths can be provided given the length of the loop?

(3) Line Qualification: Is the loop physically suitable for use by a digital subscriber loop technology? Is the service currently provisioned on the loop compatible with digital subscriber loop service?

(4) Are the services provided on the other twisted pairs in the same binder group with the loop spectrally compatible with digital subscriber loop services?

In order to answer these loop qualification questions, a system consistent with the present invention combines results obtained from testing the copper loop, results from queries of telecommunications provider database records, and information regarding the transmission and receiver characteristics of the digital subscriber.

Figure 4 illustrates the architecture of a system for qualifying loops consistent with the present invention, which may be implemented, for example, as an expert system using a conventional client-server architecture known in the art. The expert system is implemented in software residing on server 100 and performs loop qualification by combining input from a number of information sources with rules contained in knowledge base 105. Specifically, server 100 obtains information from service availability database 110, topology database 120, facilities database 130, and metallic electrical test system 140. Databases 110, 120, and 130, and test system 140 are typically owned and operated by the local telecommunications provider. It will be recognized by one skilled in the art that each database shown in Figure 4 may actually consist of several smaller databases or, alternatively, that databases may be combined, since each telecommunications provider organizes its data into databases in different ways. Server 100 interfaces to the databases and test system via a suitable communications protocol such as IP or X.25, provided by interfaces 112, 122, 132, and 142. Server 100 additionally includes software handler modules for receiving and processing information obtained from databases 110, 120, and 130, and test system 140.

Server 100 also receives information and test results directly from central office switches in the local network, three of which are shown in Figure 4 as switches 160, 170, and 180 for illustrative purposes. Server 100 is coupled to switch server 150, which is coupled to switch queues 164, 174, and 184, corresponding to switches 160, 170, and 180, respectively. Switch queues 164, 174, and 184 access data from switches 160, 170, and 180 via interfaces 162, 172, and 182, respectively. It will be recognized by one skilled in the art that switch server 150 need not be separate from server 100.

Consistent with the present invention, a user may access server 100 through either the graphical user interface of client 194, *e.g.*, a World Wide Web-based client, or character interface 190, *e.g.*, a VT100 character interface. Regardless of the interface used, a user will typically enter a unique number (*e.g.*, a telephone directory number (TDN) or an IP address) or identifier (*e.g.*, a circuit identifier) associated with the copper loop for which qualification is desired. A system consistent with the present invention also includes batch server 192, which allows qualification of numerous loops to be performed in batch, and database server 196 for storing results in results database 198.

Figure 5 is a flow chart illustrating a method for qualifying loops for digital subscriber loop services consistent with the present invention. Consistent with an embodiment of the present invention, the method is performed by software residing on server 100. The process begins by receiving as input a unique identifier corresponding to the copper loop to be qualified for digital subscriber services (step 200). The unique identifier may be a telephone directory number (TDN) as shown in Figure 5, or any other unique identifier such as an IP address or a circuit identifier. Also, server 100 may receive the identifier from any input source, including character interface 190 or web interface 194 (if a human user is accessing the system through an interface) and batch server 192 (if several qualification requests have been entered for batch processing). Most of the remaining steps in the process use the unique loop identifier to retrieve information regarding the loop.

Once receiving a loop identifier, the qualification process continues by determining whether digital subscriber loop services are available for the loop (step 210). Consistent with the present invention, the server makes this determination by querying service availability database 110 to determine whether the local telecommunications provider provides xDSL services from the office serving the customer's location. If xDSL service is not available, loop qualification terminates. If xDSL service is available, processing continues to step 220. In an alternate method consistent with the present invention, the server may choose to continue the loop qualification process although xDSL service is not available.

Next, the process determines whether the loop is on a working pair (step 220) by querying facilities database 130. Some measurement tests performed by a loop qualification method consistent with the present invention require that the loop be on a working pair. If the loop is not on a working pair, the server either terminates loop qualification (as shown in Figure 5) or chooses to continue loop qualification, although not all tests will be available for the loop. Alternatively, the loop may be temporarily assigned to line equipment and a test number so that loop qualification may be performed.

If loop qualification continues, the server determines whether the current service on the loop is compatible with xDSL service (step 230). For example, in the United States the current service cannot be T1 or ISDN. Consistent with the present invention, the server performs this step by querying facilities database 130. As discussed above, it should be apparent to one skilled in the art that, although the queries in steps 220 and 230 both access databases with information regarding facilities, the facilities database shown in Figure 4 (database 130) may consist of several smaller databases, so that the queries of steps 220 and 230 access two different, smaller databases. If the current service is not compatible, loop qualification ends. If the current service is compatible, then flow proceeds to several data collection steps. In an alternate method consistent with the present invention, the server may choose to continue the loop qualification process although the current service is not compatible with xDSL service.

A method consistent with the present invention performs some or all of data collection steps 240, 250, 260, and 270. These steps are not necessarily performed in a particular order, and some steps may be performed simultaneously. For example, Figure 5 shows steps 240 and 250 being performed at the same time as steps 260 and 270. Each of these steps involves obtaining information about the loop to be qualified from a database or a test or measurement system in the network, and all of the information obtained is used as input to step 280, which applies a plurality of rules to the information to model the response of the network and determine which digital subscriber services are available on the loop.

In step 240, the server queries topology database 120 using the unique loop identifier (*e.g.*, TDN or IP address) to obtain a variety of loop topology data. In particular, the server requests length and gauge of wire on the loop for each loop segment, cable type, the location of load coils on the loop, and the location and length of bridge taps on the loop. For example, the loop topology shown in Figure 3 is an example of data that may be obtained from topology database 120. As described above, topology database 120 may consist of several smaller databases, each of which contains different information. Step 240 may also include a query of a separate database (not shown in Figure 4) that stores recent measurements of the loop length. This data may be more accurate than a topology database operated by the telecommunications provider for storing many different types of loop topology data.

Referring again to Figure 5, in step 250 the server queries facilities database 130 using the unique loop identifier to determine the services on other cable pairs in the same binder group as the loop to be qualified. This information will be used in step 280 to determine whether xDSL services are spectrally compatible with the services on the other cable pairs in the binder so that crosstalk will not degrade service quality.

In step 260, the server requests measurements from metallic electrical test system 140, which is a remote test system such as 4TEL, manufactured by Teradyne, Inc., or Mechanized Loop Test (MLT), manufactured by Lucent Technologies. Consistent with the present invention, the server requests a measure of loop length and/or loop capacitance, which can be converted to loop length using a known mathematical relationship. The server also requests measures of longitudinal balance and wideband and narrowband electrical ingress which will be used in step 280 to determine the suitability of the loop for digital subscriber loop services. As described earlier, tests in step 260 may not be performed if the loop is not on a working pair.

In step 270, the server requests a load coil detection measurement to determine if there are any load coils in the loop. This measurement can be performed at the end office switch at which the loop terminates (*e.g.*, switch 160, 170, or 180 in Figure 4) or by metallic electrical test system 140. If the server obtains the measurement from the switch, switch server 150 receives measurements from queues 164, 174, and 184, and controls server 100's access to switch measurements. Examples of load coil detection measurements known in the art are a swept frequency measurement and a time domain reflectometry measurement. As descirbed earlier, tests in step 270 may not be performed if the loop is not on a working pair.

All of the information obtained in steps 240, 250, 260, and 270 from database queries and test and measurement systems is input to step 280. Consistent with the present invention, in step 280 an expert system resident on server 100 combines the results of steps 240, 250, 260, and 270 with a plurality of qualification rules from knowledge base 105 and information on network equipment stored in a database (not shown for the sake of clarity) to model the response of the network for the various digital subscriber loop services available to the subscriber. The expert system also determines, for each of the available digital subscriber loop services (*e.g.*, ADSL, VDSL, etc.), how much bandwidth can be supported in both upstream and downstream directions.

Consistent with the present invention, the qualification rules in knowledge base 105 are not limited to any particular set. The rules may range from the simple (*e.g.*, a loop with one or more load coils does not qualify for a digital subscriber loop service) to the more complex (*e.g.*, for a certain type of terminal equipment and a particular digital subscriber loop service with given upstream and downstream bandwidth, a combination of wire length and gauge limits can be calculated according to mathematical relationships to satisfy given signal attenuation and/or bit error rate requirements).

Consistent with the present invention, there may be a conflict between data retrieved from a database and data measured in real-time using a measurement system or test system. In such cases, knowledge base 105 can also include rules for reconciling the differences. For example, if data retrieved from a database is known not to have been updated recently, then a qualification method consistent with the present invention would rely on measured data, which may be more accurate.

The ultimate output of a system consistent with the present invention is a list of digital subscriber loop service packages that the loop can support. For a particular type of xDSL service (*e.g.*, ADSL), there may be multiple packages, each of which defines a different class of service, including upstream and downstream bandwidth. For example, a loop may be able to support an ADSL package with downstream/upstream bit rates of 640k/272k, but the same loop may not support ADSL with bit rates of 640k/680k because of the loop length and topology. Alternatively, a system consistent with the present invention may determine whether a loop can support a specified digital subscriber loop service with given upstream and downstream bandwidths. In this case, the system user may enter the service type and bandwidth desired. In addition to simply listing qualified services, the system may provide the user with diagnostic information explaining why a particular decision was reached.

It will be apparent to those skilled in this art that various modifications and variations can be made to the loop qualification scheme of the present invention without departing from the spirit and scope of the invention. Other embodiments of the invention will be apparent to those skilled in this art from consideration of the specification and practice of the invention disclosed herein. In particular, the method is not limited to implementation in a client/server architecture or as an expert system. Nor is the invention limited to the user interfaces described. For example, a machine application program interface can provide access to the system from another system or as part of a larger provisioning system. A method consistent with the present invention can also be used to qualify loops for other services whose qualification requires access to database and/or real-time measurements. It is intended that the specification and examples be considered exemplary only, with the true scope and spirit of the invention being indicated by the following claims.

Claims

1. A method for qualifying a twisted pair loop for a digital subscriber service having loop topology restrictions, the method comprising the steps of:

receiving a unique identifier corresponding to the loop;

identifying a topology corresponding to the identified loop; and

determining whether the identified loop meets the loop topology restrictions of the digital subscriber service based on the identified topology.

2. The method of claim 1 further including the step of computing a bandwidth that can be supported on the loop in response to the topology.

3. The method of claim 1 wherein the identifying step includes the substeps of determining a length corresponding to the loop and determining a gauge corresponding to the loop.

4. The method of claim 3 wherein the substep of determining a length includes the substeps of requesting a capacitance measurement of the loop from a metallic electrical testing system and converting the capacitance measurement into the length.

5. The method of claim 3 wherein the substep of determining a length includes the substep of requesting a length measurement from a metallic electrical testing system.

6. The method of claim 3 wherein the substep of determining a length includes the substep of querying a database containing a recent length measurement of the loop.

7. The method of claim 3 wherein the substep of determining a length includes the substep of querying a database containing a known length of the loop.

8. The method of claim 3 wherein the substep of determining a gauge includes the substep of querying a topology database containing the gauge of the loop.

9. The method of claim 1 wherein the loop contains a plurality of loop segments, and wherein the identifying step includes the substeps of determining a length corresponding to each of the plurality of loop and segments and determining a gauge corresponding to each of the plurality of loop segments.

10. The method of claim 9 wherein the substep of determining a length includes the substep of querying a database containing the length of each of the plurality of loop segments.

11. The method of claim 9 wherein the substep of determining a gauge includes the substep of querying a database containing the gauge of each of the plurality of loop segments.

12. The method of claim 1 wherein the identifying step includes the substep of querying a database for the position of a bridge tap in the loop.

13. The method of claim 1 wherein the identifying step includes the substep of querying a database for the length of a bridge tap in the loop.

14. The method of claim 1 wherein the identifying step includes the substep of querying a database for the number of bridge taps in the loop.

15. The method of claim 1 wherein the identifying step includes the substep of querying a database for the position of a load coil in the loop.

16. The method of claim 1 wherein the identifying step includes the substep of querying a database for the number of load coils in the loop.

17. The method of claim 1 wherein the identifying step includes the substeps of requesting a load coil measurement of the loop from a test system at a switch connected to the loop.

18. The method of claim 17 wherein the load coil measurement is a swept frequency measurement.

19. The method of claim 17 wherein the load coil measurement is a time domain reflectometry measurement.

20. A method for qualifying a twisted pair loop for a digital subscriber service, the method comprising the steps of:

receiving a unique identifier corresponding to the loop;

identifying a first cable pair and a binder corresponding to the identified loop having the first cable pair corresponding to the identified loop and a second cable pair; and

determining whether services provided on the second cable pair are compatible with the digital subscriber service.

21. The method of claim 20 wherein the identifying step includes the substep of querying a database correlating the binder to the first and second cable pairs and services provided on the cable pairs, and wherein the determining step includes the substep of querying the database.

22. A method for qualifying a twisted pair loop for a digital subscriber service, the method comprising the steps of:

receiving a unique identifier corresponding to the loop;

identifying a current service on the identified loop; and

determining whether the current service is compatible with the digital subscriber service.

23. The method of claim 22 wherein the identifying step includes the substep of querying a database correlating the identifier to the current service on the loop.

24. The method of claim 22 further comprising the step of determining whether the identifier corresponds to a working loop.

25. A method for qualifying a twisted pair loop for a digital subscriber service having longitudinal balance restrictions, the method comprising the steps of:

receiving a unique identifier corresponding to the loop;

requesting a longitudinal balance measurement of the identified loop from a metallic electrical testing system; and

determining whether the measurement meets the restrictions.

26. A method for qualifying a twisted pair loop for a digital subscriber service having electrical ingress restrictions, the method comprising the steps of:

receiving a unique identifier corresponding to the loop;

requesting an electrical ingress measurement of the identified loop from a metallic electrical testing system; and

determining whether the measurement meets the restrictions.

27. A method for qualifying a twisted pair loop for a digital subscriber service, the method comprising the steps of:

receiving data corresponding to physical characteristics of the loop; and

applying a plurality of qualification rules to the data to determine whether the loop is suitable for the digital subscriber service.

28. The method of claim 27 wherein the receiving step includes the substep of receiving data from a metallic loop electrical test system.

29. The method of claim 27 wherein the receiving step includes the substep of receiving data from a database.

30. The method of claim 27 wherein the receiving step includes the substep of receiving data from a switch connected to the loop.

31. The method of claim 27 wherein the applying step is performed by an expert system.

32. A method for qualifying a twisted pair loop for a telecommunications service, the method comprising the steps of:

receiving data corresponding to physical characteristics of the loop; and

applying a plurality of qualification rules to the data to determine whether the loop is suitable for the telecommunications service.

33. The method of claim 32 wherein the applying step is performed by an expert system.

34. A system for qualifying a twisted pair loop for a digital subscriber service having loop topology restrictions, the system comprising:

an interface for receiving a unique identifier corresponding to the loop;

means for identifying a topology corresponding to the identified loop; and

means for determining whether the identified loop meets the topology restrictions of the digital subscriber service based on the identified topology.

35. The system of claim 34 wherein the identifying means includes means for querying a database.

36. The system of claim 34 wherein the identifying means includes means for requesting a measurement from a test system.

37. A system for qualifying a twisted pair loop for a digital subscriber service comprising:

means for receiving data corresponding to physical characteristics of the loop; and

means for applying a plurality of qualification rules to the data to determine whether the loop is suitable for the digital subscriber service.

38. The system of claim 37 further wherein the means for applying includes an expert system, the expert system including a knowledge base containing the plurality of qualification rules.

39. A system for qualifying a twisted pair loop for a digital subscriber service having loop topology restrictions, said system comprising:

an interface for receiving a unique identifier corresponding to the loop;

a memory comprising a loop qualification program for identifying a topology corresponding to the identified loop, and for determining whether the identified loop meets the loop topology restrictions; and

a processor for running the loop qualification program.

40. A system for qualifying a twisted pair loop for a digital subscriber service comprising:

an interface for receiving data corresponding to physical characteristics of the loop;

a memory comprising a knowledge base containing a plurality of rules, and a loop qualification program for applying the plurality of rules; and

a processor for running the loop qualification program.

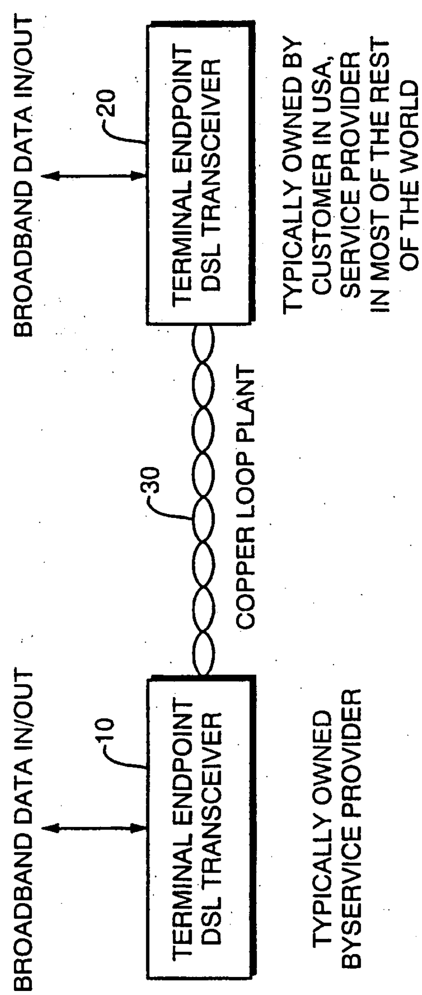
BROADBAND DATA IN/OUT
10
TERMINAL ENDPOINT DSL TRANSCEIVER
TYPICALLY OWNED BYSERVICE PROVIDER
30
COPPER LOOP PLANT
BROADBAND DATA IN/OUT
20
TERMINAL ENDPOINT DSL TRANSCEIVER
TYPICALLY OWNED BY CUSTOMER IN USA, SERVICE PROVIDER IN MOST OF THE REST OF THE WORLD

FIG. 1

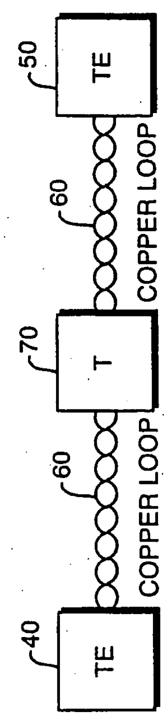
40
TE
60
COPPER LOOP
70
T
60
COPPER LOOP
50
TE

FIG. 2

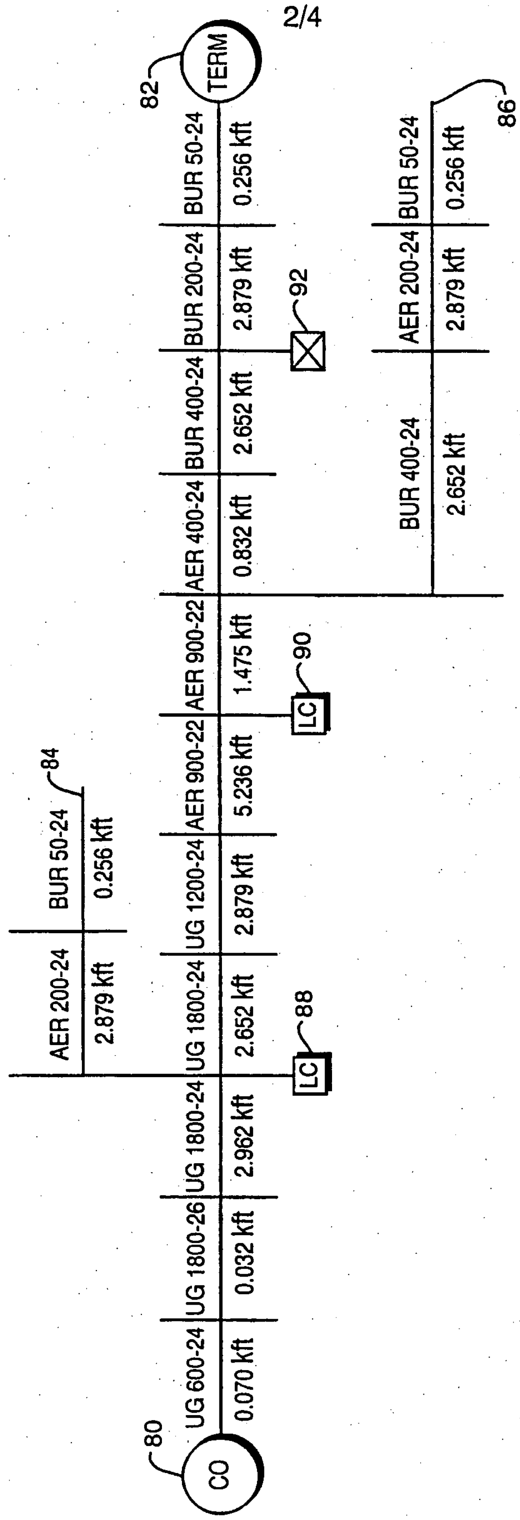
CO
80
UG 600-24
0.070 kft
UG 1800-26
0.032 kft
UG 1800-24
2.962 kft
UG 1800-24
2.652 kft
LC
88
UG 1200-24
2.879 kft
AER 900-22
5.236 kft
AER 900-22
1.475 kft
LC
90
AER 400-24
0.832 kft
BUR 400-24
2.652 kft
BUR 200-24
2.879 kft
92
BUR 50-24
0.256 kft
TERM
82
AER 200-24
2.879 kft
BUR 50-24
0.256 kft
84
BUR 400-24
2.652 kft
AER 200-24
2.879 kft
BUR 50-24
0.256 kft
86

FIG. 3

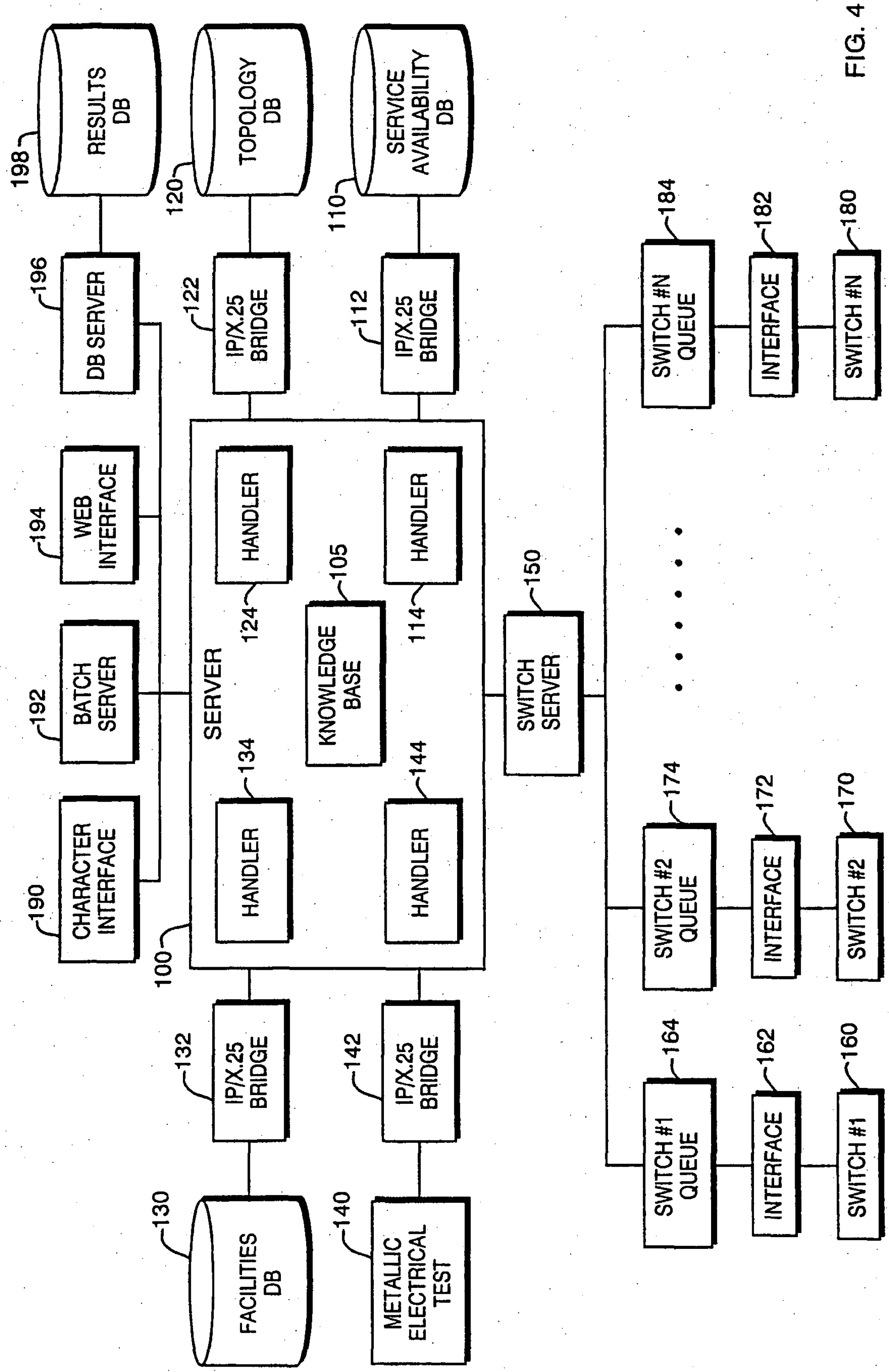
RESULTS DB
198
TOPOLOGY DB
120
SERVICE AVAILABILITY DB
110
DB SERVER
196
IP/X.25 BRIDGE
122
IP/X.25 BRIDGE
112
WEB INTERFACE
194
BATCH SERVER
192
CHARACTER INTERFACE
190
SERVER
100
HANDLER
124
KNOWLEDGE BASE
105
HANDLER
114
HANDLER
134
HANDLER
144
SWITCH SERVER
150
IP/X.25 BRIDGE
132
IP/X.25 BRIDGE
142
FACILITIES DB
130
METALLIC ELECTRICAL TEST
140
SWITCH #N QUEUE
184
INTERFACE
182
SWITCH #N
180
SWITCH #2 QUEUE
174
INTERFACE
172
SWITCH #2
170
SWITCH #1 QUEUE
164
INTERFACE
162
SWITCH #1
160

FIG. 4

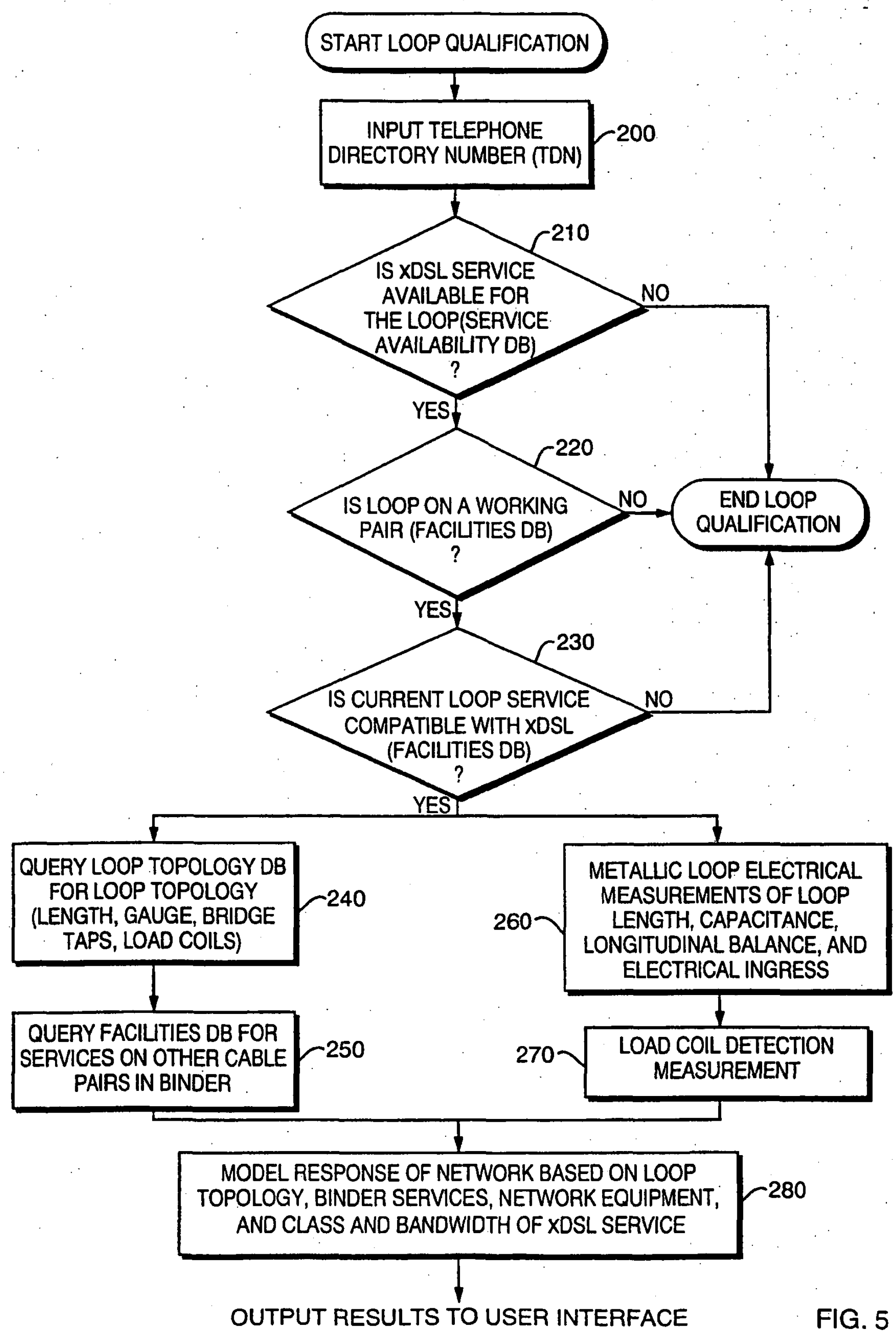
START LOOP QUALIFICATION
INPUT TELEPHONE DIRECTORY NUMBER (TDN)
200
IS xDSL SERVICE AVAILABLE FOR THE LOOP(SERVICE AVAILABILITY DB) ?
210
NO
YES
IS LOOP ON A WORKING PAIR (FACILITIES DB) ?
220
NO
END LOOP QUALIFICATION
YES
IS CURRENT LOOP SERVICE COMPATIBLE WITH xDSL (FACILITIES DB) ?
230
NO
YES
QUERY LOOP TOPOLOGY DB FOR LOOP TOPOLOGY (LENGTH, GAUGE, BRIDGE TAPS, LOAD COILS)
240
METALLIC LOOP ELECTRICAL MEASUREMENTS OF LOOP LENGTH, CAPACITANCE, LONGITUDINAL BALANCE, AND ELECTRICAL INGRESS
260
QUERY FACILITIES DB FOR SERVICES ON OTHER CABLE PAIRS IN BINDER
250
LOAD COIL DETECTION MEASUREMENT
270
MODEL RESPONSE OF NETWORK BASED ON LOOP TOPOLOGY, BINDER SERVICES, NETWORK EQUIPMENT, AND CLASS AND BANDWIDTH OF xDSL SERVICE
280
OUTPUT RESULTS TO USER INTERFACE

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/11052

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G06F 9/00; H04B 3/23, 3/32
US CL :702/57; 370/286, 294, 401; 375/296, 346, 349; 364/141
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 702/57; 370/286, 294, 401; 375/296, 346, 349; 364/141

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,181,198 A (LECHLEIDER) 19 January, 1993 (19.01.93), Abstract, figs.1-7, cols.1-3.	1-40
A	US 5,504,896 (SCHELL et al.) 02 April, 1996 (02.04.96), Abstract, figs.1-10, cols.1-2.	1-40

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05 JULY 1999	27 JUL 1999

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	HIEN VO
Facsimile No. (703) 305-3230	Telephone No. (703) 308-5253

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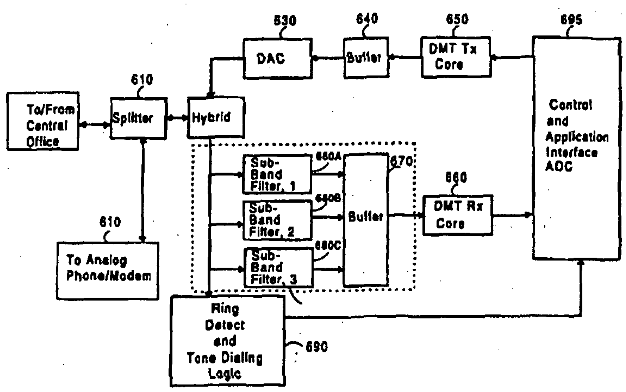
(54) **Multicarrier transmission with variable data rate**

(57) A high speed communications system is provided which uses a selectable, desirable portion of the total available bandwidth of a transmission channel. In a preferred embodiment, the invention is an ADSL compatible modem which selects a sub-set of the available downstream DMT sub-channels based on an evaluation of such sub-channels by appropriate signal processing circuitry. An analog front end (AFE) contains sub-band filtering causes an upstream transceiver to use only this selected number of available sub-channels for downstream data transmission. This reduces hardware costs and complexity while still preserving compatibility with applicable ADSL standards and providing a high speed data link. The target data rate of the modem can be further enhanced to the point of achieving full protocol capability by increasing or upgrading the AFEs, and/or the signal processing circuitry in order to increase the number of processable transmitted downstream sub-channels.

FIGURE 6



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2.16.7/3.6

Descripti n

FIELD OF THE INVENTION

The invention relates generally to an improved high-speed communications system which establishes a data link using only a selectabl portion of the total availabl bandwidth of a channel. The present invention has particular applicability to systems which use rate adaptable techniques such as the discrete multi-tone modulation (DMT) technique and CAP for transmitting data in Digital Subscriber Lines and similar environments. By limiting the data throughput of the link to some adjustable fraction of the total available data rate, the present invention significantly reduces hardware costs and allows a downstream user to configure a data link whose performance is directly controllable by the processing power available to such user. In this manner, the system is completely forward compatible and expandable in functionality, and permits a user to increase throughput to the point of achieving full potential of the available channel bandwidth .

BACKGROUND OF THE INVENTION

Remote access and retrieval of data and information are becoming more desirable and common in both consumer and business environments. As data and information transfer is becoming more and more voluminous and complex, using traditional data links such as voice-band modems is too slow in speed. For example, the use of the Internet to locate and access information is increasing daily, but the retrieval of typical graphics, video, audio, and other complex data forms is generally unsatisfyingly slow using conventional voice-band modems. In fact, the slow rate of existing dial-up analog modems frustrates users, and commerce and interaction using the Internet would have been even higher were it not for the unacceptable delays associated with present day access technology. The ability to provide such desired services as video on demand, television (including HDTV, video catalogs, remote CD-ROMs, high-speed LAN access, electronic library viewing, etc., are similarly impeded by the lack of high speed connections.

Since the alternatives to copper line technology have proven unsatisfactory, solutions to the high speed access problem have been focused on improving the performance of voice band modems. Voice band modems operate at the subscriber premises end over a 3 kHz voice band lines and transmit signals through the core switching network, the phone company network treats them exactly like voice signals. These modems presently transmit up to 33.6 kbps over a 2-wire telephone line, even though the practical speed only twenty years ago was 1.2 kbps. The improvement in voice band modems over the past 20 years has resulted from significant advances in algorithms, digital signal processing, and semiconductor technology. Because such modems are limited to voice bandwidth (3.0 kHz), the rate is bound by the Shannon limit, around 30 kbps. A V.34 modem, for example, achieves 10 bits per Hertz of bandwidth, a figure that approaches the theoretical Shannon limits.

There is a considerable amount of bandwidth available in copper lines, however, that has gone unused by voice band modems, and this is why a proposal known as Asymmetric Digital Subscriber Line (ADSL) was suggested in the industry as a high-speed protocol/connection alternative. The practical limits on data rate in conventional telephone line lengths (of 24 gauge twisted pair) vary from 1.544 Mbps for an 18,000 foot connection, to 51.840 Mbps for a 1,000 foot connection. Since a large proportion of current telephone subscribers fall within the 18,000 foot coverage range, ADSL can make the current copper wire act like a much "bigger pipe" for sending computer bits and digital information (like movies and TV channels), while still carrying the voice traffic. For example, an ADSL modem can carry information 200 times faster than the typical voice band modem used today.

ADSL is "asymmetric" in that more data goes downstream (to the subscriber) than upstream (back from the subscriber). The reason for this is a combination of cost, demand, and performance. For example, twisted pair wiring coupling increases with the frequency of the signal. If symmetric signals in many pairs are used within a cable, the data rate and line length become significantly limited by the coupling noise. Since the preponderance of target applications for digital subscriber services is asymmetric, asymmetric bit rate is not perceived to be a serious limitation at this time. Therefore, the ADSL standard proposes up to 6 Mbps for downstream, and up to 640 kbps for upstream. For example, video on demand, home shopping, Internet access, remote LAN access, multimedia access, and specialized PC services all feature high data rate demands downstream, to the subscriber, but relatively low data rates demands upstream. The principal advantage is that all of the high speed data operations take place in a frequency band above the voice band, leaving Plain Old Telephone Service (POTS) service independent and undisturbed, even if an ADSL modem fails. ADSL further provides an economical solution for transmission of high bandwidth information over existing copper line infrastructures.

Specifically, the proposed standard for ADSL divides the available transmission bandwidth into two parts. At the lower 4 kHz band, ordinary (POTS) is provided. The bulk of the rest bandwidth in the range from 4 kHz to about 1 MHz is for data transmission in the downstream direction, which is defined to be from the exchange to the subscriber. The upstream control channel uses a 160 kHz band in between. The signals in each channel can be extracted with an appropriate band -pass filter.

A DMT implementation of ADSL uses the entire available 1 MHz range of a copper phone line. It merely splits the signal into 255 separate channels, and each 4 kHz channel can be made to provide a bit rate up to the best present day voice band (33.6 kbs) modems. This results essentially in overall performance which is equivalent to around two hundred V.34 modems used in parallel on the same line. Because each channel can be configured to a different bit rate according to the channel characteristics, it can be seen that DMT is inherently "rate-adaptive" and extremely flexible for interfacing with different subscriber equipment and line conditions.

A number of problems arise, however, in attempting to implement a full scale ADSL transceiver cost-effectively.

First, to achieve this high bit rate transmission over existing telephone subscriber loops, advanced analog front end (AFE) devices, complicated digital signal processing techniques, and high speed complex digital designs are required. As a result, this pushes current technology limits and imposes both high cost and power consumption. For example, AFE devices in modem applications provide the interface between analog wave forms and digital samples for digital hardware/software processing. In high speed modern technologies such as ADSL, AFE devices need to operate at a very high sampling rate and high accuracy. For example, the DMT technology has a spectrum of 1 MHz and requires sampling above 50 MHz if a sigma-delta analog-to-digital (ADC) method is used. This thus requires the state-of-art ADC technology and imposes a high cost for end users.

Second, the time domain signal in ADSL/DMT transmissions is a summation of a large number of carriers modulated by quadrature amplitude modulation (QAM). This typically results in a large peak-to-peak deviation. As a result, even though a high speed AFE is made possible, a large dynamic range and high resolution AFE is required at the same time to minimize quantization errors.

Third, in addition to the high sampling rate and resolution requirement for ADSL AFEs, the other hardware and software in ADSL environment also needs to operate at a much higher speed than current conventional modem counterparts. For example, to implement the DMT technology in software, a custom and dedicated digital signal process (DSP) of a power of several hundred MIPS (millions instructions per second) is required to process many components such as error encoding and decoding, spectrum transforms, timing synchronization, etc. As with the AFE part of the system, this high speed requirement for the signal processing portion of ADSL also results in less flexible, high component costs.

Fourth, requiring a communications device (such as a modem) to fully supp ort the total throughput of a standard such as ADSL may be inefficient in some cases, since many prospective users of high-speed data links may not need to use all the available bandwidth provided by such standards. It is generally more preferable therefore to permit users to throttle or scale the data throughput in a manner they can control, based on their particular application needs, hardware cost budget, etc. For example, a full-scale ADSL system may have the performance level of 200 times conventional V.34 modems, but it is apparent that even a performance improvement of 10 - 20 times than present day available analog modems would be sufficient for many consumer applications, such as Internet access and similar uses. Thus, unlike conventional analog modems, which are available in various speeds varying generally from 14.4 to 56 Kbps, there are no known ADSL modems which offer scalable performance levels to users.

Fifth, in addition to the implementation challenge, the T1E1.4 ADSL standard does not specify the system interface and user model. Although various high level interface to support T1 /E1, ATM, etc. have been described, system integration with high level protocols such as TCP/IP and interface with computer operating systems have not yet been defined. As a result, there is uncertainty how existing and future modem-based applications can work with the ADSL technology. For example, when users run an Internet application which sends and receives data to and from an Internet service provider (ISP), a mutually agreed protocol is required to set up a call and transfer data. Possible protocols available at various levels include ATM (asynchronous transfer mode), TCP/IP, ISDN, and current modem AT commands. Either one of these or a possibly new protocol needs to be defined to facilitate the adoption of ADSL technology.

SUMMARY OF THE INVENTION

An object of the present invention therefore is to provide a communications system which is fully compatible with high speed, rate adaptable protocols such as are used with ADSL, but which system is nevertheless implementable with simpler analog font end receiving/transmitting circuitry and is thus reduced in cost and complexity;

A further object of the present invention is to provide a communications system which is fully compatible with high speed, rate adaptable modulation protocols such as used with ADSL, but which system is nevertheless implementable with simpler digital signal processing circuitry and is thus reduced in cost and complexity;

Another objective of the present invention is to provide a method for transmitting data within a fractional, desirable portion of available bandwidth in a channel by modulating only a limited number of desirable sub-channel data carriers, so that a high speed data link can be achieved that is faster, and has reduced computation and hardware demands;

Yet a further objective of the present invention is to provide a communications system with smaller peak-to-peak deviation in the sub-channels signals, so as to reduce the dynamic range required for the front end ADC, and to minimize quantization errors.

Another objective of the present invention is to provide a high speed communications system having a data throughput that is easily controllable and expandable, so that the performance range of such system can be configured to any fractional percentage of total bandwidth available in a transmission channel, up to and including full bandwidth use of the channel;

A related objective of the present invention is to provide a h igh speed communications system that is modular so that forward compatible and expandable functionality can be incorporated flexibly and with a minimum of effort on the part of a user of such system;

Yet a further objective is to provide a system that is compatible with high speed protocols used in ADSL, but which is also easily adaptable to support preexisting high level data protocols, including those presently used for controlling high speed voice band modems;

A further object of the present invention is to provide a high speed communications system that self-calibrates its own performance level, based on the processing power available to such system;

Another objective of the present invention is to provide a high speed communications system that permits a user to configure the performance parameters of such system using conventional personal computer hardware, software and operating systems;

A further object of the present invention is to provide an interface between a host operating system and a high speed communications system that provide forward compatible and expandable functionality;

An additional aim of the present invention is to provide an improved system for concurrent control of conventional voice data traffic on a POTS channel, and upstream/downstream communications on separate sub-channels;

These objects and others are accomplished by providing a communications system that permits a host processing device to receive selected data within a narrow bandwidth from an upstream transciever which can and normally transmits a large bandwidth analog data transmission signal through a connected channel. A channel interface circuit AFE samples the received analog signal to generate a digital signal. Only a limited portion of the bandwidth may be sampled, thus reducing front end complexity. A digital signal processing circuit then extracts the selected data from this limited digital signal, which is significantly easier to process than a full bandwidth digital signal. Feedback information is provided back to the upstream transmitter which causes the upstream transmitter to transmit downstream data thereafter only using the limited bandwidth of the front end, and not the full bandwidth. This feedback information contains information about the channel that suggests to the upstream transmitter that the other bandwidth in the channel is unusable. In this manner, the upstream transceiver is trained to accommodate the lower rate downstream transceiver in a manner that nevertheless preserves protocol integrity.

In a preferred embodiment, the large bandwidth analog data transmission signal is comprised of a number of DMT modulated sub-channels, and an anti- aliasing filter on the front end of the the downstream transceiver ensures that only a limited number of such sub-channels are processed by a DMT signal processing core. The feedback information consists of non-zero SNR information for the selected sub-channels, and a sub-channel blackout "mask" to eliminate the potential use of other sub-channels. The feedback information is sent by way of a front end transmitting circuit which transmits an upstream data transmission using a second frequency range different from the downstream transmission.

One implementation of the aforementioned high speed system is in a personal computer, so that the signal processing can be accomplished using a processor within such computer, which in a preferred embodiment is an X86 compatible processor. Another implementation of the aforementioned high speed system uses a dedicated signal processor for demodulating the selected sub-channels. This cuts down on processing overhead requirements for a host processing system incorporating the system. In such implementations the portion of the downstream data transmission to be processed for data extraction can be configured by a user of such systems, or alternatively, it can be dynamically determined based on an evaluation by the digital signal processing circuit of performance characteristics of different portions of the frequency spectrum within the bandwidth potential of the upstream transceiver.

In another variation, the data rate of a system such as described above can be increased by processing data from an additional second limited frequency bandwidth portion of the total available downstream bandwidth. In a preferred embodiment, this can be done by including a number of anti- aliasing filters in a modular bank as part of the analog front end section, each of which passes a different frequency bandwidth portion. By making the analog front end modular, the data rate of the overall system can be scaled in a controllable and cost-effective fashion. At the same time, each analog front end portion can be operated at a slower sampling clock and smaller dynamic range. This results in a more relaxed speed requirement and smaller quantization noise at a given number of bits per sample.

The present disclosure also includes an interface to an operating system, to facilitate controlling the high speed communications system when it is incorporated in a personal computer system. This interface ensures that the operating system treats such communications system essentially the same as other prior art voice band modems, and in a preferred embodiment, is a device driver for the Windows NT operating shell. Finally, the present disclosure also describes an applications program which permits a user of a personal computer to control the performance characteristics of the high speed communications system by setting certain system parameters when such system is incorporated in a personal computer system. This program includes an auto calibration routine for setting such system parameters, or alternatively a user of such program can tailor the settings subject to confirmation of the efficacy of such settings based on an evaluation of the processing power available to such user.

Although the inventions are described below in a preferred embodiment implementing the ADSL standard, it will be apparent to those skilled in the art the present invention would be beneficially used in any high sp ed rate-adaptable applications.

It should be noted that while some prior art devices also have limited mechanisms for achieving a reduction of nominal or peak transmission speed in a channel, they only activate or implement such mechanisms as a fallback response to a failure in the channel, or because of a transmission rate reduction in the upstream transceiver. Unlike the present invention, such prior art modems, during an initialization process, attempt to establish the highest possible transmission rate achievable by the channel and the upstream transciever. In other words, any rate reduction imposed by the downstream modem is typically considered an unintended and undesirable side effect of bad channel characteristics, and not a desirable and intentional design target as set forth in the present invention. In addition, the data rate reduction in such modems is accomplished primarily by varying the number of bits per baud (hertz) at a fixed frequency, and nor by controlling the overall frequency spectrum of the downstream data transmission. Moreover, in such prior art systems, no effort is made to measure, identify or use an optimal portion of the usable bandwidth or set of transmission sub-channels. Instead, such prior art systems typically use whatever available bandwidth or sub-channels happen to be usable at that instant in time.

Similarly, while a fixed 300 baud rate downstream modem can work with an upstream 33kbs rate modem this arrangement is also unlike the present invention. This is because, again, the bandwidth reduction in such prior art device is so large that it is considered commercially unusable by today's standards. Furthermore, the smaller bandwidth modem is not compatible with, and does not support, the higher protocols of the higher bandwidth modem, which is also undesirable from an implementation standpoint. Stated another way, unlike the present invention, the lower end modem limitations of prior art system force the data link to be set up using a low level protocol that does not take advantage of the full capabilities of more advanced protocols.

Finally, there is no mechanism for users of either of the prior art systems noted above to expand the functionality of such modems in a controlled, flexible, and modular manner.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a pictorial depiction of the ADSL/DMT bandwidth allocation for upstream and downstream data in a channel based on frequency division multiplexing (FDM) configuration.

Figure 1B shows the relationship between a sub -band filter and an analog to digital converter that can be used in an analog front end (AFE) of the present invention ;

Figure 1C is a pictorial depiction of a SNR curve for a typical subscriber loop channel using sub-channel modulation;

Figures 1D - 1G are mathematical modellings and charts that further explain the underlying physical premises of the present invention based on DMT ;

Figure 2 is a block diagram of a general implementation of a communications system employing the present invention, adapted for use in an ADSL environment ;

Figure 3A is a block diagram of a dedicated hardware implementation of a communications system employing the present invention, also adapted for use in an ADSL environment;

Figure 3B is a block diagram of a mixed hardware an d software based implementation of a communications system employing the present invention, also adapted for use in an ADSL environment;

Figure 4 is a block diagram depicting the general structure of the data pump device driver used in the mixed implementation shown in Fig. 3;

Figure 5 is a flowchart depicting the general operation of the control and application interface used in the mixed implementation shown in Fig. 3 ;

Figure 6 is a block diagram of an implementation of a communications system employing the present invention, also adapted for use in an ADSL environment, in which it is depicted how a user can modularly expand throughput capability by adding additional AFE stages to process a greater percentage of the available bandwidth in the channel.

DETAILED DESCRIPTION OF THE INVENTION

While some of the concepts set forth immediately below are well-known, a brief explanation of ADSL technology is provided with reference to Figure 1 to facilitate an understanding of the present invention. As explained above, it is well-known in th art to use DMT to effectuate the ADSL standard. In contrast to most modulation schemes, such as AM/FM transmissions that use one carrier, DMT uses multiple carriers to transmit data bits. Specifically, T1E1.4 ADSL standards specify an up to 255 channels for downstream transmission from the central office to subscribers and up to 31 channels for upstream transmission from subscribers to the central office. As shown in Figure 1, each carrier has a bandwidth of 4.3125 kHz. The total bandwidth is 1.1 MHz for a total of 255 channels. In the upstream direction, a "pilot" tone in the approximate range of 69 kHz, is used for maintaining timing synchronization. A similar pilot tone is transmitted in the downstream direction in the vicinity of 276 kHz.

Since upstream and downstream transmissions are over the same 2-pair twisted wire, they need to be separated by either echo cancellation (EC) or frequency division multiplexing (FDM). Echo cancellation allows simultaneous transmissions in both directions but requires a complex echo canceler implementation. On the other hand, FDM uses two different frequency bands for separate downstream and upstream transmissions. As shown in Figure 1, the upstream transmission uses subchannels from channel number 6 to 31, and the downstream transmission uses subchannels from channel number 41 to 255. While the remainder of the discussion below focuses on an system employing FDM, it will be appreciated by those skilled in the art that the present invention is adaptable and can be used beneficially with echo-cancellation approaches as well.

As with most communication environments, the transmission bit rates for both upstream and downstream communications in ADSL are not fixed but instead are determined by the quality of the channel. In the present invention, a number of well-known techniques can be used advantageously for setting up the initial data link. In general, these techniques work as follows: during initialization, the channel quality is measured and a certain data rate (typically a number of bits) is assigned for each DMT subchannel; thereafter, a "hand-shaking" process is used to dynamically and adaptively change the bit loadings (and energy levels). The latter is often necessary because (among other things) changes may occur in the overall channel characteristics, changes in the target bit rate may be needed, or new bit distributions in the sub-channels may be required because of degradations in one of the sub-channels.

The quality of the sub-channel response can be measured by the received signal to noise (SNR) ratio. According to the Shannon theorem, the upper limit of the number of bits per unit Hz that can be transmitted is $\log_2(1+SNR)$. Therefore, by measuring the received SNR at the receiver end, one can determine the number of bits allocated for each subchannel modulation. The total data throughput race achieved by the system, therefore, is simply the sum of all the data rates of all the usable subchannels.

According to the T1 E1.4 ADSL standards, data bits are grouped and processed every 250 µsec. The number of bits that can be processed over one such time frame is the summation of the bits allocated for each subcharnel determined from the previous channel response measurement. For a given number of bits assigned to a certain subchannel, quadrature amplitude modulation (QAM) is used to convert bits to a complex value, which is then modulated by the subchannel carrier at the corresponding frequency.

The above is a merely a brief summary of the general operation of a typical DMT/ADSL communications system. The general circuits used in prior art ADSL systems, the specifics of the bit/energy loading process for the sub-channels, the bit fine tuning process, and the details of the modulation of the sub-channels, are well-known in the art, and will not be discussed at length herein except where such structures or procedures have been modified in accordance with the teachings herein.

The full downstream data throughput of a typical p rior art ADSL standard transceiver approaches 6 Mbps, which is more than 200 times the speed of conventional analog modem technology. This requirement was imposed since a large part of the initial motivation to implement ADSL was to achieve high speed multimedia communications and video teleconferencing. Nevertheless, a large number of potential users do not want or need to have such wide bandwidth capability. For example, many potential users of ADSL (or similar high speed loops), including many who are intending to use such links primarily for Internet access, only need to achieve downstream transmission speeds that are in the hundreds of kilobits per second range. This data rate is in fact achievable using only a fraction of the available bandwidth of ADSL. By processing only a fraction of the available bandwidth of the ADSL standard, the present invention permits a limited but extremely useful ADSL modem to be implemented with significantly less expense and complexity than previously possible. At the same time, because the present invention has modular characteristics, the proposed implementation of the present invention affords users an easy path to forward and upward expansion of the overall functionality of their system.

The principle behind this aspect of the present invention is as follows: As shown in Fig. 1B, if the transmission in the channel is restricted to a smaller bandwidth by an anti-aliasing filter 80, according to the Nyquist sampling theorem, the sampling rate of AFE devices (such as ADC 81) that perform analog to digital conversion can be significantly reduced. Specifically, if the total downstream bandwidth is limited to some fractional total B Hz (in a preferred embodiment using DMT in an ADSL environment, B = 20 DMT channels or about 86 kHz) as shown below, we can limit the Nyquist sampling rate to around 180 kHz. This is achievable with ADCs having greatly simplified hardware and reduced performance requirements, in contrast to the full ADSL bandwidth approach, which processes 200 DMT channels or 900 kHz in the case of full ADSL implementation.

The total accumulated bit race of an ADSL communications system using the present invention can be calculated as follows. Suppose a total number of k subchannels (out of a total of M possible) are to be supported and each channel is allocated b_k bits for transmission. The total accumulated bit rate (R) is:

$$R = (\Sigma_{i=1,k} b_i) * 4 \text{ kHz (bits/sec)}$$

where 4 kHz is the framing race defined by T1E1.4 ADSL standards. If k=20 channels and the average number of bits per channel is 6, then total bit rate (R) is approximately 480 kbits/sec. It can be seen that this fractional use of the ADSL bandwidth nevertheless provides about 9 times the performance of a conventional analog 56 kbits/sec digital modem. The benefits of this approach of the present invention are apparent. The overall performance and cost of a high speed communications system can be scaled and controlled in direct relationship to the particular needs of particular users. In general, the data rate supportable by (and the relative cost of) any particular implementation of the present invention is generally determined by two factors: (1) the capacity of the AFE; and (2) the capacity of the hardware performing the DMT.

The capacity of an AFE is generally measured by the maximum sampling speed it can achieve. As explained above, the sampling speed in turn determines the upper limit of the frequency band B (in kHz) that can be obtained. At the defined channel separation of 4.3125 kHz for ADSL, the total number of subchannels that can be supported is less than or equal to B/4.1325. A suitable ADC can be selected, therefore, based on the particular data rate and cost requirements of any particular user.

The other factor that limi ts the number of subchannels (and achievable data rate) is the processing power available for DMT modulation and demodulation routines. For example, a variety of performance levels (achievable data rates) are possible with well-known dedicated signal processing hardware, such as digital signal processors, as discussed in more detail below with reference to Figure 2. Alternatively, as shown in Figure 3, if such routines are implemented primarily by software and run by a host CPU, the required processing power (MIPS) generally increases directly as function of the number of subchannels that need to be processed. This is because, in general, most of the processings are done in serial, or a channel by channel basis. As discussed below in more detail, the present invention makes use of a "calibration" routine for estimating the total available processing power of a users computing system in order to set an upper limit of the total subchannels that can be supported.

Irrespective of the selection of the particu lar AFE or signal processing technique used, however, another useful (but not essential) aspect of the present invention is that the sub-channels with the largest signal to noise ratio (SNR) within the passband are selected for data transmission. In other words, in the preferred embodiment of the present invention, those k subchannels within the passband that support the largest number of bits are used for processing. As seen in Fig. 1C, for example, a standard two-are subscriber line typically has a SNR curve that exhibits extensive attenuation with higher frequencies. It can be seen roughly in this figure that while there are more than 200 sub-channels provided for downstream transmission in ADSL, it is typically the case that 50% of the maximum data rate can be accomplished using only a much smaller percentage (than 50%) of the sub-channels. This fact is especially useful in considering some of the shared/ multi-channel bandwidth embodiments discussed further below.

The present invention, therefore, permits an implementation for a high speed data communications system that makes use of the best portion of the channel, while still being upwardly compatible and forward expandable. By these terms, it is meant that a system constructed in accordance with the teachings herein is completely compatible with a fully implemented version ADSL DMT modem. Moreover, it will be apparent to those skilled in the art that appropriate modifications specific to the channel and data link protocols and standards can be made so that the present invention can be advantageously employed in non-ADSL environments as well. Upward compatibility and forward expandability refer to the fact that systems constructed with the present teachings can have data rates that are easily upgraded while still preserving and maintaining compatibility with existing standards. For example, lower end users desiring less bandwidth can achieve a satisfactory performance with a minimum of cost, and can then upgrade the performance levels of their systems at later time by suitable (and preferably modular) upgrades of the AFE and signal processing hardware/software.

A system constructed in accordance with the present teachings is completely compatible with the full ADSL standard because of the following two aspects: According to the rate adaptation feature specified by the T1E1.4 ADSL standards, the bit rate for each sub-channel is determined initially (and preferably dynamically on an ongoing basis) by the sub-channel SNR analysis. Specifically, an ADSL downstream receiver can inform an upstream ADSL transmitter about the quality of the transmission; the receiver can also decide the bit rate for each sub-channel. Therefore, a downstream, partial-channel bandwidth receiver using the present invention can (based on the speed and passband of such receiver) supply an upstream, full-standard ADSL transmitter with information or control signals to effectuate a transmission only in selected sub-channels. In particular, in a preferred embodiment, the upstream ADSL transmitter is provided with SNR information for sub-channels outside the passband that is artificially contrived so as to suggest to the upstream transmitter that these sub-channels are not usable. In this manner, the downstream transmission is limited to a certain number of subchannels within the AFE and signal processing capabilities of th receiver. It can be seen, nevertheless, that this sch me is completely transparent to the transmitter, thereby permitting a system built in accordance with the present teachings to be fully compatible with the ADSL standard. While not possible at this time within the ADSL standard, it is apparent that other high-speed data protocols may use a control signal, instead, to provide for express limiting and control of the identity of the sub-channels transmitting information.

As the technology improves for AFE devices and DMT implementation, the number of subchannels supported by a system using the present invention can increase. As a result, such systems can upgrade completely to a full T1E1.4 ADSL implementation using a single higher end modular replacement APE devices, or alternatively, a number of lower end modular AFE devices.

GENERAL EMBODIMENT OF PRESENT INVENTION

The basic structure of the present inve ntion is depicted generally in Fig. 2. In general, the present invention can be embodied in different combinations of hardware and software. The primary difference between these embodiments is the specific implementation of the DMT core. These specific embodiments are described in more detail below with reference to Figs. 3A and 3B.

The structure and operation of ADSL transceivers is well-known in the art, and for that reason the present description primarily details those aspects of such transceivers which are necessary to an understanding of the inventions herein. As seen in Fig. 2, a channel 100 is made of a regular copper wire "loop", and each such loop may have differing electrical properties, transmission lengths (sizes), varying attenuation characteristics, and a number of impairments or interferences. Splitter 210, a conventional and well-known circuit, separates a DMT signal occupying more than 200 sub-channels from a lower end 4 kHz POTS analog signal. The latter can be used for simultaneous voice or conventional analog modem. Hybrid circuit 220 is also well-known in the art, and consists primarily of conventional transformers and isolation circuitry used in a wide variety of high-speed devices interfacing to standard telephone lines. A ring detect logic circuit 290 can also be implemented using accepted techniques, to alert a Control Interface 295 to the existence of a transmission signal originating from an upstream transceiver (not shown).

The full bandwidth signal is either low passed or bandpass limited to a frequency width B by suitable, well-known techniques as it passes through bandpass Filter and Analog/Digital Converter 280, so that only a fraction of the signal in the frequency domain is passed on to Buffer and DMT Receive Core 260. Again, the only important consideration for Subband Filter 280 is that it must constrain the bandwidth of the incoming signal to be $\leq$ B, where the sampling rate of the Analog/Digital Converter is $\geq$ 2B. This can be accomplished by using well-known filter designs. By suitable selection of circuitry for Filter and ADC 280, the overall system cost and performance can be scaled accordingly. In a preferred embodiment, the signal passed through Filter and ADC 280 occupies a spectrum between approximately 200 and 400 kHz. This selection is based primarily on an expected average performance of a typical two-wire line. It will be apparent to those skilled in the art that different bandpass widths and regions may be more suitable or optimal for other kinds of data links, or other kinds of multi-carrier modulation schemes.

Moreover, in some instances, while it is somewhat more expensive to implement, an adaptive or tunable filter may be substituted, such that the target frequencies of the passband are adjustable uniquely for each new data link. In such cases, the bandpass can be configured to coincide with the sub-channels having the highest achievable SNR, including the subchannels that must be supported for protocol or other system overhead reasons. Also, in some applications, the analog-to-digital conversion may be performed by a digital signal processor, or by the host computer and therefore, the sampling rate can be dynamically controlled and matched to the bandpass target frequency and frequency breadth. This feature, in turn, would assist dynamic scaling of the data throughput based on system computing power and overhead requirements.

Furthermore, in this preferred embodiment, using a multi-carrier approach implementation for ADSL, a pilot tone at 276 kHz must be allowed within the passband. It is apparent that other protocols may require similar pilot tones, and the design of comparable filters to achieve the functionality of Filter and ADC 280 is well within the ordinary skill of one in the art.

DMT Receiver Core 260 is generally responsible for monitoring and measuring the SNR of the sub-channels falling within the frequency range passed by FILTER and ADC 280, and for extracting the original data stream from the numerous sub-carriers. In a preferred embodiment, Control Interface 295 receives system configuration information from a host 298. This information may contain such parameters as target throughput rare R, target error rate, target center frequencies F for FILTER and ADC 280, target frequency width B, etc. By evaluating the SNR and bit capacities of the sub-channels computed by DMT Receiver Core 260, and taking into consideration the target data rate R, Control Interface 295 can select a number k of sub-channels up to and including the total available number M of sub-channels to carry the data stream from the upstream transmitter (not shown). The number of sub-channels that can be used for carrying data is directly related to the bandpass frequency B as described above. In a preferred embodiment, M = 200+ (ADSL) and Control Interface 295 will usually configure k = 20.

For every sub-channel other than the selected k sub-channels, a "mask" or blackout control/feedback signal is generated and transmitted by DMT Tx Core 250, Buffer 260 and DAC 230 to the upstream transceiver. This ensures that any subsequent data transmissions by the upstream transceiver only use the selected k sub-channels. This feedback information is provided, therefore, irrespective of the transmitting capacity of the upstream transceiver, and even during times when the channel 100 is capable of supporting more than k sub-channels. In this manner, the present system is perceived by upstream transceiver to be compatible with protocols and performance characteristics of the upstream transceiver, because the upstream transmitter receives feedback information indicating merely that the two systems are connected through a channel with substantial signal attenuation characteristics for data signals outside the k sub-channels. Based on the inherent rate adaptiveness of ADSL and other similar protocols, the upstream transceiver will automatically train itself to use orily the k sub-channels predetermined by the downstream transceiver. It should be noted that the DAC 230 and Buffer 240 in the front end transmitting circuit preferably transmit any upstream data transmissions using a second frequency bandwidth different from that of the downstream data transmission. However, this is not necessary in systems using echo-cancellation. Furthermore, in ADSL applications, the size of this bandwidth is considerably smaller, and uses only L sub-channels, where $L < M$. In other xDSL applications, L may be on the same order or larger than M.

Again, while the ADSL standard fixes the data error rate to be 10^{-7}, it is conceivable that other applications of the present invention may tolerate a reduced error rate. For example, if maximum data throughput is required (i.e., the margin is less constrained) then the largest bit capacity sub-channels within B can be selected. Alternatively, if the system is error-performance driven and has more relaxed throughput requirements, than the 20 subchannels with the best margin are selected. A suitable combination of sub-channels can be selected by one skilled in the art based on the particular system requirements which may vary from application to application. Moreover, Controller Interface 295 may optimize the desired sub-channel mix dynamically depending on the type of data transmitted in channel 100. For example, streaming audio or video, or pictorial graphics, may require less integrity and error performance than other kinds of data used by n applications programs running on host 298. The specifics of the structure, operations and techniques used by Controller Interface 295 are not constrained by any requirements of the present invention, and can be implemented in various ways well-known to those seed in the art.

The operation of the remainder of the circuitry shown in Fig. 2 is also relatively straightforward and not unlike a typical multi-carrier modulation system. Control Interface 295 ensures that DMT Transmit Core 250 performs bit and energy loading only for those sub-carriers necessary to effectuate a selected host throughput rate/error rate combination. As with the circuitry used for Filter ADC 280, the circuitry for performing the functions of DAC 230 can be implemented in programmable form to allow for greater flexibility.

Finally, while not presently supported in ADSL protocols, it is nevertheless possible that the filter in block 280 can be eliminated entirely in some applications when the sub-channel or downstream transmission frequencies can be configured through appropriate handshaking or similar procedures. In other words, if the upstream transmitter can be configured to transmit using only a portion of the bandwidth available in the channel, the advantages of the present invention can still be realized, because the ADC portion of block 280 can still be relatively less complex, since it will be processing at a much slower sampling rate than that required for a full spectrum implementation. Moreover, such an implementation would also yield the same commensurate savings in the DMT processing core, and reduced quantization errors.

Some special features of the present invention include the fact that:

(i) unlike hardware architectures implementing a full T1E1.4 ADSL standard, the present invention uses a filter in the front end. As mentioned earlier, the use of this filter is to allow low speed sampling by the ADC. If suitable handshaking between the upstream and downstream transcievers can be effectuated to generate a reduced downtstream transmission, the filter can be eliminated.

(ii) standard ring detection logic is incorporated to support existing modem features;

(ii) DMT Rx core 260 is basically implemented the same way as specified by T1E1.4, but with some important differences, specifically:

[a] due to subband filtering and lower speed sampling, the frequency channels at the output of FFT (not shown) in the DMT Rx Core have a frequency shift

[b] Since not all 256 subchannels are necessarily supported by the DMT Rx Core 260, actual FFT implementation can be smaller, simpler and more cost-effective;

(iv) Control logic 295 permits the system to behave essentially like a conventional analog modem, and is used to support necessary setup tasks such as dialing and handshaking;

(v) The use of limited bandwidth from the downstream channel reduces the need for echo-cancellation circuitry, because there is less need for overlap between the upstream and downstream transmissions, and this further reduces system complexity and cost;

(vi) Because a smaller portion of the spectrum is processed by the present invention, the peak-to-peak deviation of the downstream signal is reduced, and this helps to minimize quantization errors.

DEDICATED HARDWARE BASED EMBODIMENT

Figure 3A illustrates an embodiment of the present invention that can be g enerally described as a dedicated hardware implementation. For the present discussion of Fig. 3A, it can be assumed that those circuits having like numbered references are the same and/or perform the same function as their counterpart in Fig. 2. For example, unless otherwise indicated, there is no material difference between Splitter 210 (Fig. 2) and Splitter 310 (Fig. 3A).

In this embodiment, the DMT sub-channel modulation core is implemented completely in dedicated processing hardware. For thin appliction, DMT Receiver Core 260 typically includes a digital signal processor (DSP) (not shown) and including on-board program ROM (or other suitable memory) for storing executable microcode routines for performing bit, energy and SNR measurements of the carriers in the sub-channels. In such an embodiment, due to the power of the DSP, there is typically no need for processing assistance from a user's host processor 398. This embodiment therefore may be advantageously employed where host processing power limitations are a consideration.

A user of a system shown in Fig. 3A can expand the functionality (i.e., data throughput rate and modem features) of such system by upgrading the DMT Receiver Core 260, and where necessary, the AFE 280 as well. The system of Fig. 3A can be incorporated on a typical printed circuit board. By mounting or packaging the circuits used in such blocks in an accessible fashion, they can be replaced or supplemented much in the same way present users of personal computers can upgrade their motherboards to include additional DRAM. One practical alternative, for example, would be to have multiple available slots to accommodate new subband pass filters for passing a greater portion of the downstream transmission to be processed by the DMT core logic. Other practical and simple variations of this approach will be apparent to those skilled in the art.

PARTIAL SOFTWARE BASED EMBODIMENT

In the above dedicated hardware embodiment, the overall speed (data throughput) can be maximized but with less flexibility for upgrades. This is because upgrades to such a system must take the form of hardware replacements, which can be more costly and difficult for the user to incorporate. On the other hand, as depicted in Fig. 3B, a number of important functions of a communications system can be completely implemented in software, in an analogous fashion to what is commonly described in the art as a "software" modem. In this case, the overall speed of the system depends on the user's processor power available at host 398, and only the AFE portion need be implemented in hardware.

The primary differences between the embodiments of Fig. 3A and 3B are the following: (1) implementation of DMT modulation; (2) implementation of the control and handshaking functions; and (3) implementation of the control interface. As seen in Figures 3B and 4, DMT Receive Core 460 and DMT Transmit Core 450 are implemented in a data pump device driver by the host system 398. In a preferred embodiment, host system 398 includes some form of multipurpose microprocessor (such as an x86 type processor) running a suitable operating system (such as Windows by Microsoft), and is capable of executing suitable low level drivers for the DMT modulation (Fig. 4), as well as high level application software for implementing Control Interface 500 (Fig. 5). Host processor system 398 communicates over a standard bus interface 385 (i.e., a PCI bus) to Front End circuitry 396 for implementing a high speed modem. As with the circuitry in conventional analog modems, this circuitry of the present invention can be effectively incorporated on a PC motherboard (i.e., Bus Interface 385 and Front End Circuitry 396 can be merged so that they are essentially part of host system 398) or on a separate printed circuit board , or as a stand-alone unit physically separated from host 398. While this approach may not provide as much throughput performance, it has the advantage of being less expensive than the pure hardware approach of Fig. 2, and much easier to upgrade.

In the "software" modem implementation of Fig. 3 using a typical PC running Windows, the DMT Tx core 450, Rx Core 460 and Control/Handshaking logic are implemented as a Windows Data Pump Device Driver 400, which consist of DMT routines, associated control and handshaking codes, and an interface to kernel 480.

A more detailed characterization of a portion of host processing system 398 is depicted in Fig. 4, which illustrates a preferred embodiment of a device driver 400 as it would be constituted for a computer operating system shell 480. In the present embodiment, Microsoft Windows NT is considered, but it is understood that other comparable environments may be used, including UNIX, Windows 95, etc. As is well-known, operating system 480 is responsible for supervising and controlling the operation of processing system 398 and all of its associated peripheral devices. Operating system 480 also includes various interactive control and graphical application interfaces (Fig. 5) for permitting a user of processing system 398 to run various applications programs, and to set up, control, configure, monitor and utilize peripheral devices such as disk drives, printers, monitors, modems and the like.

To assist operating system 480 to interact and control such peripheral devices, it is also well-known to use device drivers, which are essentially low-level hardware routines executed by a host processor and operating system. A device driver is a memory image file or executable file that contains all the code necessary to instruct a host processor to interface and drive a particular device within a computing system. Device driver 400 acts as an interface between an operating system 480 (in this case, Microsoft Windows NT) and hardware 396. In this case, for xample, device driver 400 supports hardware 396 (see Fig. 3B), which is embodied in a typical printed circuit board (or external device). The teachings herein therefore provide for a new device driver that in combination with hardware 396 operates as a "software" modem. In this manner, operating system 480 classifies this combination as an ADSL modem, or in other words, another typical personal computer peripheral device, analogous to conventional voice-band modems.

Generally speaking, device driver 400 works as follows: a user of processing system 398 desiring to establish a data link to a remote site for transmitting/receiving data initiates such link through an application program (Fig. 5). Operating system 480 (Fig. 4) interprets and services this request by passing control of this task to device driver 400, which first generates appropriate instructions for a Device Initialization 440. In a preferred embodiment, Modem card 396 is initialized through Bus Interface 410 using conventional voice band modem control commands, so that the present invention is compatible with preexisting applications programs written for controlling modems using operating system 480. Similarly, therefore, control and data signals are interpreted and transmitted by operating system 480 to a Serial Port Interface 475 so that conventional modem dialing instructions and handshaking signals can be imparted to Modem Card 396 to establish a link through channel 100 to an upstream conventional ADSL transciever (not shown). As explained above, after suitable handshaking protocols have been completed, the upstream fully compatible ADSL transceiver will begin transmitting data on all available M usable sub-channels. This downstream data is filtered by FILTER/ADC 380 and at this time, information for only N sub-channels ($N<=M$) is temporarily held in Buffer 370. At or before this same time, an interrupt is generated by bus interface 385 and passed through device driver bus interface 410 to alert Interrupt Service Router 415 to the existence of downstream data requiring processing. Thereafter, DMT Receive Core 460 begins processing the downstream data stream in response to control information from ISR 415. A demultiplexer 465 extracts and correlates the data in the various sub-channels before passing it on to Serial Port Interface 470, and back to Operating System 480. In this manner, Device Driver 400 coordinates with Modem card 396 to effectuate a sofware modem whose performance is directly correlated to the computing power of a processor contained within the host processing device.

As mentioned earlier, Device Driver 400 also contains control information for configuring the number and selection of sub-channels to be used in the particular data link established through channel 100 with the upstream transciever during an initialization process. As also mentioned above, this control information may be self-determined by a user of host processing system 398, or alternatively, automatically sensed and monitored by such processing system, based on a computing performance rating for such system determined in a calibration routine. In either event, during the initialization process (and at all times subsequent) the upstream transceiver is induced to use such sub-channels only for the ensuing data transmission. This is accomplished by transmitting SNR information that is interpreted by the upstream transceiver as zero for all but $K \leq N$ of the sub-channels of the driver selection. This data is passed under control of Operating System 480 through Serial Port 475, Framing control 455 and DMT Transmit Core 450 before being sent out to Modem Card 396 and channel 100.

It is understood, of course, that ADSL Modem 396 can also respond to a request from a remote modem for initiating the data link. The process for initializing the link, nevertheless, is essentially the same as that described above. Device driver 400 can also contain control logic for supporting typical dial-up modem operations and control codes from conventional modem application programs typically implemented in voice-band modems, such as setting up Originate/Answer modes, monitoring call progress, performing modem diagnostics, configuring receive/transmit buffer sizes, supporting facsimile transmissions, as well as performing enhanced error control, data compression and flow control between Modem Card 396 and Operating System 480. Device Driver 400 can also support other conventional "always-on" data link connections as desired, such as may be found in typical ethernet network connections, and other dedicated applications.

Given the teachings of the present invention, the general design of the above Data Pump Device Driver 400 is a routine task well within the abilities of one skilled in the art. The specifics of such implementation are not critical or essential to the present inventions, and will vary from application to application according to system designer requirements, so they are not included here. Again, while this embodiment of the present invention is set out in the context of a PC based host processor running Windows, it will be apparent to those skilled in the art that above description is merely an exemplary implementation. The referenced DMT routines, associated control and handshaking codes can be employed in numerous host processing/operating system environments, and in a variety of different coding organizations (high level or low level processing forms) well-known in the

In the preferred embodiment implemented using a standard PC running Windows, Control/Application interface 500 includes Win32 codes which provide standard modem utility functions and interface with Data Pump Device Driver 400. In Fig. 5, a flowchart of the operation of the Control/Application Interface 500 can be seen ., which interface is discussed in more detail below.

Anoth r particularly beneficial aspect of the embodiment of Fig. 3B is the provision of a self-determining "performance" or calibration rating that can be used to determine an optimal or maximum data throughput rate. In other words, the system of Fig. 3B can automatically and adaptively configure a host system 398 to a particular throughput rate based on an evaluation of the availabl computing power. In a preferred embodiment, the performance rating is determined based on a calibration rouune executed by Data Pump Device Driver 400. This routine sets a timer, and counts how many DMT frames can be processed within the given time; this gives a relative figure of merit for the particular host system in question. For each sub-channel to be added, one DMT frame needs to be processed within a small fraction of 250 μs. Therefore, by incrementally increasing the sub-channel count, the overall effect on total system processing overhead can be determined. Control/Application Interface 500 provides the user with control to set a threshold of available host power for implementing the high speed link. Based on this threshold of available power (which can be nominally set to 20%) the number of subchannels that can be supported can be gleaned very quickly.

In view of current technology, when DMT processing is implemented in software, the host processing power is more likely to be the limiting factor than the frequency band of the subband filter 80 in Figure 1B. Nevertheless, because host processors (and especially microprocessors) are evolving in performance at a fairly rapid rare, the present invention affords users an opportunity to realize a high speed data link with performance that is controllable, and which improves whenever there is an upgrade in the host processing system. Since many typical present day personal computer systems have easily accessible and replaceable host processors, users of the present invention can easily and flexibly expand and enhance the throughput and functionality of an ADSL modem.

An example of the flow chart for an ADSL mo dem application/control program 500 designed in accordance with the present teachings is shown in Fig. 5. With the teachings herein, a user of host processing system 398 can, for the first time, dynamically control a forward compatible and expandable modem, such as an ADSL modem, using modem-control applications software that is analogous to that only previously available for voice band modems. In a preferred embodiment, ADSL Modem Card 396 is automatically detected by Operating System 480 and set up by initialization routine 505 by Modem Device Driver 400. A separate detection routine 510 determines whether or not ADSL Modem Card 396 has been upgraded with an additional AFE (as described generally with reference to Figure 6 below), or alternatively whether a processor used in a host system has changed. The purpose of this step is primarily to determine whether entries in a Device Parameters Table 560 need to be updated because of changes in computing power, front end capabilities or other parameters that may necessitate a modification of the data throughput characterization of the overall system when used in a communications mode.

A calibration routine 520 is then executed to determine the nominal setup parameters for the overall system in the manner described earlier. The results from this operation are stored in Device Paramater Table 560 where they then become accessible to various application programs that may make use of ADSL Modem Card 396 and Device Driver 400. The information stored in table 560 can include any or all of the following (a) measurements of the computing power available to the host processor; (b) measurements of the number of frames processable by the system within a particular time period; (c) estimations of the expected loading on the processing system based on demands of other applications programs and peripheral devices; (d) minimum and maximum data throughput estimations and/or targets; (e) data identifying the type of host processor; (f) data identifying the number and type of AFEs in ADSL Modem card 396; (g) estimations and/or target system loading rates available for a datalink (i.e., maximum available processing time to be used by the system during data transmission); (h) data transmit and receive buffer sizes; (i) interrupt or similar priority data for the modem card; (j) estimations and/or target system sub-channel utilization; (k) estimations and/or target system sub-channel bit capacity information; etc. It will be apparent to skilled artisans that the above are just examples of the types of information that may be pertinent to the performance of a high speed communications system, and that other parameters may be considered depending on the environment, application, etc. in which the present invention is used.

After performing Auto Calibration routine 520, the results of the same are presented to the user for acceptance and verification at step 525. At this point, the user can accept the predetermined configuration data at step 526 (i.e., such as proposed maximum and minimum throughput rates, loading rates, etc.) and this would otherwise invoke an end of modem setup routine 590. Should the user not want to accept the recommended parameters, a Manual Configuration routine 530 is executed. At this juncture, various system performance data can be presented to the user for review, along with a list of modifiable system options 532. If for example, the user elects to increase the desired throughput rate, a Verification routine 540 is then executed to determine whether such rate is reasonably sustainable within the other parameters of the system. If the new proposed configuration data is otherwise acceptable, then the Device Parameter Table 560 is updated, and the setup routine again ends. Otherwise, the user is alerted by a Notification/Suggestion routine 550, which points out the failure of the proposed configuration, and, if possible, makes suggestions to the user for modifying the system options 532 so that overall compliance can be achieved within the performance capability of the host processing system. The program then loops back to Acceptance routine 525, and thereafter the process is repeated until an acceptable configuration has been achieved, and any changes have been incorporated into Device Parameter Table 560.

While some of the operational steps above are described as implemented solely by Operating system 480 and

Device Driver 400, it is understood that such operations occur under direction of modem applications program 500, or in some cases, based on initialization routines executed by the host processing system. Moreover, to simplify the presentation of the present invention, only some of the features that may be implemented are described above, and many other well-known operational steps normally associated with setting up or monitoring modems are omitted.

As with the design of the above Data Pump Device Driver 400, the general design of the Control/Application Interface 500 required to accomplish the above functions is a routine task well within the abilities of one skilled in the art given the teachings herein. The specifics of such implementation are not critical or essential to the present inventions, and will vary from application to application according to system designer requirements, so they are not included here. Again, while this embodiment of the present invention is set out in the context of a PC based host processor running Windows, it will be apparent to those skilled in the art that above description is merely an exemplary implementation. The referenced Control/Application Interface can be employed in numerous host processing/operating system environments, and in a variety of different coding organizations (high level or low level processing forms) well-known in the art.

MULTIPLE AFE AND LOWER SAMPLING SPEED EMBODIMENT

Figure 6 illustrates an example of the present invention wherein a user can achieve significantly increased data throughput using multiple low cost, low sampling speed AFEs, generally designated 680A, 680B, 680C, etc. As described above, these AFEs may be in separate, modular form and configured in a bank form so that they can be incorporated conveniently on a printed circuit board (or similar mounting) or integrated in a single IC chip. Each AFE can be implemented in a fixed hardware configuration, or individually programmed/controlled to pass a certain portion of the downstream data transmission. Assuming suitable processing power is available for DMT modulation/demodulation (either through a dedicated or software implementation as described above in connection with Figs. 3A and 3B) a user of such system can achieve substantially expanded functionality by upgrades having performance characteristics and costs of their choice.

UNDERLYING THEORY OF PRESENT INVENTION FOR ADSL/DMT APPLICATIONS

A discussion of the underlying theory supporting the premise of the present invention now follows. In particular, this section shows the mathematical foundation For the use of multiple low speed AFE's to sample a full bandwidth ADSL/DMT signal. It will be apparent to those skilled in the art, after reading this discussion, that the present inventions can be advantageously used in a number of rate adaptable communications environments, including CAP implementations of ADSL.

DMT Transmitter

To simplify the present discussion, only a subset of the DMT transmitter is considered, as shown in Figs 1D and 1E. The combined model that includes the channel response and the DMT receiver is shown below, where only one branch of band-pass filtering and sampling is shown for simplicity. To further simplify, the channel response and the SFIR are combined together.

In this subsection, we analyze the signal over one band pass filtering process. The result shows that the DMT signals within the band pass can be recovered with the same use of impulse response shortening technique. With use of multiple AFE's that cover different frequency bands, all DMT subchannels can be recovered.

IFFT

In an ADSL environment as shown in Fig. 1D, N (N=512) frequency domain variables are transformed into the time domain by IFFT block 60

$$y_n = \sum_{i=0}^{N-1} x_n e^{j2\pi in/N}$$

Cyclic Prefix

c time domain variables at the end are added to the prefix of the sequence as shown in Fig. 1D by block 70 $\{z_n\}=\{z_{-c},z_{-c+1},\cdots,z_{-1},z_0,z_1,\cdots,z_{N-1}\}=\{y_{N-c},\cdots,y_{N-1},y_0,\cdots,y_{N-1}\}$

AFE/DAC

Discrete time domain sequence are converted by AFE 75 to the continuous time domain waveform as follows:

$$z(t)=\sum_{n=-\infty}^{\infty} z_n p_{TX}(t-nT_c),$$

where $p_{TX}(t)$ is the transmitter pulse of the AFE/DAC used, and T_c is the transmitter DAC clock period and equal to

$$T_c=\frac{250\mu\text{sec}}{N+c}$$

according to the DMT ADSL specifications.

Channel

With reference now to Fig. 1E, if the channel impulse response is $h_c(t)$, we have

$$u(t)=\sum_{n=-\infty}^{\infty} z_n p_{RX}(t-nT_c)$$

where $p_{RX}(t)=p_{TX}(t)\otimes h_c(t)$.

Bandpass Filtering

If the bandpass filter 80 has an impulse response of

$$h_{BPF}(t),\ v(t)=,\ \sum_{n=-\infty}^{\infty} z_n p_{BPF}(t-nT_c)$$

where $p_{BPF}(t)=p_{RX}(t)\otimes h_{BPF}(t)$.

AFE/ADC

Let the sampling clock be $T_s=T_c\times L$. This means a slower sampling by a factor of L for AFE 81. Thus,

$$w_k=\sum_{n=-\infty}^{\infty} z_n p_{BPF}(kT_s-nT_c)=\sum_{n=-\infty}^{\infty} z_n p_{BPF}([kL-n]T_c)$$

For causal pulse $p_{BPF}(t)$, we have

$$w_k=\sum_{n=-\infty}^{\infty} z_n p_{BPF}((kL-n)T_c)=\sum_{n=0}^{\infty} z_{kL-n} p_{BPF}(nT_c)$$

Shortening FIR (SFIR)

After AFE discrete time sampling, a time domain equalizer (TEQ) called SFIR 82 is used to reduce the combined discrete time impulse response t a duration smaller than c. If the SFIR response is $h_{SFIR}[n]$, we have

$$\begin{aligned} r_k &= \sum_{i=0}^{\infty} w_{k-i} h_{SFIR}[i] \\ &= \sum_{i=0}^{\infty} \left[\sum_{n=-\infty}^{\infty} z_n p_{BPF}([kL-n-iL]T_c) \right] h_{SFIR}[i] \\ &= \sum_{n=-\infty}^{\infty} z_n h_{tot}[kL-n] \\ &= \sum_{n=0}^{\infty} z_{kL-n} h_{tot}[n] \end{aligned}$$

where

$$h_{tot}[kL-n] = \sum_{i=0}^{\infty} h_{SFIR}[i] p_{BPF}([kL-n-iL]T_c)$$

Physical Meaning of $h_{tot}[n]$

If we perform discrete Fourier transform at block 84 for $h_{tot}[n]$, we obtain $H_{tot}[\omega] = H_{SFIR}[L\omega] H_{BPF}[\omega]$ where $H_{SFIR}[L\omega]$ and $H_{BPF}[\omega]$ are the DFT's with period $1/(LT_c)$ and $1/T_c$, respectively. Their spectra can be illustrated as shown in Fig. 1F for L=5.

Dropping Cyclic Prefix

By dropping the cyclic prefix of length c/L, at block 83 we consider only $s_k = r_k, k=0, \cdots, N_1-1$, where $N_1 = N/L$.

FFT

Performing FFT at block 84 for s_k, $k=0, \cdots, (N/L)-1$, one obtains:

$$
\begin{aligned}
q_n &= \sum_{l=0}^{N_1-1} s_l e^{-j2\pi nl/N_1} \\
&= \sum_{k=0}^{N_1-1} r_k e^{-j2\pi nk/N_1} \\
&= \sum_{k=0}^{N_1-1} \left(\sum_{i=0}^{\infty} z_{kL-i} h_{tot}[i] \right) e^{-j2\pi nk/N_1} \\
&= \sum_{k=0}^{N_1-1} \sum_{i=0}^{\infty} z_{kL-i} h_{tot}[i] e^{-j2\pi n(kL-i)/N_1} e^{-j2\pi ni/N_1} \\
&= \sum_{i=0}^{\infty} \sum_{k=0}^{N_1-1} z_{kL-i} e^{-j2\pi n(kL-i)/N_1} h_{tot}[i] e^{-j2\pi ni/N_1} \\
&= \sum_{i=0}^{c} \sum_{k=0}^{N_1-1} z_{kL-i} e^{-j2\pi n(kL-i)/N_1} h_{tot}[i] e^{-j2\pi ni/N_1} \\
&= \sum_{i=0}^{c} \sum_{k=0}^{N_1-1} y_{kL-i} e^{-j2\pi n(kL-i)/N_1} h_{tot}[i] e^{-j2\pi ni/N_1}
\end{aligned}
$$

where we assume $h_{tot}[i]$ is only nonzero for $i = 0, \cdots, c$. For a given i, let us define

$$l' = \lceil i/L \rceil;$$

We can then define $i' = l'L - i$, where $i' = 0, \ldots, L-1$. Therefore, $i = l'L - i'$
From the above definitions, we have

$$
\begin{aligned}
\sum_{k=0}^{N_1-1} y_{kL-i} e^{-j2\pi n(kL-i)/N_1} &= \sum_{k=0}^{l'-1} y_{kL-i} e^{-j2\pi n(kL-i)/N_1} + \sum_{k=l'}^{N_1-1} y_{kL-i} e^{-j2\pi n(kL-i)/N_1} \\
&= \sum_{k=0}^{l'-1} y_{(k-l')L+i'} e^{-j2\pi n((k-l')L+i')/N_1} + \sum_{k=l'}^{N_1-1} y_{(k-l')L+i'} e^{-j2\pi n((k-l')L+i')/N_1} \\
&= \sum_{k=0}^{l'-1} y_{(k-l'+N_1)L+i'} e^{-j2\pi n([k-l'+N_1]L+i')/N_1} + \sum_{k=0}^{N_1-1-l'} y_{kL+i'} e^{-j2\pi n(kL+i')/N_1} \\
&= \sum_{k=N_1-l'}^{N_1-1} y_{kL+i'} e^{-j2\pi n(kL+i')/N_1} + \sum_{k=0}^{N_1-1-l'} y_{kL+i'} e^{-j2\pi n(kL+i')/N_1} \\
&= \sum_{k=0}^{N_1-1} y_{kL+i'} e^{-j2\pi n(kL+i')/N_1}
\end{aligned}
$$

Therefore,

$$\begin{aligned} q_n &= \sum_{i=0}^{c}\sum_{k=0}^{N_1-1} y_{kL-i} e^{-j2\pi n(kL-i)/N_1} h_{tot}[i] e^{-j2\pi ni/N_1} \\ &= \sum_{i=0}^{c}\left[\sum_{k=0}^{N_1-1} y_{kL+i'} e^{-j2\pi n(kL+i')/N_1}\right] h_{tot}[i] e^{-j2\pi ni/N_1} \\ &= \sum_{i=0}^{c}\left[\sum_{k=0}^{N_1-1}\left(\sum_{l=0}^{N-1} x_l e^{j2\pi(kL+i')l/N}\right) e^{-j2\pi n(kL+i')/N_1}\right] h_{tot}[i] e^{-j2\pi ni/N_1} \\ &= \sum_{i=0}^{c}\left[\sum_{k=0}^{N_1-1}\sum_{l=0}^{N-1} x_l e^{j2\pi(kL+i')(l-n)/N}\right] h_{tot}[i] e^{-j2\pi ni/N_1} \\ &= \sum_{i=0}^{c}\left[\sum_{l=0}^{N-1} x_l \sum_{k=0}^{N_1-1} e^{j2\pi(kL+i')(l-n)/N}\right] h_{tot}[i] e^{-j2\pi ni/N_1} \end{aligned}$$

Since

$$\sum_{k=0}^{N_1-1} e^{j2\pi(kL+i')(l-n)/N} = 0 \text{ when } (l-n) \neq mN_1 ,$$

we have

$$q_n = N_1 \sum_{i=0}^{c}\left[\sum_{m=0}^{L-1} x_{mN_1+n} e^{j2\pi i' m/L}\right] h_{tot}[i] e^{-j2\pi ni/N_1}$$

Knowing that $h_{tot}[i]$ is zero for $i < 0$ and $i > c$, we have

$$\begin{aligned} q_n &= N_1 \sum_{i=0}^{c}\left[\sum_{m=0}^{L-1} x_{mN_1+n} e^{j2\pi i' m/L}\right] h_{tot}[i] e^{-j2\pi ni/N_1} \\ &= N_1 \sum_{i=-\infty}^{\infty}\left[\sum_{m=0}^{L-1} x_{mN_1+n} e^{j2\pi i' m/L}\right] h_{tot}[i] e^{-j2\pi ni/N_1} \\ &= N_1 \sum_{l=-\infty}^{\infty}\sum_{i'=0}^{L-1}\left[\sum_{m=0}^{L-1} x_{mN_1+n} e^{j2\pi i' m/L}\right] h_{tot}[lL-i'] e^{-j2\pi n(lL-i')/N} \\ &= N_1 \sum_{m=0}^{L-1} x_{mN_1+n} \sum_{i'=0}^{L-1} e^{j2\pi i' m/L} \sum_{l=-\infty}^{\infty} h_{tot}[lL-i'] e^{-j2\pi n(lL-i')/N} \end{aligned}$$

Since

$$\sum_{l=-\infty}^{\infty} h_{tot}[lL-i']e^{-j2\pi n(lL-i')/N} = \sum_{l=-\infty}^{\infty} h_{tot}[lL-i']e^{-j\omega(lL-i')T_c}\Big|_{\omega=2\pi n/NT_c}$$

$$= F\left\{h_{tot}(t)\sum_l \delta(t-[lL-i']T_c)\right\}\Big|_{\omega=2\pi n/NT_c}$$

$$= \frac{1}{2\pi}\mathrm{H}_{tot}(\omega)\otimes\left[\frac{2\pi}{LT_c}\sum_l \delta(\omega-\frac{2\pi l}{LT_c})e^{j2\pi l i'/L}\right]_{\omega=2\pi n/NT_c}$$

$$= \frac{1}{LT_c}\sum_l \mathrm{H}_{tot}(\frac{2\pi n}{NT_c}-\frac{2\pi l}{LT_c})e^{j2\pi l i'/L}$$

we have

$$q_n = N_1\sum_{m=0}^{L-1} x_{mN_1+n}\sum_{i'=0}^{L-1} e^{j2\pi i' m/L}\sum_{l=-\infty}^{\infty} h_{tot}[lL-i']e^{-j2\pi n(lL-i')/N}$$

$$= N_1\sum_{m=0}^{L-1} x_{mN_1+n}\sum_{i'=0}^{L-1} e^{j2\pi i' m/L}\frac{1}{LT_c}\sum_l \mathbf{H}_{tot}(\frac{2\pi n}{NT_c}-\frac{2\pi l}{LT_c})e^{j2\pi l i'/L}$$

$$= \frac{N_1}{LT_c}\sum_{m=0}^{L-1} x_{mN_1+n}\sum_l \mathbf{H}_{tot}(\frac{2\pi n}{NT_c}-\frac{2\pi l}{LT_c})\sum_{i'=0}^{L-1} e^{j2\pi(l+m)i'/L}$$

$$= \frac{N_1}{T_c}\sum_{m=0}^{L-1} x_{mN_1+n}\mathbf{H}_{tot}(\frac{2\pi n}{NT_c}+\frac{2\pi m}{LT_c})$$

$$= \frac{N_1}{T_c}\sum_{m=0}^{L-1} x_{mN_1+n}\mathbf{H}_{tot}(\frac{2\pi}{NT_c}(mN_1+n)), \qquad n=0,\ldots,N_1-1$$

$$= N_1\sum_{m=0}^{L-1} x_{mN_1+n}\mathbf{H}_{tot}[mN_1+n], \qquad n=0,\ldots,N_1-1$$

where

$$\mathbf{H}_{tot}[n] = \frac{1}{T_c}\mathbf{H}_{tot}(\frac{2\pi}{NT_c}n), \text{ for } 0\le n<N$$

Relationship between q_n and x_n

As shown in Fig. 1G if $\mathbf{H}_{tot}[n]$ is a bandpass filter and nonzero only in the intervals $[k(N/2L), (k+1)(N/2L)]$ and $[(2L-k-1)(N/2L), (2L-k)(N/2L)]$, where $0 \le k < L$, the possible values of m that

$$\mathbf{H}_{tot}[m(N/L)+n]$$

is nonzero for $0 \le n < (N/L)$ are as follows.

Even k

If k is even, we can have $m=k/2$ and $0 \le n < (N/2L)$ so that

$$\mathbf{H}_{tot}\{m(N/L)+n\}$$

is nonzero over the interval $[k(N/2L), (k+1)(N/2L)]$, and $m=(L-1)-k/2$ and $(N/2L) \le n < (N/L)$ so that

$$\mathbf{H}_{tot}\{m(N/L)+n\}$$

is nonzero over the interval $[(2L-k-1)(N/2L), (2L-k)(N/2L)]$.

Odd k

If k is odd, we can have $m=(k-1)/2$ and $(N/2L) \le n < (N/L)$ so that

$$\mathbf{H}_{tot}\{m(N/L)+n\}$$

is nonzero over the interval $[k(N/2L), (k+1)(N/2L)]$, and $m=L-(k-1)/2$ and $0 \le n < (N/2L)$ so that

$$\mathbf{H}_{tot}\{m(N/L)+n\}$$

is nonzero over the interval $[(2L-k-1)(N/2L), (2L-k)(N/2L)]$.

The above discussion is illustrated in Fig. 1G for $L = 3$.

In another variation that can be used in the present invention, similar advantages to those obtained by limiting bandwidth in the received signal in the downstream transceiver can be obtained by also optionally limiting the upstream data rate of the transceiver as well. In other words, the ADSL standard provides for 31 channels in the upstream direction, but many applications do not require this amount of bandwidth. The constraints, requirements and costs associated with the DMT modulation signal processing, and DAC 330 also can be significantly reduced by transmitting only a sub-set of the available 31 sub-channels. The determination of the appropriate sub-channels would be accomplished in essentially the same manner as set forth above, except that the information on upstream sub-channel SNR usually must be determined by the upstream transceiver, and then fed back to the downstream transceiver. To save time and overhead complexity, and given the fact that there is less variation in bit capacity in sub-channels in this frequency band, one approach also would be to simply select a fixed sub-set of such sub-channels-without regard to their actual performance characteristics. In a software modem environment, Control/Application software 500 would provide a user with selectable control to effectuate a restricted upstream transmission on limited sub-channels. Again, with respect to the ADSL standard, the only requirement in this respect is that the upstream pilot tone must also be transmitted to establish a valid data link An optional limited "upstream" transmission can be effectuated in a variety of ways by the circuitry already described above in connection with Figs. 2 and 3. The exact details of such implementation will be apparent to those of skill in the art given the present teachings.

Although the present invention has been described in terms of a preferred ADSL embodiment, it will be apparent to those skilled in the art that many alterations and modifications may be made to such embodiments without departing from the teachings of the present invention. For example, it is apparent that the present invention would be beneficial used in any xDSL or high speed multi-carrier application environment. Other types of VLSI and ULSI components beyond those illustrated in the foregoing detailed description can be used suitably with the present invention. Accordingly, it is intended that the all such alterations and modifications be included within the scope and spirit of the invention as defined by the following claims.

Claims

1. A high speed communications system capable of supporting a downstream data transmission from a upstream transceiver using a analog signal consisting of M data carrying signals contained within a bandwidth F, said system comprising:

a channel interface circuit for coupling to and receiving said analog signal; and

a front end receiving circuit for processing the analog signal and converting it to a digital signal;

a processing circuit for extracting N data carrying signals (N <M) from the digital signal using a first frequency portion f1 of the digital signal (f1 <F).

2. The system of claim 1, wherein the N data carrying signals are selected by the processing circuit based so as to minimize the amount of processing required to extract the selected data from the digital signal.

3. The system of claim 2, wherein the N data carrying signals can be selected during a initialization process setting up a data link to the upstream transceiver.

4. The system of claim 3, wherein M data carrying signals can be sent by the upstream transmitter during a initialization process, and thereafter, only N data carrying signals are sent.

5. The system of claim 1, wherein the front end circuit includes: (i) a sub-band filter for passing the first frequency bandwidth portion f1 of said bandwidth F; (ii) and an analog to digital converter.

6. The system of claim 1, wherein the selected data further includes data obtained from an additional second frequency bandwidth portion f2 of said bandwidth F, so that an additional number of data carrying signals P from the M data carrying signals (N+P < M) can be processed.

7. The system of claim 6, further including one or more sub-band filters for passing the first frequency bandwidth portion f1 and second frequency bandwidth portion f2 of said bandwidth F and an analog to digital converter.

8. The system of claim 7, wherein a target data rate of the system can be increased by processing an additional number of data carrying signals P from the M data carrying signals, where N+P <M.

9. The system of claim 1, wherein the selected data to be extracted from the bandpassed data can be controlled by a user of such system.

10. The system of claim 9, wherein a user of such system can increase a target data rate of the system by modularly augmenting the front end circuit to include additional bandwidth and analog to digital conversion capacity such that an additional number of data carrying signals P from the M data carrying signals (N+P <M) can be processed.

11. The system of claim 1, further including a front end transmitting circuit for transmitting control information to cause said upstream transceiver to transmit downstream data only using the N data carrying signals.

12. The system of claim 11, wherein the control information transmitted to the upstream transceiver includes feedback information indicating that only N of the M data carrying signals are desirable for downstream data transmission, even during times when said channel is capable of supporting more than N data carrying signals.

13. The system of claim 12, wherein the control information transmitted to the upstream transceiver further includes feedback information indicating that: (i) the system can support any data protocols used by said upstream transceiver; and (ii) that they are connected through a channel with substantial signal attenuation characteristics for data signals other than the N data carrying signals.

14. The system of claim 1, further including a front end transmitting circuit for transmitting an upstream data signal using a second frequency bandwidth F2 different from F, and L data carrying signals, and where L < M.

15. A high speed communications system for processing an analog data signal from a channel capable of supporting M modulated sub-channels, said system comprising:

a channel interface circuit for coupling to and receiving said analog data signal from the channel;

a analog front end circuit for processing the analog data signal and converting it to a digital signal;

a processing circuit for extracting data from the digital signal, the digital signal including data taken from a number N of said sub-channels, where N is intentionally selected to have a value less than M and where N is negotiated with an upstream transceiver during a initialization procedure.

16. The system of claim 15, where the N sub-channels are initially loaded with bit capacities that are left essentially unchanged unless said channel characteristics vary.

17. The system of claim 15, wherein the selection of the N sub-channels can be done during the initialization procedure.

18. The system of claim 15, wherein the value of N is based on signal processing capability of the processing circuit.

19. The system of claim 15, wherein a target data rate of the system can be increased by processing a additional number of sub-channels P from the M sub-channels, and where N+P <M.

20. The system of claim 15 further including a front end transmitting circuit for transmitting control information to cause said upstream diver to transmit downstream data only using the N sub-channels.

21. The system of claim 15, wherein the upstream transceiver uses discrete multi-tone (DMT) modulation for generating the M modulated sub-channels, and the channel supports asymmetric digital subscriber loop (ADSL) transmission standards.

22. A high speed communications system for processing an analog data signal from a channel capable of supporting M modulated sub-channels, said system comprising:

a channel interface circuit for coupling to and receiving said analog data signal from the channel;

an analog front end circuit for processing the analog data signal and converting it to a digital signal;

a bus interface circuit for transmitting the digital signal to a host processing device, and for receiving a transmission control signal from the host processing device to cause said upstream transmitter to transmit using only from a number N of said sub-channels, where N is intentionally selected to have a value less than M, and where N is negotiated with a upstream transceiver during a initialization procedure.

23. The system of claim 22, wherein the value of N is based on signal processing capability of the host processing device.

24. The system of claim 22, wherein a data rate of the system can be increased by processing an additional number of sub-channels P from the M sub-channels, and where N+P < M.

25. The system of claim 22, wherein the upstream transceiver uses discrete multi-tone (DMT) modulation for generating the M modulated sub-channels, and the channel supports asymmetric digital subscriber loop (ADSL) transmission standards.

26. A method of processing a xDSL signal from a digital subscriber loop, said method including the steps of:

negotiating a reduced data rate R' for said signal between a downstream and a upstream transceiver; and

thereafter transmitting said xDSL signal from the upstream transciever to the downstream transceiver utilizing a number of sub-channels N to effectuate the reduced data rate R', where N is intentionally selected to be less than a maximum number of sub-channels M supported by said digital subscriber loop;
wherein the number of sub-channels N is based on signal processing capability available to the downstream transceiver.

27. The method of claim 26, wherein the data rate of the system can be increased by processing an additional number of sub-channels P from the M sub-channels, and where N+P <M.

28. The method of claim 26, wherein the upstream transceiver uses discrete multi-tone (DMT) modulation for generating the M sub-channels.

29. The method of claim 26, wherein the reduced data rat R' can be specified by a user operating the downstream transceiver.

30. A high speed communications data receiver for communicating through a channel at a data rate X with a upstream transmitter capable of transmitting a data stream at a rate Y (X<Y), the receiver comprising:

a channel interface circuit for coupling to and receiving said data stream; and
an analog front end circuit for data sampling the analog signal and converting it to a digital signal; and
a processing circuit for extracting selected data from the digital signal, and for generating a transmission control signal for causing said upstream transmitter to transmit at a data rate substantially equal to said data rate X during a data stream transmission; and
wherein data sampling requirements of the analog front end circuit and extracting of the processing circuit are reduced because data sampling and extracting is only performed for a fractional portion of the data stream.

31. The system of claim 30, wherein the analog front end circuit further includes one or more sub-band filters for filtering the analog data signal to generate the fractional portion of the data stream that requires data sampling and extracting.

32. The system of claim 30, further including a front end transmitting circuit for transmitting the transmission control signal from the processing circuit to cause said upstream transceiver to transmit downstream data only at said data rate X.

33. The system of claim 32, wherein the control information transmitted to the upstream transceiver includes feedback information indicating that the maximum downstream data transmission data rate is X, even during times when said channel is capable of supporting more than said data rate X.

34. The system of claim 30, further including a front end transmitting circuit for transmitting an upstream data transmission using a data rate Z, where Z < Y.

35. The system of claim 30, wherein the ratio of X to Y is approximately .5 or less, and this ratio can be increased through modular additions to the analog front end circuit.

36. A high speed communications data receiver for communicating through a channel with an upstream transmitter that is capable of transmitting a data signal with a particular frame rate T and data rate Y, the receiver comprising:

a channel interface circuit for coupling to and receiving said data signal; and
an analog front end circuit for sampling the data signal and converting it to a digital signal; and
a processing circuit that: (i) is configurable for processing the digital signal at a data rate <=X and using said frame rate T, where X is determined for such processing circuit prior to initialization of a data transmission and X < Y/2; (ii) generates a transmission control signal for causing said upstream transmitter to transmit at a data rate no greater than X during a data transmission;
wherein signal processing requirements for the processing circuit are reduced because processing is only performed at a fractional rate of the available data rate of said transmission protocol.

37. The system of claim 36, wherein the control information transmitted to the upstream transceiver includes feedback information indicating that the maximum downstream data transmission data rate is X, even during times when said channel is capable of supporting more than said data rate X.

38. The system of claim 36, wherein the feedback information including the data rate X can be controlled by a user of such system.

39. The system of claim 36, wherein the ratio of X to Y is approximately .2 or less.

40. A high speed communications system for transmitting digital information in a channel capable of supporting a transmission bandwidth F, said system comprising:

an upstream data transceiver capable of modulating the digital information to generate an analog data signal data transmission using said transmission bandwidth F; and

a downstream data transceiver channel interface circuit for coupling to and receiving said analog data signal from the upstream data transciever through said channel, the downstream data transceiver including:

(i) a front end receiving circuit for processing the analog data signal and converting it to a digital signal; and
(ii) a processing circuit for demodulating the digital signal, the digital signal including data from a first frequency bandwidth portion f1 of said bandwidth and for generating feedback information indicating to the upstream transceiver that the bandwidth other than f1 is unsuitable for data transmission; and
(iii) a front end transmitting circuit for transmitting the feedback information using a second frequency bandwidth portion f2 to cause said upstream transceiver to transmit downstream data only using the first frequency portion f1.

41. The system of claim 40, wherein the ratio of f1 to F is approximately .5 or less, and this ratio can be increased through modular additions to the front end receiving circuit.

42. The system of claim 40, wherein the feedback information contains intentionally altered channel characteristic information.

43. The system of claim 41, wherein the feedback information, including the size and location of first frequency portion f1, can be controlled by a user of such system.

44. A high speed communications data receiver for communicating through a channel at a controllable data rate X with an upstream transmitter capable of transmitting a data signal at a flame rate T, and a data rate Y, where X/Y < 1/2, the receiver comprising:

a channel interface circuit for coupling to and receiving said analog data signal; and
an analog front end circuit for data sampling the analog signal and converting it to a digital signal; and
a processing circuit for determining said rate X based on processing capabilities available for extracting data from the digital signal, and for generating a transmission control signal for causing said upstream transmitter to transmit using said flame rate T, and a data rate substantially equal to said data rate X during a data transmission.

45. The receiver of claim 44, wherein said rate X is determined during a calibration routine.

46. The receiver of claim 45, wherein said calibration routine is executed by a host data processor to determine the capabilities of such processor.

47. The receiver of claim 44, wherein said rate X is configurable by a user of such receiver based on performance characteristics of a host processor comprising a portion of the processing circuit.

48. The receiver of claim 44, wherein X/Y is approximately .5 or less.

49. A method for communicating through a channel with an upstream transmitter that is capable of transmitting a data signal at a frame rate T, and a data rate Y, the method comprising the steps of:

receiving said data signal; and
sampling the data signal and converting it to a digital signal; and
processing the digital signal at a data rate <=X and using said frame rate T, where X is determined prior to initialization of a data transmission and X < Y/2; and
generating a transmission control signal for causing said upstream transmitter to transmit at a data rate no greater than X during a data transmission.

50. The method of claim 49, wherein the control information transmitted to the upstream transceiver includes feedback information indicating that the maximum downstream data transmission data rate is X, even during times when said channel is capable of supporting more than said data rate X.

51. The method of claim 49, wherein the feedback information including the data rate X can be controlled by a user of such system.

52. The method of claim 49, wherein said rate X is determined during a calibration routine.

53. The method of claim 49, wherein said rate X is configurable by a user of such receiver based on performance characteristics of a host processor comprising a portion of the processing circuit.

54. A method of operating a high speed communications system that is coupled through a channel to an upstream transceiver operating at a maximum data rate Y using a bandwidth F, said method comprising:

(a) receiving an analog initialization signal having a bandwidth F from the upstream transceiver through the channel; and
(b) generating a digital signal based on sampling a portion of the analog data transmission signal corresponding to a first frequency bandwidth portion f1, where f1 <F; and
(c) processing the digital signal to extract data from the digital signal such that an effective receiving rate X (where X<Y) is achieved by the system;
(d) generating feedback information pertaining to the channel transmission characteristics indicating to the upstream transceiver that data rates higher than X should not be used;
(e) thereafter recieving an analog data signal transmitted by the upstream transceiver to have a bandwidth f1;
(f) repeating steps (b) and (c).

55. The method of claim 54, further including a step prior to step (a): receiving a control signal from a user of such system for determining the effective receiving rate X.

56. The method of claim 54, further including a step: determining an optimal bandwidth portion f1 so as to minimize the amount of processing required to extract the data from the digital signal at the receiving rate X.

57. A high speed communications transceiver for communicating with an upstream transceiver transmitting an analog data transmission signal using M data carrying signals within a bandwidth F through a channel to said system, said transceiver comprising:

a channel interface circuit for coupling to and receiving said analog data signal from the channel; and
a front end receiving circuit for sampling the analog data signal and generating a digital signal based on such analog data signal, the digital signal including data from a first frequency bandwidth portion f1 of said bandwidth F containing N data carrying signals, where N<M; and
a bus interface circuit for transmitting the digital signal to a host processing device; and
wherein the system's performance, including data rate, can be scaled based on modifications to said front end receiving circuit or said host processing device so that a the sampling of the analog data signal can be increased, and the first frequency bandwidth portion f1 can also be expanded.

58. The system of claim 57, wherein the front end receiving circuit includes a filter for passing the first frequency bandwidth portion f1 of said bandwidth F; (ii) and an analog to digital converter.

59. The system of claim 58, wherein when the modifications include additional bandpass filters for increasing the first frequency bandwith portion from f1 to f2, where F > f2 > f1, the number of data carrying signals is increased from N to N+P, where P = f2/f1*N, and N+P< M.

60. The system of claim 57, wherein the modifications include adding an additional number of front end circuits k in the system each with a bandpass frequency f1 to result in N*k data carrying signals being included within the digital signal.

61. The system of claim 57, wherein the first frequency bandwidth portion f1 is programmable.

62. The system of claim 57, further including a front end transmitting circuit for transmitting control information to cause said upstream transceiver to transmit downstream data only using the N data carrying signals.

63. The system of claim 62, wherein the control information transmitted to the upstream transceiver includes feedback information from the host processing device indicating to the upstream transceiver that only N of the M data carrying signals are desirable for downstream data transmission, even if said channel is capable of supporting more than N data carrying signals.

64. The system of claim 63, wherein the front end transmitting circuit transmits an upstream data transmission using a second frequency bandwidth F2 and L upstream data carrying signals, and where L < M.

65. The system of claim 57, further including a host processor circuit in the host processing device for extracting selected data from the N data carrying signals.

66. The system of claim 65, wherein host processor circuit includes a host microprocessor, a programmable memory coupled to the microprocessor, and a data extraction routine located in the memory which can be executed by the microprocessor.

67. The system of claim 66, wherein the modifications include upgrading said host processing circuit to include additional signal processing power for processing an additional number of data carrying signals.

68. A method of operating a high speed interface between an upstream transceiver and a host processing device at a target data rate, said method comprising:

(a) receiving an analog initialization signal having a bandwidth F from the upstream transceiver through a communications channel; and
(b) generating a digital signal based on sampling a portion of the analog initialization signal corresponding to a first frequency bandpass portion f1;
(c) transmitting the digital signal to said host processing device so that characteristics of data carrying signals contained within first frequency bandpass portion f1 can be determined, and a number of such data carrying signals can be configured for use by said host processing device to achieve said target data rate; and
(e) generating feedback information indicating to the upstream transceiver that bandwidth other than the first frequency bandpass f1 should not be used for data transmission; and
(f) receiving an analog data transmission signal having a bandwidth f1 from said upstream transceiver; and
(g) generating a digital signal based on sampling the analog data transmission signal; and
(h) transmitting the digital signal to the host processing device so that it can be processed to extract selected data from the data carrying signals;
(i) when a data rate increase is required, expanding the first frequency bandpass portion f1 and returning to step (a).

69. The method of claim 68, further including a step of: determining an optimal size and location of first frequency bandpass portion f1 so as to minimize the amount of processing required by said host processing device to extract the data from the digital signal.

70. The method of claim 68, wherein the ratio of f1 to F is approximately .5 or less, and a data rate of such interface is controlled by controlling this ratio.

71. The method of claim 68 wherein the analog data transmission is comprised of M modulated sub-channels within bandwidth F, and the selected data is contained in N of the M sub-channels within first selected frequency bandpass portion f1, where N < M.

72. The method of claim 68, further including a step: determining an optimal set of N sub-channels so as to minimize the amount of processing required to extract the data from the digital signal.

73. The method of claim 68, further including a step wherein protocol information pertaining to standards applicable to Asymmetric Digital Subscriber Loops is transmitted by the upstream data transceiver so as to set up a ADSL compatible data link.

74. The method of claim 68, wherein during step (i) the first frequency bandpass portion f1 is increased by the use of additional bandpass filters for increasing the first frequency bandwith portion from f1 to f2, where F > f2 > f1, so that the selected data is received at an increased rate equal to approximately f2/f1.

FIGURE 1

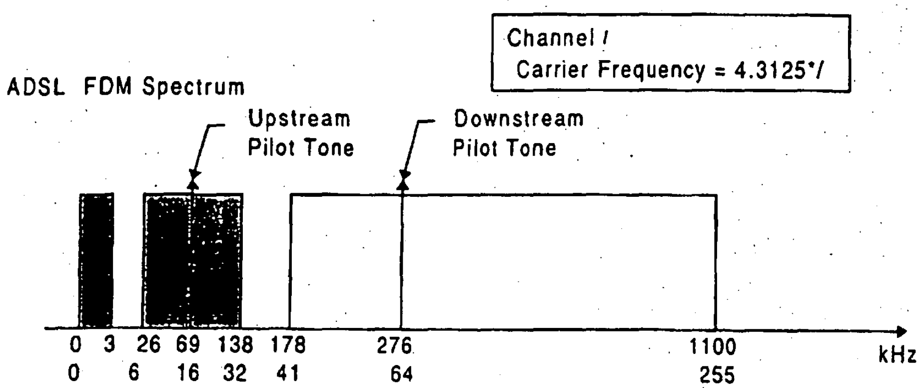


FIGURE 1B

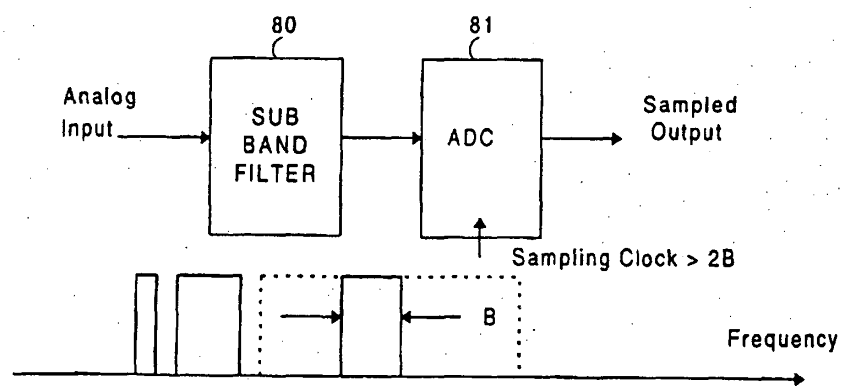


FIGURE 1C

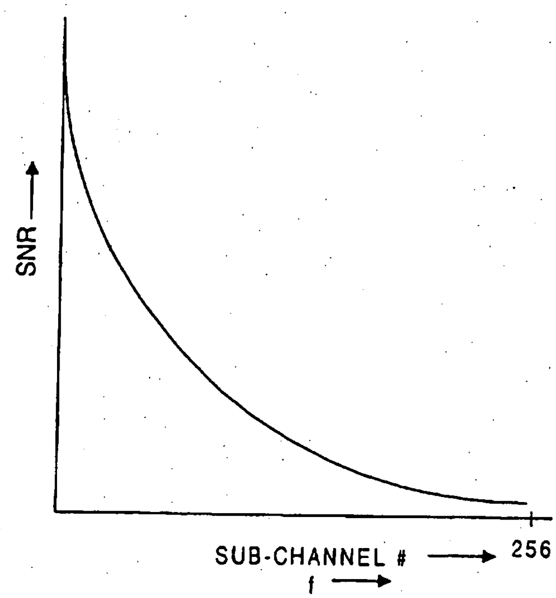


FIGURE 1D

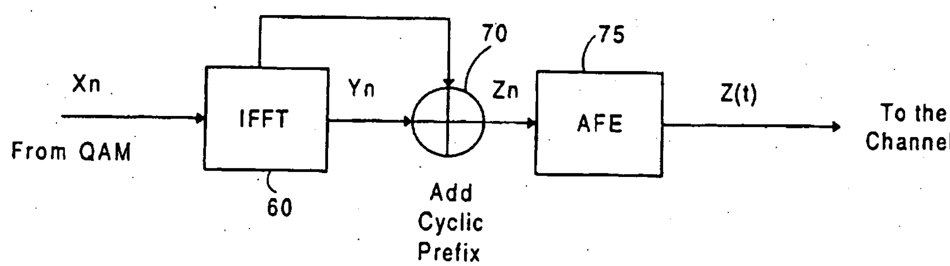


FIGURE 1E

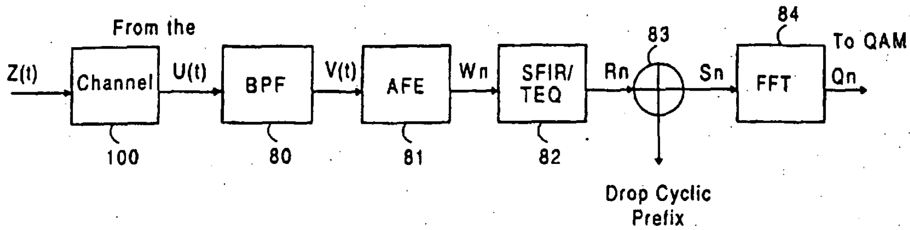


FIGURE 1F

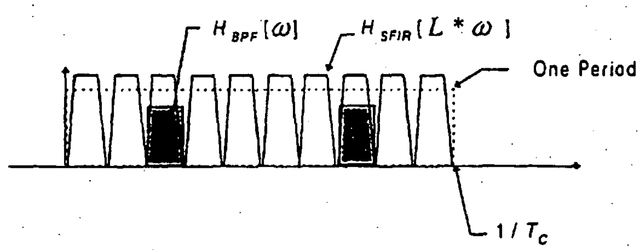


FIGURE 1G

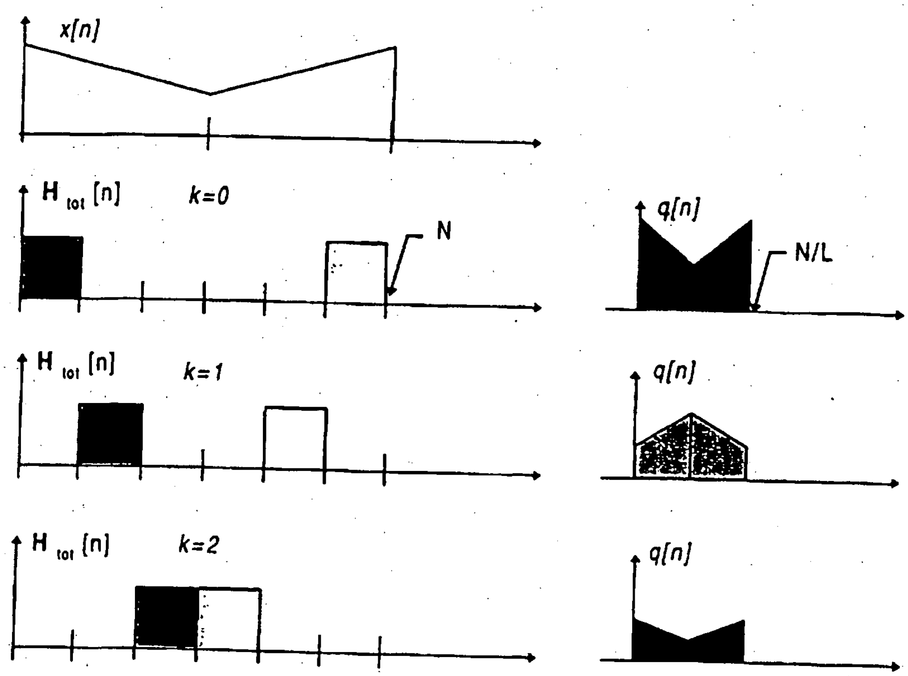
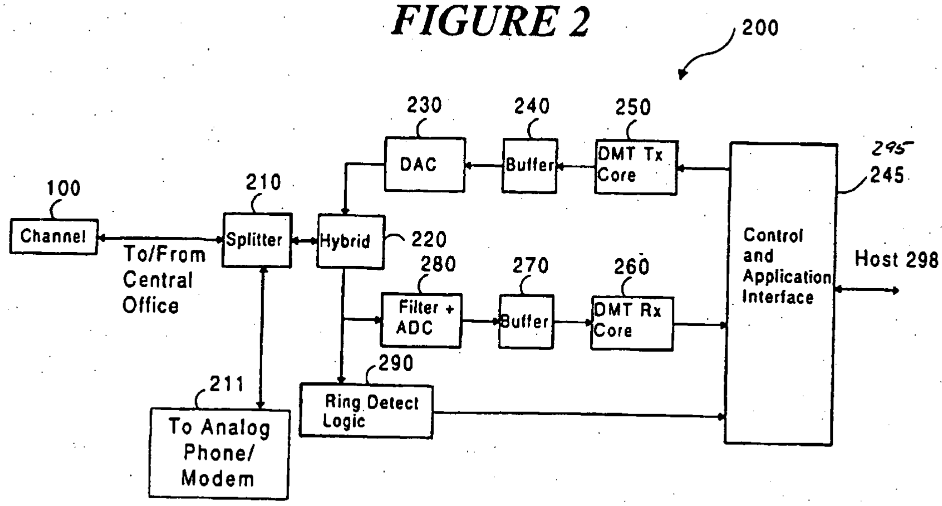


FIGURE 2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230
240
250
DAC
Buffer
DMT Tx
Core
295
245
100
210
Channel
Splitter
Hybrid
220
To/From
Central
Office
280
270
260
Control
and
Application
Interface
Host 298
Filter +
ADC
Buffer
DMT Rx
Core
290
211
Ring Detect
Logic
To Analog
Phone/
Modem

FIGURE 3A

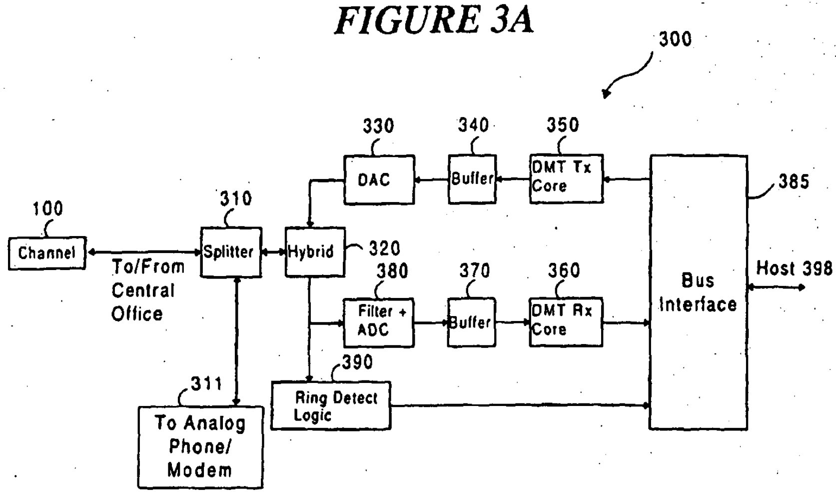


FIGURE 3B

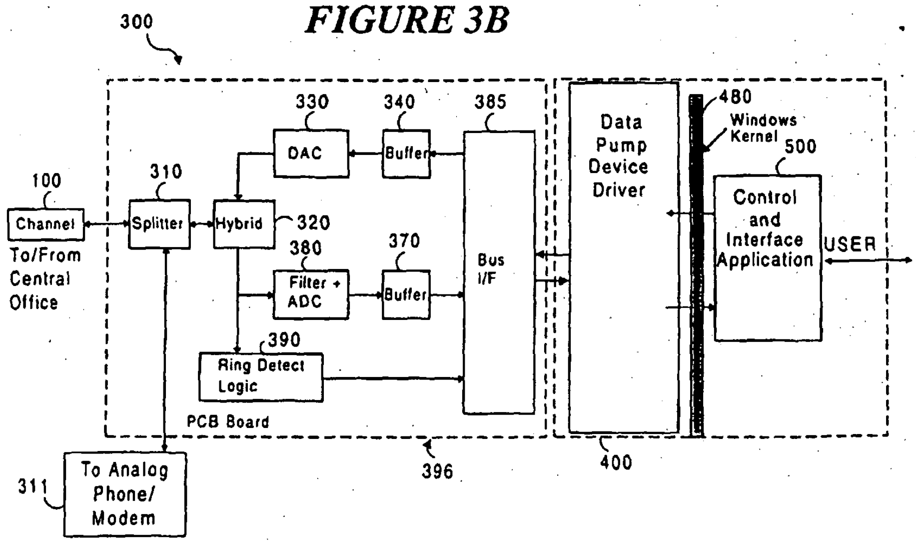
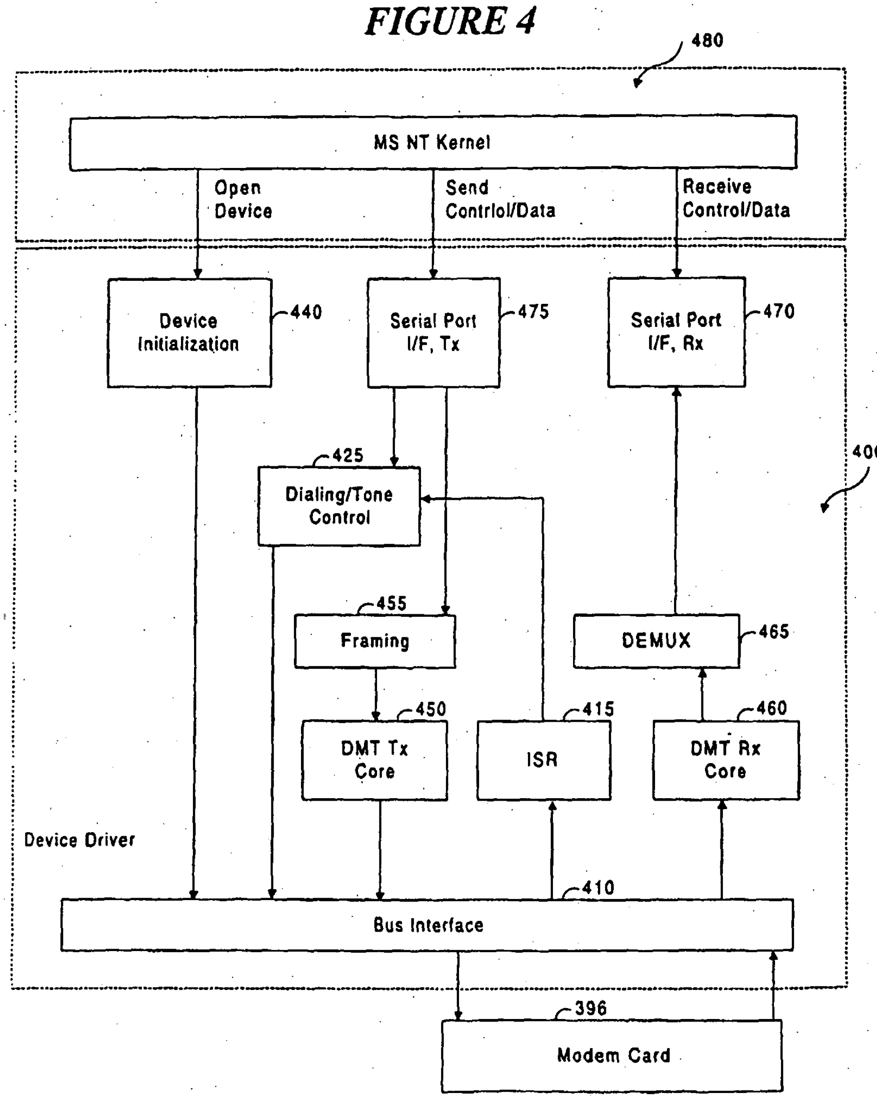


FIGURE 4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MS NT Kernel
Open Device
Send Contrlol/Data
Receive Control/Data
Device Initialization
440
Serial Port I/F, Tx
475
Serial Port I/F, Rx
470
425
Dialing/Tone Control
400
455
Framing
DEMUX
465
450
415
460
DMT Tx Core
ISR
DMT Rx Core
Device Driver
410
Bus Interface
396
Modem Card

FIGURE 5

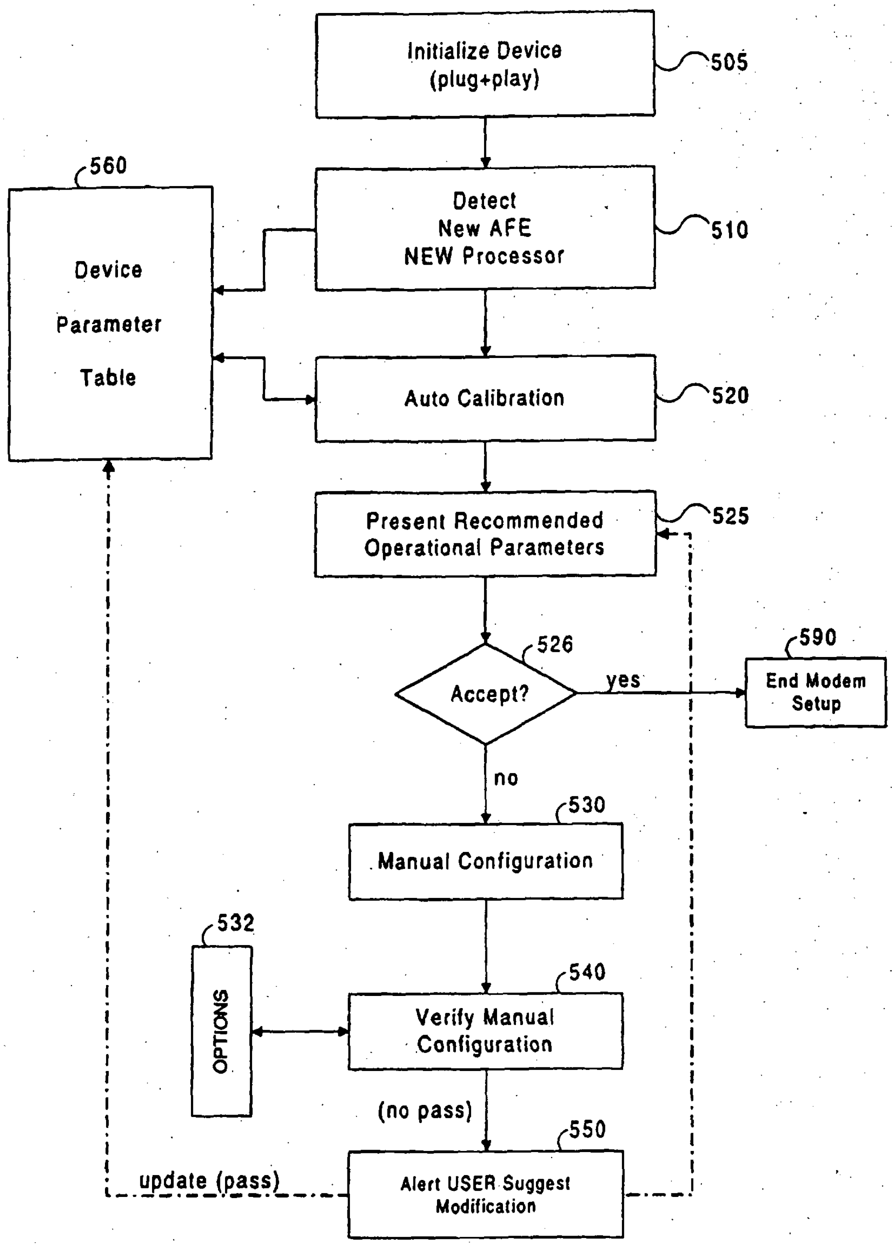
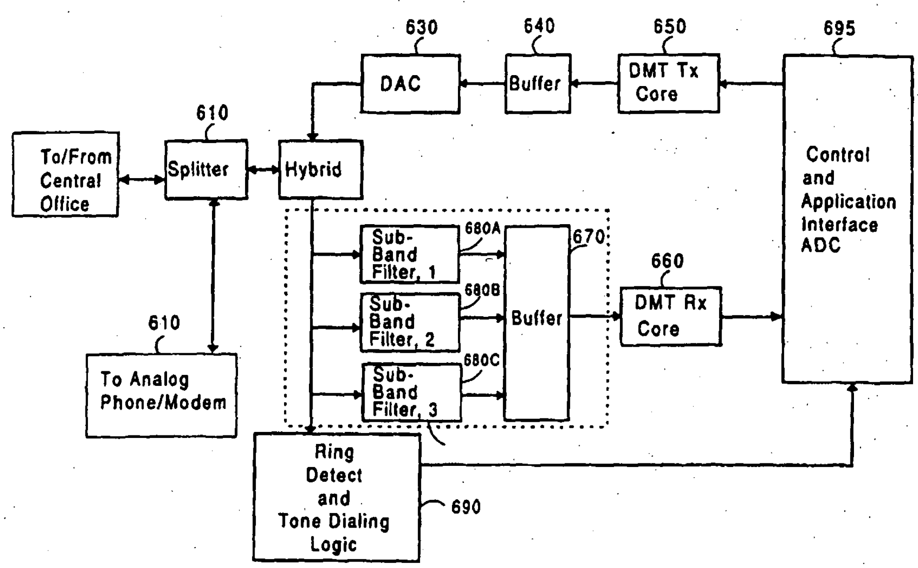

Initialize Device (plug+play)
505
Detect New AFE NEW Processor
510
560
Device Parameter Table
Auto Calibration
520
Present Recommended Operational Parameters
525
526
Accept?
yes
590
End Modem Setup
no
530
Manual Configuration
532
OPTIONS
540
Verify Manual Configuration
(no pass)
550
update (pass)
Alert USER Suggest Modification

FIGURE 6


630
640
650
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DAC
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DMT Tx
Core
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To/From
Central
Office
Splitter
Hybrid
Control
and
Application
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Sub-
Band
Filter, 1
680A
670
660
680B
Sub-
Band
Filter, 2
Buffer
DMT Rx
Core
610
680C
To Analog
Phone/Modem
Sub-
Band
Filter, 3
Ring
Detect
and
Tone Dialing
Logic
690

PATENT APPLICATION SERIAL NO. ____________________

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET

07/18/2003 DEMMANU1 00000021 10619691

01 FC:1001	750.00 OP
02 FC:1201	504.00 OP
03 FC:1202	414.00 OP

PTO-1556
(5/87)

*U.S. Government Printing Office: 2002 — 489-267/69033

PATENT APPLICATION FEE DETERMINATION RECORD
Effective January 1, 2003

Application or Docket Number
10-619-691

CLAIMS AS FILED - PART I

	(Column 1)	(Column 2)
TOTAL CLAIMS	43	
FOR	NUMBER FILED	NUMBER EXTRA
TOTAL CHARGEABLE CLAIMS	43 minus 20=	* 23
INDEPENDENT CLAIMS	9 minus 3 =	* 6
MULTIPLE DEPENDENT CLAIM PRESENT	☐	

* If the difference in column 1 is less than zero, enter "0" in column 2

SMALL ENTITY TYPE ☐ RATE	FEE	OR	OTHER THAN SMALL ENTITY RATE	FEE
BASIC FEE	375.00	OR	BASIC FEE	750.00
X$ 9=		OR	X$18=	414
X42=		OR	X84=	504
+140=		OR	+280=	
TOTAL		OR	TOTAL	1668

CLAIMS AS AMENDED - PART II

AMENDMENT A		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA
	Total	*	Minus	**	=
	Independent	*	Minus	***	=
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM ☐				

SMALL ENTITY RATE	ADDITIONAL FEE	OR	OTHER THAN SMALL ENTITY RATE	ADDITIONAL FEE
X$ 9=		OR	X$18=	
X42=		OR	X84=	
+140=		OR	+280=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

AMENDMENT B		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA
	Total	*	Minus	**	=
	Independent	*	Minus	***	=
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM ☐				

RATE	ADDITIONAL FEE	OR	RATE	ADDITIONAL FEE
X$ 9=		OR	X$18=	
X42=		OR	X84=	
+140=		OR	+280=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

AMENDMENT C		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA
	Total	*	Minus	**	=
	Independent	*	Minus	***	=
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM ☐				

RATE	ADDITIONAL FEE	OR	RATE	ADDITIONAL FEE
X$ 9=		OR	X$18=	
X42=		OR	X84=	
+140=		OR	+280=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20."
***If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3."
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

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INTERNATIONALE ANMELDUNG VERÖFFENTLICHT NACH DEM VERTRAG ÜBER DIE INTERNATIONALE ZUSAMMENARBEIT AUF DEM GEBIET DES PATENTWESENS (PCT)

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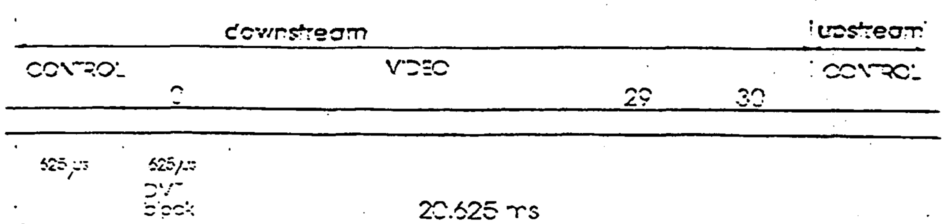
(81) Bestimmungsstaaten: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO Patent (KE, LS, MW, SD, SZ, UG), eurasisches Patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), europäisches Patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI Patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Veröffentlicht
Mit internationalem Recherchenbericht.
Vor Ablauf der für Änderungen der Ansprüche zugelassenen Frist. Veröffentlichung wird wiederholt falls Änderungen eintreffen.

(54) Title: METHOD OF BI-DIRECTIONAL DATA TRANSMISSION OVER A TWO-WIRE LINE

(54) Bezeichnung: VERFAHREN ZUR BIDIREKTIONALEN DATENÜBERTRAGUNG ÜBER EINE ZWEIDRAHTLEITUNG



(57) Abstract

Proposed is a method of bi-directional data transmission over a two-wire line. Digital data destined for transmission or reception, e.g. using discrete multitone modulation (DMT), are modulated or demodulated as appropriate and separated by time-division multiplexing. The appropriate multiplex time frame is subdivided into a predetermined number N of time slots and a number K of those time slots is assigned exclusively to one direction, e.g. transmission, the remaining time slots (= N-K in number) being assigned exclusively to the other direction (e.g. reception).

(57) Zusammenfassung

Verfahren zur bidirektionalen Datenübertragung über eine Zweidrahtleitung, wobei digitale Daten zum Senden oder Empfangen, z.B. mittels diskreter Mehrtonmodulation (DMT), moduliert bzw. demoduliert und die zu sendenden und zu empfangenden Daten durch Zeitmultiplexbetrieb getrennt werden, wobei der zugehörige Multiplex-Zeitrahmen in eine vorbestimmbare Anzahl N von Zeitschlitzen unterteilt wird, und davon eine Anzahl K von Zeitschlitzen ausschließlich einer Übertragungsrichtung, z.B. Senden, und die restliche Anzahl (N-K) von Zeitschlitzen ausschließlich der anderen Übertragungsrichtung, z.B. Empfangen, zugeordnet wird.

LEDIGLICH ZUR INFORMATION

Codes zur Identifizierung von PCT-Vertragsstaaten auf den Kopfbögen der Schriften, die internationale Anmeldungen gemäss dem PCT veröffentlichen.

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Verfahren zur bidirektionalen Datenübertragung über eine Zweidrahtleitung

Die Erfindung betrifft ein Verfahren zur bidirektionalen Datenübertragung über eine Zweidrahtleitung, wobei digitale Daten zum Senden oder Empfangen, z.B. mittels diskreter Mehrtonmodulation (DMT), moduliert bzw. demoduliert und die zu sendenden und zu empfangenden Daten, z.B. durch Frequenzmultiplexbetrieb (FDM) oder Echoauslöschung (EC), getrennt werden.

Um störende Beeinflussung von zu übermittelnden Daten zu beseitigen, führen bekannte Verfahren dieser Art die Trennung der z.B. DMT-modulierten Daten im Frequenzmultiplexbetrieb (FDM) durch, wobei unterschiedliche Frequenzbereiche für die beiden Übertragungsrichtungen festgelegt sind. Eine weitere Möglichkeit zur Trennung besteht in der Anwendung des Echoauslöschungsverfahrens (EC), bei dem durch den Einsatz adaptiver Filter der Einfluß des Sendeteils auf den Empfänger durch adaptive Filter unterdrückt wird. Andere Trennverfahren wurden im Stand der Technik in diesem Zusammenhang bisher nicht verwendet.

Das FDM-Verfahren erzeugt bei der Übertragung entsprechend den beiden Übertragungsrichtungen ein unteres und ein oberes Frequenzband. Da aber die Kabeldämpfung frequenzabhängig ist, bereitet es große Schwierigkeiten für beide Übertragungskanäle die gleiche Übertragungsqualität zu erzielen, in den überwiegenden Fällen ist die Übertragungsqualität in eine besser als in die andere Richtung. Generell ist es aber erwünscht, eine möglichst gleiche Qualität für beide Kanäle anbieten zu können. Weiters ist bei FDM die Variation der Übertragungskapazität mit erheblichem Aufwand verbunden, da dafür eine Anpassung der jeweils verwendeten Bandfilter erforderlich ist, sodaß die Kanalbandbreite entsprechend erhöht oder erniedrigt werden kann.

Das weiters aus dem Stand der Technik bekannte Echoauslöschungs-Verfahren weist ebenso wenn auch anders geartete Nachteile auf. So ist bei diesem Verfahren das Nah-Nebensprechen ein großes technisches Problem, da der Signalabstand zwischen Sende- und Empfangssignal sehr groß ist. Es müssen daher sehr hohe Anforderungen an die bei den Sende- und Empfangsteilen vorgesehenen A/D-Wandler erfüllt werden, da Sende- und Empfangssignale gleichzeitig auftreten und diese entprechend gut getrennt werden müssen. Die hohen Pegelunterschiede der Sende- und Empfangssignale erfordern eine dementsprechend hohe Auflösung der A/D-Wandler, die wiederum höhere Produktkosten zur Folge hat.

Für die Durchführung dieser bekannten Trennmethoden FDM und Echoauslöschung ist auch eine relativ hohe Rechnerleistung erforderlich, die die Kosten für die Datenübertragung stark erhöhen. Besonders bei Anwendung in Fällen, in denen wie etwa bei ADSL (Asymmetric Digtal Subscriber Line) in einer Übertragungsrichtung ("downstream) große Datenraten von einer zentralen Datenanlage zu einem an der Peripherie gelegenen Teilnehmer und vergleichsweise geringe Datenraten in die andere Übertragungsrichtung ("upstream")

übermittelt werden sollen, ist der bei diesen bekannten Datenübertragungsverfahren getriebene Aufwand nur einer schlechten Nutzung unterworfen.
Ziel der Erfindung ist es, ein Verfahren anzugeben, das sich durch geringe Komplexheit hinsichtlich Hardware-Einsatz bzw. Rechnerleistung auszeichnet, sodaß die Durchführung auf einfache und kostengünstige Weise erfolgen kann.
Weiters ist es Ziel der Erfindung, ein Verfahren zu schaffen, mit dem sich bei Übertragungen, die zu einem großen Teil nur in einer der beiden Übertragungsrichtungen vor sich gehen, mit hoher Übertragungsgeschwindigkeit durchführen lassen.
Weitere Aufgabe der Erfindung ist es, eine sehr gute Übertragungsqualität mit relativ geringem technischen Aufwand zu erreichen, wobei eine Änderung der Übertragungskapazität einfach und kostengünstig möglich sein soll.
Erfindungsgemäß wird dies dadurch erreicht, daß die zu sendenden und zu empfangenden Daten durch Zeitmultiplexbetrieb (TDM) getrennt werden, wobei der zugehörige Multiplex-Zeitrahmen in eine vorbestimmbare Anzahl N von Zeitschlitzen unterteilt wird, und davon eine Anzahl K von Zeitschlitzen ausschließlich einer Übertragungsrichtung, z.B. Senden, und die restliche Anzahl (N-K) von Zeitschlitzen ausschließlich der anderen Übertragungsrichtung, z.B. Empfangen, zugeordnet wird.
Da beim erfindungsgemäßen Verfahren entweder nur Sender- oder nur Empfängerfunktionen aktiv sind, wird weniger Prozessorleistung als bei herkömmlichen Verfahren benötigt, da letztere einen sehr hohen internen Datenverkehr zu bewältigen haben. Dadurch gelingt es, eine nach dem erfindungsgemäßen Verfahren durchgeführte Übertragung sehr kostengünstig zu implementieren.
Das erfindungsgemäße Verfahren bietet weiters den Vorteil einer gleichen Übertragungsqualität in beiden Übertragungsrichtungen, da Senden und Empfangen bei TDM mit der gleichen Leitungsdämpfung erfolgt. Dadurch können beide Übertragungsrichtungen mit geringstmöglicher Qualtitätsminderung im gleichen Frequenzbereich durchgeführt werden. Ein weiterer Vorteil des erfindungsgemäßen Verfahrens ist die sehr einfache Veränderung der Übertragungskapazität, die durch die entspechende Wahl der Anzahl der Zeitschlitze für die jeweilige Übertragungsrichtung ermöglicht wird.
Als besonders vorteilhaft bei asymmetrischer Datenübertragung kann es sein, wenn in einer Übertragungsrichtung der Großteil der Daten und in der anderen nur ein kleiner Rest übertragen wird. Dies ist dann gegeben, wenn die Anzahl N der Zeitschlitze sehr viel größer als die Anzahl K gewählt wird. Vorzugsweise ist diese Bedingung erfüllt, wenn N gleich 30 und K gleich 1 ist.
Da das erfindungsgemäße Verfahren zur Datenübertragung über Telephonleitungen eingesetzt werden kann, kann es z.B. durch die Nummernwahl auf der Leitung zu impulsartigen Störungen kommen, die einen Übertragungsfehler bewirken, der unbedingt korrigiert werden muß. Die Datenübertragung muß aber nicht über Telephonleitungen erfolgen, sie kann im Rahmen der Erfindung über jede dafür geeignete Zweidrahtleitung

geschehen. Genauso können die unterschiedlichsten elektromagnetischen Störungen, auch systemexterne, auf die Datenübertragung ihren Einfluß haben.
Das bekannte ARQ (Automatic Repeat Request)-Verfahren wird zur Fehlerkorrektur üblicherweise so eingesetzt, daß die Datenübertragung auch bei beliebigen Störungen auf der Leitung fehlerfrei bleibt, wobei der Datendurchsatz jedoch stark absinken kann, da ein fehlerhaft übertragenes Datenpaket solange wiederholt wird, bis es fehlerfrei empfangen wird.
In weiterer Ausbildung der Erfindung kann daher vorgesehen sein, daß im Multiplex-Zeitrahmen der Datenübertragung im Zeitmittel eine vorbestimmbare Anzahl von Zeitschlitzen für ARQ (Automatic Repeat Request)-Übertragungswiederholungen vorgesehen sind.
Bei dieser Ausführungsform steht somit ständig Übertragungs-Überkapazität zur Verfügung. Wird ein Datenblock fehlerhaft empfangen, fordert der Empfänger nur so oft eine Wiederholung an, wie es im Rahmen der im Zeitmittel zur Verfügung stehenden Überkapazität möglich ist, sodaß unbeeinflußt durch die Übertragungswiederholungen der nominelle Datendurchsatz konstant gehalten werden kann. Im fehlerfreien Übertragungsfall wird ein höher redundantes Signal übermittelt. Die Dauer der Zeitspanne, über die die Zeitmittelung erfolgt, ist im wesentlichen durch die Speicherkapazität des eingesetzten ARQ-Puffers begrenzt.
Nach einer anderen Variante der Erfindung kann vorgesehen sein, daß bei fehlerhafter Übertragung die Daten, z.B. mittels eines Rechenalgorithmus, modifiziert übertragen werden.
Dadurch kann der bei der Übertragung auftretende Fehler, der durch das Abschneiden eines Teils der Amplitude bei Sende-Übersteuerung hervorgerufen wird, korrigiert werden.
In besonders bevorzugter Weise kann dabei vorgesehen sein, daß die Daten durch logische Inversion modifiziert werden.
Diese Inversionsoperation stellt einen sehr einfach berechenbaren Algorithmus dar, der ohne großen Aufwand realisierbar ist.
Weiters kann vorgesehen sein, daß die Schaltfrequenz einer Störquelle, z.B. ein Netzteil, mit einer der Trägerfrequenzen der diskreten Mehrtonmodulation synchronisiert wird.
Dadurch kann das auf frequenzselektive Störungen empfindliche DMT-Verfahren gegen bekannte Störquellen gesichert werden. Bei Synchronisation der Schaltfrequenz der Störquelle auf eine der Trägerfrequenzen der DMT-Modulation wirkt sich die Störung nur auf diese Trägerfrequenz und deren Vielfache aus, sodaß sie durch einen adaptiven Algorithmus kompensiert werden können.
Bei mehreren nebeneinander geführten Zweidrahtleitungen, auf denen jeweils Daten übertragen werden, ergibt sich üblicherweise ein Übersprechen, welches auf die Übertragung naturgemäß störend wirkt.
Gemäß einer anderen Ausführungsform des erfindungsgemäßen Verfahrens, bei welchem Daten über zwei oder mehr Zweidrahtleitungen, die zumindest teilweise in

Übersprechabstand geführt sind, übertragen werden, kann vorgesehen sein, daß der Zeitmultiplex-Betrieb (TDM) auf allen Zweidrahtleitungen synchron durchgeführt wird, sodaß auf allen Zweidrahtleitungen gleichzeitig entweder gesendet oder empfangen wird.
Dadurch wird immer zur gleichen Zeit entweder gesendet oder empfangen, sodaß eine störende Beeinflussung der einzelnen Empfänger durch nicht direkt verbundene Sender vermieden werden kann.
Im folgenden wird die Erfindung anhand eines in den Zeichnungen dargestellten Ausführungsbeispieles näher erläutert.
Es zeigt dabei:
Fig.1 ein Blockschaltbild zur Durchführung einer Ausführungsform des erfindungsgemäßen Verfahrens und
Fig.2 eine schematische Darstellung eines erfindungsgemäßen Zeitrahmens.
Eine bidirektionale Datenübertragung von digitalen Daten gemäß dem in Fig.1 dargestellten Blockschaltbild wird durchgeführt, indem beim Senden die aus einer Datenquelle 1,4 kommenden digitalen Daten im Sendeteil 50 zu einem analogen Sendesignal umgewandelt und über einen Leitungsübertrager 13 einer Zweidrahtleitung 100 an einen am Ende dieser Leitung 100 gelegenen Teilnehmer übertragen werden. Demgegenüber wird ein auf der Zweidrahtleitung 100 ankommendes Signal über den Leitungsübertrager 13 als Empfangssignal an den Eingang eines Empfangteils 51 geführt und dort in digitale Daten umgewandelt. Da beim erfindungsgemäßen Verfahren nie gleichzeitig gesendet und empfangen wird, kann an Stelle einer sonst üblichen Gabelschaltung der Leitungsübertrager 13 verwendet werden, wodurch die oft problematische Anpassung der Gabelschaltung an die Leitungsimpedanz von vornherein wegfällt. Ein durch eine Gabelschaltung bedingtes störendes Übersprechen, durch welches Signalreste vom Sender zum Empfänger derselben Teilnehmerseite gelangen, scheidet somit als Störquelle für dieses Verfahren aus.
In dem in Fig.1 gezeigten Ausführungsbeispiel ist der Sende- und Empfangsteil 50, 51 sowohl einer zentralen Datenstelle C (CENTRAL) alsauch einer peripheren Datenstelle R (REMOTE) in einem einzigen Blockschaltbild dargestellt, welches so zu verstehen ist, daß die zentrale Datenstelle C über den Übertrager 13, die Zweidrahtleitung 100 und einen weiteren Übertrager 13 mit der Datenstelle R verbunden ist. Jene Funktionseinheiten, die nur zur Datenstelle C bzw. R zugehörig sind, sind mit "ATU-C only" bzw. "ATU-R only" gekennzeichnet.
Ohne Beschränkung der allgemeinen Anwendbarkeit des erfindungsgemäßen Verfahrens sei als Ausführungsbeispiel einer asymmetrischen Datenübertragung ein Heimvideosystem beschrieben, bei welchem in der zentralen Datenstelle C die Videoinformation verschiedener Videos in einem Großrechner als Daten in komprimierter Form gespeichert und über eine periphere Datenstelle R abrufbar ist. Über einen bidirektionalen Steuerkanal wird die Steuerinformation zwischen den Datenstellen C und R ausgetauscht, wobei eine Datenrate von 64 kbit/s festgelegt ist. Diese Steuerinformation kann sich auf verschiedene vom Teilnehmer auszugebende Befehle, wie etwa PLAY, REWIND o.ä, wie sie von einem

Videorecorder bekannt sind sowie interne Steuerkommandos beziehen und ist in ihrer Menge vergleichsweise gering gegenüber der von der zentralen Datenstelle C ausgesendeten Breitbandinformation, die im wesentlichen die Videoinformation beinhaltet, die mit einer Datenübertragungsrate von 2, 048 Mbit/s nur in einer Richtung von C zu R gesendet wird.
Die genannten Datenraten können jedoch für das erfindungsgemäße Verfahren aber auch gänzlich anders, z.B. viel höher gewählt werden, wobei für die nur in eine Richtung zu übermittelnde Breitbandinformation auch eine Datenrate von etwa 50 Mbit/s bis 150 Mbit/s zur Verfügung gestellt werden kann. Die übertragene Information kann dabei jede Art von Sprach-, Bild- oder Dateninformation darstellen. Ebenso ist eine andere Rate für den bidirektionalen Steuerkanal ausführbar, der aber nicht nur Steuerfunktionen sondern alle möglichen Datenübertragungsfunktionen erfüllen kann.
Am eingangsseitigen Teil des Sendeteils 50 sind für die Datenstelle C zwei verschiedene Dateneingänge und für die Datenstelle R nur ein Dateneingang ausgebildet. An den ersten Eingang, der für C und R gleich ist, gelangt der Datenstrom aus der Datenquelle 1, die z.B. im wesentlichen Steuerbefehle aussendet, die über einen nachfolgenden Verwürfler 2 in einen diesem nachfolgenden Sendepuffer 3 gelangen, wobei die aus der Datenquelle 1 kommenden Daten im Verwürfler 2 nach einem vorbestimmbaren Algorithmus gewandelt werden. Dadurch wird ein länger andauernder, konstanter logischer Zustand verhindert und eine ausgeglichene statistische Verteilung der binären Zustände erreicht. Anschließend daran erfolgt im Sendepuffer 3 eine Zwischenspeicherung der verwürfelten Signale. In der Datenstelle R sind die aus dem Sendepuffer 3 austretenden Daten über eine Vorrichtung MUX mit anderen Daten, die im ARQ-Puffer 24 erzeugt werden und Wiederholanweisungen enthalten, gemultiplext.
Am zweiten Eingang des Sendeteils 50, der nur für die Datenstelle C ausgeführt ist, kommt der Datenstrom aus der Datenquelle 4, die die Breitbandinformation generiert, über einen nachfolgenden Verwürfler 5 und über einen ARQ (Automatic Request)-Puffer 6, der einen CRC-Generator enthält, über den eine Fehlerkorrekturkodierung erfolgt, an den zweiten Eingang des Sendeteiles 50. Die im Verwürfler 5 umgewandelten Daten werden im ARQ-Puffer 6 zwischengespeichert und bei fehlerhafter Übertragung wiederholt. Eine besondere erfindungsgemäße ARQ-Übertragungstechnik wird weiter unten noch beschrieben.
Die über die Eingänge des Sendeteils 50 seriell eintreffenden Daten werden im Kodierer 7 zum Herabsetzen der Datenrate in vorbestimmbarer Länge zusammengefaßt und anhand einer Kodiertabelle einem entsprechenden Symbol zur weiteren Verarbeitung zugeordnet. Weiters wird dieses kodierte Signal in dem nachfolgenden DMT (Discrete Multi Tone)-Modulator 8 nach diesem bekannten Verfahren moduliert und über ein Hochpaß-Filter 9 geleitet, welches zur Vermeidung von Störeinflüssen im wesentlichen das Sprachfrequenzband unterdrückt. Das digitale Ausgangssignal dieses Hochpaß-Filters 9 wird über einen Digital-Analog-Wandler 10 in ein analoges Signal gewandelt, welches über ein Bandpaß-Filter 11 und anschließend über einen Verstärker 12 zum Wandler 13 gelangt. Das Bandpaß-Filter 11 erfüllt einerseits nochmals die Funktion des Hochpasses 11 und

andererseits schneidet es die durch den Analog-Digital-Wandler 10 hervorgerufenen hochfrequenten Spannungsspitzen ab. Die Frequenz der Analog-Digital-Wandlung ist zur Erfüllung des Abtasttheorems so gewählt, daß für die höchsten vorkommenden Frequenzen mindestens zweimal eine Abtastung durch den Analog-Digital-Wandler 10 erfolgt.
Der Sendeteil 50 und der Empfangsteil 51 sind durch eine TDM (Time Division Multiplex)-Einheit 30 gesteuert, sodaß erfindungsgemäß die zu sendenden und die zu empfangenden Daten durch Zeitmultiplexbetrieb getrennt werden, wobei der zugehörige Multiplex-Zeitrahmen in eine vorbestimmbare Anzahl N von Zeitschlitzen unterteilt wird, und davon eine Anzahl K von Zeitschlitzen des Zeitrahmens auschließlich einer Übertragungsrichtung, z.B. Senden, und die restliche Anzahl N-K von Zeitschlitzen ausschließlich der anderen Übertragungsrichutng, z.B. Empfangen, zugeordnet wird. Dazu steuert die TDM-Einheit den Sendeteil 50 und den Empfangsteil 51, indem sie zur gegebenen Zeit diese aktiviert. Der Sendeteil 50 und der Empfangsteil 51 sind dabei nie gleichzeitig in Betrieb, wodurch die für die Steuerung benötigte Prozessorleistung entsprechend niedrig ausgelegt werden kann. Da dadurch auch eine Beeinflussung des eigenen Senders auf den Empfänger ausgeschlosssen ist, ist für den Analog-Digital-Wandler 16 des Empfängerteils nur eine geringe Auflösung erforderlich. Dieser Vorteil wirkt sich infolge der direkten Proportionalität von Auflösung und Preis bei Analog-Digital-Wandlern sehr kostengünstig aus.
Das erfindungsgemäße Verfahren hat den Vorteil eines relativ geringen Bandbreitenbedarfes und einer sehr geringen Komplexheit, die sich bei der Hardware bzw. bei der benötigten Rechnerleistung zeigt. Bei herkömmlichen Verfahren zur Trennung von Senden und Empfangen geht ein beträchtlicher Teil der Rechnerleistung für interne Kommunikation verloren, während beim erfindungsgemäßen Verfahrern diese Rechner-Hilfskapazität sehr gering gehalten werden kann.
Das erfindungsgemäße Verfahren hat dort seine Grenze, wo sich der Anteil des Sendens und Empfangens der 50%-Prozentgrenze nähert, da dann andere Verfahren etwa wie Echo-Cancelling o.ä. mit gleichgroßem oder kleinerem Aufwand durchgeführt werden können.
In Fig.2 ist der in Zeitschlitze unterteilte Zeitrahmen, wie er im erfindungsgemäßen Verfahren zur Anwendung gelangt, dargestellt. Die beiden Übertragungsrichtungen sind durch die Ausdrücke "upstream" und "downstream" gekennzeichnet. Der ganze Zeitrahmen ist in diesem Beispiel 20,625 ms lang und in verschiedene Schlitze zu 625 μs aufgeteilt, wobei die Mehrzahl der Daten in downstream-Richtung übertragen wird. Diese Aufteilung ist besonders dann von Vorteil, wenn in einer Übertragungsrichtung ein bidirektionaler Kanal mit geringer und ein unidirektionaler Kanal mit hoher Datenrate benötigt wird. In dem dargestellten Ausführungsbeispiel werden über den bidirektionalen Kanal durch die mit CONTROL bezeichneten Zeitschlitze in downstream- und upstream-Richtung Steuerbefehle und über den unidirektionalen Kanal durch die mit VIDEO bezeichneten 30 downstream-Zeitschlitze mit im Zeitmittel einem Hilfsschlitz Videoinformation übertragen. Diese Art der Übertragung kann für beliebige Informationen erfolgen.

Die Verteilung der Sende- bzw. Empfangskapazitäten ist den jeweiligen Verhältnissen durch Wahl der Anzahl der upstream bzw. downstream-Zeitschlitze anpaßbar. Bei sich ändernden Auslastungen kann dieses Verhältnis automatisch entsprechend dem aktuellen Bedarf abgestimmt werden. Die festgelegten Sende- und Empfangszeiten haben gegenüber einer Frequenzmultiplex-Übertragung den Vorteil, daß nicht gleichzeitig empfangene und zu sendende Daten verarbeitet werden müssen, wodurch die Rechnerleistung bzw. der Hardware-Aufwand entsprechend niedrig ausgelegt werden kann. In jedem DMT-Schlitz wird eine codierte und DMT-modulierte Dateneinheit übertragen.

Für ARQ-Übertragungswiederholungen wird gemäß einer erfindungsgemäßen Ausführungsform im Multiplex-Zeitrahmen der Datenübertragung im Zeitmittel eine vorbestimmbare Anzahl von Zeitschlitzen für ARQ-Übertragungswiederholungen vorgesehen sind. Dazu werden beim Senden der Daten diese ständig in den ARQ-Sendepuffer 6 eingeschrieben und von diesem wieder an den Kodierer 7 weitergegeben. Dabei werden die vom Puffer 6 abgehenden Daten schneller übertragen als dieser gefüllt wird. In der dabei entstehenden Lücke wird erneut jeweils der letzte Datenblock eingetragen, dieser wird jedoch empfängerseitig als wiederholter Block erkannt und automatisch beseitigt. Somit wird im fehlerfreien Übertragungsfall ständig mit Überkapazität gesendet, ohne daß der übertragene Informationsgehalt größer ist.

Sobald ein Übertragungsfehler auftritt, erkennt der Empfänger in der peripheren Datenstelle R den Fehler mittels seiner CRC- Fehlererkennung in der ARQ-Einheit 24 und gibt darauf den Befehl über den Multiplexer des Sendepuffers 3 zur Datenwiederholung weiter, der dann als Steuerinformation über den bidirektionalen Kanal gesendet wird. In der zentralen Datenstelle C wird diese Information nach Durchlaufen des Empfängerteils 51 im Empfängerpuffer 27 gedemultiplext und ein Steuerbefehl an den ARQ-Puffer 6 gegeben, die fehlerhafte Übertragung zu wiederholen.

Dafür steht in diesem Ausführungsbeispiel im Zeitmittel nur ein Hilfsschlitz zur Verfügung, was einer Überkapazität von 3,33% entspricht. Dauer und Anzahl der Hilfsschlitze sind in diesem Zusammenhang keiner Einschränkung unterworfen und können innerhalb des technisch Realisierbaren beliebig den jeweiligen Verhältnissen angepaßt werden.

Nach einer Fehlübertragung wird nun im darauffolgenden Zeitrahmen, die Wiederholungsübertragung durchgeführt, die sich über mehrere nacheinanderfolgende Zeitschlitze erstrecken kann. Gemittelt über die Zeit sollte in diesem Beispiel nur ein Zeitschlitz pro Rahmen für die Wiederholungen benutzt werden.

Die Zeitspanne, über die dabei das Zeitmittel berechnet wird, ist durch die Größe des ARQ-Pufferspeichers festgelegt. Sobald dieser mit Information vollgeschrieben ist, können keine weiteren Wiederholungen durchgeführt werden und der fehlerhafte Datenblock muß als transparent ausgegeben werden.

Gegenüber einem herkömmlichen ARQ-Verfahren ist die für die Datenwiederholungen festgelegte Zeitspanne im Zeitmittel fixiert. Dadurch kann es nicht passieren, daß aufgrund einer länger andauernden Störung die Übertragung solange wiederholt wird bis sie fehlerfrei ist und damit die Übertragungszeit sich stark erhöht. Durch das bekannte ARQ-Verfahren wird die Datenübertragung auch bei beliebigen Störungen solange wiederholt, bis sie fehlerfrei empfangen wird, wodurch der Datendurchsatz aber sehr stark sinkt. Hingegen wird durch die feste Überkapazität, die zwischen 2 und 10%, vorzugsweise aber zwischen 3 und 5% liegt, im erfindungsgemäßen Verfahren die Übertragung nur so oft wiederholt, wie es im Rahmen der Überkapazität möglich ist, um den nominellen Datendurchsatz aufrecht zu erhalten. Kann bei mehreren aufeinanderfolgenden falschen Datenblöcken einer nicht mehr wiederholt und richtig empfangen werden, wird er transparent ausgegeben.

Bei einem durch die diskrete Mehrtonmodulation (DMT) modulierten Signal ist das Verhältnis von Spitzenwert zu Mittelwert sehr groß, sodaß ein Abkappen ("Clipping") der Signalspitze eine häufige Fehlerquelle darstellt. Um diesen Fehler auf einfache Weise zu korrigieren, kann nach einer fehlerhaften Datenübertragung die digitale Bitfolge beim Wiederholvorgang im Sender z.B. durch einen Rechenalgorithmus, modifiziert werden und dann erneut übertragen werden. Im Empfänger wird der verwendete Rechenalgorithmus entsprechend in Umkehrung angewendet und die Daten wiedergewonnen. Dadurch kann dieser Übertragungsfehler sehr effektiv ausgeschaltet werden. Im besonderen ist es schaltungs- oder rechentechnisch auf einfache Weise durchführbar, die fehlerhaften Daten in invertierter Form zu übertragen

Eine weitere Störquelle beim DMT-Verfahren ergibt sich aus der Schaltfrequenz der eingesetzten Spannungsversorgung, z.B. des Netzteils, da diese Schaltfrequenz im Übertragungsbereich liegt und somit als frequenzselektive Störung ihre Auswirkung zeigt. Hinzu kommt die Abhängigkeit dieser Störungen von anderen Einflußgrößen, etwa die gerade am Netzteil vorliegende Last. Diese Art von Störungen können verringert werden, indem die Schaltfrequenz des Netzteils auf eine der Trägerfrequenzen der DMT-Modulation synchronisiert wird. Damit wirkt sich diese Störung nur auf diese Trägerfrequenz und ihre Vielfache aus, sodaß sie sehr leicht durch einen adaptiven Algorithmus kompensiert werden können.

In Fig.1 ist weiters der dem Sendeteil 50 entsprechende Empfangsteil 51 dargestellt. Die über die Zweidrahtleitung 100 und den Übertrager 13 von der anderen Teilnehmerseite einlangenden Signale werden über einen Bandpaß 14 und über eine AGC (Automatic Gain Control)-Einheit, die unabhängig von den momentanen Signalverhältnissen auf der Leitung ein annähernd amplitudenkonstantes Signal erzeugt, an den Eingang eines zum Empfangsteil 51 gehörigen Analog-Digital-Wandlers 16 geführt, dessen Ausgang mit einem Hochpaß-Filter 17 verbunden ist. Das am Eingang des Hochpasses 17 anliegende Signal wird über einen AGC-Regelkreis 18 als Stellgröße zur AGC-Einheit 15 rückgeführt.

Nach dem Hochpaß 17 erfolgt die Demodulation des Signals, aus welchem nur in der peripheren Datenstelle R der mitübertragene Pilotton einer Pilot-AGC-Einheit 20 zugeführt wird, woraus in der Taktgewinnungseinheit 21 ein Referenzsignal für die Takterzeugungseinheit 31 der peripheren Datenstelle R gewonnen wird. Diese Takterzeugungseinheit 31 generiert für die TDM-Einheit 30 und für den Systemtakt die

Zeitbasis. Die Datenstelle C benötigt keine Taktgewinnungseinheit, da hier eine unabhängige Zeitbasis vorgesehen ist.
Die durch die Übertragungsstrecke bewirkten linearen Verzerrungen werden in einem an den DMT-Demodulator 19 anschließenden Entzerrer 22 mit update-Funktion beseitigt. Daran anschließend findet in einem Dekodierer 23 das Umschlüsseln entsprechend einer Dekodiertabelle statt, woraufhin am Ausgang des Dekodieres 23 wieder ein serieller Bitstrom vorliegt, der über zwei Ausgänge geführt wird. Der für Datenstelle C und R gleich ausgeführte erste Ausgang besteht aus einem Empfangs-Puffer 27 für Steuerinformation, einem nachfolgenden Entwürfler 28, in welchem die Daten in ihrer richtigen Reihenfolge wiederhergestellt werden und der Datensenke 29, die die gesendeten Steuerdaten empfängt. Der zweite Ausgang des Empfangsteils 51, welcher nur für die Datenstelle R vorgesehen ist, ist mit einem ARQ-Puffer 24 verbunden, der die übertragene Breitbandinformation aus der Datenstelle C zwischenspeichert, verifiziert und bei Bedarf über eine im ARQ-Puffer 24 integrierte Steuereinheit den Befehl zum nochmaligen Senden der fehlerhaft übertragenen Daten an den Multiplex-Eingang des Sendepuffers 3 gibt, der zur Datenstelle C rückübertragen wird. Am Ausgang des ARQ-Puffers 24 ist ein Entwürfler 25 und daran anschließend eine Datensenke 26 zur Übernahme der Breitbandinformation angeschlossen.
Werden Daten über zwei oder mehr Zweidrahtleitungen, die zumindest teilweise in Übersprechabstand geführt sind, übertragen, kann es geschehen, daß durch die gegenseitige induktive Beeinflussung der Zweidrahtleitungen es zum Übersprechen kommt. Besonders in einer zentralen Datenanlage, in der viele abgehende Zweidrahtleitungen nebeneinander geführt werden, kann es zu dieser unerwünschten Störung kommen.
Bei einer Ausführungsform des erfindungsgemäßen Verfahrens wird diese Art der Störung vermieden, indem der Zeitmultiplex-Betrieb auf allen Zweidrahtleitungen synchron durchgeführt wird. Dies bedeutet, daß gleichzeitig über alle Zweidrahtleitungen entweder gesendet oder empfangen wird, sodaß keine Beeinflussung mehr möglich ist.

Patentansprüche

1. Verfahren zur bidirektionalen Datenübertragung über eine Zweidrahtleitung, wobei digitale Daten zum Senden oder Empfangen, z.B. mittels diskreter Mehrtonmodulation (DMT), moduliert bzw. demoduliert und die zu sendenden und zu empfangenden Daten, z.B. durch Frequenzmultiplexbetrieb (FDM) oder Echoauslöschung (EC), getrennt werden, **dadurch gekennzeichnet**, daß die zu sendenden und zu empfangenden Daten durch Zeitmultiplexbetrieb (TDM) getrennt werden, wobei der zugehörige Multiplex-Zeitrahmen in eine vorbestimmbare Anzahl N von Zeitschlitzen unterteilt wird, und davon eine Anzahl K von Zeitschlitzen ausschließlich einer Übertragungsrichtung, z.B. Senden, und die restliche Anzahl (N-K) von Zeitschlitzen ausschließlich der anderen Übertragungsrichtung, z.B. Empfangen, zugeordnet wird.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet**, daß N gleich 30 und K gleich 1 ist.

3. Verfahren nach Anspruch 1 oder 2, **dadurch gekennzeichnet**, daß im Multiplex-Zeitrahmen der Datenübertragung im Zeitmittel eine vorbestimmbare Anzahl von Zeitschlitzen für ARQ (Automatic Repeat Request)-Übertragungswiederholungen vorgesehen sind.

4. Verfahren nach Anspruch 1, 2 oder 3, **dadurch gekennzeichnet**, daß bei fehlerhafter Übertragung die Daten, z.B. mittels eines Rechenalgorithmus, modifiziert wiederholt übertragen werden.

5. Verfahren nach Anspruch 4, **dadurch gekennzeichnet**, daß die Daten durch logische Inversion modifiziert werden.

6. Verfahren nach Anspruch 1 bis 5, **dadurch gekennzeichnet**, daß die Schaltfrequenz einer Störquelle, z.B. ein Netzteil, mit einer der Trägerfrequenzen der diskreten Mehrtonmodulation synchronisiert wird.

7. Verfahren nach Anspruch 1 bis 6, wobei Daten über zwei oder mehr Zweidrahtleitungen, die zumindest teilweise in Übersprechabstand geführt sind, übertragen werden, **dadurch gekennzeichnet**, daß der Zeitmultiplex-Betrieb (TDM) auf allen Zweidrahtleitungen synchron durchgeführt wird, sodaß auf allen Zweidrahtleitungen gleichzeitig entweder gesendet oder empfangen wird.

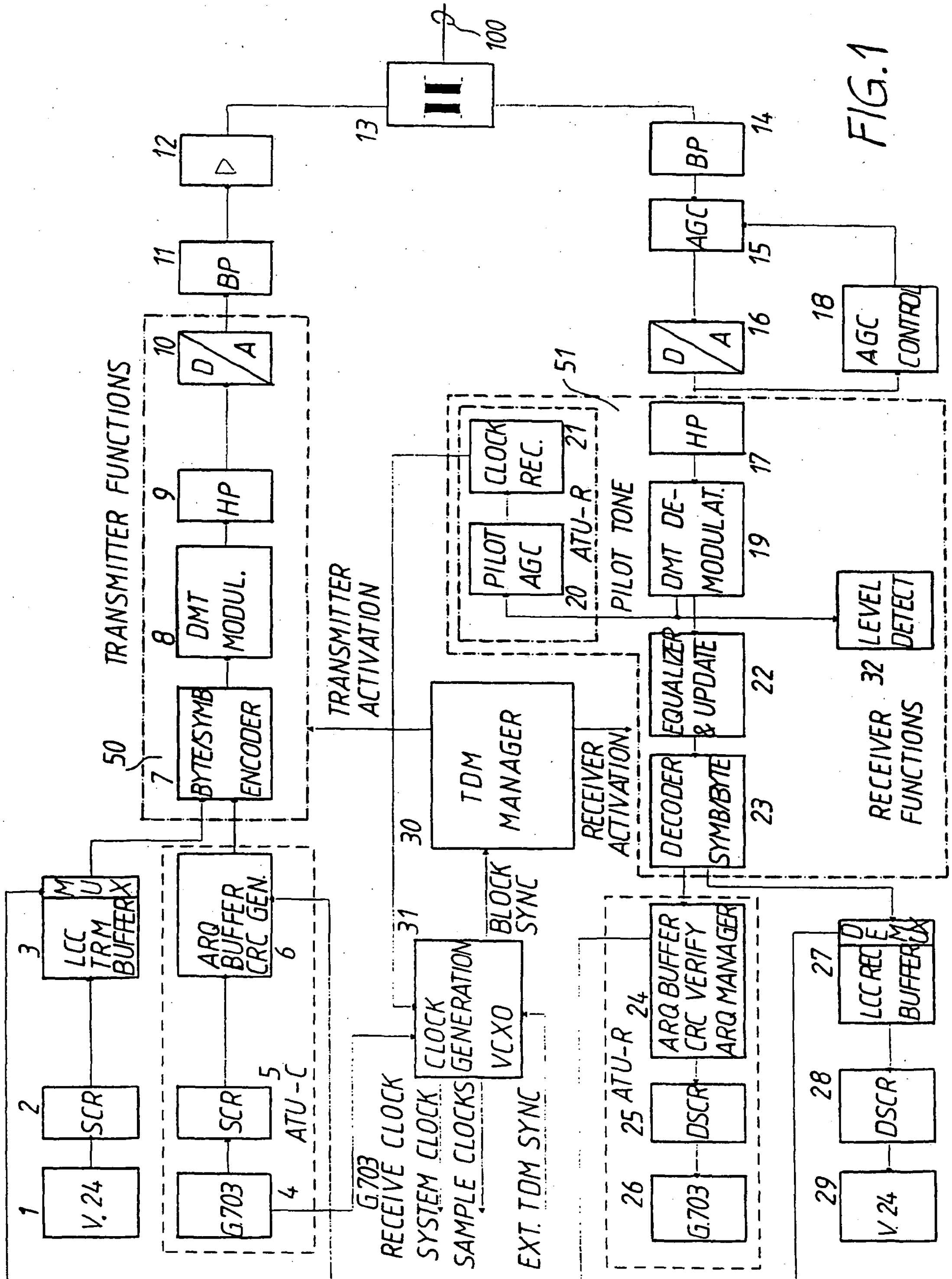

FIG. 1

ERSATZBLATT (REGEL 26)

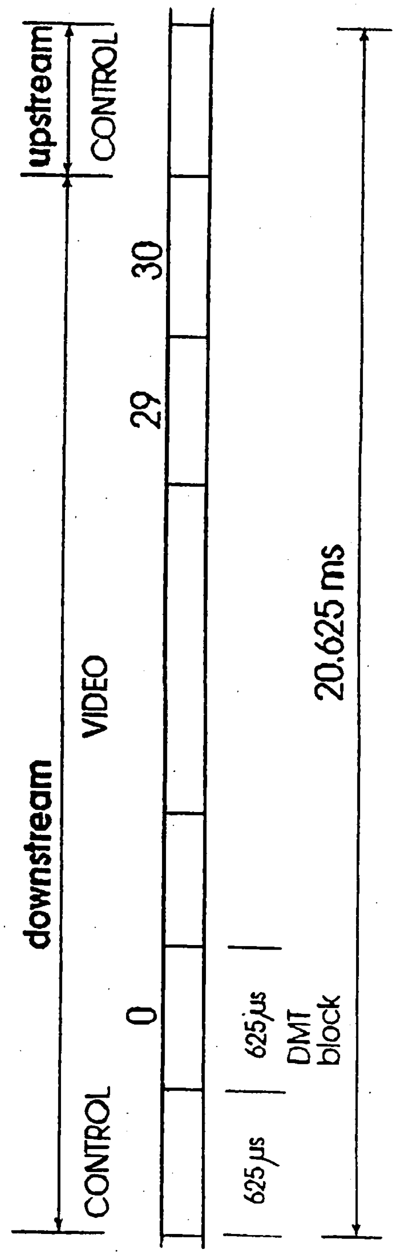
upstream
CONTROL
30
29
downstream
VIDEO
20.625 ms
0
625 µs
DMT
block
CONTROL
625 µs

FIG.2

INTERNATIONAL SEARCH REPORT

International Application No
PCT/AT 96/00112

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04L5/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04L H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US,A,4 796 255 (WESTBROOK ET AL.) 3 January 1989 see column 1, line 17 - line 59 see column 2, line 45 - line 68	1,2
A	see figures 1,2 ---	3-7
X	SINGAPORE ICCS '94. CONFERENCE PROCEEDINGS. (CAT. NO.94TH0691-6), PROCEEDINGS OF ICCS '94, SINGAPORE, 14-18 NOV. 1994, ISBN 0-7803-2046-8, 1994, NEW YORK, NY, USA, IEEE, USA, pages 571-575 vol.2, XP002016282 YONG HOON KIM ET AL.: "Dynamic frame control for TDD based wireless LAN" see page 572, paragraph 2.1 see figures 1,2 --- -/--	1,2

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
18 October 1996	12.11.96
Name and mailing address of the ISA	**Authorized officer**
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ghigliotti, L

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Intern. .onal Application No
PCT/AT 96/00112

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, NOV. 1994, USA, vol. 43, no. 4, ISSN 0018-9545, pages 934-945, XP002016283 WAI-CHOONG WONG ET AL.: "Shared time division duplexing: an approach to low-delay high-quality wireless digital speech communications" see paragraph II, pages 935-936 see figure 1 ---	1,2
X	GB,A,2 145 609 (GEN. ELECTRIC CO. PLC) 27 March 1985 see abstract see page 2, line 41 - line 54 see figure 2 ---	1,2
X	US,A,4 841 521 (AMADA ET AL.) 20 June 1989 see abstract see figures 1,3 -----	1,2

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/AT 96/00112

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A-4796255	03-01-89	NONE		
GB-A-2145609	27-03-85	US-A-	4644525	17-02-87
US-A-4841521	20-06-89	CA-A-	1274928	02-10-90
		DE-A-	3717854	10-12-87
		JP-A-	63099642	30-04-88

INTERNATIONALER RECHERCHENBERICHT

Intern. ...nales Aktenzeichen
PCT/AT 96/00112

A. KLASSIFIZIERUNG DES ANMELDUNGSGEGENSTANDES
IPK 6 H04L5/14

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IPK 6 H04L H04N

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Während der internationalen Recherche konsultierte elektronische Datenbank (Name der Datenbank und evtl. verwendete Suchbegriffe)

C. ALS WESENTLICH ANGESEHENE UNTERLAGEN

Kategorie*	Bezeichnung der Veröffentlichung, soweit erforderlich unter Angabe der in Betracht kommenden Teile	Betr. Anspruch Nr.
X	US,A,4 796 255 (WESTBROOK ET AL.) 3.Januar 1989 siehe Spalte 1, Zeile 17 - Zeile 59 siehe Spalte 2, Zeile 45 - Zeile 68	1,2
A	siehe Abbildungen 1,2 ---	3-7
X	SINGAPORE ICCS '94. CONFERENCE PROCEEDINGS. (CAT. NO.94TH0691-6), PROCEEDINGS OF ICCS '94, SINGAPORE, 14-18 NOV. 1994, ISBN 0-7803-2046-8, 1994, NEW YORK, NY, USA, IEEE, USA, Seiten 571-575 vol.2, XP002016282 YONG HOON KIM ET AL.: "Dynamic frame control for TDD based wireless LAN" siehe Seite 572, Absatz 2.1 siehe Abbildungen 1,2 --- -/--	1,2

[X] Weitere Veröffentlichungen sind der Fortsetzung von Feld C zu entnehmen

[X] Siehe Anhang Patentfamilie

* Besondere Kategorien von angegebenen Veröffentlichungen :

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18.Oktober 1996	12. 11. 96
Name und Postanschrift der Internationale Recherchenbehörde Europäisches Patentamt, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Bevollmächtigter Bediensteter Ghigliotti, L

Formblatt PCT/ISA/210 (Blatt 2) (Juli 1992)

INTERNATIONALER RECHERCHENBERICHT

Internationales Aktenzeichen
PCT/AT 96/00112

C.(Fortsetzung) ALS WESENTLICH ANGESEHENE UNTERLAGEN

Kategorie*	Bezeichnung der Veröffentlichung, soweit erforderlich unter Angabe der in Betracht kommenden Teile	Betr. Anspruch Nr.
X	IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, NOV. 1994, USA, Bd. 43, Nr. 4, ISSN 0018-9545, Seiten 934-945, XP002016283 WAI-CHOONG WONG ET AL.: "Shared time division duplexing: an approach to low-delay high-quality wireless digital speech communications" siehe Absatz II, Seiten 935-936 siehe Abbildung 1 ---	1,2
X	GB,A,2 145 609 (GEN. ELECTRIC CO. PLC) 27.März 1985 siehe Zusammenfassung siehe Seite 2, Zeile 41 - Zeile 54 siehe Abbildung 2 ---	1,2
X	US,A,4 841 521 (AMADA ET AL.) 20.Juni 1989 siehe Zusammenfassung siehe Abbildungen 1,3 -----	1,2

1

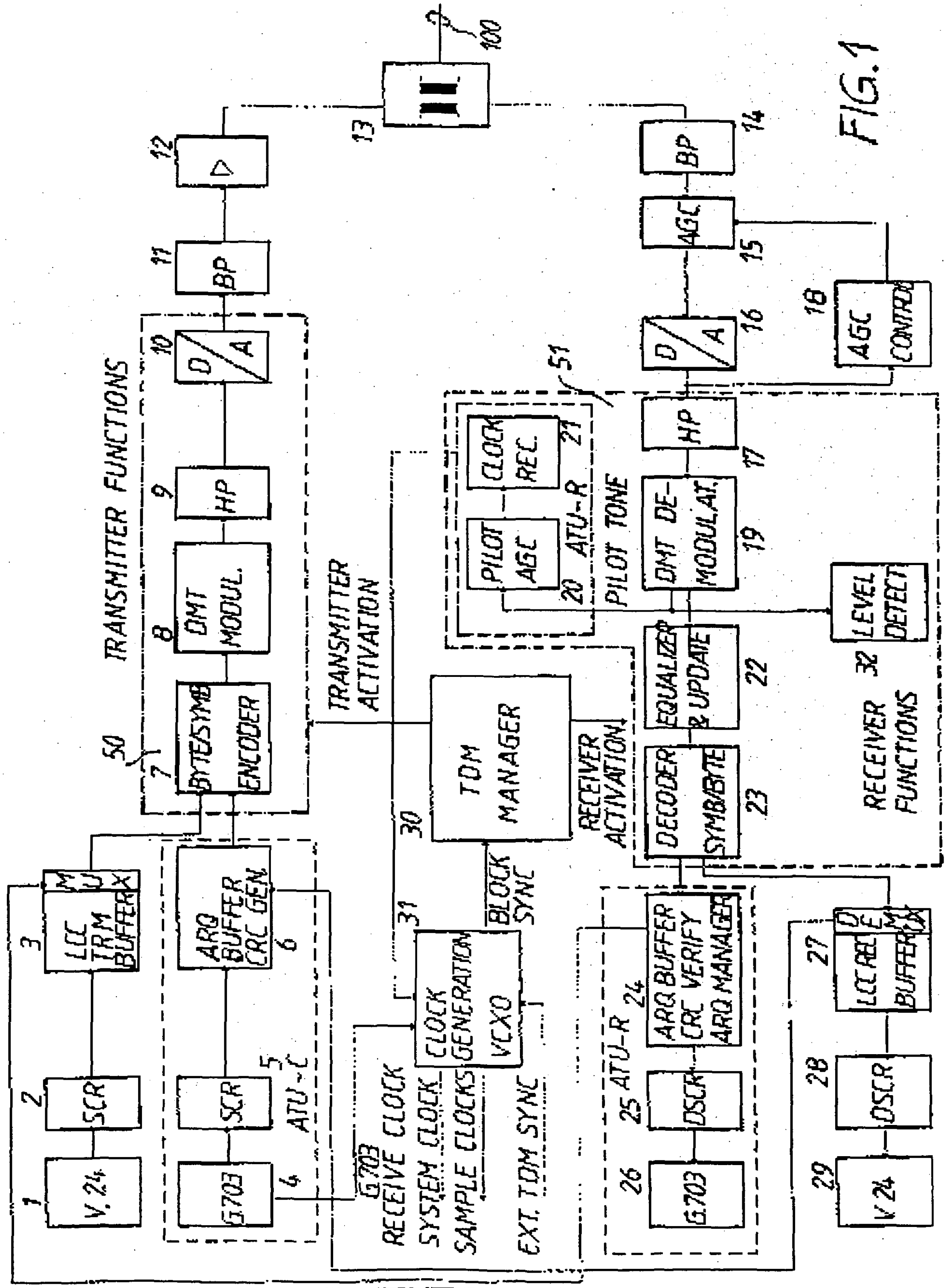
INTERNATIONALER RECHERCHENBERICHT

Angaben zu Veröffentlichungen, die zur selben Patentfamilie gehören

Intern. ...ales Aktenzeichen
PCT/AT 96/00112

Im Recherchenbericht angeführtes Patentdokument	Datum der Veröffentlichung	Mitglied(er) der Patentfamilie	Datum der Veröffentlichung
US-A-4796255	03-01-89	KEINE	
GB-A-2145609	27-03-85	US-A- 4644525	17-02-87
US-A-4841521	20-06-89	CA-A- 1274928	02-10-90
		DE-A- 3717854	10-12-87
		JP-A- 63099642	30-04-88

Formblatt PCT/ISA/210 (Anhang Patentfamilie)(Juli 1992)


TRANSMITTER FUNCTIONS
V.24
SCR
LCC TRM BUFFER
MUX
G703
SCR
ARQ BUFFER CRC GEN.
ATU-C
BYTE/SYMB ENCODER
DMT MODUL.
HP
D/A
BP
TRANSMITTER ACTIVATION
TDM MANAGER
RECEIVER ACTIVATION
BLOCK SYNC
CLOCK GENERATION VCXO
G703 RECEIVE CLOCK
SYSTEM CLOCK
SAMPLE CLOCKS
EXT. TDM SYNC
PILOT AGC
CLOCK REC.
ATU-R
PILOT TONE
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AGC
ARQ BUFFER CRC VERIFY ARQ MANAGER
DSCR
G703
LCC REC BUFFER
DEMUX
V.24

FIG. 1

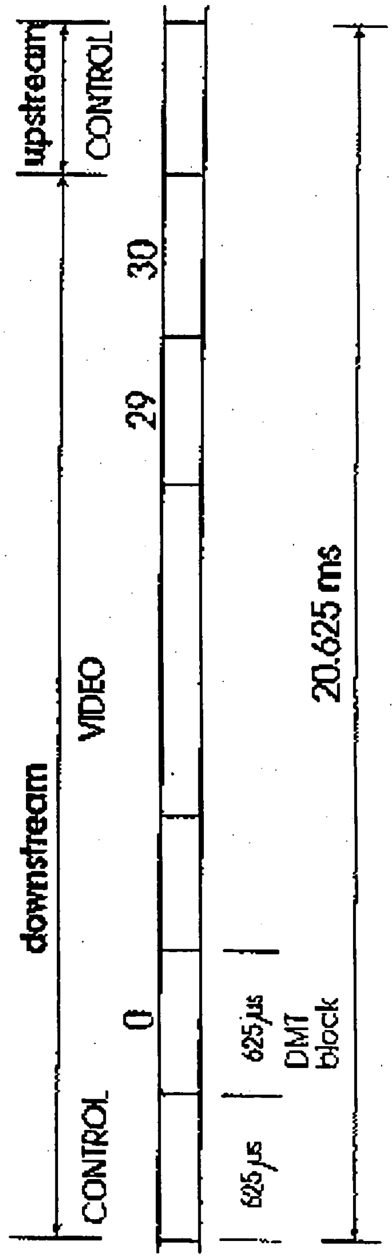

downstream
upstream
CONTROL
VIDEO
CONTROL
0
29
30
625 µs
625 µs
DMT
block
20.625 ms

FIG.2

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classificati n 6 :
H04L 12/00

A2

(11) International Publication Number: WO 99/26375

(43) International Publication Date: 27 May 1999 (27.05.99)

(21) International Application Number: PCT/US98/23336

(22) International Filing Date: 2 November 1998 (02.11.98)

(30) Priority Data:
60/066,021 14 November 1997 (14.11.97) US

(71) Applicant (*for all designated States except US*): TEKTRONIX, INC. [US/US]; 14150 S.W. Karl Braun Drive, Mail Stop 50–LAW, P.O. Box 500, Beaverton, OR 97077 (US).

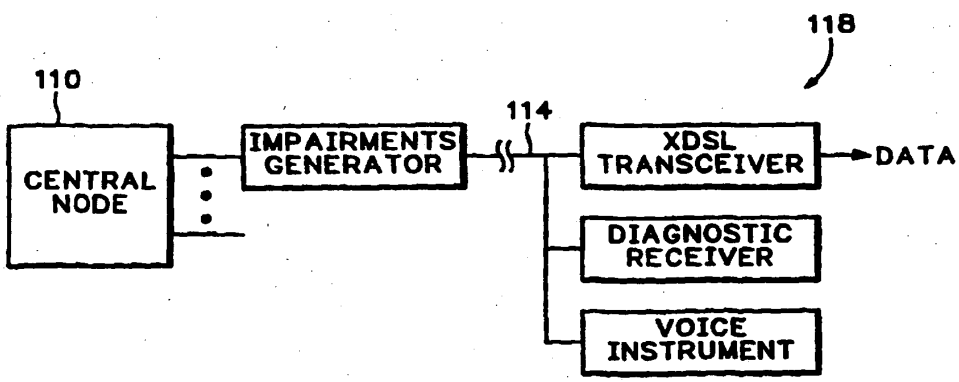
(72) Inventor; and
(75) Inventor/Applicant (*for US only*): HAKANSON, Eric, W. [US/US]; 12190 N.W. Welsh Drive, Portland, OR 97229 (US).

(74) Agent: BUCHER, William, K.; Tektronix, Inc., Mail Stop 50–LAW, P.O. Box 500, Beaverton, OR 97077 (US).

(81) Designated States: CA, CN, KR, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: METHOD OF OPERATING A DIGITAL DATA DISTRIBUTION NETWORK



(57) Abstract

Digital data in error protected packets is used to modulate a carrier and the modulated carrier is impressed on a digital data distribution network for transmission to a receiver over a transmission path. In order to monitor operation of the data distribution network, the transmission path is impaired to a selected extent upstream of a transmission path segment that is to be tested and an error protected data packet is transmitted over the transmission path to the receiver. A determination is made at the receiver whether the received data packet is error free, and, if not, a message is transmitted from the receiver to the transmitter.

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METHOD OF OPERATING A DIGITAL DATA DISTRIBUTION NETWORK

Background of the Invention

This invention relates to method of operating a digital data distribution network.

In a conventional cable television system, a video information signal in analog form, such as the NTSC composite video signal, is employed to modulate the RF carrier of an assigned RF transmission frequency channel at the system headend and the RF signal is distributed over a cable network to multiple subscriber nodes. At a subscriber node there may be a cable-ready television receiver including a tuner which can select the frequency channel and a detector which recovers the video information signal from the selected channel and employs it to control operation of the television display.

A data distribution system in which the information signal is transmitted in digital form has well known advantages over a system in which the information signal is transmitted in analog form. Accordingly, it has been proposed by the United States Federal Communications Commission (FCC) that terrestrial transmission systems under the jurisdiction of the FCC should phase out use of the NTSC composite video signal by 2007 and should instead use digital video information signals to modulate RF carriers. The digital video information signal provided by a video signal source will then be composed of a succession of bits segregated into digital data packets. The data packets modulate an RF carrier which is broadcast from the transmitter. Each period of the RF carrier conveys several bits of the digital information signal in one symbol. For example, in the 64QAM modulation scheme, each symbol conveys six bits of the digital information signal. The television receiver selects the frequency channel, detects an analog information signal, converts the detected information signal to digital form and recovers the digital data packets. The digital information signal is then used to control operation of the television display.

The change in standards from analog to digital for terrestrial television transmission effectively dictates that cable television systems will also have to provide digital video signals in order for the video signals to be compatible with digital television receivers.

Referring to FIG. 1, a digital cable television system includes a digital processing interface 8 which receives a digital video information signal, such as the MPEG transport stream, and generates an error protected digital signal composed of a succession of error protected digital signal packets. The error protected digital signal is applied to a modulator 10 which employs it to modulate an RF carrier which is typically in the frequency range 50-550 MHz, although it may be higher or lower. The digitally modulated RF carrier is supplied to a transmitter 14 which impresses the signal on a propagation medium 16. In the case of a cable television system, the propagation medium is a network of coaxial cables configured as a trunk extending from the transmitter 14 and having numerous branches connected to the trunk by directional couplers 18, sub-branches connected to the branches by directional couplers, and so on, and connected at the subscriber nodes to digital television receivers 20.

Each receiver 20 has a front end 22 including a tuner (not shown) which converts the RF signal to intermediate frequency and an analog-to-digital converter (ADC) 26 which digitizes the IF signal and provides a digital output signal to a demodulator 30. The demodulator 30 removes the IF component and provides a digital output signal, which, ideally, should match the error protected digital signal provided to the modulator 10. The receiver front end 22 also includes a digital processing circuit 32 which carries out the inverse of the error protection algorithm employed at the headend and ideally provides at its output a digital video information signal which matches the signal supplied to the digital processing interface 8. The digital video information signal from the digital processing circuit 32 is supplied through a decoder (not shown) which the MPEG transport stream and supplies an analog video signal to display circuitry 34 to control operation of the television display.

Error protection is employed in the digital cable television system to allow correction of bit errors, i.e. incorrect values of digital 1 or digital 0, in the output signal of the demodulator 30 caused by impairments in the transmission path from the input of the modulator 10 to the output of the demodulator 30.

Provided that the bit error rate is below a critical value, known as the critical bit error rate and generally considered to be about 10^{-4} for a digital television signal, digital error correction techniques can correct the errors and provide a signal having a bit error rate that may be less than 10^{-11}, which is sometimes referred to as quasi-error free. The maximum bit error rate that can be tolerated is considered to be about 10^{-3} before error correction.

Some video signals in a cable system are transmitted in encrypted form in order to restrict their use to subscribers who have paid an additional fee, either on a periodic basis for premium channels or on a pay-per-view basis for particular programs. In this case, the digital processing interface 8 not only applies a digital error protection algorithm but also encrypts the digital video information signal, so that the digital data packets provided to the modulator 10 are error protected and encrypted. In order to decrypt the digital data packets and regenerate the analog video signal, the subscriber is provided with a set top terminal 40 which is connected between the cable system connection and the display circuitry 34, by-passing the front end 22. The set top terminal includes a tuner (not shown) an ADC 42, a demodulator 44 and a digital processing circuit 46, performing the same general functions as the front end 22, but the digital processing circuit 46 performs not only error correction to recreate the digital signal applied to the modulator 10 but also decryption in order to extract the digital video information signal supplied to the digital processing interface 8. It is expected that much of the programming distributed by digital transmission cable systems will be transmitted in encrypted form, so that a subscriber will need a set top terminal, or equivalent functionality built into the television receiver, in order to display a variety of programming.

The economic value of a cable television distribution system resides in its ability to distribute video payload, i.e. the program material that subscribers wish to view, to a large number of subscribers without excessive degradation. The system operator derives revenue based on the system's ability to distribute the video payload. Accordingly, it is important that the system operator be warned of impairments in the distribution system, so that these impairments can be corrected before they adversely affect the ability of the system to distribute video payload and hence the revenue derived by the system operator. The operator must therefore be able to measure impairments in transmission quality so that appropriate repairs can be made. Typical impairments that should be detected and repaired are reductions in signal-to-noise ratio (SNR), e.g. due to noise being coupled into the transmission channel, reductions in frequency response, reductions in phase response, phase noise, jitter, addition of interfering signals and addition of multipath signals.

Hitherto, it has been suggested that the bit error rate of an RF digital transmission system may be a satisfactory measure of transmission channel quality, but this measure is subject to disadvantage because an RF data distribution system in which the information signal is digital is subject to the "cliff effect," in that the curve that relates bit error rate to the quality of the transmission channel, expressed as signal-to-noise ratio, has a very steep drop off. Thus, referring to FIG. 2, a change of less than 1.5 dB in signal-to-noise ratio can cause the bit error rate to change from less than 10^{-4} to more than 10^{-3}. The curves shown in FIG. 2 assume that the only impairment is noise when in fact there will always be other impairments, which can make the drop off even steeper. Accordingly, the system operator is not alerted to impairment of the transmission quality of the channel either by BER measurements or by a relatively small increase in subscriber complaints. On the contrary, the operator may not learn of an impairment until the system fails. This makes it difficult to monitor the noise margin in the system, to track degradations and fix degradations before a system failure.

In a report issued by the European Telecommunications Standards Institute (ETR 290: May 1997), it is suggested that the estimated noise margin is a better indicator of transmission channel quality than bit error rate. The estimated noise margin is based on the probability of mathematically added noise causing a bit error and is approximately the difference between the current estimated signal-to-noise ratio and the estimated signal-to-noise ratio at which the bit error rate exceeds the critical bit error rate. Use of the estimated noise margin to identify impairments is subject to disadvantage because it is computationally expensive and is not applicable to impairments other than noise. Further, its reliability is limited because there is an unknown set of errors associated with calculating the estimated noise margin. Since the estimated noise margin is not the same as the actual noise margin, there is a possibility that the current signal-to-noise ratio is substantially less than the estimated signal-to-noise ratio, and consequently the actual noise margin may be substantially less than the estimated noise margin. It would therefore be desirable to determine the actual noise margin of the transmission channel.

Summary of the Invention

In accordance with a first aspect of the invention there is provided a method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate at least one carrier and impressing the modulated carrier on the network, said method comprising (a) generating an error protected data packet for transmission over the transmission path, (b) impairing the transmission path to a selected extent upstream of a transmission path segment that is to be tested, (c) transmitting the data packet over the transmission path, (d) receiving the data packet at the receiver, and (e) determining whether the received data packet is error free.

In accordance with a second aspect of the invention there is provided a method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate at least one carrier and impressing the modulated carrier on the network, said method comprising (a) generating an error protected data packet for transmission over the transmission path, (b) transmitting the data packet over the transmission path as an analog signal, (c) receiving the analog signal at the receiver, (d) recording the analog signal received at the receiver, and (e) transmitting the record of the analog signal to a remote location for analysis.

In accordance with a third aspect of the invention there is provided a method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate at least one carrier and impressing the modulated carrier on the network, said method comprising generating an error protected data packet for transmission over the transmission path, impairing the transmission path to a selected extent upstream of a transmission path segment that is to be tested, transmitting the data packet over the transmission path, receiving the data packet at the receiver, and counting bit errors in the received data packet.

In accordance with a fourth aspect of the invention there is provided a method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate a carrier and impressing the modulated carrier on the network, said method comprising (a) generating an error protected data packet for transmission over the transmission path, (b) impairing the transmission path to a selected extent upstream of a transmission path segment that is to be tested, (c) transmitting the data packet over the transmission path as an analog signal, and (d) receiving the analog signal at the receiver.

Brief Description of the Drawings

For a better understanding of the invention, and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which

FIG. 1 is a partial schematic block diagram of a proposed form of cable television system,

FIG. 2 is a graph illustrating bit error rate as a function of signal-to-noise ratio in a digital data communication system.

FIG. 3 is a partial schematic block diagram of the headend and receiver in a cable television system embodying the present invention,

FIG. 4 is a map of part of a cable television system, and

FIG. 5 is a partial schematic block diagram of a digital subscriber line system.

Detailed Description

A first application of the invention will be described with reference to a digital cable television system.

The cable TV system shown in FIGS. 3 and 4 is used to distribute digital video information signals from a headend 48 to subscriber nodes 50. Referring to FIG. 3, the headend 48 includes a digital processing interface 8, a modulator 10 and a transmitter 14 similar to the corresponding elements shown in FIG. 1. The digital processing interface receives the MPEG 2 transport stream and performs various operations, including energy dispersal, error protection, interleaving and base band shaping in order to generate inphase and quadrature signals which are applied to the modulator 10. All the functions of the digital processing interface, and possibly also the functions of the modulator, may be performed in a single integrated circuit. In addition, the headend 48 includes an impairments generator 60. The impairments generator 60 may be located between the transmitter 14 and the cable network 16, as shown in FIG. 3, or it may be incorporated in the digital processing interface 8 or the modulator 10. The effect of the impairments generator 60 is to degrade to a selectively controllable extent the quality of the transmission path between the digital processing interface 8 and the subscriber nodes 50. The impairments generator may function by adding noise to the transmission channel or degrading the frequency response or phase response of the transmission channel. Further, the impairments generator may introduce "spurs" (spurious modulation products) and phase noise or jitter. The manner in which the impairments can be applied to the transmission channel is well known to those skilled in the art. Considering, for example, the signal-to-noise ratio, the quality of the channel may be degraded at the headend using an impairments generator that couples noise into the transmission channel. The extent to which the signal-to-noise ratio is degraded depends on the amplitude of the noise.

As shown in FIG. 4, the cable network 16 includes a trunk extending from the headend 48. Branches and sub-branches are connected to the trunk by directional couplers 18. Each subscriber node 50 is at the end of a branch or sub-branch. The cable system operator maintains a map of the cable network, showing schematically the topology of the path to each subscriber node 50. At each active subscriber node 50, there is a diagnostic cable receiver 64 (FIG. 3) connected between the cable network and the display circuitry 34 of the subscriber's digital television receiver. The cable receiver 64 may be implemented as a set top terminal or it may be housed in the same cabinet as the digital television receiver. Each cable receiver has a unique ID and the cable system operator maintains a database relating cable receiver IDs with the subscriber nodes and billing addresses. If the database also relates the cable receiver IDs with physical addresses, the system operator is able to determine not only the physical location of each cable receiver but also the topology of the path between the headend and each cable receiver.

Referring to FIG. 3, the cable receiver 64 includes a tuner (not shown) for converting the received signal to the intermediate frequency, an ADC 66, a demodulator 68, a digital processing circuit 70 and a decoder (not shown), similarly to the set top terminal 40 described with reference to FIG. 1. A controller 74 included in the cable receiver controls operation of the other components of the cable receiver 64.

The capabilities of the digital processing circuit 70 are expanded relative to those of the digital processing circuit 46. The digital processing circuit 70 has a video data output for supplying the MPEG transport stream to the decoder, which supplies an analog video signal to the display circuitry 34 of the digital television receiver. The digital processing circuit 70 includes an error bits counter which accumulates the number of error bits in the received signal. The error bits counter can be queried by the controller 74 and reset from time to time, so that the controller is able to calculate the bit error rate based on the error bit count and the time that has elapsed since the counter was reset. The controller 74 supplies a digital data word representing the calculated value of the bit error rate to a digital processing interface 76, which produces an error protected data packet.

The cable receiver 64 also includes a memory 80 which can be enabled to store the output signal of the ADC 66 during a selected interval. The stored digital signal is applied to the digital processing interface 76 to generate an error protected data packet. The error protected data packet produced by the digital processing circuit 76, either from the bit error rate word or from the signal provided by the memory 80, is supplied to a modulator 82. The modulator 82 uses the error protected data packet to modulate an RF carrier, typically at a frequency in the range 5-50 MHz, although it may be higher or lower. The modulated RF signal is applied to a transmitter 84 which impresses the signal on the cable network.

The headend 48 of the cable system also includes a receiver 90 for receiving the return messages provided by the transmitter 84 in each of the cable receivers 64. The receiver 90 includes a tuner (not shown), an ADC 92 which digitizes the return message signal, a demodulator 94 which removes the IF component and provides a digital output signal which, ideally, should match the error protected return message packet provided by the digital processing interface 76, a digital processing circuit 96 which carries out the inverse of the error protection algorithm employed in the digital processing interface 76 and ideally provides at its output a data signal which matches the input signal provided to the digital processing interface 76, and a report/display device 98. It will be understood that the headend includes a controller (not shown) for controlling operation of the various components thereof.

In a first mode of operation of the cable television system shown in FIG. 3, the system is used to measure the bit error rate of the transmission channel to each of the subscriber nodes. In this mode of operation, the headend controller issues a signal which is transmitted to the cable receivers, instructing the cable receivers to calculate bit error rate during a selected measurement interval, which may be defined by reference to start and stop flags included in the data stream or by reference to specific start and stop times supplied to the cable receivers by the headend.

During the measurement interval, the controller 74 calculates the bit error rate and provides an output word representative thereof. The calculated bit error rate is reported back to the headend with the cable receiver ID and a report or display is generated. The report/display device may accumulate information received from numerous cable receivers 64 and generate a report or display showing trends in bit error rate with time.

Alternatively, or in addition, the report/display device may generate a report or display showing bit error rate as a function of the locations of the cable receivers in the cable network, for example. The system operator is thereby able to determine, on a node-by-node basis, the bit error rates of the signal propagation paths between the transmitter 14 and the subscriber nodes. By comparing the bit error rates reported by different cable receivers, the cable system operator may be able to determine the location in the cable network of a particular impairment. For example, referring to FIG. 4, if the cable receivers at nodes 50C and 50D have poor transmission margin compared to the terminals at nodes 50A, 50B, 50E and 50F, indicated by high bit error rate, then it is likely that there is an impairment between the directional couplers 18_2 and $18_{2,1}$.

It will be appreciated that a test of this nature will generate a response message from each cable receiver, and accordingly it may be advantageous to instruct only selected cable receivers to calculate the bit error rate and provide return messages.

As noted previously, the bit error rate of the propagation path may be of limited value for monitoring degradation of the transmission quality, and it may be better to measure noise margin.

In order to measure the noise margin, i.e. the difference between the current signal-to-noise ratio and the SNR at which the bit error rate exceeds the critical bit error rate, the headend controller instructs the cable receivers (or a selected group of cable receivers) to report when the bit error rate calculated by the controller 74 exceeds the critical bit error rate. The headend controller operates the impairments generator 60 to add a noise impairment to the signal emitted by the transmitter. The noise amplitude is progressively increased, for example in stair-step fashion. In each of the cable receivers addressed by the headend controller, the controller 74 provides an output indicating the bit error rate. When the bit error rate at a given cable receiver 64 without addition of the noise impairment is sufficiently low, and the bit error rate with addition of the noise impairment exceeds the critical bit error rate, the level of impairment introduced by the impairments generator is approximately equal to the noise margin for the transmission channel from the transmitter 14 to that cable receiver. (If the impairments generator were upstream of the transmitter, the level of impairment introduced by the impairments generator would be related to the noise margin for the segment of the transmission path between the impairments generator and the cable receiver.) The cable receiver reports that the critical bit error rate has been exceeded, and includes its ID in the report. The cable system operator is thereby able to determine the noise margin to critical bit error rate on a node-by-node basis by correlating the cable receiver IDs with the level of impairment at which each cable receiver provides a report. It is, of course, necessary to correlate the report that the critical bit error rate has been exceeded with the noise level at which the report was generated. This may be accomplished by including framing bits in the signal transmitted by the head end in the event that the cable receiver reports immediately that the critical bit error rate has been exceeded. Alternatively, the headend controller may maintain a log recording level of impairment as a function of time and the report could include a time stamp indicating the time at which the critical bit error rate was exceeded.

It may be helpful in locating system impairments in the system shown in FIG. 3, to apply an impairment to the transmission channel and observe the effect of that impairment at multiple locations simultaneously.

If there is an impairment in the trunk of the cable network or in a major branch, it is likely that many cable receivers will respond to the stair-step type of impairment and the reverse transmission system would become jammed by the message storm. This can be avoided by testing all cable receivers at relatively short intervals, with a small level of impairment. Appropriate selection of the level of impairment should ensure that relatively few cable receivers will report a malfunction or failure condition. If this indeed occurs, the operator then has confidence that the transmission channel has a reasonable margin. If there is an unexpectedly large number of return messages, the headend controller may broadcast a message to all cable receivers instructing them not to send error information but to reset and measure again. The headend then repeats the test with a lower level of impairment in order to locate the regions of the network for which the noise margin is smallest. At longer intervals, e.g. daily or monthly, the operator tests all cable receivers with a stair-step sequence of impairments preceded by a message that the cable receivers should report the result of the test only when polled. The headend then polls the cable receivers and the cable receivers respond to the poll by reporting the actual transmission margin. The polling is best done during an idle period, so as not to interfere with revenue generating transmissions. Since the transmission margin from the headend to each cable receiver can be inexpensively monitored, the problem of locating an impairment in the cable network is greatly simplified.

If multiple impairments exist, it can be difficult to locate the impairment responsible for a failure condition. For example, referring to FIG. 4, the reduction in transmission margin downstream of an impairment in cable segment 102 may be quite small and may be swamped by another impairment upstream in the system, e.g. in cable segment 104. Alternatively, two different impairments, e.g. in cable segments 102 and 106, may cause similar reductions in transmission margin, thus leading to the erroneous conclusion that there is a single impairment in a branch that is common to the nodes 50C and 50E, e.g. cable segment 104. If the impairments are of different types, e.g. noise and jitter, this problem can be solved by classifying the impairments.

In order to classify impairments, it is necessary to observe the effect of the impairments on symbols, as opposed to the bits used to encode the symbols.

Impairments can be classified by comparing the waveform of the signal received at the subscriber node with the waveform of the transmitted signal.

This is accomplished by using the memory 80 to capture the digital output signal of the ADC 66 during a test interval and transmitting the captured waveform back to the headend. The digital processing circuit 96 provides an output signal that matches the captured portion of the output signal of the ADC 66 and can be compared with the output signal of the transmitter 14 during the corresponding time interval, so that the effect of the impairments on symbols can be determined.

Alternatively, the captured sample of the waveform can be analyzed locally using a measurement instrument.

There are several ways in which impairments can be classified. One technique is to derive the error vector waveform and extract the spectrum of the error vector. The presence of various impairments, such as noise, coherent distortions and spurious modulation products, can be deduced from the spectrum of the error vector. Amplitude and phase modulation impairments can be deduced from the Hilbert Transform of the error vector waveform.

The error vector waveform is derived by subtracting the signal received at the input of the cable receiver from the transmitted signal. Typically, the cable receiver will include an equalizer downstream of the ADC, often as part of the demodulator. If the equalizer is upstream of the point at which the received signal is read for storing in the memory 80, it affects the timing of the received signal and its effect must be removed in order for the received signal waveform to reflect the condition of the transmission path. This can be accomplished by using the equalizer coefficients to create a digital filter having a transfer function that is the inverse of the transfer function of the equalizer. The error vector waveform is then generated by subtracting the output waveform of the digital filter from the transmitted waveform.

Once the impairments have been classified, a particular existing system impairment is chosen for testing. The chosen impairment might be the impairment suspected of most likely causing a reduced transmission margin. The impairments generator then adds this impairment, at a sufficient level that the combined effect of the existing system impairment and the added impairment will be greater than the level previously detected for the existing impairment. Since the normal cable receiver is not calibrated for level, and there is a potential for destructive interference between the existing system impairment and the added impairment, the new aggregate level of impairment is best measured by repeating the recording and classification process and determining by how much the level of impairment has changed. If addition of this impairment causes a system failure report from the cable receiver at one subscriber node but not from the cable receiver at another node, it can be inferred that the two nodes are affected by different impairments.

If multiple similar impairments exist simultaneously, the impairments cannot be separated by classification and the problem of locating the impairments is more complex. However, if several of the diagnostic cable receivers are instructed to record the received waveform simultaneously, signal processing of the digitized waveforms can be used to extract the separate locations of the multiple similar impairments. The cable receivers can be made to measure simultaneously by means of two mechanisms. In accordance with the first mechanism, a protocol that instructs all cable receivers (possibly just all unused cable receivers or just selected cable receivers) to tune to a particular channel and stop recording when the end of a particular data packet is received can be broadcast to all (or some) cable receivers. This method can provide robust, but relatively coarse, timing. More precise time correlation can be achieved by inserting a time mark in the broadcast waveform, and suitable signal processing can then be used to align the received waveforms with the broadcast waveform. The time mark may be inserted by transmitting a message such that there will be a transition through a selected signal level, e.g. zero volts, at a selected time, typically late in a packet.

One way of extracting the separate locations of multiple impairments has two steps. First, the error vector waveform for each subscriber node is generated by subtracting the transmitted waveform from the waveform received at each node. Second, the cross-correlation function cev (X, Y) of the error vector waveforms for two subscriber nodes 50X and 50Y is derived. Error vectors that are common to the two nodes are revealed by the cross-correlation function. When computing the cross-correlation functions along the logical path of the network from an end point (such as a subscriber node) toward the transmitter, the location of the impairment can be determined when the value of the cross-correlation function becomes smaller. For example, referring again to

FIG. 4, and assuming that cev (E, F) indicates a common impairment and cev (A, F) indicates that the common impairment is missing, there must be an impairment between the logical locations of nodes 50A and 50E in the transmission path to node 50F. If cev (C, F) indicates a common impairment, the impairment must be between the nodes 50A and 50C. Since the only part of the network between nodes 50A and 50C that is in the transmission path to node 50F is the segment between the coupler 18_1 and the coupler 18_2, the impairment must be located there.

As a second example, if cev (C, D) indicates a common impairment and cev (A, D) indicates that the common impairment is missing, there must be an impairment logically located between node 50A and the coupler $18_{2,1}$. This implies that the impairment must be located between the directional coupler 18_1 and the coupler $18_{2,1}$. If cev (D, E) indicates that the common impairment is missing, the impairment is not between directional coupler 18_1 and the directional coupler 18_2, and so the impairment must be between the directional coupler 18_2 and the coupler $18_{2,1}$.

It is necessary to carry out the tests using the impairments generator with minimal disturbance to the revenue generating communication traffic. This is accomplished by adding the impairments only to selected packets or segments of data having a relatively low value with respect to the revenue generating communication traffic.

Most digital video transmission systems utilize the MPEG transport stream. The MPEG transport stream is composed of several MPEG elementary streams which are multiplexed to produce the MPEG transport stream. Stuffing bits are inserted in order to create the constant bit rate MPEG transport stream. It is important that the impairment should degrade only the stuffing bits or other non-customer (i.e. non-payload) bits. Since the impairments are added in the analog domain (in the case of the impairments generator being downstream of the transmitter), the impairments are applied to the transmitted symbols, in which several bits are encoded. Interleaving in constructing the transmitted data stream may result in a symbol containing bits derived from multiple elementary streams. Accordingly, it is necessary to detect when a symbol consists entirely of non-customer bits and degrade only those symbols. The cable receiver 64 can be instructed to pick out a degraded symbol by including a private data message in the MPEG transport stream. The message might, for example, instruct the cable receiver to pick out a numerically specified symbol after the next sync byte after the Program Clock Reference for a specified Program ID. It will be appreciated that the impairments could be added in the digital domain, e.g. in the digital processing interface 8. In this case, while the impairments are added in the digital domain, they are nevertheless a description of the desired analog waveform, so the impairments are of an analog nature.

An alternative is to include the impairment at a time when all of the payload bits are of relatively low perceived value. For example, the operator might include a special announcement simultaneously on all of the program streams contained in a single transmitted channel. The time of transmission of this announcement is chosen so that the balance between the loss of advertising revenue and the benefit of announcing the quality enhancement efforts is optimized. The announcement might indicate that the system operator is testing the network to ensure that subscribers receive the best possible quality, and thereby has some value. In either case, it is necessary to ensure that the symbol that is degraded does not contain customer bits or that the probability of causing an uncorrectable error is acceptably low.

A cable television network may be used to provide bidirectional voice communication, similarly to the public telephone network. In this case, the subscriber's telephone instrument is not connected to the public telephone network but is connected through a suitable adapter to the television cable network. The adapter digitizes the subscriber's outgoing voice message and employs it to modulate a carrier, and similarly detects and converts to analog form an incoming digitized voice message. The headend is connected to the telephone instrument of the other party to the call through another network, which might be the public telephone network or include another cable distribution system. In either case, voice messages are transmitted bidirectionally between the subscriber node and the headend over the cable network by digitizing the voice messages and modulating a carrier with the digitized voice messages. The test method described herein can be used for testing a transmission channel used for voice transmission by providing a diagnostic function in the equipment at the subscriber node. The diagnostic function may be added to the functions performed in the subscriber's telephone/cable adapter or may alternatively be provided by a separate diagnostic receiver.

Bidirectional voice transmissions tend to be bursty, but excessive latency in response may be objectionable to the user. Accordingly, test packets should only be used during transmission if they are short enough that they will not cause excessive latency. Alternatively, since voice transmissions tend to be relatively short and have a protocol for starting and finishing each transmission session, test packets may be sent when setting up a call, tearing down a call, or during idle times.

FIG. 5 illustrates schematically a public telephone network including a node 110, such as a central office or fiber node, and subscriber lines 114 extending from the central node 110 to respective subscriber nodes 118. Analog voice traffic may be carried on the lines 114. Digital data may also be transmitted over the subscriber lines. For example, the central node may be connected to an internet service provider and provide for data transmission between a subscriber node and the ISP. In accordance with an xDSL protocol, such as ADSL (asynchronous digital subscriber line), the digital data is used to modulate one or more carriers, each having a frequency outside the audio range and the digital data can then be transmitted concurrently with the analog voice traffic. In this case, the central node includes an xDSL transceiver and the subscriber node also includes an xDSL transceiver, for transmitting data between the central node and the subscriber node using the ADSL protocol.

The invention may be used to test the subscriber lines 114 to ensure that the digital data can be transmitted error free. At the subscriber node, the xDSL transceiver includes, or is provided with, a diagnostic receiver which operates similarly to the diagnostic cable receiver illustrated in FIG. 3. This provides a technique for detecting impairments in the transmission channel from the central node to individual subscriber nodes before the transmission channel is degraded to such an extent that error protected data packets cannot be recovered at the subscriber node. The other functions described with reference to FIGS. 3 and 4, such as transmission of messages to a central location and remote classification of impairments, apply to the system described with reference to FIG. 5.

In the case of data transmission, it is much simpler to include impaired packets in the transmission because data transmissions are usually bursty. By using a broadcast protocol, many subscriber lines can be tested in parallel by sending test packets to all subscriber nodes simultaneously. When testing an individual subscriber line, it is necessary to control operation of the impairments generator to ensure that the packet address will not be impaired, so that the subscriber node can correctly identify a packet intended for it. Rather, only the data inside the packet should be impaired.

It will be appreciated that the invention is not restricted to the particular embodiments that have been described, and that variations may be made therein without departing from the scope of the invention as defined in the appended claims and equivalents thereof. For example, although the description of FIGS. 3 and 4 refers to the return path from the subscriber node 50 to the headend 48 as being the cable that is used for transmission from the headend to the subscriber node, it may instead be implemented by another medium, such as the public switched telephone network.

Claims

1. A method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate at least one carrier and impressing the modulated carrier on the network, said method comprising:

(a) generating an error protected data packet for transmission over the transmission path,

(b) impairing the transmission path to a selected extent upstream of a transmission path segment that is to be tested,

(c) transmitting the data packet over the transmission path,

(d) receiving the data packet at the receiver, and

(e) determining whether the received data packet is error free.

2. A method according to claim 1, further comprising, if the transmission path is not error free, transmitting a message from the receiver to the transmitter.

3. A method according to claim 1, wherein step (c) comprises progressively increasing the extent to which the transmission path is impaired.

4. A method according to claim 1, wherein the network has a plurality of receivers and digital data is transmitted to the receivers over respective transmission paths, step (b) comprises transmitting the data packet to the receivers over the respective transmission paths, step (d) comprises receiving the data packet at each receiver, and step (e) comprises determining at each receiver whether the received data packet is error free.

5. A method according to claim 4, further comprising, if the transmission path to a selected receiver is not error

free, transmitting a message from the selected receiver to the transmitter, and analyzing messages received at the transmitter.

6. A method according to claim 4, wherein the method comprises detecting receivers that report higher than average error rates and comparing the transmission paths to the respective receivers in a manner such as to derive information from the receivers that report higher than average error rates.

7. A method according to claim 4, wherein step (c) comprises progressively increasing the extent to which the transmission path is impaired and the method further comprises:

transmitting a message from a receiver to the transmitter if the transmission path to that receiver is not error free, and

correlating messages received at the transmitter with the extent to which the transmission path is impaired.

8. A method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate at least one carrier and impressing the modulated carrier on the network, said method comprising:

(a) generating an error protected data packet for transmission over the transmission path,

(b) transmitting the data packet over the transmission path as an analog signal,

(c) receiving the analog signal at the receiver,

(d) recording the analog signal received at the receiver, and

(e) transmitting the record of the analog signal to a remote location for analysis.

9. A method according to claim 8, wherein step (e) comprises transmitting the record of the analog signal to the transmitter for analysis.

10. A method according to claim 8, wherein step (d) comprises digitizing the analog signal and the method further comprises deriving digital data from the digitized signal, forming a data packet from the digital data derived from the digitized signal, transmitting the data packet to the transmitter as an analog signal, digitizing the analog signal received at the transmitter, and processing the digitized signal at the transmitter.

11. A method according to claim 10, wherein the step of processing the digitized signal at the transmitter comprises deriving the error vector waveform for the transmission path to the receiver.

12. A method according to claim 8, wherein the network has a plurality of receivers and digital data is transmitted to the receivers over respective transmission paths, step (d) comprises digitizing the analog signal at each receiver, and the method further comprises deriving digital data from the digitized signal at each receiver, forming data packets at the respective receivers from the digital data derived from the digitized signal at each receiver, transmitting the data packets to the transmitter as analog signals, digitizing the analog signals received at the transmitter, and processing the digitized signals at the transmitter, and the step of processing the digitized signal at the transmitter comprises deriving the error vector waveforms for the transmission paths to at least first and second receivers and deriving the correlated error vector function for the transmission paths to the first and second receivers.

13. A method according to claim 8, wherein the network has a plurality of receivers and digital data is transmitted

to the receivers over respective transmission paths, and the method comprises deriving digital data from the digitized signal at each receiver, transmitting the digital data to the transmitter, and analyzing data received from multiple receivers to extract the locations of uncorrelated impairments.

14. A method according to claim 8, comprising processing the digitized signal to classify an impairment in the transmission path and testing the transmission margin of the transmission path with respect to the impairment by impairing the transmission path using that impairment.

15. A method according to claim 8, further comprising impairing the transmission path to a selected extent upstream of a transmission path segment to be tested.

16. A method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate at least one carrier and impressing the modulated carrier on the network, said method comprising:

generating an error protected data packet for transmission over the transmission path,

impairing the transmission path to a selected extent upstream of a transmission path segment that is to be tested,

transmitting the data packet over the transmission path,

receiving the data packet at the receiver, and

counting bit errors in the received data packet.

17. A method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate a carrier and

impressing the modulated carrier on the network, said method comprising:

(a) generating an error protected data packet for transmission over the transmission path,

(b) impairing the transmission path to a selected extent upstream of a transmission path segment that is to be tested,

(c) transmitting the data packet over the transmission path as an analog signal, and

(d) receiving the analog signal at the receiver.

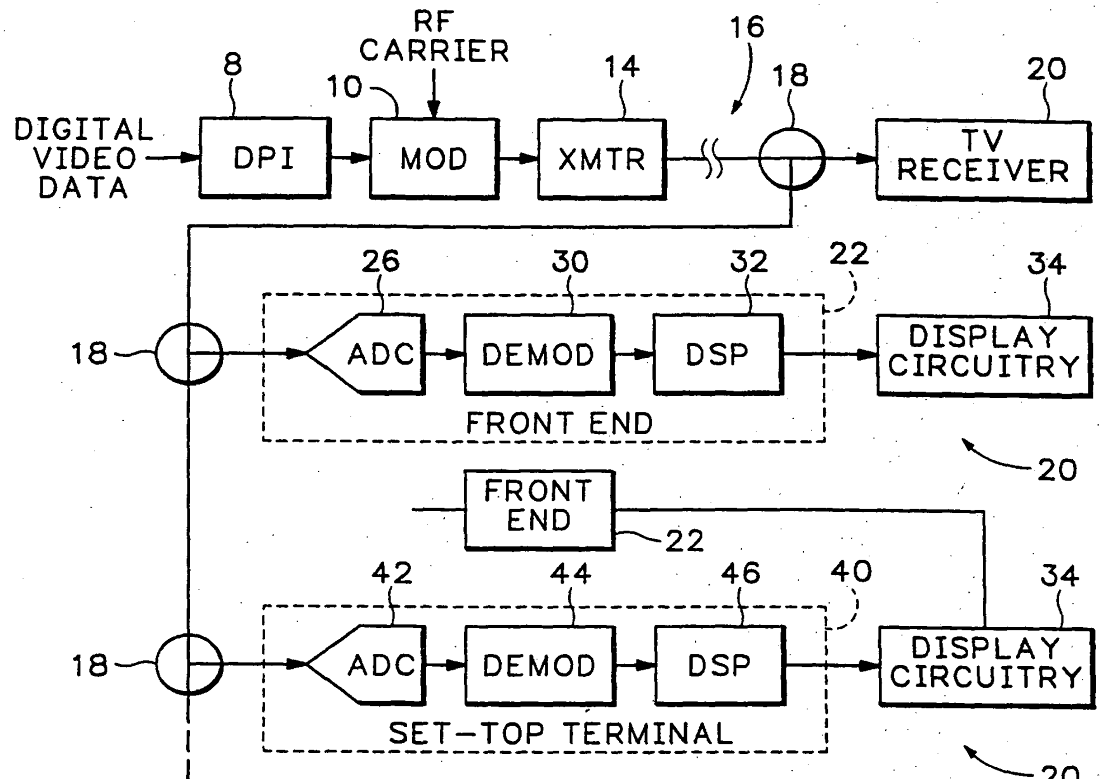
18. A method according to claim 17, wherein the step of impairing the transmission path comprises impairing the transmission path by reducing its signal-to-noise ratio.

19. A method according to claim 17, wherein the step of impairing the transmission path comprises impairing the transmission path by reducing its frequency response.

20. A method according to claim 17, wherein the step of impairing the transmission path comprises impairing the transmission path by reducing its phase response.

21. A method according to claim 17, wherein the step of impairing the transmission path comprises impairing the transmission path by reducing its impulse response.

22. A method according to claim 17, wherein the step of impairing the transmission path comprises impairing the transmission path by introducing phase noise or jitter.


RF
CARRIER
16
8
10
14
18
20
DIGITAL
VIDEO
DATA
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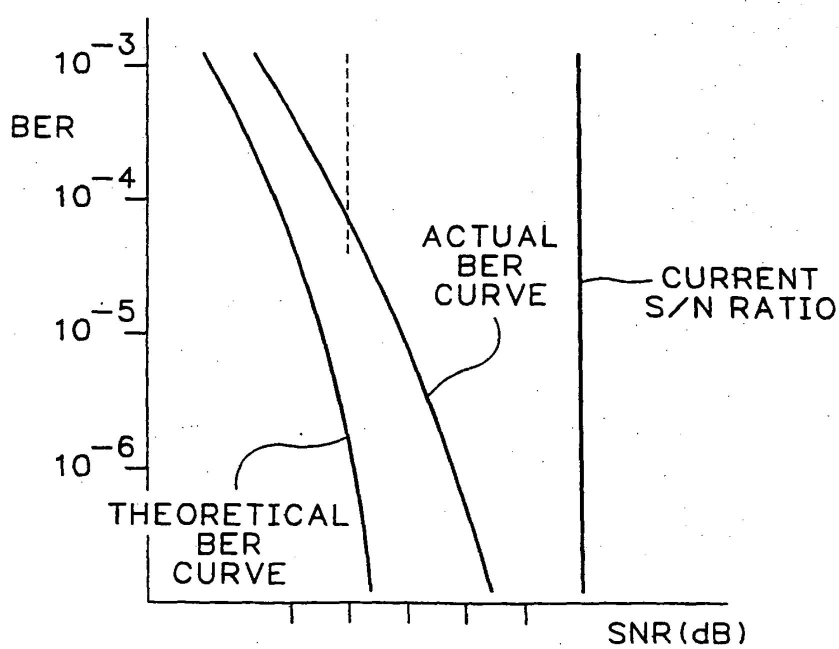
MOD
XMTR
TV
RECEIVER
26
30
32
22
34
18
ADC
DEMOD
DSP
DISPLAY
CIRCUITRY
FRONT END
20
FRONT
END
22
42
44
46
40
34
18
ADC
DEMOD
DSP
DISPLAY
CIRCUITRY
SET-TOP TERMINAL
20

FIG.1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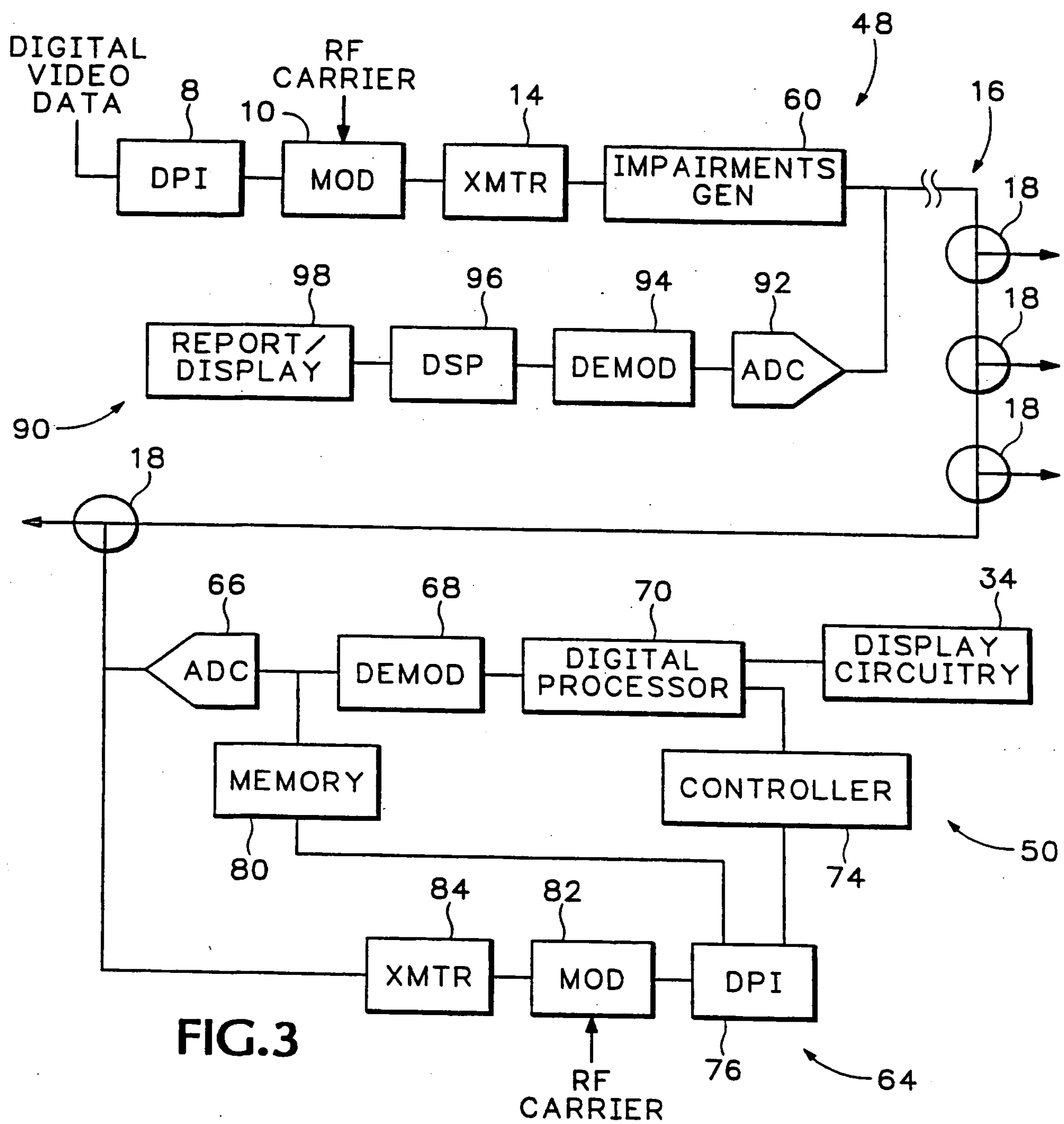
BER
10^{-4}
10^{-5}
10^{-6}
ACTUAL
BER
CURVE
CURRENT
S/N RATIO
THEORETICAL
BER
CURVE
SNR(dB)

FIG.2



DIGITAL VIDEO DATA
8
DPI
10
RF CARRIER
MOD
14
XMTR
60
IMPAIRMENTS GEN
48
16
18
18
18
98
REPORT/ DISPLAY
96
DSP
94
DEMOD
92
ADC
90
18
66
ADC
68
DEMOD
70
DIGITAL PROCESSOR
34
DISPLAY CIRCUITRY
MEMORY
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CONTROLLER
74
50
84
XMTR
82
MOD
DPI
76
RF CARRIER
64

FIG.3

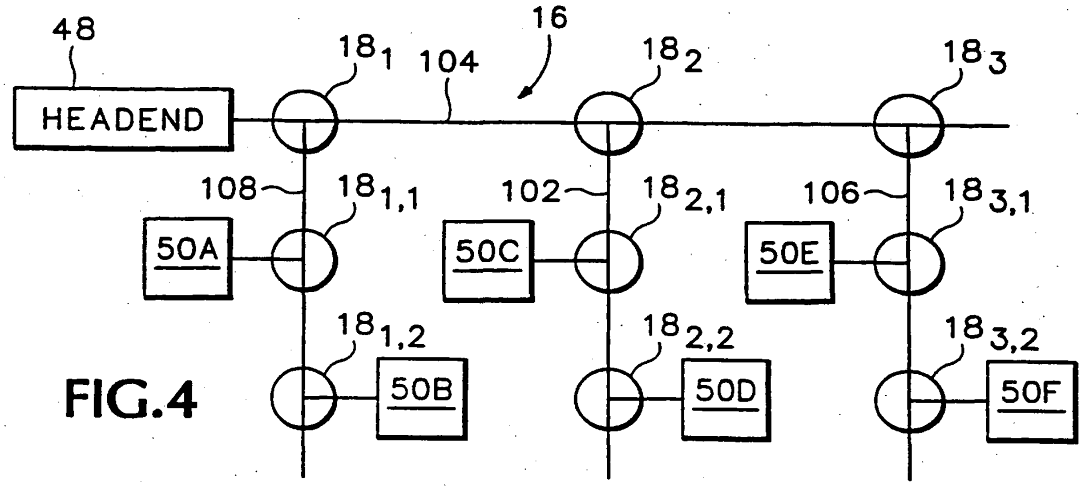

48
HEADEND
16
18_1
104
18_2
18_3
108
$18_{1,1}$
102
$18_{2,1}$
106
$18_{3,1}$
50A
50C
50E
$18_{1,2}$
$18_{2,2}$
$18_{3,2}$
50B
50D
50F

FIG.4

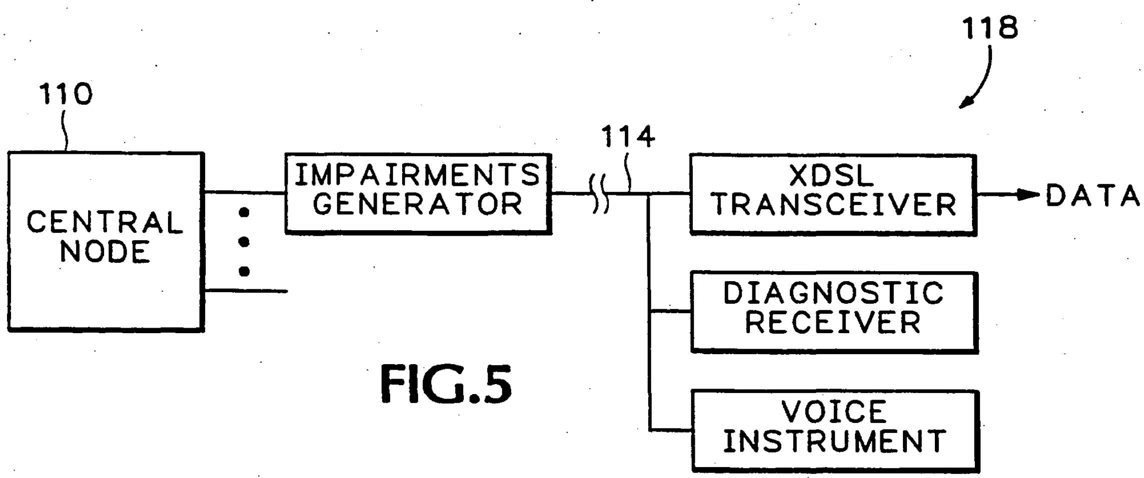

118
110
114
CENTRAL NODE
IMPAIRMENTS GENERATOR
XDSL TRANSCEIVER
DATA
DIAGNOSTIC RECEIVER
VOICE INSTRUMENT

FIG.5

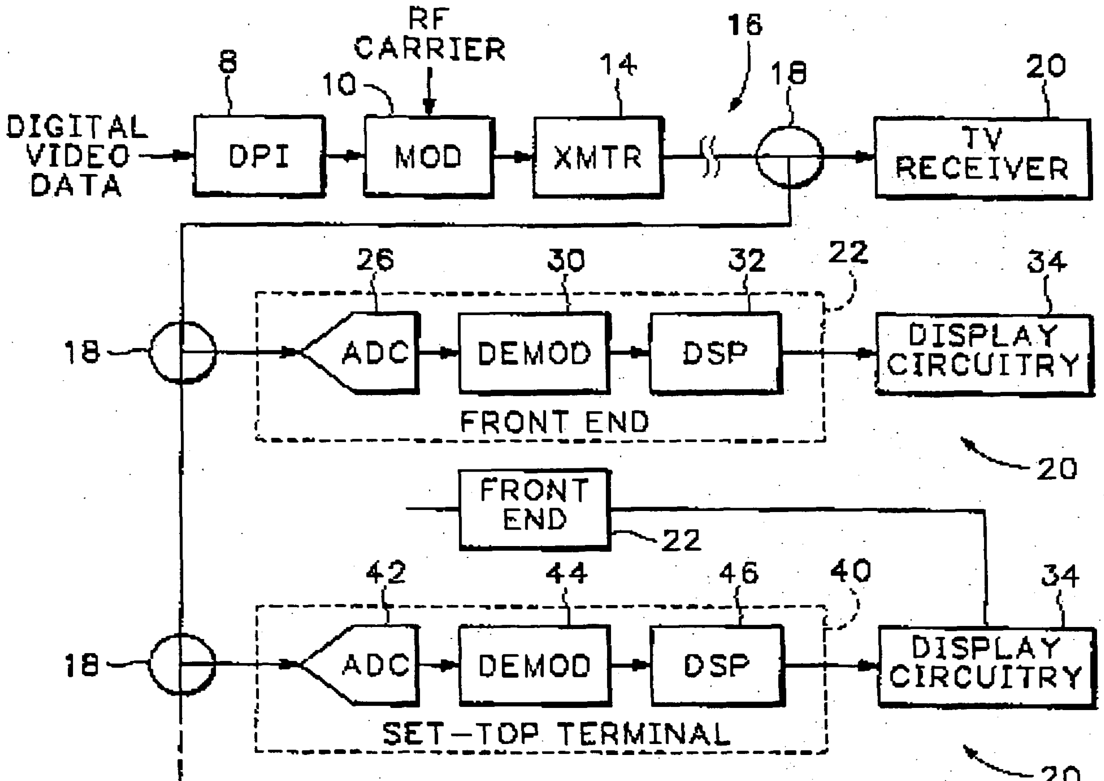
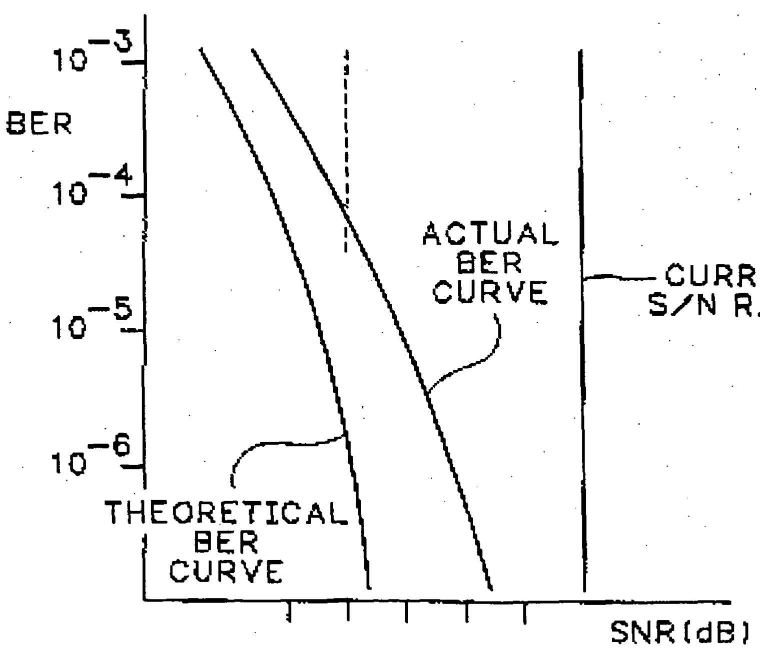

RF CARRIER
8
10
14
16
18
20
DIGITAL VIDEO DATA
DPI
MOD
XMTR
TV RECEIVER
26
30
32
22
34
18
ADC
DEMOD
DSP
DISPLAY CIRCUITRY
FRONT END
20
FRONT END
22
42
44
46
40
34
18
ADC
DEMOD
DSP
DISPLAY CIRCUITRY
SET-TOP TERMINAL
20

FIG.1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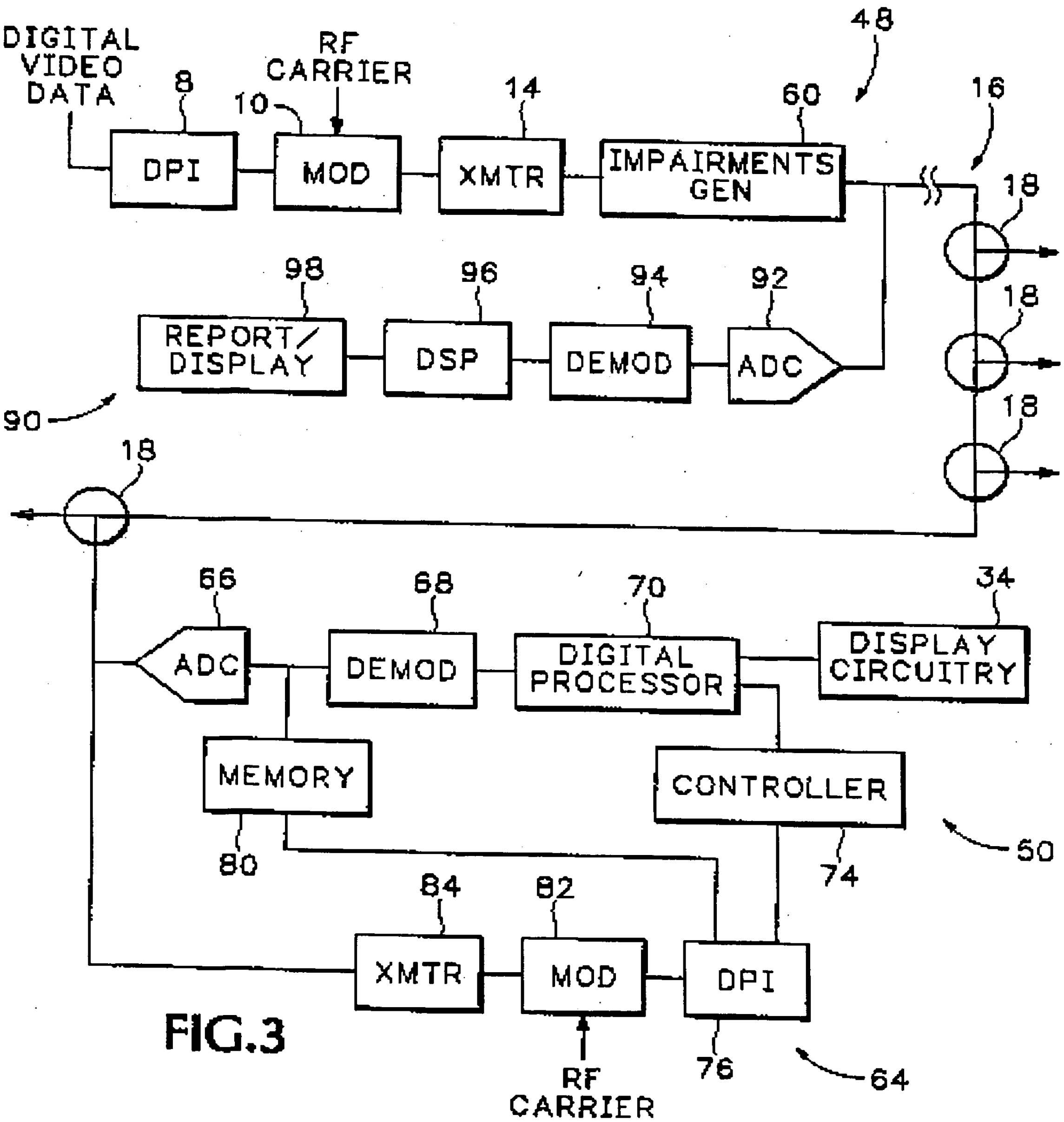
BER
10^{-4}
10^{-5}
10^{-6}
ACTUAL BER CURVE
CURRENT S/N RATIO
THEORETICAL BER CURVE
SNR(dB)

FIG.2



DIGITAL VIDEO DATA
8
DPI
10
RF CARRIER
MOD
14
XMTR
60
IMPAIRMENTS GEN
48
16
18
18
18
98
REPORT/ DISPLAY
96
DSP
94
DEMOD
92
ADC
90
18
66
ADC
68
DEMOD
70
DIGITAL PROCESSOR
34
DISPLAY CIRCUITRY
MEMORY
80
CONTROLLER
74
50
84
XMTR
82
MOD
DPI
76
64
RF CARRIER

FIG.3

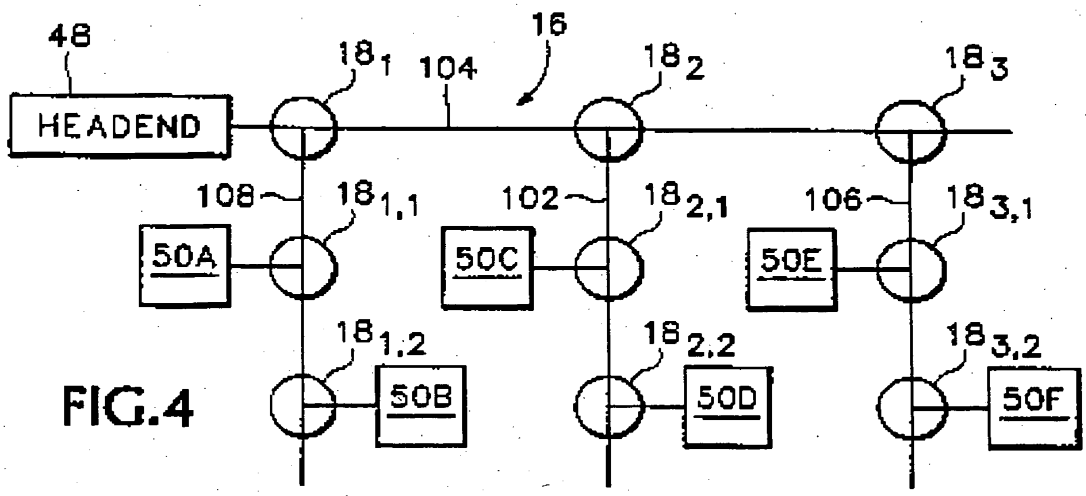

48
HEADEND
16
18 1
104
18 2
18 3
108
18 1,1
102
18 2,1
106
18 3,1
50A
50C
50E
18 1,2
18 2,2
18 3,2
50B
50D
50F

FIG.4

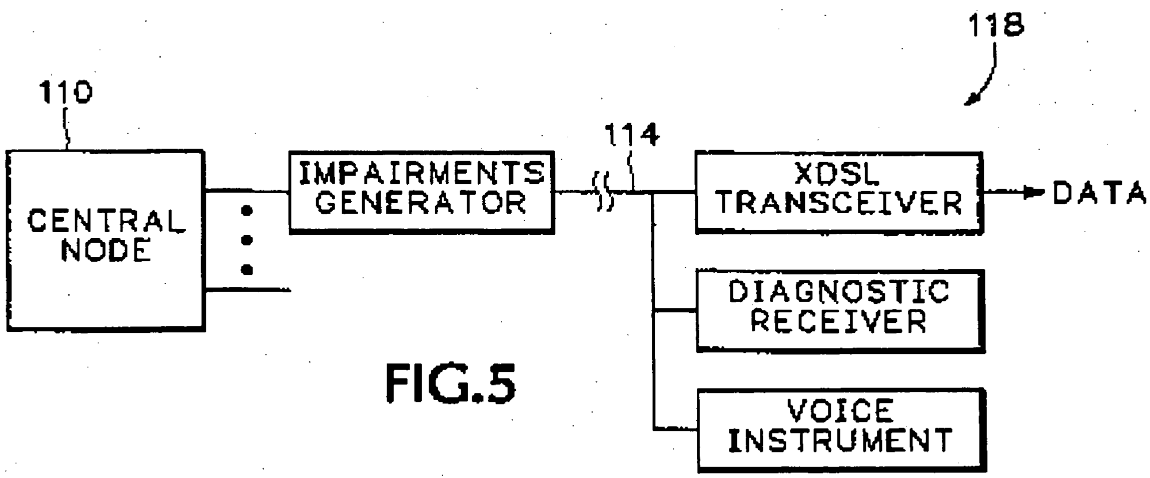

118
110
CENTRAL NODE
IMPAIRMENTS GENERATOR
114
XDSL TRANSCEIVER
DATA
DIAGNOSTIC RECEIVER
VOICE INSTRUMENT

FIG.5

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classificati n 6 : H04L 1/24, 1/14	A3	(11) International Publication Number: WO 99/26375 (43) International Publication Date: 27 May 1999 (27.05.99)

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(71) Applicant (*for all designated States except US*): TEKTRONIX, INC. [US/US]; 14150 S.W. Karl Braun Drive, Mail Stop 50-LAW, P.O. Box 500, Beaverton, OR 97077 (US).

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(74) Agent: BUCHER, William, K.; Tektronix, Inc., Mail Stop 50-LAW, P.O. Box 500, Beaverton, OR 97077 (US).

(81) Designated States: CA, CN, KR, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

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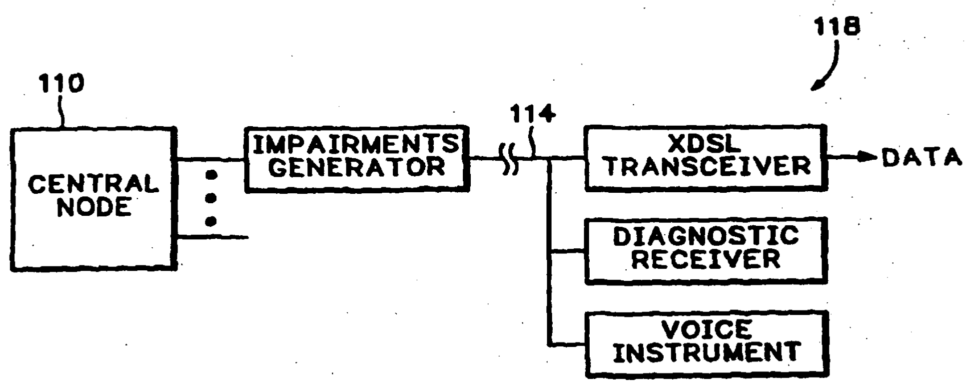
(54) Title: METHOD OF OPERATING A DIGITAL DATA DISTRIBUTION NETWORK



(57) Abstract

Digital data in error protected packets is used to modulate a carrier and the modulated carrier is impressed on a digital data distribution network for transmission to a receiver over a transmission path. In order to monitor operation of the data distribution network, the transmission path is impaired to a selected extent upstream of a transmission path segment that is to be tested and an error protected data packet is transmitted over the transmission path to the receiver. A determination is made at the receiver whether the received data packet is error free, and, if not, a message is transmitted from the receiver to the transmitter.

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/23336

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04L1/24 H04L1/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04L H04N H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 655 068 A (OPOCZYNSKI ADAM) 5 August 1997 see abstract; figure 9 see column 2, line 33 - line 58 see column 4, line 44 - line 58 see column 5, line 6 - line 22 see column 5, line 47 - line 51 see column 8, line 30 - line 42 ---	1-7, 16-18
Y	US 4 384 354 A (CRAWFORD THOMAS M ET AL) 17 May 1983 see abstract; figure 6 see column 2, line 56 - column 3, line 16 see column 4, line 36 - line 62 see column 6, line 61 - column 7, line 10 see column 7, line 14 - line 33 see column 12, line 60 - line 62 see column 13, line 19 - line 29 ---	1-7, 16-18

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
27 May 1999	09. 08. 1999

Name and mailing address of the ISA	Authorized officer
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Form PCT/ISA/210 (second sheet) (July 1992)

International Application No
PCT/U. 98/23336

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	see column 3, line 17 - line 21 see column 4, line 48 - line 51	10
A	US 5 608 728 A (MAZZA-BRENNAN CYNTHIA ET AL) 4 March 1997 see abstract see column 2, line 23 - line 49 see column 4, line 17 - line 31 see column 5, line 23 - line 32	8-14
A	EP 0 905 940 A (LUCENT TECHNOLOGIES INC) 31 March 1999 see abstract; figure 4 see column 3, line 38 - line 43 see column 4, line 23 - line 33 see column 5, line 28 - line 43	8-14
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Intern...onal application No.
PCT/US 98/23336

INTERNATIONAL SEARCH REPORT

B x I Observations wher ertain claim w re found unsearchabl (Continuation f item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-7, 16-22

   Group 1 relates to the operation of a data distribution network whereby the transmission path is impaired upstream of a segment of a transmission segment that is to be tested. Subsequently, it is determined whether transmitted error protected packets are error free.

2. Claims: 8-15

   Group 2 relates to the operation of a data distribution network whereby the receiver records the received transmitted error protected packets (analogue signal) which are then sent back to a remote location (that can be the transmitter) for analysis.

INTERNATIONAL SEARCH REPORT

Inf ation on patent family members

International Application No
PCT/US 98/23336

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(22) International Filing Date: 17 April 2000 (17.04.00)

(30) Priority Data:
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(71) Applicant: TERADYNE, INC. [US/US]; 321 Harrison Avenue, Boston, MA 02118 (US).

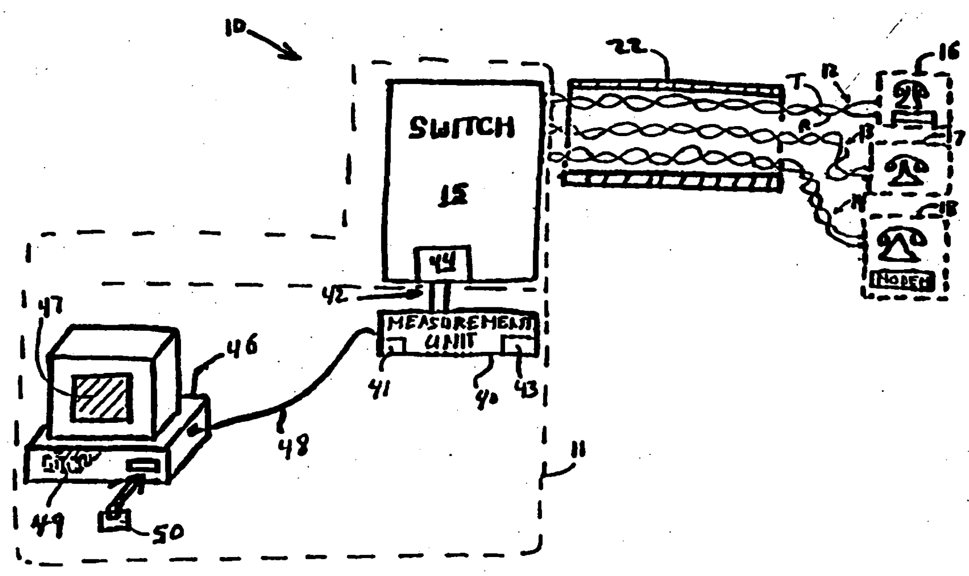
(72) Inventors: RUDINSKI, Ilia, L.; 1717 W. Crystal Lane, Mount Prospect, IL 60056 (US). SCHMIDT, Kurt, E.; 6444 W. Brever Road, Burlington, WI 53105 (US).

(74) Agent: WALSH, Edmund, J.; Teradyne, Inc., 321 Harrison Avenue, Boston, MA 02118 (US).

(81) Designated States: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: DETERMINING THE PHYSICAL STRUCTURE OF SUBSCRIBER LINES



(57) Abstract

A method determines a structure of a subscriber line. The method includes searching a reference set for a match between the subscriber line and a model line of the reference set and identifying that the subscriber line has a specific physical structure. The match is based on electrical properties of the lines. The act f identifying is responsive to finding a match with one of the model lines that has the specific physical structure.

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DETERMINING THE PHYSICAL STRUCTURE OF SUBSCRIBER LINES

This is a continuation-in-part of Application No. U.S. Application No. 09/294,563, filed April 20, 1999.

Background of the Invention

This application relates generally to communications networks, and more particularly, to determining electrical properties of multi-wire communication lines.

Recently, there has been an increased demand for the subscriber lines of plain old telephone services (POTS's) to carry high-speed digital signals. The demand has been stimulated by home access to both the Internet and distant office computers. Both types of access typically employ a POTS line as part of the path for carrying digital signals.

POTS's lines were built to carry voice signals at audible frequencies and can also carry digital signals as tone signals in the near audible frequency range. Modern digital services such as ISDN and ADSL transmit data at frequencies well above the audible range. At these higher frequencies, POTS's lines that transmit voice signals well may transmit digital signals poorly. Nevertheless, many telephone operating companies (TELCO's) would like to offer ISDN and/or ADSL data services to their subscribers.

Telephone lines between a TELCO switch and subscribers' premises are frequent sources of poor performance at the high frequencies characteristic of ISDN and ADSL transmissions. Nevertheless, high cost has made widespread replacement of these subscriber lines an undesirable solution for providing subscribers with lines capable of supporting ISDN and ADSL. A less expensive alternative would be to repair or remove only those subscriber lines that are inadequate for transmitting high-speed digital data.

To limit replacement or repair to inadequate lines, TELCO's have placed some emphasis on developing methods for predicting which subscriber lines will support data services, such as ISDN and ADSL. Some emphasis has been also placed on predicting frequency ranges at which such data services will be supported. Some methods have also been developed for finding faults in subscriber lines already supporting data services so that such faults can be repaired.

Current methods for predicting the ability of subscriber lines to support high-speed digital transmissions are typically not automated, labor intensive, and entail test access at multiple points. Often, these methods entail using skilled interpretations of high frequency measurements of line parameters to determine data transmission abilities. At a network scale, such tests are very expensive to implement.

The present invention is directed to overcoming or, at least, reducing the affects of one or more of the problems set forth above.

Summary of the Invention

In a first aspect, the invention provides a method of determining a physical structure of a subscriber line. The method includes searching a reference set for a match between the subscriber line and a model line of the reference set and identifying that the subscriber line has a specific physical structure. The match is based on electrical properties of the lines. The act of identifying is responsive to finding a match with one of the model lines that has the specific physical structure.

In a second aspect, the invention provides a method of qualifying a subscriber line for a data service. The method includes searching a reference set of model lines for a best match to a subscriber line by comparing sets of electrical properties and determining that the subscriber line has a specific physical structure. The act of determining is responsive to the best matching model line having the specific physical structure. The method also includes disqualifying the subscriber line for the data service, in part, in response to determining that the specific physical structure corresponds to a disqualified line.

In a third aspect, the invention provides a method of providing a data service. The method includes searching for a match between electrical properties of a subscriber line and a model line of a reference set and determining whether the subscriber's line is qualified for the data service. The act of determining is based in part on whether the best matching model line has one of a bridged tap and a mixture of gauges. The method also includes performing a business action in response to determining that the subscriber's line is qualified.

In a fourth aspect, the invention provides a data storage device that stores an executable program of instructions for causing a computer to perform one or more of the above-described methods.

Various embodiments use test accesses, which provide data on low frequency electrical properties of subscriber lines, to make predictions about high frequency performance.

Brief Description of the Drawings

Other features and advantages of the invention will be apparent from the following description taken together with the drawings in which:

FIG. 1 shows a portion of a POTS network having a system for detecting faults in subscriber telephone lines;

FIG. 2A shows a first measuring setup for making one-ended electrical measurements on a subscriber telephone line;

FIG. 2B is an equivalent circuit for the measuring setup of FIG. 2A;

FIG. 2C shows a second measuring setup for making one-ended electrical measurements on a subscriber telephone line;

FIG. 3 illustrates signal distortions produced by the test bus and standard voice test access;

FIG. 4 shows a split pair fault in a subscriber line;

FIG. 5 shows how a splice error can produce a split pair fault;

FIG. 6A shows a phase measurement signature of a resistive imbalance on a subscriber line;

FIG. 6B shows a phase measurement signature of a split pair fault on a subscriber line;

FIG. 7 is a flow chart illustrating a method of detecting faults on subscriber lines with the system of FIGs. 1, 4, and 5;

FIG. 8 is a flow chart illustrating a method of qualifying subscriber lines with the method of FIG. 7;

FIG. 9 shows a method of providing high speed data services using the methods of FIGs. 7 and 8;

FIG. 10A-10E show exemplary subscriber lines having different gauge mixes;

FIG. 11 shows a subscriber line with a bridged tap;

FIG. 12A-12E shows exemplary structures of subscriber lines having one bridged tap;

FIG. 13 is a flow chart for a method of determining the specific physical structure of a subscriber line from a reference set;

FIG. 14 is a flow chart for a method of finding a best match between a subscriber and model lines;

FIG. 15 is a flow chart for a method of qualifying subscriber lines; and

FIG. 16 is a flow chart for a business method of providing high-speed data services to subscribers.

FIG. 17 is a flow chart for a stacked method of detecting bridged taps using auxiliary variables;

FIG. 18A shows predicted and actual signal attenuations of nominal subscriber lines;

FIG. 18B shows predicted and actual signal attenuations of non-nominal subscriber lines;

FIG. 18C shows predicted, shifted predicted, and actual signal attenuations for an exemplary nominal subscriber line;

FIG. 19 shows an exemplary decision tree;

FIG. 20 illustrates the action of the rules of the decision tree of FIG. 19 on a set of subscriber lines;

FIG. 21 is a flow chart illustrating a method of creating the decision trees with machine learning methods; and

FIG. 22 is a flow chart for a method of determining the branching rules of the decision tree illustrated in FIGs. 19-20.

Description of the Preferred Embodiments

MEASUREMENT AND TEST APPARATUS

FIG. 1 shows a portion of a POTS network 10 that has a system 11 for detecting faults in subscriber lines 12-

14. The subscriber lines 12-14 connect subscriber units 16-18, i.e., modems and/or telephones, to a telephony switch 15. The switch 15 connects the subscriber lines 12-14 to the remainder of the telephone network 10. The switch 15 may be a POTS switch or another device, e.g., a digital subscriber loop access multiplexer (DSLAM).

Each subscriber line 12-14 consists of a standard twisted two-wire telephone line adapted to voice transmissions. The two wires are generally referred to as the ring AR@ and tip AT@ wires.

A large portion of each subscriber line 12-14 is housed in one or more standard telephone cables 22. The cable 22 carries many subscriber lines 12-14, e.g., more than a dozen, in a closely packed configuration. The close packing creates an electrical environment that changes transmission properties of the individual subscriber lines 12-14.

Electrical measurements for detecting line faults are performed by a measurement unit 40. In various embodiments, the measurement unit 40 includes one or both devices 41 and 43. Each device 41, 43 performs one-ended electrical measurements on selected lines 12-14. In preferred embodiments, the electrical measurements are one-ended. The device 41 performs measurements on tip and ring wires of a selected subscriber line 12-14 in a common mode configuration and produces results useful for detecting split pairs. The device 43 can measure admittances of the tip and ring wires of a selected line 12-14 either separately or together and produces data useful for determining the specific physical line structure. The measurement unit 40 may also house other devices (not shown) for performing other types of electrical measurements, i.e., one-ended or two-ended measurements. The measurement unit 40 couples to the switch 15 via a test bus 42.

The devices 41, 43 connect to the switch 15 through the test bus 42 and a standard voice test access 44. The voice test access 44 electrically connects either the device 41 or device 43 to the subscriber lines 12-14 selected for testing. The voice test access 44 generally transmits electrical signals with low frequencies between about 100 Hertz (Hz) and 20 kilo Hz (KHz). But, the test access 44 may transmit signals at higher frequencies, e.g., up to 100 to 300 KHz, in some switches 15.

The measurement unit 40 is controlled by computer 46, which selects the types of measurements performed, the device 41, 43 used, and the subscriber lines 12-14 to test. The computer 46 sends control signals to the measurement unit 40 via a connection 48, e.g., a line, network, or dedicated wire, and receives measurement results from the measurement unit 40 via the same connection 48.

The computer 46 contains a software program for controlling line testing by the measurement unit 40 and for detecting line conditions or faults with results from the measurement unit 40. The software program is stored, in executable form, in a data storage device 49, e.g., a hard drive or random access memory (RAM). The program may also be encoded on a readable storage medium 50, such as an optical or magnetic disk, from which the program can be executed.

To perform a test, the measurement unit 40 signals the voice test access 44 to connect the line 12-14 to be tested to wires of the bus 42 for connecting to internal devices 41, 43. Then, one or both of the internal devices 41, 43 performs electrical measurements on the selected line 12-14. After the measurements are completed, the measurement unit 40 signals the switch 15 to disconnect the line 12-14 from the wires of the bus 42.

The computer 46 can classify selected subscriber lines 12-14 prior to fully connecting the lines 12-14 for data services. The range of possible classes to which a line 12-14 can be assigned will depend on the business needs of a TELCO. A simple, but very useful set of classes is "qualified" and "disqualified" to provide data services. Qualification is based on determining, with high certainty, that a selected line 12-14 will support a specified data service. Disqualification is based on determining, with high certainty, that the selected line 12-14 will not support the specified data service.

FIG. 2A shows a first setup 52 for performing one type of one-ended electrical measurements with the device 41. The measurements are used to detect faults such as split pairs in the subscriber lines 12-14 of FIG. 1.

The device 41 has a variable frequency voltage source 54 for driving the tip and ring wires T, R of the subscriber line 12-14 under test. The voltage source drives both wires together, i.e., in a common mode configuration, at a frequency controlled by th measurement unit 40. The tip and ring wires T, R of the line 12-14 under test are connected to the device 41 via the voice test access 44.

The voltage source 54 connects to one side of resistors R_1 and R_2. The second side of resistors R_1 and R_2 connect to the respective tip and ring wires T, R of the subscriber line 12-14 under test. Thus, the voltage source 54 drives the tip and ring wires T, R in common mode through the corresponding resistors R_1 and R_2.

The resistors R_1 and R_2 have equal resistances so that the voltage source 54 induces equal voltages V_1, V_2 between each resistor R_1, R_2 and ground if the currents I_T, I_R therein are also equal. Differences in the input impedances Z_T, Z_R of the tip and ring wires T, R make the voltages V_1, V_2 differ in amplitude and/or phase. For example, mutual inductance effects produced by a split pair can make the input impedances Z_T, Z_R unequal.

Voltmeters VM_1 and VM_2 measure amplitudes and phases of voltages V_1 and V_2, respectively. From measurements of the voltmeters VM_1 and VM_2, the computer 46 can obtain the phase difference between V_1 and V_2.

FIG. 2B shows an equivalent circuit 55 for the measurement setup 52 of FIG. 4. In the common mode configuration, the tip and ring wires T, R act as elements of independent circuits 56, 57 that connect the voltage source 54 to a common ground 58. The tip wire T is equivalent to an impedance Z_T in the circuit 56, and the ring wire R is equivalent to an impedance Z_R in the circuit 57.

The input impedances Z_T and Z_R may have different amplitudes and/or phases due to the presence of a fault on either the tip or ring wires T, R. Different values for Z_T and Z_R produce different currents I_T and I_R in the circuits 56 and 57 and different measured voltages V_1 and V_2. The phase of the voltage difference $V_1 - V_2$ is proportional to the phase difference between the input impedances of the tip and ring wires T, R. In the phase of the difference $V_1 - V_2$, termination effects associated with the attached subscriber unit 16 can largely be ignored.

FIG. 2C shows a measuring setup 60 for performing one-ended electrical measurements on a selected subscriber line 12-14 with the device 43 shown in FIG 1. The device 43 measures electrical properties, which can be used to determine the specific physical structure of the lines 12-14 and to determine line conditions and faults as is described below. Some methods for detecting line faults and conditions with the device 43 have been described in

U.S. Application No. 09/294,563 ('563), filed April 20, 1999. The '563 application is incorporated herein, by reference, in its entirety.

The device 43 is adapted to measure admittances between the tip wire T, ring wire R, and ground G for a subscriber line 12-14 being tested. The tip and ring wires T, R of the line 12-14 being tested couple to driving voltages V_1' and V_2' through known conductances G_t and G_r. The tip and ring wires T, R also connect to voltmeters V_t and V_r. The V_t and V_r voltmeters read the voltage between the tip wire T and ground G and between the ring wire R and ground G, respectively. The readings from the voltmeters V_t and V_r enable the computer 46 to determine three admittances Y_{tg}, Y_{tr}, and Y_{rg} between the pairs tip-ground, tip-ring, and ring-ground, respectively. The device 43 can measure the admittances at preselected frequencies in the range supported by the voice test access 44. The '563 application has described methods for performing such measurements.

Referring to FIG. 3, the computer 46 may compensate for signal distortions introduced by the test bus 42 and/or the voice test access 44. To perform compensation, the computer 46 treats the two lines of the combined bus 42 and test access 44 as a linear two port systems. Then, the currents and voltages I_T', V_T' and I_R', V_R' at the output terminals of the measurement device 40 are related to the currents and voltages I_T, V_T and I_R, V_R on the output terminals of the tip and ring wires T, R by the following 2x2 matrix equations:

$[I_T, V_T] = A(f)\ [I_T', V_T']^t$ and $[I_T, V_T] = A'(f)\ [I_R', V_R']^t$.

The frequency dependent matrices A(f) and A'(f) are determined experimentally for each bus 42 and voice test access 44. Then, the computer 46 calculates the impedances or admittances of the tip and ring wires T, R with the currents and voltages I_T, V_T and I_R, V_R obtained from the above equations.

The measurement unit 40 and computer 46 can detect faults such as split pairs, resistive imbalances, metallic faults, load coils, bridged taps, gauge mixtures, and high signal attenuations. Co-pending U.S. Patent Application 09/285,954 ('954), filed April 2, 1999, describes the detection of some of these faults and is incorporated herein by reference in its entirety.

SPLIT PAIRS

Referring again to FIG. 1, close proximity can inductively produce cross talk between the subscriber lines 12-14. Cross talk is frequently caused by large noise or ringing signals on one of the lines 12-14. The large signal inductively produces signals on nearby lines 12-14. To reduce cross talk, the tip and ring wires T, R of each subscriber line 12-14 are either tightly twisted together or kept in close proximity in the cable 22. In this way, stray signals affect both wires of a pair so that induced signals do not impact the difference signal between the tip and ring wires.

Referring to FIG. 4, the tip and ring wires T', R' of a subscriber line 24 are separated spatially in a portion of cable 26. The portion of the subscriber line 24 in which the tip and ring wires T', R' are spatially separated is referred to as a split pair. A split pair T', R' has a high risk of picking up cross talk other lines 28-29 in the same cable 26 or external noise sources such as power lines (not shown).

Split pairs also introduce impedance discontinuities into subscriber lines, because the split pair creates a localized and abrupt impedance variation. Impedance discontinuities can cause signal reflections and high signal attenuations for high-speed digital transmissions.

FIG. 5 illustrates one type of split pair, i.e., a split pair caused by a splice error. The splice error occurred when two portions of a subscriber line 32, which are located in two different cables 33, 34, were joined. The splice 35 has joined tip and ring wires T_1, R_2 from two different twisted pair lines 36, 37 in the cable 33 to tip and ring wires T_3, R_3 of a single twisted pair 38 in the adjacent cable 34. The tip and ring wires T_1, R_2 of the portion of the subscriber line 32 are widely separated in a substantial portion of the cable 33. Thus, the tip and ring wires T_1, R_2 form a split pair.

Detection of split pair faults is difficult for several reasons. First, split pairs do not produce easily detected effects such as metallic faults, i.e., broken wires or shorted wires, or impedance imbalances. Second, split pairs produce cross talk that produce intermittent faults depending on the signals on nearby lines, e.g., intermittent ringing signals. The intermittency makes such faults difficult to recognize.

Conventional tests have not been very successful in detecting split pairs. Nevertheless, split pairs can degrade the quality of a subscriber line for high-speed data services.

FIG. 6A and 6B provide graphs 68, 69 of the phase of the voltage difference $V_1 - V_2$ between resistors R_1 and R_2 while testing two exemplary subscriber lines 12-14 with the measurement setup 52 of FIG. 4. The graphs 68, 69 provide frequency sweeps of the phase difference, which show signatures of faults that can interfere with high-speed data services, e.g., ISDN or ADSL.

Referring to FIG. 6A, the graph 68 shows a signature for a resistive imbalance fault on the tested subscriber line 12-14. The signature for a resistive imbalance is a pronounced peak in the phase of the voltage difference $V_1 - V_2$. The peak appears in the phase difference between impedances of the tip and ring wires. The peak has a narrow width that is typically not more than a few hundred to about 2 KHz. Typically, the phase has a height of greater than about 5°.

Referring to FIG. 6B, the graph 69 shows a signature for a split pair fault on the tested subscriber line 12-14. The signature is a flat and substantially constant phase for $V_1 - V_2$, i.e., a substantially constant non-zero phase difference between the input impedances Z_T, Z_R of the wires T, R. Typically, the phase has a value of between about .5° and 1.5°. The nonzero and flat phase extends over a region of frequencies having a width of at least 5,000 kilo Hz. The phase of Z_T and Z_R may remain flat, nonzero, and peakless from about 100 Hz to about 20,000 Hz if a split pair is present, i.e., over the frequency range measurable through the voice test access 44, shown in FIG. 1. A nonzero and substantially frequency independent phase difference between the input impedances Z_T, Z_R of the tip and ring wires is a signature for a split pair on the subscriber line 12-14 being tested.

FIG. 7 is a flow chart illustrating a method 70 of detecting a fault in the subscriber lines 12-14 with the system 11 of FIG. 1. The computer 46 selects the subscriber line 12-14 to test for faults (step 72). The measurement unit 40 electrically connects to the selected line 12-14 via the voice test access 44 of the TELCO switch 15 (step 74). The connection produces the measurement setup 52 illustrated in FIGs. 4 and 5.

The measurement unit 40 performs one-ended electrical measurements to determine a signal proportional to the phase difference of the input impedances Z_T, Z_R of the tip and ring wires of the selected line 12-14 (step 76). The quantity actually measured is the phase of $V_1 - V_2$, which is proportional to the phase of the difference of the input impedances Z_T, Z_R. The device 41 measures the phase by driving the tip and ring wires in the common mode configuration shown in FIG. 4. The driving frequencies are between about 100 Hz to 20,000 kilo Hz and accessible via the voice test access 44. Such frequencies are very low compared to transmission frequencies of high-speed data services such as ISDN and ADSL.

The computer 46 analyzes the measurements of the phase as a function of frequency to determine whether the phase has a signature for a line fault (step 78). The line faults that produce signatures in the phase include split pairs and resistance imbalances as described above in relation to FIGs. 6B and 6A, respectively. Other signatures are possible, e.g., for other types of faults. If a signature for a line fault is found, the computer 46 identifies that a fault has been detected (step 80). The identification may entail making a reporting act. The reporting act may include making an entry in a file that lists the faults on the subscriber lines 12-14, displaying a warning on an operator's display screen 47 or on a screen of a service technician (not show), or informing a program that allocates subscriber lines 12-14. If no signatures for line faults are found, the computer 46 identifies the absence of the line faults associated with signatures for the selected line 12-14, e.g., by performing a reporting act (step 82).

FIG. 8 is a flow chart illustrating a method 90 for a test that determines whether the subscriber lines 12-14 of FIG. 1 qualify or disqualify for a high-speed data service. To start a test, an operator or the computer 46 selects a subscriber line 12-14 (step 92). The operator or computer 46 also selects the type of data service for which the selected subscriber line 12-14 is to be tested (step 94). For example, the types of service may be ISDN or ADSL. After selecting the line 12-14 and service type, the measurement unit 40 performs one-ended electrical measurements to detect preselected types of faults in the selected line 12-14 (step 96). The one-ended measurements include tests according to the method 70 of FIG. 7 to detect split pairs.

The other types of line faults and conditions, which are selected for testing, depend on the types and speeds of data services, the properties of the switch 15, and the type of modem to be used. Frequently, tests check for high signal attenuations, resistive imbalances, and the presence of load coils, metallic faults, or bridged taps, because these conditions and faults can disqualify a line for high-speed data service. But, line qualification tests may also check for capacitive imbalances, and above-threshold noise levels, because these conditions can also affect qualification results. Methods and apparatus for detecting some of these conditions and faults are described in co-pending patent applications.

One such application is U.K. Patent Application No. 9914702.7, titled "Qualifying Telephone Lines for Data Transmission", by Roger Faulkner, filed June 23, 1999, which is incorporated herein by reference, in its entirety. Other such co-pending applications include the above-mentioned '954 and '563 patent applications.

If one of the preselected types of faults or line conditions is detected, the computer 46 reports that the selected subscriber line 12-14 is disqualified for the selected data transmissions (step 98). Otherwise, the computer 46 reports that the selected line 12-14 qualifies for the selected data service (step 100).

To report the tested line's status, the computer 46 makes an entry in a list stored in the storage device 49. The list identifies the line, data service, and qualification or disqualification status. The computer 46 may also report the line's status by displaying a disqualification or qualification signal on the display screen 47 visible to an operator.

FIG. 9 is a flow chart for a method 101 used by a TELCO to provide a high-speed data service, e.g., ISDN or ADSL, to telephone subscribers. The TELCO programs the computer 46 of FIG. 1 to automatically select individual subscriber lines 12-14 connected to the local switch 15 (step 102). In response to selecting the line 12-14, the voice test access 44 connects the selected line 12-14 to the measurement unit 40 for testing (step 104). The measurement unit 40 connects the selected line 12-14 to the measurement device 41 and may also connect the selected line 12-14 to other internal measurement devices (not shown). The computer 46 and measurement unit 40 determine whether the selected line 12-14 has a split pair and qualifies for the data service according to the methods 70, 90 of FIGs. 7 and 8 (step 106). Next, the computer 46 updates a list recording the identities of lines 12-14 that qualify and of lines 12-14 having split pairs (step 108). The computer 46 waits a preselected time and restarts the testing for another of the lines 12-14 at step 102.

The TELCO regularly checks the list to determine whether any of the lines 12-14 have split pairs (step 110). If a line has a split pair, the TELCO performs a business action based on the presence of the split pair fault (step 112). The business action may include sending a worker to repair or replace the affected line 12-14, designating the affected line 12-14 as unable to transmit data, or setting a lower billing rate based on the presence of the fault.

The TELCO also regularly checks the list to determine whether any of the lines 12-14 qualify for the high-speed data service (step 114). In response to finding that one or more of the lines 12-14 qualify, the TELCO performs a business action related to the line's qualification (step 116). For example, the TELCO may offer the high speed data service to subscribers who have the lines 12-14 qualified for the data service and who do not presently subscribe to the data service.

SPECIFIC PHYSICAL STRUCTURE OF SUBSCRIBER LINES

Referring again to FIG. 1, the subscriber lines 12-14 may have widely different physical structures. A line's specific physical structure is described by properties such as line length, gauge or gauges, and content of bridge taps. Interpretations of electrical measurements to obtain line transmission properties such as the signal attenuation are dependent upon the specific physical line structure. Thus, knowing the specific physical structure of a subscriber line aids in predicting how well the line 12-14 will support high speed digital data services, e.g., to predict maximum data speeds.

FIGs. 10A-E illustrate parameters that describe gauge mix parameters through exemplary lines 121-125 in which drawing widths represent wire gauges. The lines 121, 122 have uniform structures described by different wire gauges. The lines 124, 125 have segmented structures in which adjacent segments have different wire gauges, i.e., mixtures of gauges. The gauge composition of these lines 124, 125 is described by segment lengths and segment gauges. The structures are also described by the serial layout of the segments. The line 123 has different tip and ring wires T_4, R_4 and is described by the gauges of the T_4 and R_4 wires.

Referring now to FIG. 11, a subscriber line 127 has an extra twisted wire pair 128 spliced onto the line 127. The spliced on wire pair 128 is referred to as a bridged tap. The existence or absence of bridged taps is a parameter that also influences how well the subscriber line 127 will support high-speed digital data services.

In the United States, many subscriber lines have bridged taps because of the way in which telephone lines were laid out in housing subdivisions. Telephone lines were laid out prior to determining the exact positioning of the houses of the subdivisions. The lines ran near planned positions of several houses. When the houses were later built, the builder connected the telephone units to the nearest point on one of the originally laid telephone lines. Unconnected portions of the original lines produced bridged taps.

The bridged tap 128 reflects signals from termination 129. The reflected signals then travel back to the subscriber line 127 and interfere with signals on the subscriber line 127. The most harmful interference occurs when the reflected signal is out of phase with the incoming signal. In such a case, the reflected signal destructively interferes with the incoming signal on the subscriber line 127.

The length of the bridged tap 128 determines the phase difference between the original and reflected signals. For high-speed digital signals whose frequencies extend to about 1 mega Hertz (MHz), e.g., ADSL signals, a substantial cancellation can occur if the bridged tap 128 has a length between about 200 to 700 feet. In the United States, the bridged taps left over from the construction of many housing subdivisions have lengths in this range.

Thus, the ability to detect and remove the bridged tap 128 is useful to TELCO's that want to offer high-speed digital data services to their subscribers.

FIGs. 12A-12E illustrate structure parameters that describe bridged taps 130, 134 through exemplary subscriber lines 135-139. The lines 135, 136 have bridged taps 130, 131 described by different physical lengths. The lines 137-138 have bridged taps 132, 133 described by different locations along the lines 137, 138. The line 139 has a bridged tap 134, which is at least partially described by its location along a particular segment of the line 139. Finally, the lines 136, 139 have bridged taps 131, 134 described by different gauges.

To determine the specific physical structures of unknown subscriber lines, a reference set of model lines may be employed. A reference set is an ensemble of model lines with different and known specific physical structures. To determine the specific physical structure of an unknown subscriber line, measured properties of the unknown line are compared to the same properties in model lines. If a match is found, the unknown line has the same specific physical structure as the matching model line.

Reference data on the specific physical structures of the model lines may be compiled in either a reference data file or a set of reference equations. Both the reference data file and the set of reference equations index the individual model lines by values of a preselected set of measurable electrical properties. In some embodiments, the preselected electrical properties are the frequency-dependent admittances measurable with the device 43 of FIG. 2C.

The content of model lines in the reference set may be tailored to the expected structures of the unknown subscriber lines. For example, if the unknown lines do not have bridged taps, the reference set might not have model lines with bridged taps. On the other hand, if the unknown lines may have bridged taps, the reference set includes some model lines with bridged taps. Knowledge of the practices used to lay out the subscriber lines under test can help to determine the best content of model lines for the reference set. For different subscriber line populations, reference sets can be selected empirically or based on human knowledge.

Typically, the reference set includes model lines having uniformly varying values of the parameters described in relation to FIGs. 10A-10E and 12A-12E. The model lines have a distribution of lengths and may include one, two, or three segments with zero, one, or two bridged taps, and a distribution of subscriber termination loads. The segments and bridged taps can have varying lengths, locations, and gauges.

FIG. 13 is a flow chart for a method 140 of determining the specific physical line structure of the subscriber lines 12-14 of FIG. 1 from a reference set of model lines. To start, an operator or the computer 46 selects a subscriber line (ssl) to test (step 142). The computer 46 directs the measuring unit 40 to perform preselected one-ended electrical measurements on the selected subscriber line over a range of frequencies (step 144).

In one embodiment, the electrical measurements are one-ended and performed with the device 43, shown in FIG. 2C. During the measurements, the voltage source 54 drives the tip and/or ring wires of the selected subscriber line 12-14 with voltage sources V_1', V_2'. The driving frequency is swept over a range, e.g., from about 100 Hertz to about 20,000 to 40,000 Hertz, and one or more of the admittances Y_{tg}, Y_{tr}, Y_{rg} are measured for various driving frequencies.

The measurements provide complex input admittances, i.e., amplitudes and phases for a preselected set of frequencies "f".

After performing the measurements, the computer 46 searches for a "best" match between model lines belonging to the reference set and the selected subscriber line (step 146). The search for matches involves comparing preselected electrical properties of the selected subscriber line to the same properties for the model lines. For the selected subscriber line, the values of the preselected electrical properties are obtained from the one-ended electrical measurements. For the model lines, the values of the same electrical properties are either looked up from a file in the data storage device 49 or calculated from a set of reference equations. The comparison determines which model line "best" matches the selected subscriber line.

The computer 46 identifies a specific physical line structure for the selected subscriber line 12-14 has the same form as the specific physical line structure of the "best" matching model line (step 148). Identifying the specific physical line structure may include reporting the structure, e.g., displaying values of parameters for the specific physical structure to a operator, writing the values to a file, or providing the values to a software application. For example, the software application may use the match information to qualify or disqualify the selected line 12-14. The parameters may provide gauge mixtures and tap locations and positions.

For the model lines, the specific physical structures are either stored in the same file listing the electrical properties of the model lines or determined from the reference equations. Actual values of the electrical properties and structure parameters of the model lines are obtained prior to testing the subscriber line by analytic calculations or experimentation.

In a preferred embodiment, the computer 46 finds the "best" matching model line by calculating an error function for each model line (ml). The error function has one of two forms E or E' given by:

$E = \Sigma_f\ W(f)|M_{ml}(f) - M_{sl}(f)|$ and $E' = \Sigma_f\ W(f)|M_{ml}(f) - M_{sl}(f)|^{2Q}$.

$M_{ml}(f)$ and $M_{ssl}(f)$ are the values of the preselected frequency-dependent electrical properties of the model line (ml) and the selected subscriber line (ssl), respectively. Q and W(f) define the form of the error functions, i.e., E or E'. Q is a fixed integer, e.g., 1 or 2. W(f) is positive definite weight function, e.g., a function of frequency "f" or a constant.

In some embodiments, the preselected electrical properties $M_{ml}(f)$, $M_{ssl}(f)$ are the phases of one or more complex admittances of the lines ssl, ml. Various embodiments employ either the phase of the tip-to-ground admittance Y_{tg}, the phase of the ring-to-ground admittance Y_{rg}, and/or the phase of the tip-to-ring admittance Y_{tr}. If the tip-to-ground or ring-to-ground admittances Y_{tg}, Y_{rg} are used, many termination effects due to the subscriber units 16-18 of FIG. 1 are not seen. The phase of these admittances is often small, e.g., 4° or less, and approximately equals the ratio of the imaginary to real parts of the admittance. For such a case and Q = 1, the error function E' is:

$$E' = \Sigma_f[\ \mathrm{Im(admittance)}_{ml}/\mathrm{Re(admittance)}_{ml} - \mathrm{Im(admittance)}_{ssl}/\mathrm{Re(admittance)}_{ssl}\ ]^2.$$

In another embodiment, the preselected electrical properties $M_{ml}(f)$, $M_{ssl}(f)$ are the full complex admittances of the lines ssl, ml, i.e., Y_{tg}, Y_{rg}, and/or Y_{tr}. Using the complex admittances themselves can reduce computational times.

Finally, in some embodiments, the best match to the selected subscriber line 12-14 may include a several different model lines, e.g., model lines generating errors with a below threshold value. In these embodiments, the computer 46 identifies the selected subscriber line 12-14 as having one or more common features of all of the "best matching" lines. For example, the computer 46 may identify the specific physical structure of the selected subscriber line 12-14 as having a bridged tap if all of the best matching model lines have a bridged tap. Then, the computer 46 may use the presence of a bridged tap in combination with other measurements to qualify or disqualify the line 12-14.

FIG. 14 illustrates a method 150 of determining "best" matches by using the above-described phases. The computer 46 determines the length of the selected subscriber line using low frequency measurements for line capacitance performed by the measurement unit 40 and device 43 (step 152). Next, the computer 46 selects a model line having the same length as the selected subscriber line (step 154).

The computer 46 restricts comparisons to model lines with the same length as the subscriber line, because physical line length affects the values of the phases of admittances. Limiting comparisons to this subset of the reference set eliminates false matches with model lines whose lengths differ from the length of the selected subscriber line.

The computer 46 calculates the error function E', based on the phase of preselected admittances, for the selected model line (step 155). The computer 46 checks whether other model lines remain with the same length (step 156). If other lines remain, the computer 46 repeats the determination of E' for another selected model line (157). If no lines remain, the computer 46 reports the model line having the smallest value for the error function E' as the "best" match to the selected subscriber line (step 158).

Since the reference set may contain as many as 10,000 to 100,000 model lines, the method 150 may search the reference set hierarchically to reduce the total number of searches. In a hierarchical scheme, a first search divides the reference set into non-overlapping groups of model lines. Each group has a large number of lines with similar specific physical structures and defines one model line as a representative of the group. The first search uses the method 150 to determine a "best" match between the selected subscriber line and one of the representative model lines. A second search uses the method 150 on the model lines of the group associated with the best matching representative model line found from the first search.

FIG. 15 is a flow chart illustrating a method 160 of qualifying subscriber lines, e.g., lines 12-14 of FIG. 1, for a high-speed data service, e.g., ISDN or ADSL. After selecting a subscriber line to test, the computer 46 searches a reference set of model lines for a "best" match to the selected subscriber line by using the methods 140, 150 of FIGs. 13 and 14 (step 162). The computer 46 identifies the selected subscriber line as having a bridged tap or mixture of gauges in response to the "best" match model line having a bridged tap or mixture of gauges, respectively (step 163). The computer 46 qualifies or disqualifies the selected subscriber line for the data service, at least in part, based upon whether the subscriber line has a bridged tap or mixture of gauges (step 164).

In some embodiments, the computer 46 uses the signal attenuation to qualify or disqualify the selected subscriber line according to a method described in co-pending U.S. Application No. 08/294,563 ('563). In those embodiments, the computer 46 calculates the signal attenuation by the methods described in the '563 application. Then, the computer 46 adjusts the calculated value of the signal attenuation up or down depending on a quality factor. The quality factor depends on the specific physical structure of the line, e.g., upon whether a bridged tap and/or a mixture of gauges is absent or present in the subscriber line.

According to the value of the quality factor, the computer 46 adjusts a calculated signal attenuation up or down by preselected amounts. For example, the attenuation may be decreased, unchanged, and increased in response to the quality factor being good, average, and poor, respectively. Then, the computer uses the adjusted signal attenuation to determine to qualify or disqualify the subscriber line for the data service according to methods described in the '563 application.

In other embodiments, the computer 46 uses some specific physical line structures as disqualifiers. For example, if the above-described methods lead to the detection of a bridged tap, the computer 46 may disqualify the line for the data service.

FIG. 16 is a flow chart illustrating a business method 165, which a TELCO uses to provide a high-sp ed data service to subscribers. The TELCO determines which subscriber lines 12-14 of FIG. 1 are qualified and/or disqualified for the data service according to the method 160 of FIG. 15 (step 166).

Using the method 160, the computer 46 determines whether line structures, e.g., bridged taps and/or selected mixtures of gauges, are present. The specific physical structure is then used to adjust predictions of electrical properties of the subscriber line, e.g., a signal attenuation. If the adjusted values of the electrical properties are outside of thresholds for the data service the line is disqualified.

Among subscribers with qualified lines 12-14, the TELCO determines which subscribers having qualified lines do not subscribe to the data service (step 167). The TELCO offers the data service to subscribers having qualified lines and not presently subscribing to the service (step 168).

In response to finding subscribers with disqualified lines 12-14, the TELCO repairs or replaces those lines 12-14 (step 169).

STACKED BRIDGED TAP DETECTION

Referring again to FIG. 1, tests for bridged taps preferably use one-ended electrical measurements that are performed on subscriber lines 12-14 via the "standard" voice test access 44. The voice test access 44 acts as a low pass filter, which screens out frequencies above 20 to 100 KHz. Thus, electrical measurements are generally restricted to low frequencies between about 20 Hz and 100 KHz.

Bridged taps manifest their presence by peaks in the signal attenuation at high frequencies, e.g., between about 200 KHz and 1,000 KHz. Predicting features of the high- frequency signal attenuation from the low-energy measurements, which are available through the voice test access 44, is difficult and error prone. Present methods falsely predict the presence or absence of bridged taps in about 40% of the cases. False predictions are costly to subscribers and TELCO's, because they can result in lost opportunities for high-speed data services and can also result in investments in transmission equipment that lines do not support.

The accuracy of tests for line conditions and faults, e.g., bridged taps, can be improved with stacked generalization methods that use multiple layers of classifiers. The classifiers determine values of auxiliary variables, which are the labels they assign to classify subscriber lines 12-14. Auxiliary variables are generated as outputs of classifiers. The auxiliary variables are thus, related to electrical measurements on the lines 12-14 indirectly through probabilistic relations embodied in the classifiers. The classifiers of the stack may be decision trees, neural networks, case-based reasoners, or statistically based classifiers. The old electrical properties and new auxiliary variables can be combined in classifiers that provide strong correlations between values of these quantities and the presence or absence of line faults and conditions, such as bridg d taps and gauge mixtures.

FIG. 17 is a flow chart illustrating a method 170 for using stacked classifiers to detect selected line conditions or faults from electrical measurements made with the system 11 of FIG. 1. The system 11 preferably performs one-ended electrical measurements on a selected subscriber line 12-14 using either setup 52 or setup 60, shown in FIGs. 2A-2C, 3 (step 172). To these measurements, the computer 46 applies a set of rules that define a preselected set of derived electrical properties for the selected line 12-14 (step 173). Algebraic relations relate the derived properties to the measurements. The measured and derived electrical properties are listed in Appendix A.

The measured and derived properties together form the input properties for the stack of classifiers. These input properties may include a preliminary value of the signal attenuation, the line length, line impedances, and ratios of line impedances. The selection of the input line properties for the stack can be changed to accommodate different expected compositions of the subscriber lines 12-14 being tested.

In each layer U, V of classifiers, shown in FIG. 17, the computer 46 determines values of one or more auxiliary variables for the selected line 12-14. The auxiliary variables may be logic-type variables indicating that the line 12-14 is labeled by a characteristic. The auxiliary variables may also be probability-type variables each indicating the likelihood that the line 12-14 is labeled by one of a plurality of characteristics.

In the first layer U of the stack, the computer 46 applies a first classifier to input electrical measurements and properties to determine a first auxiliary variable (step 175). The first auxiliary variable characterizes the line 12-14 with a label "nominal" or a label "non-nominal".

In a nominal line, low frequency properties provide a good prediction of the signal attenuation at the high frequencies where bridged taps strongly affect attenuation. Thus, knowing a value of an auxiliary variable that labels a line as nominal or non-nominal can improve the accuracy of predictions about the presence of line faults like bridged taps.

Also in the first layer U, the computer 46 applies one or more second classifiers to the input electrical properties to determine one or more other auxiliary variables (step 176). These auxiliary variables provide a preliminary prediction of whether the selected line 12-14 is qualified or disqualified for one or more high-speed data services. In some embodiments, values of the auxiliary variables, found at step 176, indicate whether the subscriber line 12-14 is qualified for ISDN or ADSL data services or neither.

Disqualification for high-speed data service correlates with presence of a bridged tap, because a bridged tap lowers a line's capability to carry high-frequency signals. Thus, knowing a value of an auxiliary variable that preliminarily labels a line as qualified or disqualified for data transmissions can improve the accuracy of predictions about the presence or absence of bridged taps.

Steps 175 and 176 may be performed in parallel or sequentially. If these steps 175 and 176 are sequential, the value of the auxiliary variable output by the earlier step may be used in the later step. If step 175 is earlier, the classifier of step 176 may use the auxiliary variable labeling the line 12-14 as nominal or non-nominal, as an input. If step 176 is earlier, the classifier of step 175 may use the auxiliary variables providing a preliminary qualification or disqualification for data transmissions as inputs.

At the second layer V of the stack, the computer 46 applies a classifier to the auxiliary variables from steps 175 and 176 and the electrical measurements and properties from steps 172 and 173. This classifier determines whether the selected subscriber line 12-14 has a preselected type of line fault or condition (step 177). For example, the fault or condition may be existence of a bridged tap or a gauge mixture.

The layered stack U, V can predict the presence or absence of bridged taps with a substantially increased accuracy. The two-layered stack of FIG. 17 can predict the presence of bridged taps with an accuracy of between about 75% and 85% and the absence of bridged taps with an accuracy of greater than about 97%.

In steps 175, 176, and 177, classifiers analyze input data to determine the values of output data. Henceforth, the input data, which includes one-ended measurements, properties derived from one-ended measurements, and/or auxiliary variables, are referred to as line features. The output data, which are values of auxiliary variables, are referred to as classifying labels.

Their line features and labels can describe the classifiers of steps 175, 176, and 177. The classifier in step 175 uses the selected measured and derived electrical properties of the selected line 12-14 as features to form classes with labels "nominal" and "non-nominal". The classifier of step 176 uses the same features to form classes with labels "ISDN qualified", "ADSL qualified", or "data service disqualified" in one embodiment. The classifier of step 177 uses the same features and values of the characterizing labels from steps 175, 176 to form classes with labels "bridged tap present" and "bridged tap absent".

The label "nominal" describes a type of signal attenuation over a range that includes both low measurement frequencies and high data service frequencies. For a nominal line, the difference between actual and predicted signal attenuations AA(f) and PA(f) has a simple dependence on frequency "f". The actual signal attenuation AA is the attenuation of the line determined from direct double-ended electrical measurements. The predicted signal attenuation PA is the attenuation obtained from one-ended electrical measurements, e.g., using the system 11 of FIG. 1.

The predicted signal attenuation PA(f) may be obtained from a subscriber line's capacitance, e.g., the capacitance C^{tg}_{30Hz} between tip wire and ground measured at 30 Hz. One form for the predicted signal attenuation PA(f) is:

$$PA(f) = K(f)C^{tg}_{30Hz}.$$

In this formula, K(f) = -.1729, -.2074, -.2395, -.2627, and -.2881 dB/nano-Farads for respective frequencies f equal to 100, 200, 300, 400, and 500 KHz.

Another form for the predicted attenuation PA(f) is described in co-pending U.K. Patent Application 9914702.7.

For a nominal line, the difference, DFF(f), between the actual and the predicted signal attenuations AA(f), PA(f) has one of the following forms:

1) DFF(f) < 3.5 dB for 100 KHz < f < 500 KHz;

2) 3.5 dB ≤ DFF(f) < 10.0 dB for 100 KHz < f < 500 KHz; or

3) DFF(f) ≥ 10.0 dB for 100 KHz < f < 500 KHz.

If the frequency dependent difference DFF(f), i.e., |AA(f)-PA(f)|, does not have form 1, 2, or 3, the line 12-14 is classified as a non-nominal line. Thus, a direct determination of whether a particular line 12-14 is nominal requires both one-ended and two-ended measurements to obtain both PA(f) and AA(f).

FIG. 18A shows predicted and actual attenuations of exemplary nominal lines A, B, and C. For the line A, predicted and actual attenuations PA_A and AA_A differ by less than 3.5 dB for the entire frequency range between 100 and 500 KHz. The line A has a DFF(f) of form 1. For the line B, predicted and actual attenuations PA_B, AA_B differ by between 4 and 9 dB over the 100 KHz to 500 KHz frequency range. The line B has a DFF(f) of form 2. For the line C, predicted and actual attenuations PA_C, AA_C differ by between more than 10.0 dB over the 100 KHz to 500 KHz frequency range. The line C has a DFF(f) of form

3.

FIG. 18B shows predicted and actual attenuations of exemplary non-nominal lines D and E. For the line D, predicted and actual signal attenuations PA_D, AA_D differ by about 8 dB at 200 and 400 KHz and are equal at 150 and 300 KHz. This form for PA_D and AA_D does not correspond to a DFF(f) of form 1, 2, or 3. For the line E, predicted and actual signal attenuations PA_E, AA_E differ by less than 3.5 dB at frequencies between 100 and 200 KHz and by more than 8 dB at frequencies between 400 and 500 KHz. This form for PA_E and AA_E also does not correspond to a DFF(f) of form 1, 2, or 3.

In the non-nominal lines D and E wide fluctuations occur in DFF(f). These fluctuations make a constant shift of the predicted attenuation PA(f) a poor approximation to the actual attenuation AA(f) over the whole range that includes both high and low frequencies.

FIG. 18C shows predicted and actual signal attenuations PA_F, AA_F for another nominal subscriber line F. A shifted predicted attenuation SPA_F, which has been obtained by shifting the predicted attenuation PA_F by a constant, is also shown. For the nominal line F, the shifted predicted attenuation SPA_F provides a better approximation to the actual attenuation AA_F that the predicted attenuation PA_F over the entire range between 100 KHz and 500 KHz.

The actual and predicted signal attenuations AA(f), PA(f) of nominal lines are approximately related by a constant shift over a wide frequency range. The wide frequency range includes both low measurement frequencies and high frequencies where effects of bridged taps are directly observable.

In step 176 of FIG. 17, the labels ISDN qualified, ADSL qualified, and data service disqualified are defined by the value of the actual signal attenuation at 100 KHz and 300 KHz. High-speed data qualified and disqualified lines satisfy:

Class Label	100 KHz	300 KHz
ADSL qualified	attenuation > -47dB	attenuation > -40
ISDN qualified	attenuation > -47dB	attenuation ≤ -40
Disqualified	attenuation ≤ -47dB	attenuation ≤ -40

Thus, qualification or disqualification of a line 12-14 for ADSL and ISDN are defined by the value of the actual signal attenuation at two high frequencies, i.e., 100 KHz and 300 KHz.

FIG. 19 illustrates a decision tree 180 that determines a classifying label, e.g., an auxiliary variable, generated in steps 175-177 of FIG. 17. A separate classifier, e.g., a decision tree, is used to determine each such label.

The decision tree 180 has a hierarchical arrangement of branching tests 1, 1.1-1.2; 1.1.1-2.2.2,..., which are grouped into descending levels 1, 2, 3.... Each test assigns feature data received from a higher level to disjoint subsets in the next lower level. The subsets of the lower level are located at ends of arrows starting at the test. For example, test 1.1 assigns feature data to subsets 1.1 and 1.2, which are located at the ends of arrows 6 and 7, see FIG. 20. At the lower level, another set of tests can act on the feature data.

FIG. 20 illustrates how the tests 1, 1.1, 1.2,... of the various levels of the decision tree 180 of FIG. 19 act on a set of feature data associated with the subscriber lines 12-14. Each successive test partitions the set, i.e., by using values of the selected features, into increasingly disjoint output subsets. For example, test 1 partitions the initial feature data into subset 1 and subset 2. The distal end of each path through the decision tree 180 assigns a subscriber line to a final subset in which the lines are primarily associated with one value of the classifying label of the tree 180. Some decision trees 180 determine a probability that the subscriber line 12-14 has the value of the label of the final subset to which it is assigned.

FIG. 21 is a flow chart for a method 190 of creating decision trees for use as the classifiers in steps 175, 176, and 177 of FIG. 17. The method 190 uses machine learning methods.

To employ machine learning, a training set of subscriber line data is created (step 192). The content the training set includes model lines with different values of the labels used by the decision tree to classify lines. If the decision tree classifies lines with the label "bridged tap present" and "bridged tap absent", then some of the lines of the training sets will have bridged taps and some of the lines will not have bridged taps. Similarly, in a stack of trees that classifies lines with a particular label, each tree therein is constructed from a training set having lines with different values of the particular label.

For each line of the training set, a computer and/or operator determines the values of a set of potential features and the classifying labels (194).

The potential features include one-ended measured and derived electrical properties that may be used in the tests of the decision tree. The potential electrical properties of one embodiment are listed in Appendix A. The potential features also include values of any auxiliary variables that may be used in the tests of the decision tree. For example, a decision tree used in step

177 of FIG. 17 would also include, as potential features, auxiliary variables determining whether a line is nominal and preliminarily qualified for preselected data services.

The classifying labels are the values of the auxiliary variables output by the decision tree. The values of these output auxiliary variables may, for example, include a determination of whether a line is nominal, qualified, or has a bridged tap.

Determinations of values of the classifying labels for the lines of the training set may use both one-ended and two-ended electrical measurements. For example, to classify a line of the training set as nominal or non-nominal a two-ended measurement of the actual attenuation and a one-ended measurement of the predicted attenuation are needed. Similarly, to determine the classifying label associated with qualification for data services, two-ended measurements of the actual attenuation are used. The two-ended measurements are not, however, used as inputs in the construction of decision trees.

From the values of the potential features and classifying labels of each line in the training set, the computer 46 recursively determines the branching tests of the decision tree (step 196).

FIG. 22 is a flow chart for a method 200 of determining the branching tests of the decision tree 180 shown in FIGs. 19-20. For each potential feature, the computer 46 constructs a test and partitions the training set into groups of disjoint subsets (step 202). The test associated with a feature assigns each line of the training set to subsets according to a value of that feature for the line.

The computer 46 evaluates gain ratio criteria for the partitioning of the training set produced by each potential feature (step 204). The gain ratio criteria measures increases in consistency of line membership for different values of the classification label in each subset. The computer 46 uses the gain ratio criteria to find a best test and defines test 1 of the decision tree 180 to be the best test (step 206).

The computer loops back to perform steps 202, 204, and 206 for each subset produced by test 1 to determine the tests of level 2 of the decision tree 180 (loop 208). In these determinations, the subsets produced by the best test of level 1 become training sets for finding the tests of level 2. After performing steps 202, 204, and 206 for the subsets 1 and 2, the computer 46 has determined the tests 1.1 and 1.2 of the level 2 (loop 208). The computer 46 performs loop 208 either until further branches produce line classification errors below a preselected threshold or until no features remain.

Several methods exist for defining the best branching tests at each level of the decision tree 180 of FIG. 19. The C4.5 method defines best tests as tests producing the highest values of the gain ratio criteria. The C4.5* method randomly picks the best tests from the tests whose values of the gain ratio criteria are within a preselected selection percentage of the highest value.

The C4.5* algorithm predicts probabilities that a line with features "d" will be partitioned into each final subset of the decision tree. The probability that the line will be in the majority final subset L is:

$$P_L(d) = 1 - (\Sigma_{(j \text{ not in } L)} N_j + 1)/(\Sigma_{(i \text{ in } L)} N_i + 2).$$

Here, N_i is the number of lines in subset "i". The probability that the line will be in a subset "i" is:

$$P_i(d) = [1 - P_L(d)](N_i/\Sigma_{(j \text{ in } L)} N_j).$$

In embodiments using the C4.5* algorithm, the above-described probabilities are the auxiliary variables used as features in the steps 175-177 of FIG. 17.

Various embodiments combine the methods of detecting line faults (70, 90), determining lines structures (140, 160), and stacking fault detection (170), shown in FIGs. 7, 8, 13, 15, 17. By combining the above-mentioned methods, these embodiments can better classify subscriber lines according to a variety of criteria. These criteria include presence of line conditions and faults, line speed, and qualification status.

Other embodiments are within the scope of the following claims.

What is claimed is:

```
30Hz Raw Measurements:
      Ytr(30) - Admittance tip-to-ring measured at 30Hz
      Ytg(30) - Admittance tip-to-ground measured at 30Hz
      Yrg(30) - Admittance ring-to-ground measured at 30Hz

30Hz Derived Measurements:
      30Gtr - Conductance tip-to-ring measured at 30Hz = real(Ytr(30))
      30Str - Susceptance tip-to-ring measured at 30Hz = imag(Ytr(30))
      30Gtg - Conductance tip-to-ground measured at 30Hz = real(Ytg(30))
      30Stg - Susceptance tip-to-ground measured at 30Hz = imag(Yt(30))
      30Ctr - Capacitance tip-to-ring measured at 30Hz = Str(30)/(2*pi*30)
      30Ctg - Capacitance tip-to-ground measured at 30Hz = St(30)/(2*pi*30)
      Lmeas - Length in kft measured at 30Hz = 30Ctg/17.47

150Hz-20KHz Raw Measurements:
      Ytr(f) - Admittance tip-to-ring where f=150Hz.600Hz.1050Hz.1500Hz....19950Hz
      Ytg(f) - Admittance tip-to-ground where f=150Hz.600Hz.1050Hz.1500Hz....19950Hz
      Yrg(f) - Admittance ring-to-ground where f=150Hz.600Hz.1050Hz.1500Hz....19950Hz

150Hz-20KHz Derived Measurements:
      150Gtr - Conductance tip-to-ring measured at 150Hz = real(Ytr(150))
      600Gtr - Conductance tip-to-ring measured at 600Hz = real(Ytr(600))
        .
        .
      19950Gtr - Conductance tip-to-ring measured at 19950Hz = real(Ytr(19950))

      150Str - Susceptance tip-to-ring measured at 150Hz = imag(Ytr(150))
      600Str - Susceptance tip-to-ring measured at 600Hz = imag(Ytr(600))
        .
        .
      19950Str - Susceptance tip-to-ring measured at 19950Hz = imag(Ytg(19950))

      150Gtg - Conductance tip-to-ground measured at 150Hz = real(Ytg(150))
      600Gtg - Conductance tip-to- ground measured at 600Hz = real(Ytg(600))
        .
        .
      19950Gtg - Conductance tip-to- ground measured at 19950Hz = real(Ytg(19950))

      150Stg - Susceptance tip-to- ground measured at 150Hz = imag(Ytg(150))
      600Stg - Susceptance tip-to- ground measured at 600Hz = imag(Ytg(600))
        .
        .
      19950Stg - Susceptance tip-to- ground measured at 19950Hz = imag(Ytg(19950))

      150Ctr - Capacitance tip-to-ring measured at 150Hz = 150Str/(2*pi*150)
      600Ctr - Capacitance tip-to-ring measured at 600Hz = 600Str/(2*pi*600)
        .
        .
      19950Ctr - Capacitance tip-to-ring measured at 19950Hz = 19950Str/(2*pi*19950)

      150Ctg - Capacitance tip-to-ground measured at 150Hz = 150Stg/(2*pi*150)
      600Ctg - Capacitance tip-to-ground measured at 600Hz = 600Stg/(2*pi*600)
        .
        .
      19950Ctg - Capacitance tip-to-ground measured at 19950Hz = 19950Stg/(2*pi*19950)
```

150Hz-20KHz Secondary Derived Measurements:

C30/C4K - Ratio of tip-to-ground Capacitance at 30Hz to 4200Hz
C4K/C10K - Ratio of tip-to-ground Capacitance at 4200Hz to 10050Hz
Cslope - Tip-to-ground Capacitance ratio slope = (C4K/C10K)/(C30/C4K)
C30-C4K - Difference in tip-to-ground Capacitance at 30Hz and 4200Hz
C4K-C10K - Difference in tip-to-ground Capacitance at 4200Hz and 10050Hz
Cdelta - Tip-to-ground Capacitance difference delta = (C4K-C10K)/(C30-C4K)

G4K/G30 - Ratio of tip-to-ground Conductance at 4200Hz to 30Hz
G10K/G4K - Ratio of tip-to-ground Conductance at 10050Hz to 4200Hz
Gslope - Tip-to-ground Conductance ratio slope = (G10K/G4K)/(G4K/G30)
G4K-G30 - Difference in tip-to-ground Conductance at 30Hz and 4200Hz
G10K-G4K - Difference in tip-to-ground Conductance at 4200Hz and 10050Hz
Gdelta - Tip-to-ground Conductance difference delta = (G10K-G4K)/(G4K-G30)

C30/G30 - Ratio of Tip-to-ground Capacitance to Conductance at 30Hz
C30/G4K - Ratio of Tip-to-ground Capacitance at 30Hz to Conductance at 4200Hz
C4K/G4K - Ration of Tip-to-ground Capacitance to Conductance at 4200Hz

Gtr_dmax - Maximum positive slope of Gtr(f) = max(derivative(Gtr(f)/df))
Gtr_fmax - Frequency at which Gtr_dmax occurs
Gtr_dmin - Maximum negative slope of Gtr(f) = min(derivative(Gtr(f)/df))
Gtr_fmin - Frequency at which Gtr_dmin occurs
Gtr_fpk - Frequency of first peak (local maxima)in Gtr(f)
Gtr_fval - Frequency of first valley(local minima)in Gtr(f)
Gtr_d_delta - Gtr Max/Min Derivative difference = Gtr_dmax-Gtr_dmin
Gtr_pk_delta - Gtr peak/valley frequency difference = Gtr_fval-Gtr_fpk
Gtr_pk - Value of Gtr(f) at frequency Gtr_fpk
Gtr_val - Value of Gtr(f) at frequency Gtr_fval
Gtr_delta - Gtr peak/valley difference = Gtr_pk-Gtr_val

Gtg_dmax - Maximum positive slope of Gtg(f) = max(derivative(Gtg(f)/df))
Gtg_fmax - Frequency at which Gtg_dmax occurs
Gtg_dmin - Maximum negative slope of Gtg(f) = min(derivative(Gtg(f)/df))
Gtg_fmin - Frequency at which Gtg_dmin occurs
Gtg_d_delta - Gtg Max/Min Derivative difference = Gtg_dmax-Gtg_dmin

Ctr_dmax - Maximum positive slope of Ctr(f) = max(derivative(Ctr(f)/df))
Ctr_fmax - Frequency at which Ctr_dmax occurs
Ctr_dmin - Maximum negative slope of Ctr(f) = min(derivative(Ctr(f)/df))
Ctr_fmin - Frequency at which Ctr_dmin occurs
Ctr_fpk - Frequency of first peak (local maxima)in Ctr(f)
Ctr_fval - Frequency of first valley(local minima)in Ctr(f)
Ctr_d_delta - Ctr Max/Min Derivative difference = Ctr_dmax-Ctr_dmin
Ctr_pk_delta - Ctr peak/valley frequency difference = Ctr_fval-Ctr_fpk
Ctr_val - Value of Ctr(f) at frequency Ctr_fval

Ctg_dmax - Maximum positive slope of Ctg(f) = max(derivative(Ctg(f)/df))
Ctg_fmax - Frequency at which Ctg_dmax occurs
Ctg_dmin - Maximum negative slope of Ctg(f) = min(derivative(Ctg(f)/df))
Ctg_fmin - Frequency at which Ctg_dmin occurs
Ctg_d_delta - Ctg Max/Min Derivative difference = Ctg_dmax-Ctg_dmin

Str_dmax - Maximum positive slope of Str(f) = max(derivative(Str(f)/df))
Str_fmax - Frequency at which Str_dmax occurs
Str_dmin - Maximum negative slope of Str(f) = min(derivative(Str(f)/df))
Str_fmin - Frequency at which Str_dmin occurs

150Hz-20KHz Secondary Derived Measurements:

Str_fpk - Frequency of first peak (local maxima) in Str(f)
Str_fval - Frequency of first valley (local minima) in Str(f)
Str_d_delta - Str Max/Min Derivative difference = Str_dmax-Str_dmin
Str_pk_delta - Str peak/valley frequency difference = Str_fval-Str_fpk
Str_pk - Value of Str(f) at frequency Str_fpk
Str_val - Value of Str(f) at frequency Str_fval
Str_delta - Str peak/valley difference = Str_pk-Str_val

Stg_dmax - Maximum positive slope of Stg(f) = max(derivative(Stg(f)/df))
Stg_fmax - Frequency at which Stg_dmax occurs
Stg_dmin - Maximum negative slope of Stg(f) = min(derivative(Stg(f)/df))
Stg_fmin - Frequency at which Stg_dmin occurs
Stg_fpk - Frequency of first peak (local maxima) in Stg(f)
Stg_fval - Frequency of first valley (local minima) in Stg(f)
Stg_d_delta - Stg Max/Min Derivative difference = Stg_dmax-Stg_dmin
Stg_pk_delta - Stg peak/valley frequency difference = Stg_fval-Stg_fpk

Gtg20k/Gtg8k - Ratio of Gtg at 19950Hz and 8250Hz
Gtg20k/Gtg4k - Ratio of Gtg at 19950Hz and 4200Hz
Cgt30/Cgt20k - Ratio of Ctg at 30Hz and 19950Hz
Cgt30/Cgt8k - Ratio of Ctg at 30Hz and 8250Hz

What is claimed is:

1. A method of determining a physical structure of a subscriber line, comprising:

searching a reference set for a match between the subscriber line and a model line of the reference set, the match being based on electrical properties of the lines; and

identifying that the subscriber line has a specific physical structure in response to finding a match with one of the model lines that has the specific physical structure.

2. The method of claim 1, further comprising:

performing electrical measurements to determine the electrical properties, the electrical measurements being one-ended measurements.

3. The method of claim 2, wherein the act of searching comprises:

evaluating an error function for each model line to determine quality of the match between values of the electrical properties of the model and subscriber lines.

4. The method of claim 2, wherein the one-ended measurements determine one of a tip-to-ring admittance, a tip-to-ground admittance, and a ring-to-ground admittance.

5. The method of claim 4, wherein the electrical properties include a quantity representative of a phase of an impedance of the subscriber line.

6. The method of claim 4, wherein the act of

performing includes transmitting a voltage signal to the subscriber line through a test access of a switch or a DSLAM device.

7. The method of claim 2, wherein the act of identifying indicates that the subscriber line has one or more bridged taps in response to the matching model line having one or more bridged taps.

8. The method of claim 2, wherein the act of identifying indicates that the subscriber line has a mixture of gauges in response to the matching model having a mixture of gauges.

9. The method of claim 2, wherein the act of searching for comprises:

looking up values of the electrical properties of the model lines in a data storage device.

10. The method of claim 2, wherein the act of searching comprises:

computing values of a portion of the electrical properties of the model lines using a reference equation.

11. The method of claim 2, wherein the one-ended measurements are performed at a plurality of frequencies.

12. The method of claim 11, further comprising:

calculating a value of signal attenuation for the subscriber line from the one-ended measurements; and

increasing the calculated value in response to determining that the line has a bridged tap.

13. A method of qualifying a subscriber line for a data service, comprising:

searching a reference set of model lines for a best match to a subscriber line by comparing sets of electrical properties;

determining that the subscriber line has a specific physical structure in response to the best matching model line having the specific physical structure; and

disqualifying the subscriber line for the data service, in part, in response to determining that the specific physical structure corresponds to a disqualified line.

14. The method of claim 13, wherein the electrical properties are obtained from one-ended measurements on the subscriber line.

15. The method of claim 14, wherein the act of searching for a best match comprises:

evaluating an error function for each model line to determine quality of correspondence between the electrical properties of the model line and of the subscriber line.

16. The method of claim 14, wherein the compared properties include a quantity indicative of the phase an impedance of the subscriber line.

17. The method of claim 14, further comprising:

making one-ended electrical measurements on the subscriber line at a plurality of frequencies to obtain the electrical properties.

18. The method of claim 17, further comprising:

calculating a value of signal attenuation for the subscriber line from the one-ended measurements; and

increasing the value in response to determining that the line has a bridged tap.

19. The method of claim 18, wherein the act of disqualifying is responsive to the increased value being greater than a predetermined threshold value for the data service.

20. The method of claim 17, wherein the one-ended measurements determine one of a tip-to-ring admittance, a tip-to-ground admittance, and a ring-to-ground admittance.

21. The method of claim 17, wherein the making one-ended measurements includes driving the subscriber line through a test access of a switch or DSLAM device.

22. A method of providing a data service, comprising:

searching a reference set of model lines for a best match to a subscriber's line by comparing measured electrical properties to properties of the model lines;

determining whether the subscriber's line is qualified for the data service based in part on whether the best matching model line has a one of a bridged tap and a mixture of gauges; and

performing a business action in response to determining that the subscriber's line is qualified.

23. The method of claim 22, wherein the business

action includes offering one of the data service and a service quality-level agreement to the subscriber.

24. The method of claim 22, wherein the act of offering comprises:

performing one of a repair and a replacement of the subscriber line in response to determining that subscriber line is disqualified.

25. The method of claim 22, further comprising:

repeating the acts of searching, determining, and performing for a plurality of subscriber lines connected to one telephony switch or one DSLAM device.

26. The method of claim 22, wherein the act of searching for a best match comprises:

evaluating an error function for each model line to determine quality of a correspondence between the electrical properties of the model line and the subscriber line.

27. The method of claim 22, wherein the compared properties include a quantity indicative of a phase of an impedance of the subscriber line.

28. The method of claim 22, further comprising:

performing one-ended electrical measurements at a plurality of frequencies to obtain the electrical properties.

29. The method of claim 22, wherein the act of determining further comprises:

calculating a value of a signal attenuation for the subscriber line from the one-ended measurements;

increasing the value in response to determining that the line has a bridged tap or a mixture of gauges; and

wherein the act of qualifying is responsive to the increased value being less than a predetermined threshold value for the data service.

30. A data storage device storing an executable program of instructions for determining a structure of a subscriber line, the instructions to cause a computer to:

search a reference set for a match between the subscriber line and a model line of a reference set, the match being based on electrical properties of the lines; and

identify that the subscriber line has a specific physical structure in response to finding a match with one of the model lines that has the specific physical structure.

31. The device of claim 30, wherein the electrical properties are determined from one-ended measurements.

32. The device of claim 30, wherein the instructions to search cause the computer to:

evaluate an error function for each model line to determine quality of the match between values of the electrical properties of the model and subscriber lines.

33. The device of claim 30, wherein the electrical properties include a quantity representative of a phase of an impedance of the subscriber line.

34. The device of claim 31, wherein the

instructions to identify cause the computer to indicate that the subscriber line has one or more bridged taps in response to the matching model line having one or more bridged taps.

35. The device of claim 31, wherein the instructions to identify cause the computer to indicate that the subscriber line has a mixture of gauges in response to the matching model having a mixture of gauges.

36. The device of claim 31, wherein the electrical properties in a property at a plurality of frequencies.

37. The device of claim 31, the instructions further causing the computer to:

calculate a value of signal attenuation for the subscriber line from the one-ended measurements; and

increase the calculated value in response to determining that the line has a bridged tap.

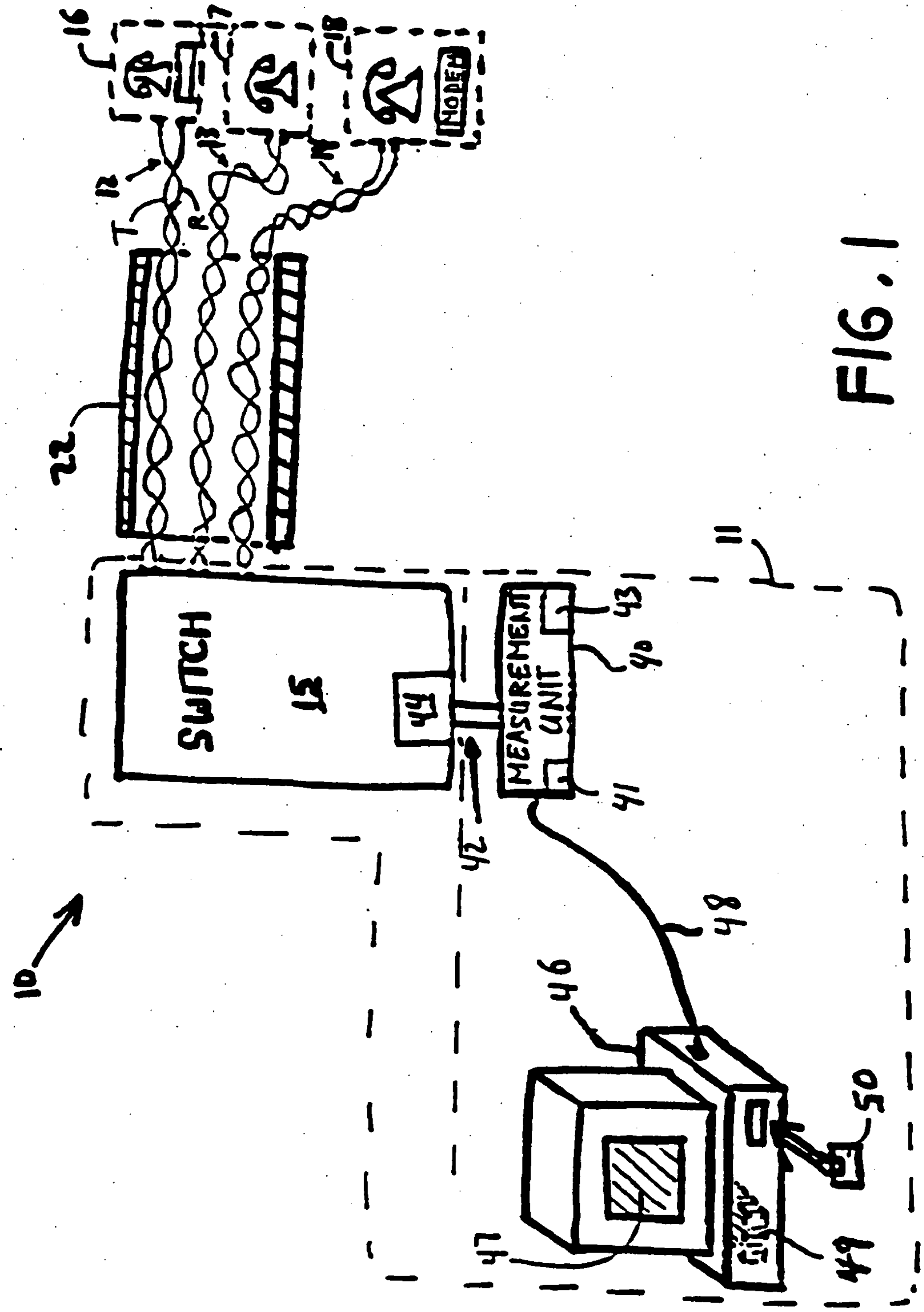

SWITCH
15
44
MEASUREMENT UNIT
MODEM
10
11
16
17
18
22
40
41
42
43
46
47
48
49
50

FIG. 1

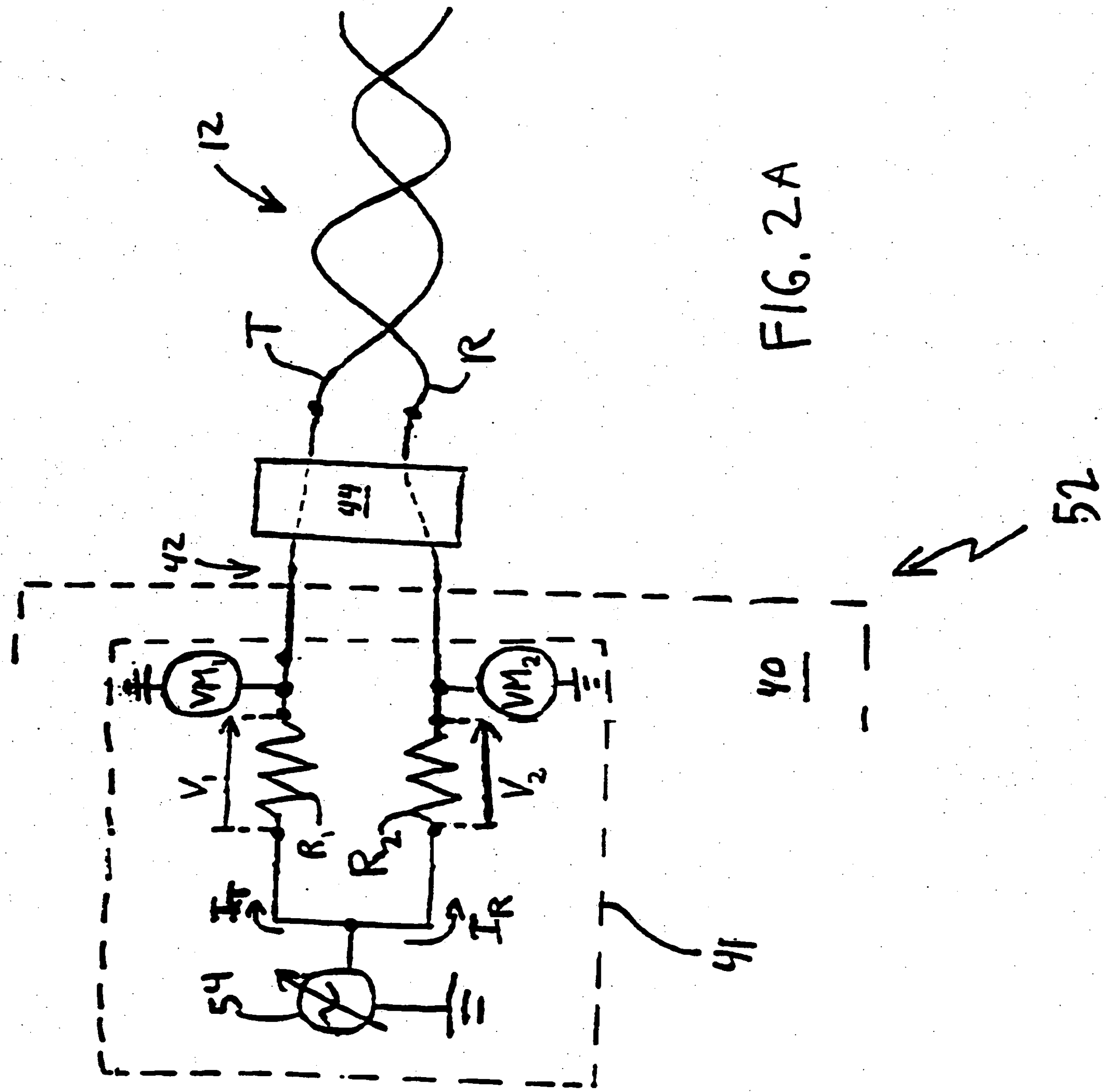


FIG. 2A

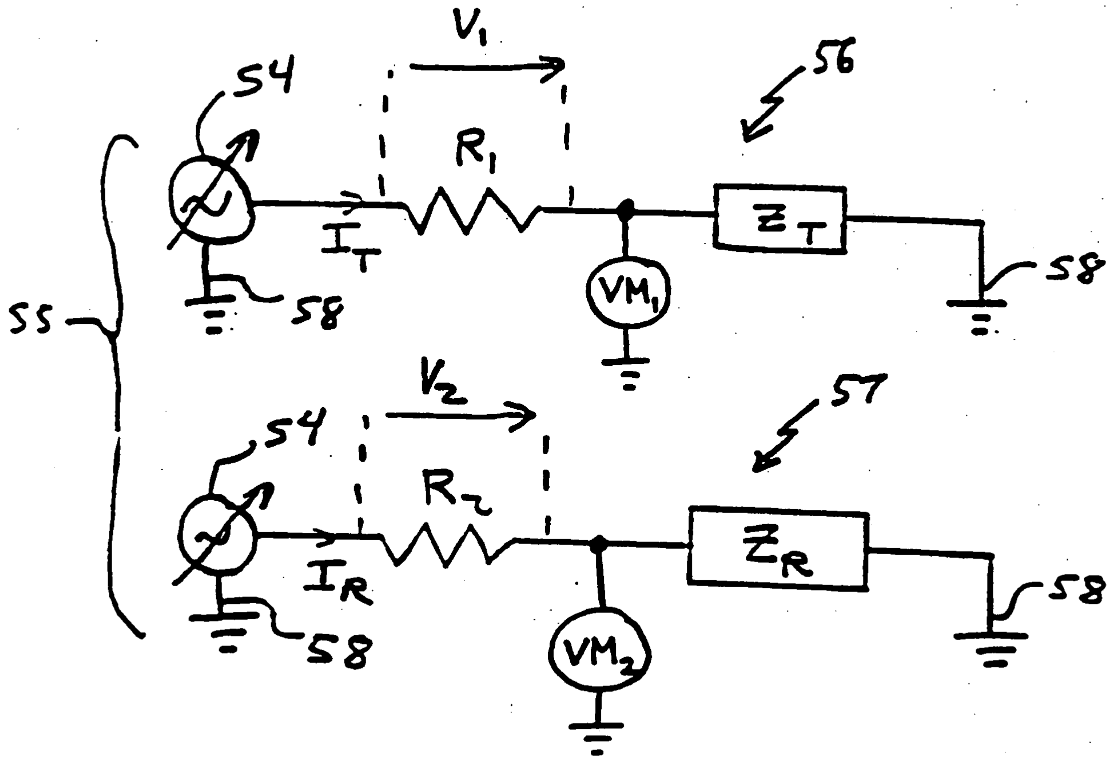


FIG. 2B

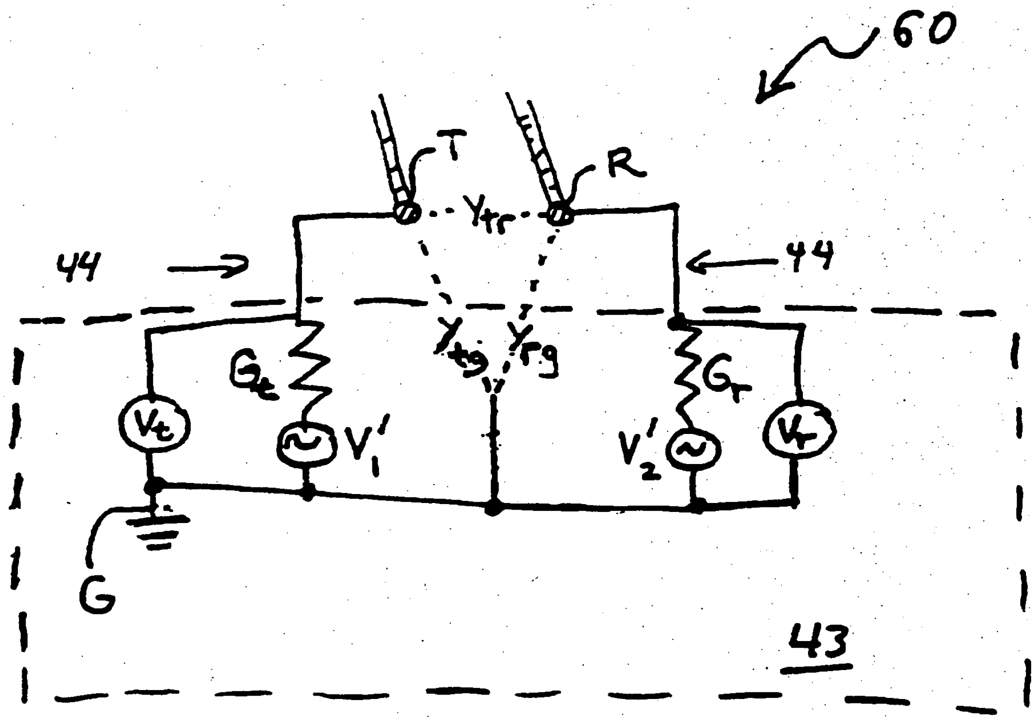


FIG. 2C

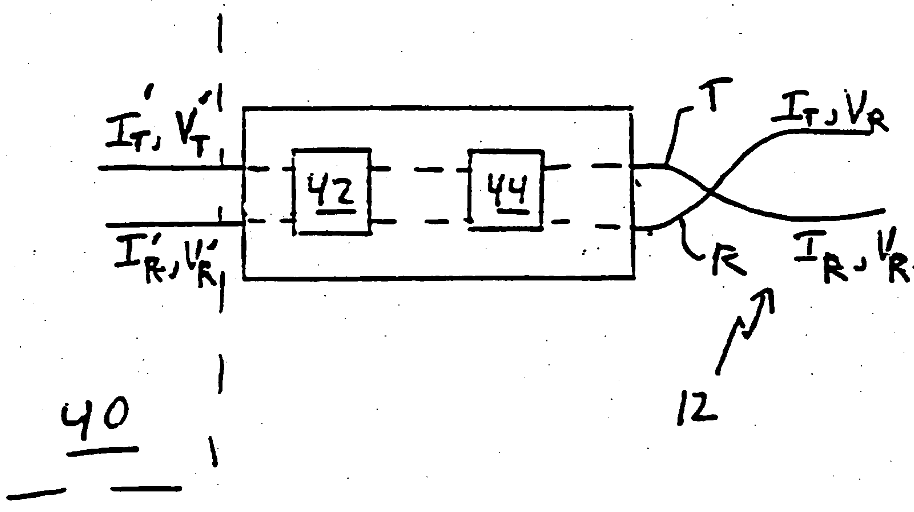


FIG. 3

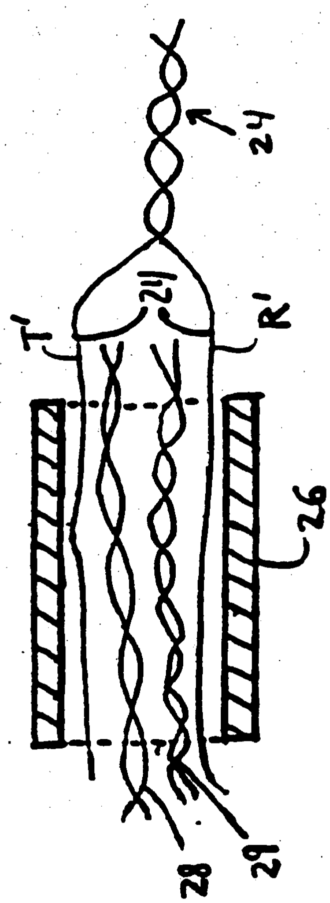


FIG. 4

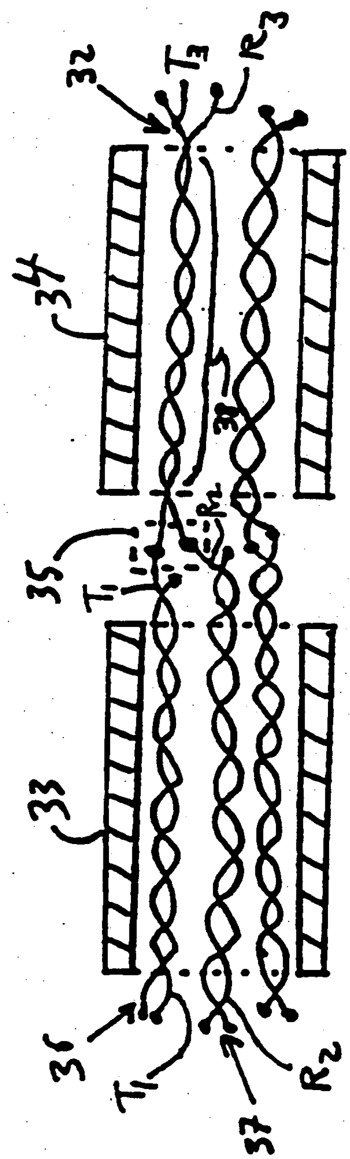


FIG. 5

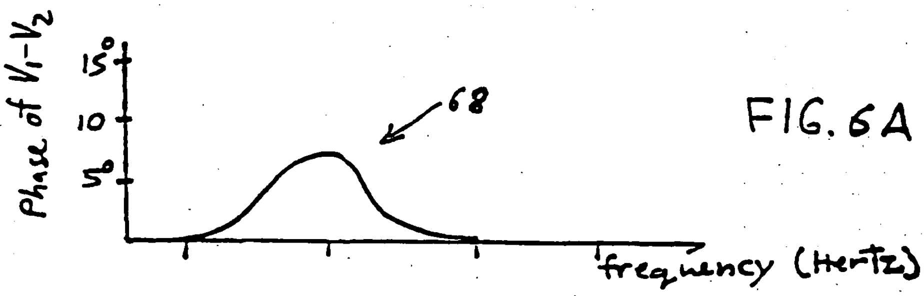

Phase of V_1-V_2
15°
10
5°
68
frequency (Hertz)

FIG. 6A

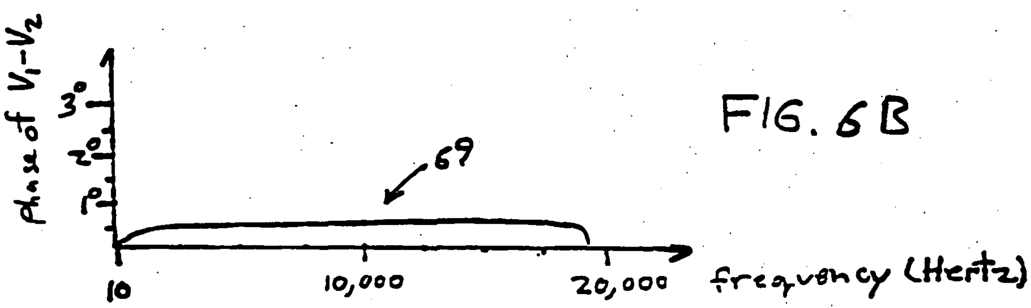
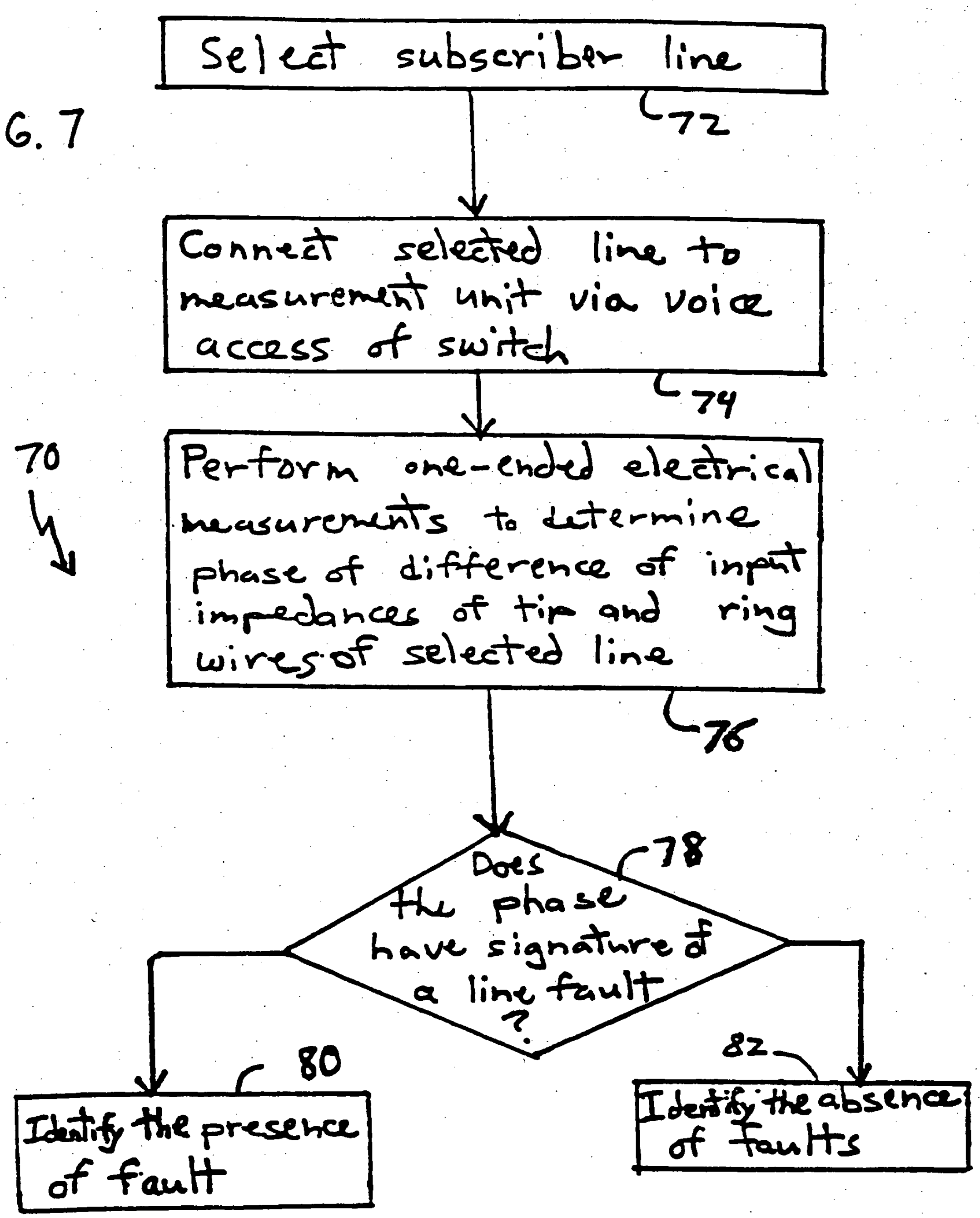

Phase of V_1-V_2
3°
2°
1°
69
10
10,000
20,000
frequency (Hertz)

FIG. 6B

FIG. 7


Select subscriber line
72
Connect selected line to measurement unit via voice access of switch
74
70
Perform one-ended electrical measurements to determine phase of difference of input impedances of tip and ring wires of selected line
76
Does the phase have signature of a line fault ?
78
80
Identify the presence of fault
82
Identify the absence of faults

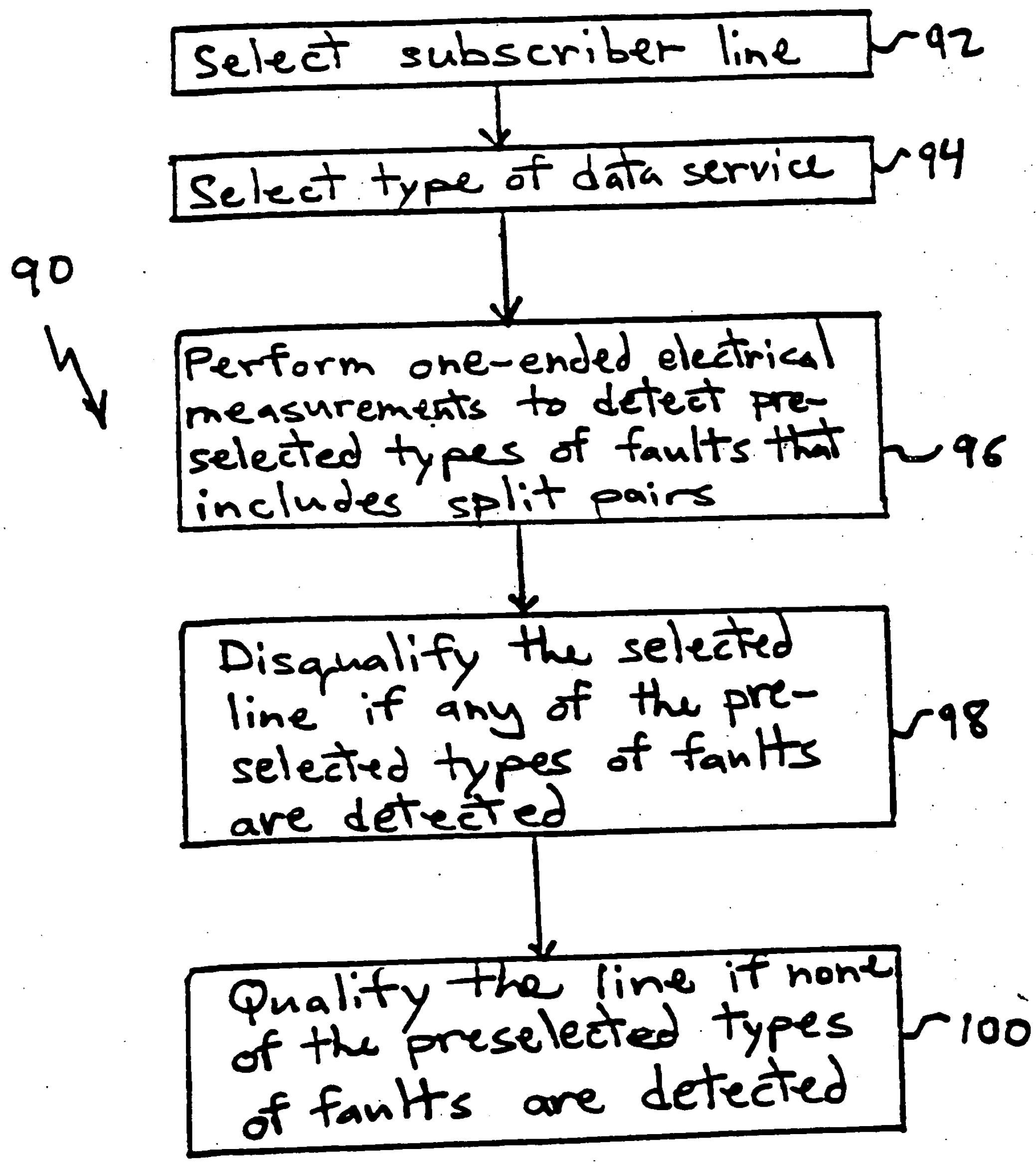

Select subscriber line
92
Select type of data service
94
90
Perform one-ended electrical measurements to detect pre-selected types of faults that includes split pairs
96
Disqualify the selected line if any of the pre-selected types of faults are detected
98
Qualify the line if none of the preselected types of faults are detected
100

FIG. 8

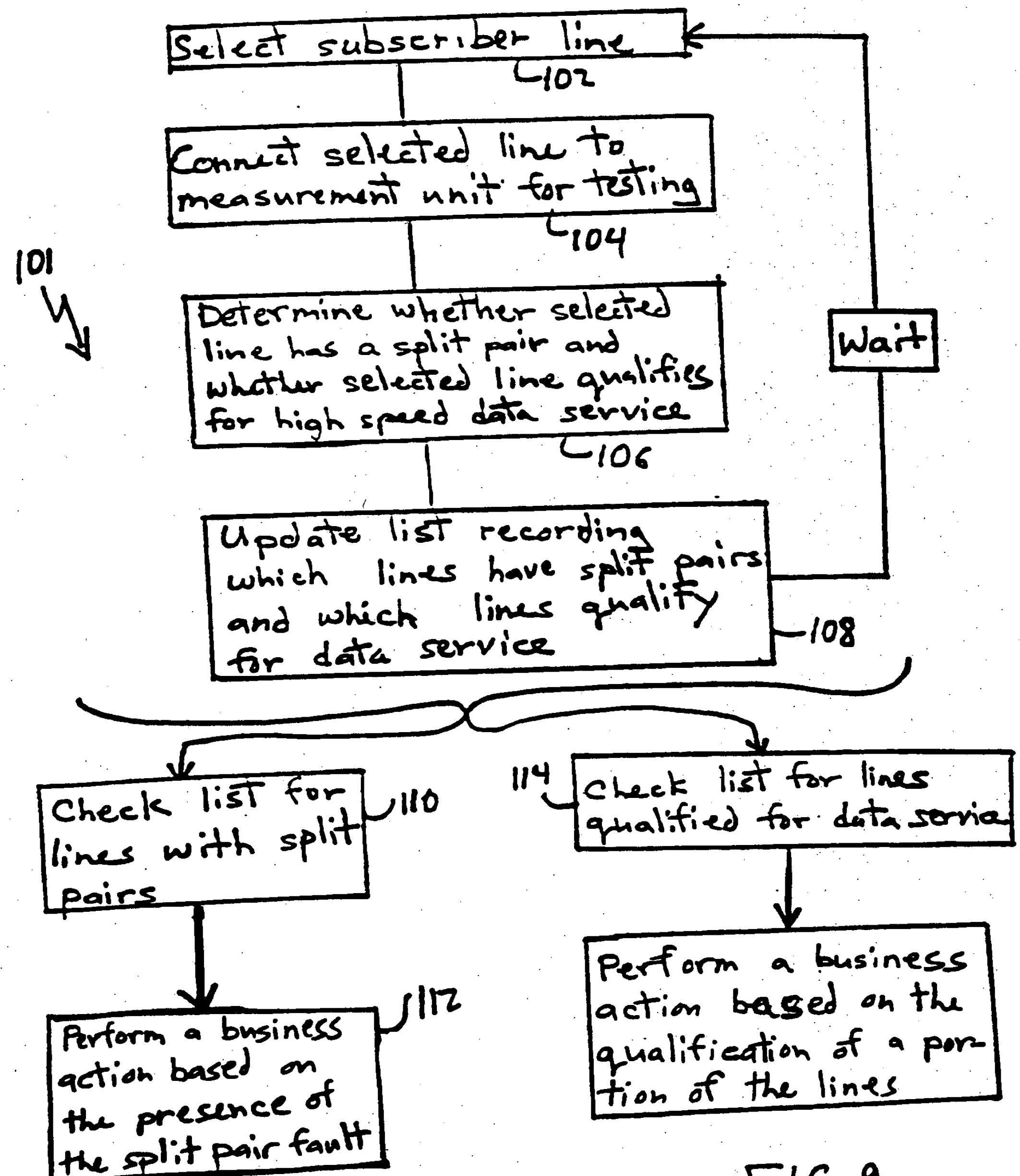

Select subscriber line
102
Connect selected line to measurement unit for testing
104
101
Determine whether selected line has a split pair and whether selected line qualifies for high speed data service
106
Wait
Update list recording which lines have split pairs and which lines qualify for data service
108
Check list for lines with split pairs
110
114
Check list for lines qualified for data service
Perform a business action based on the presence of the split pair fault
112
Perform a business action based on the qualification of a portion of the lines

FIG. 9

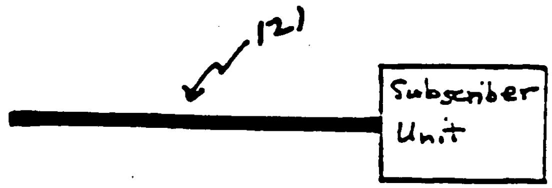


FIG. 10A

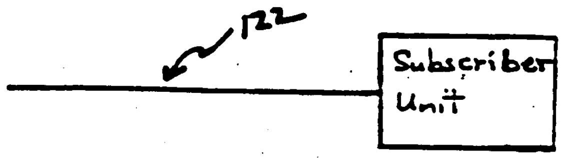


FIG. 10B

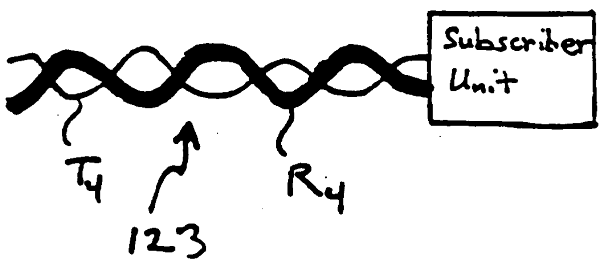


FIG. 10C

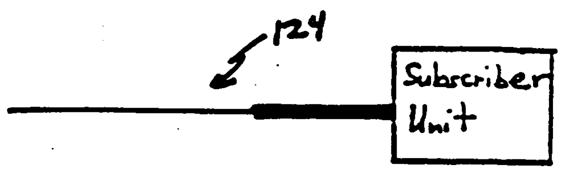


FIG. 10D

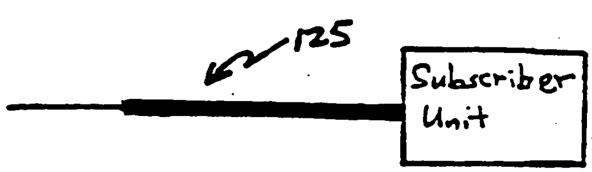


FIG. 10E

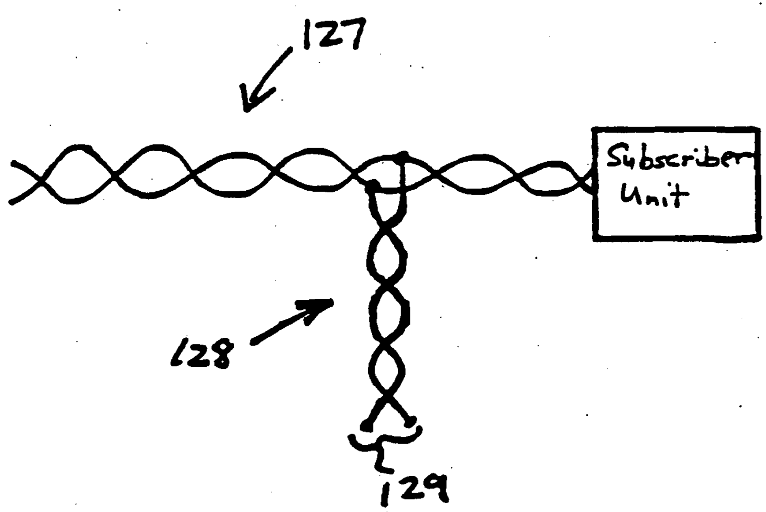


FIG. 11

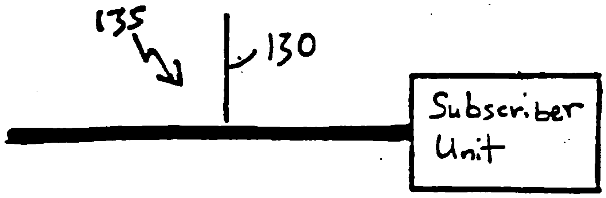


FIG. 12 A

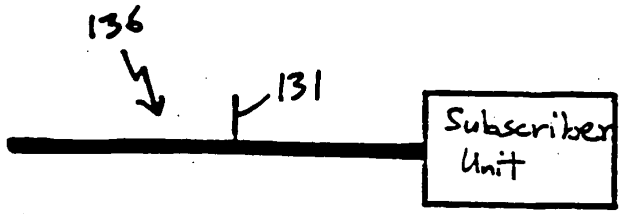


FIG. 12 B

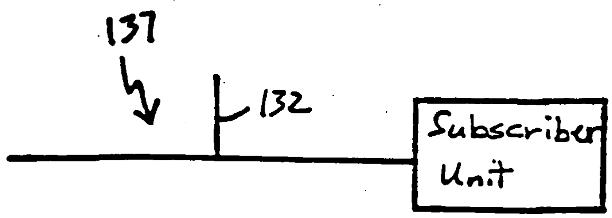


FIG. 12 C

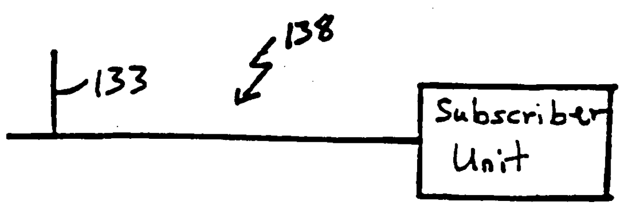


FIG. 12 D

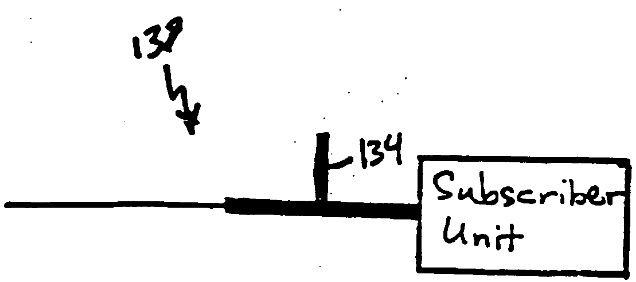


FIG. 12 E

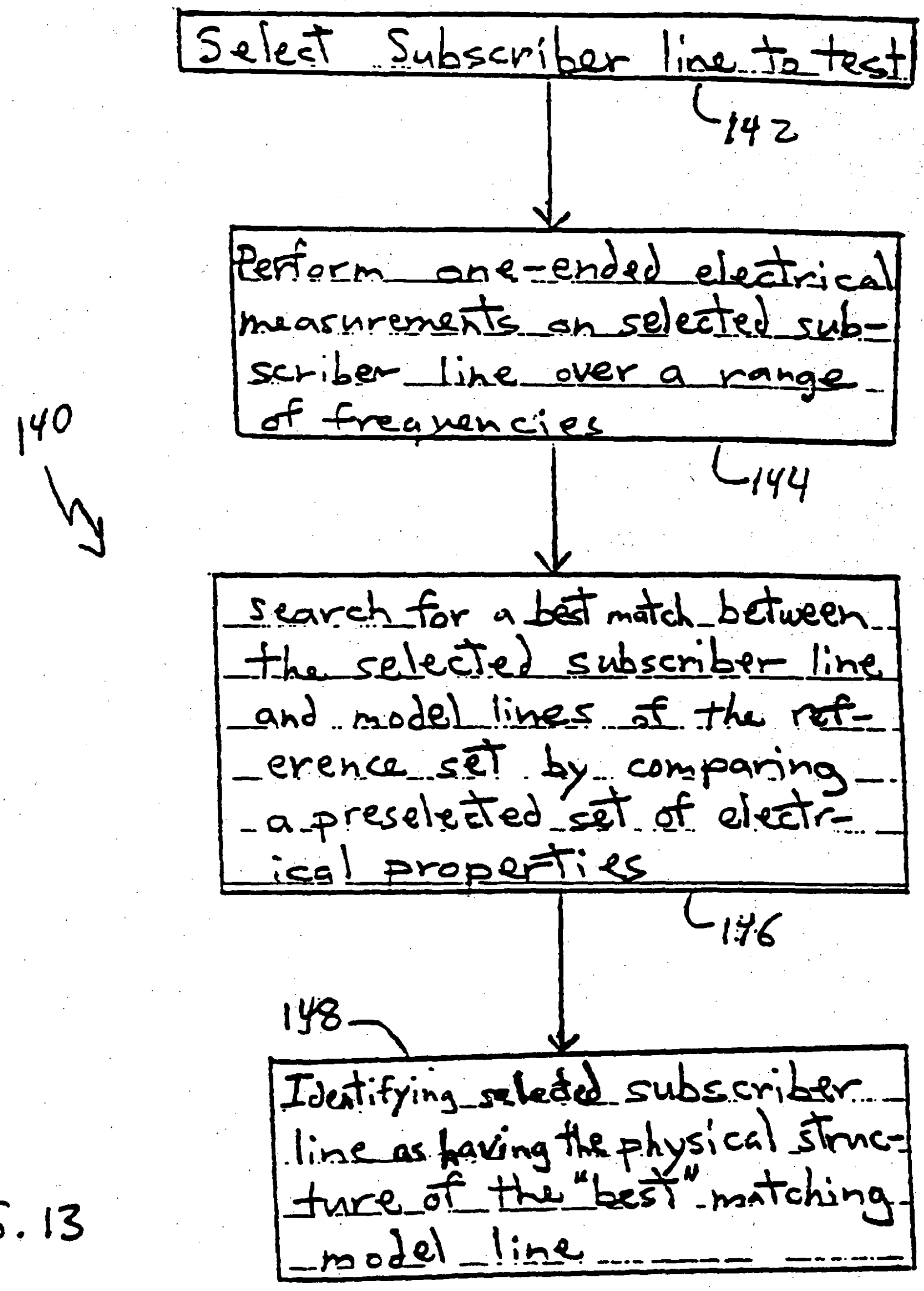

Select Subscriber line to test
142
Perform one-ended electrical measurements on selected subscriber line over a range of frequencies
144
140
Search for a best match between the selected subscriber line and model lines of the reference set by comparing a preselected set of electrical properties
146
148
Identifying selected subscriber line as having the physical structure of the "best" matching model line

FIG. 13

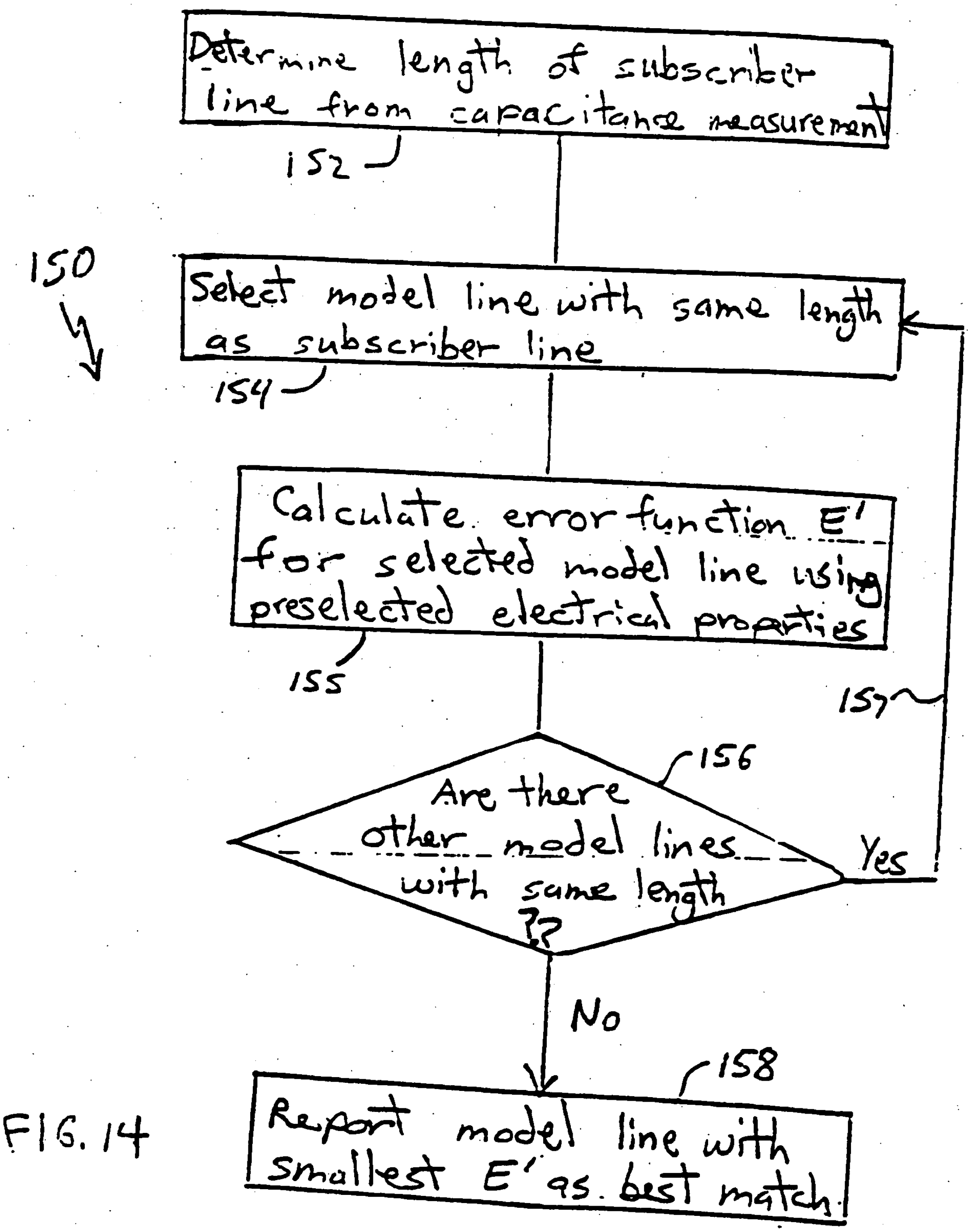

150
Determine length of subscriber line from capacitance measurement
152
Select model line with same length as subscriber line
154
Calculate error function E' for selected model line using preselected electrical properties
155
157
156
Are there other model lines with same length ??
Yes
No
158
Report model line with smallest E' as best match

FIG. 14

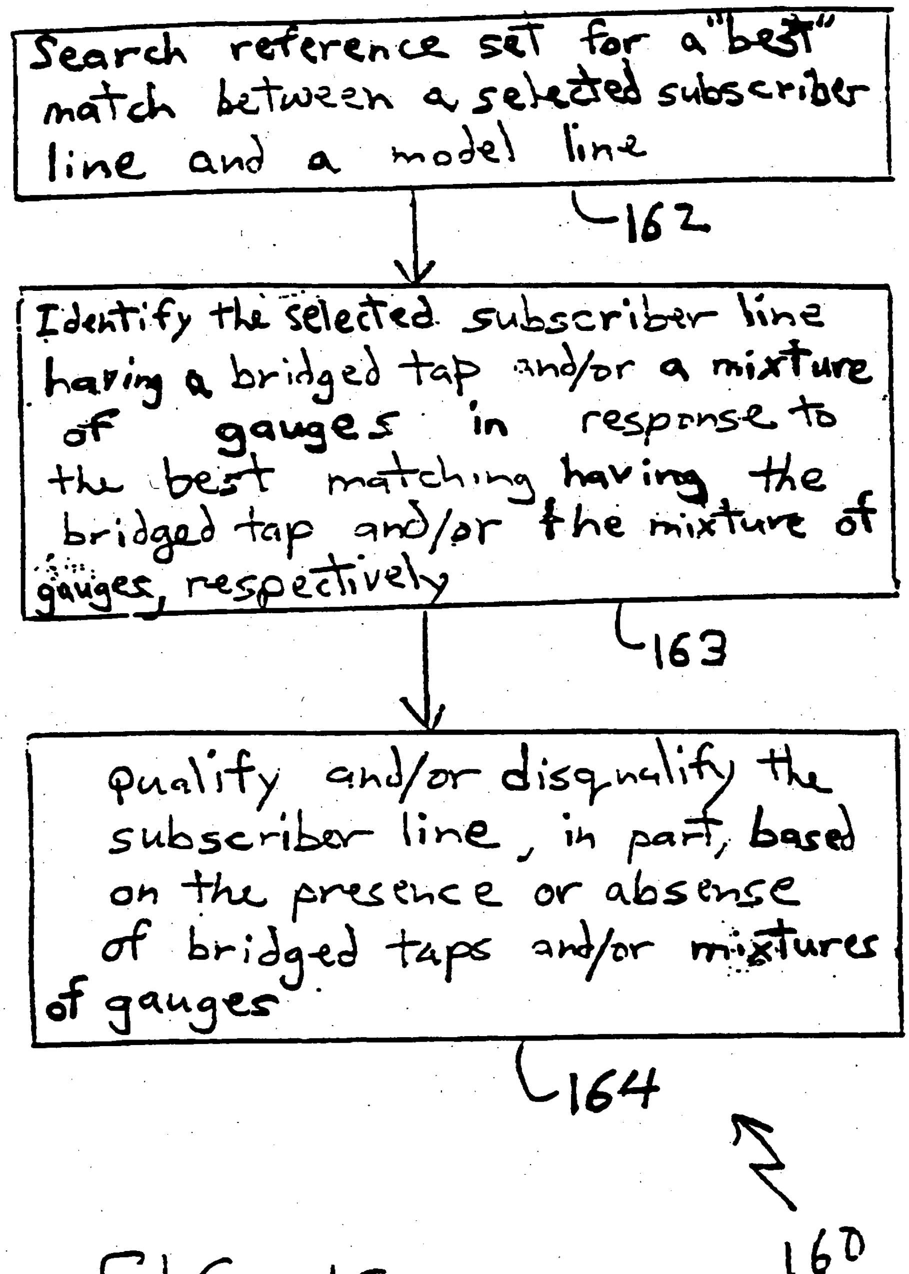

Search reference set for a "best" match between a selected subscriber line and a model line
162
Identify the selected subscriber line having a bridged tap and/or a mixture of gauges in response to the best matching having the bridged tap and/or the mixture of gauges, respectively
163
qualify and/or disqualify the subscriber line, in part, based on the presence or absense of bridged taps and/or mixtures of gauges
164
160

FIG. 15

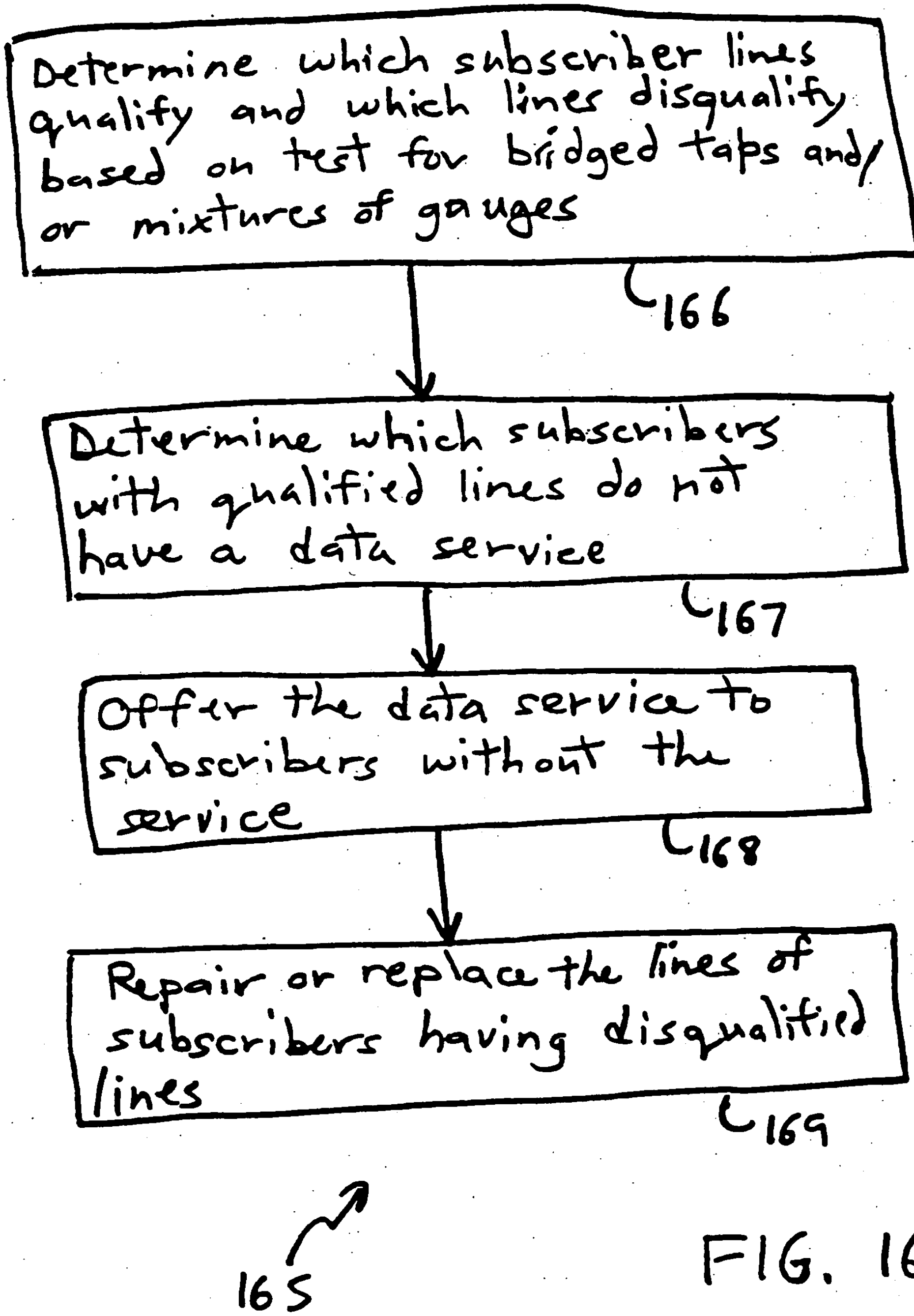

Determine which subscriber lines qualify and which lines disqualify based on test for bridged taps and/or mixtures of gauges
166
Determine which subscribers with qualified lines do not have a data service
167
Offer the data service to subscribers without the service
168
Repair or replace the lines of subscribers having disqualified lines
169
165

FIG. 16

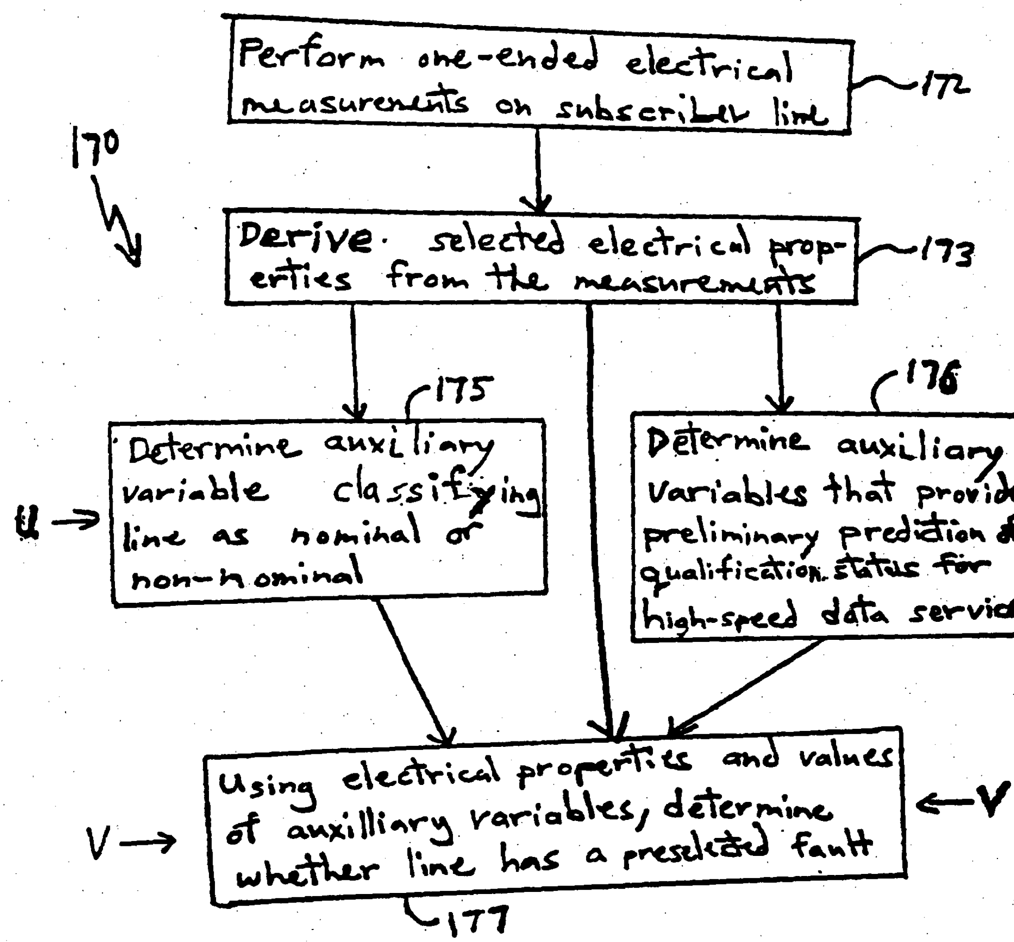

Perform one-ended electrical measurements on subscriber line
172
170
Derive selected electrical properties from the measurements
173
175
Determine auxiliary variable classifying line as nominal or non-nominal
U
176
Determine auxiliary variables that provide preliminary prediction of qualification status for high-speed data service
U
Using electrical properties and values of auxilliary variables, determine whether line has a preselected fault
V
V
177

FIG. 17

FIG. 18A

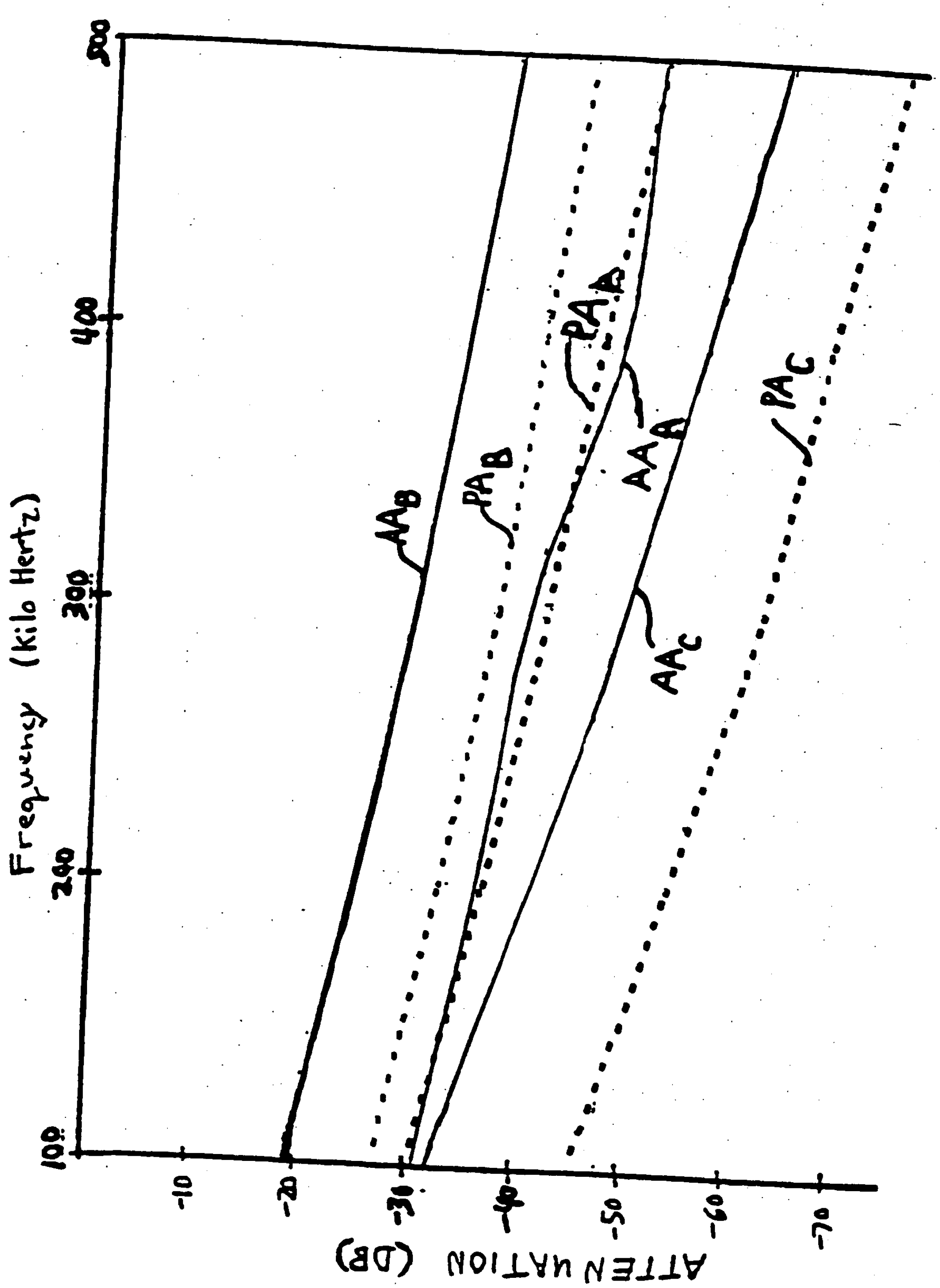

Frequency (Kilo Hertz)
100
200
300
400
500
-10
-20
-30
-40
-50
-60
-70
ATTENUATION (DB)
AAB
PAB
PAA
AAA
AAC
PAC

FIG. 17B

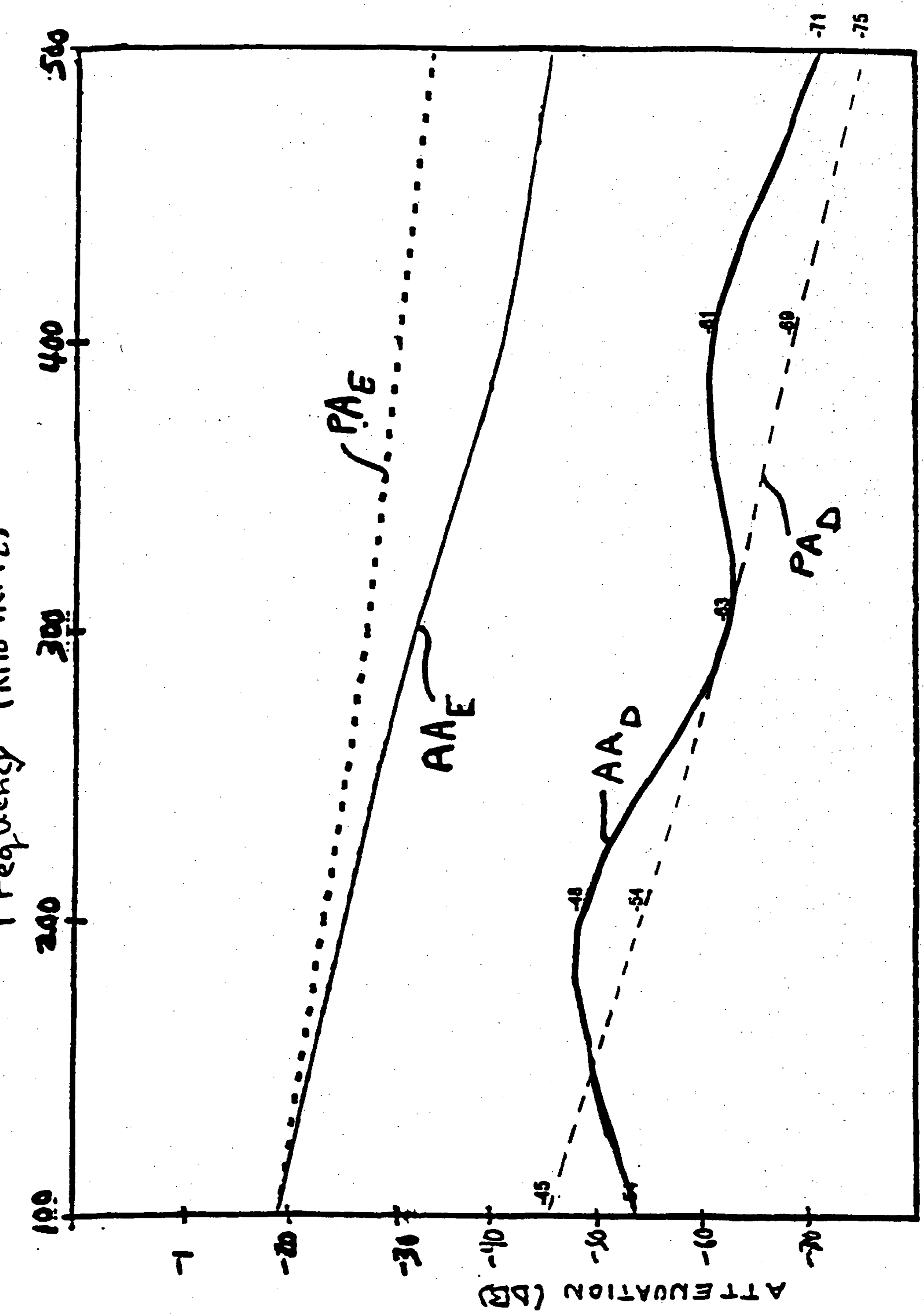
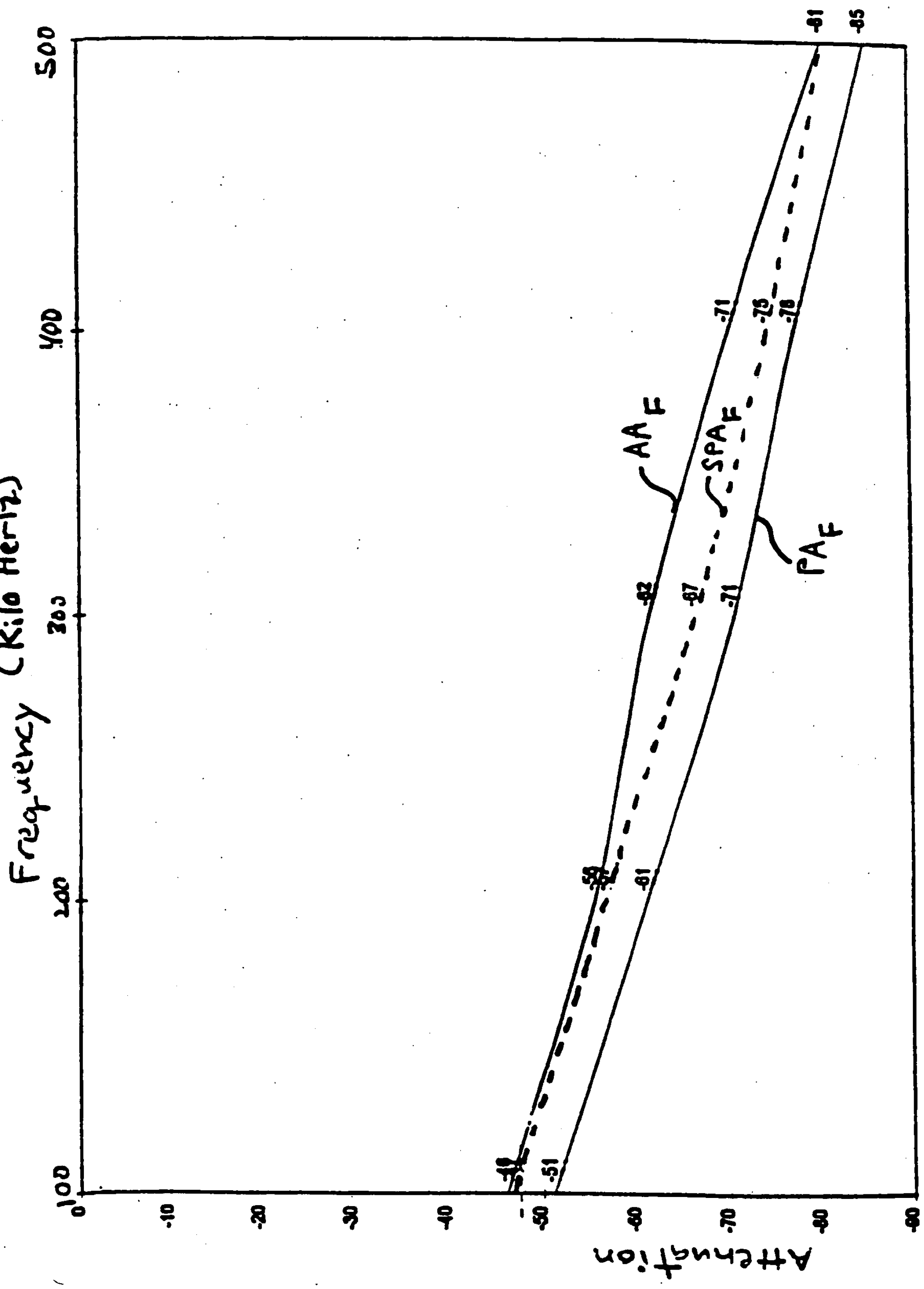

Frequency (Kilo Hertz)
100
200
300
400
500
ATTENUATION (dB)
-20
-30
-40
-50
-60
-70
PA_E
AA_E
AA_D
PA_D
-45
-54
-48
-63
-61
-60
-71
-75

FIG. 18C


Frequency (Kilo Hertz)
Attenuation
AA_F
SPA_F
PA_F
100
200
300
400
500
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-51
-58
-61
-62
-67
-71
-75
-78
-81
-85

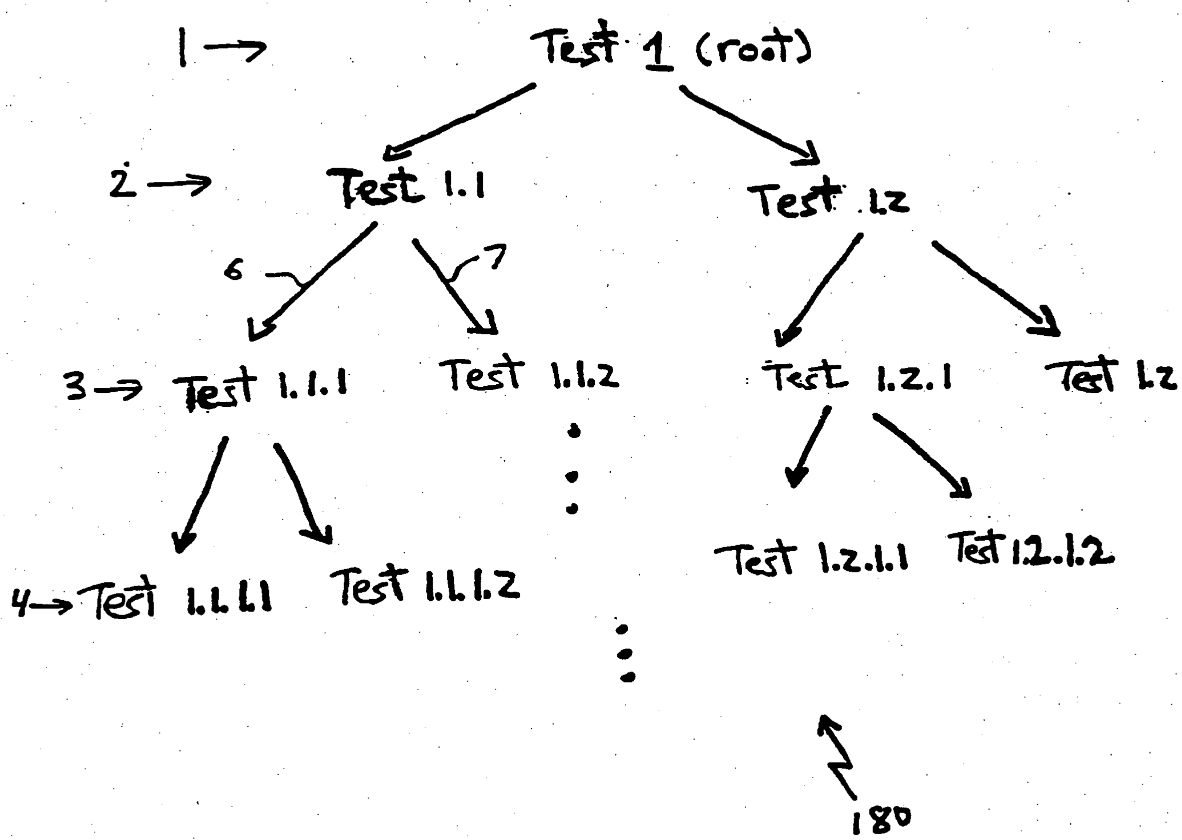
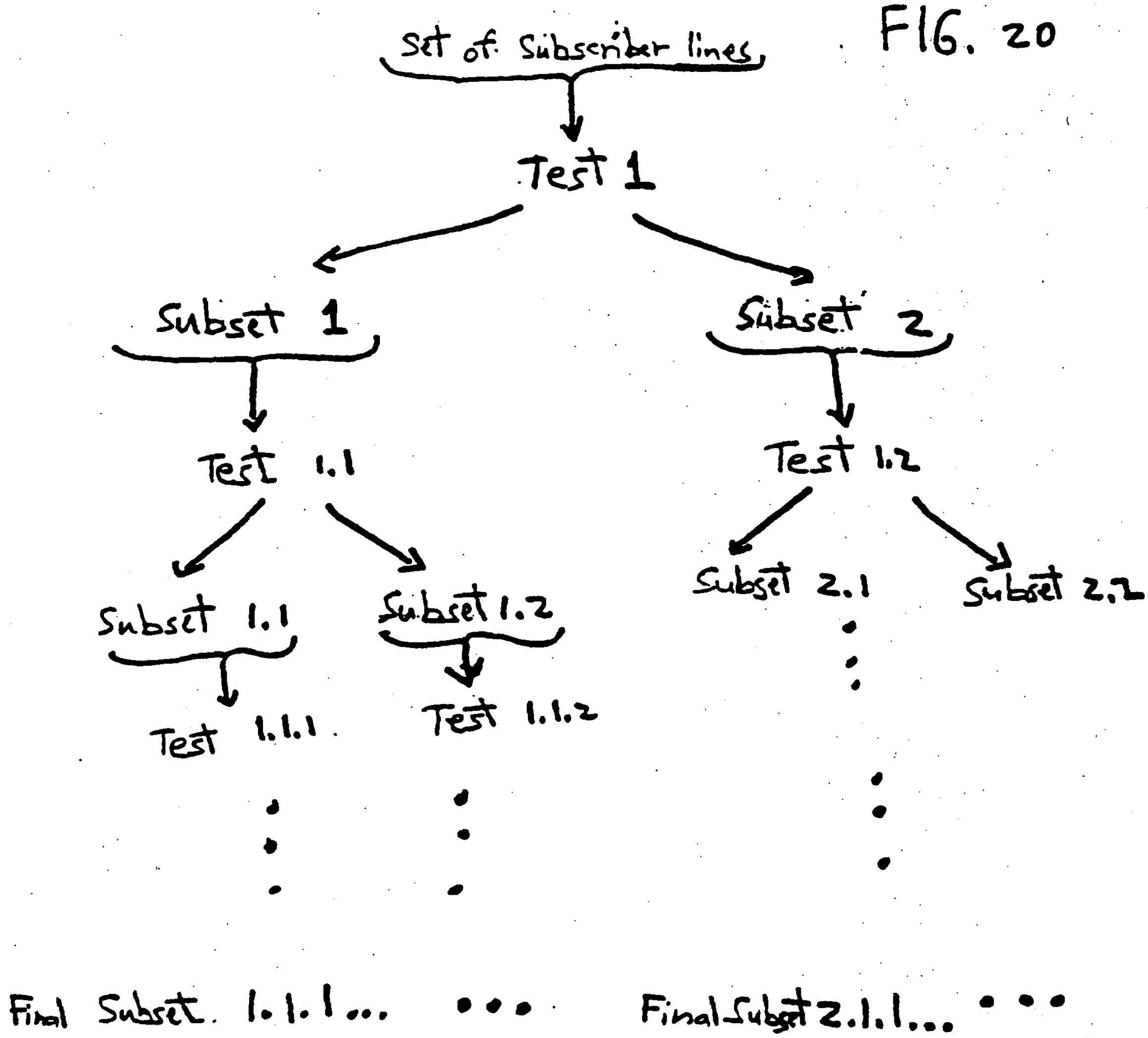

1 →
Test 1 (root)
2 →
Test 1.1
Test 1.2
6
7
3 →
Test 1.1.1
Test 1.1.2
Test 1.2.1
Test 1.2
4 →
Test 1.1.1.1
Test 1.1.1.2
Test 1.2.1.1
Test 1.2.1.2
180

FIG. 19

FIG. 20


Set of Subscriber lines
Test 1
Subset 1
Subset 2
Test 1.1
Test 1.2
Subset 1.1
Subset 1.2
Subset 2.1
Subset 2.2
Test 1.1.1
Test 1.1.2
Final Subset 1.1.1...
Final Subset 2.1.1...

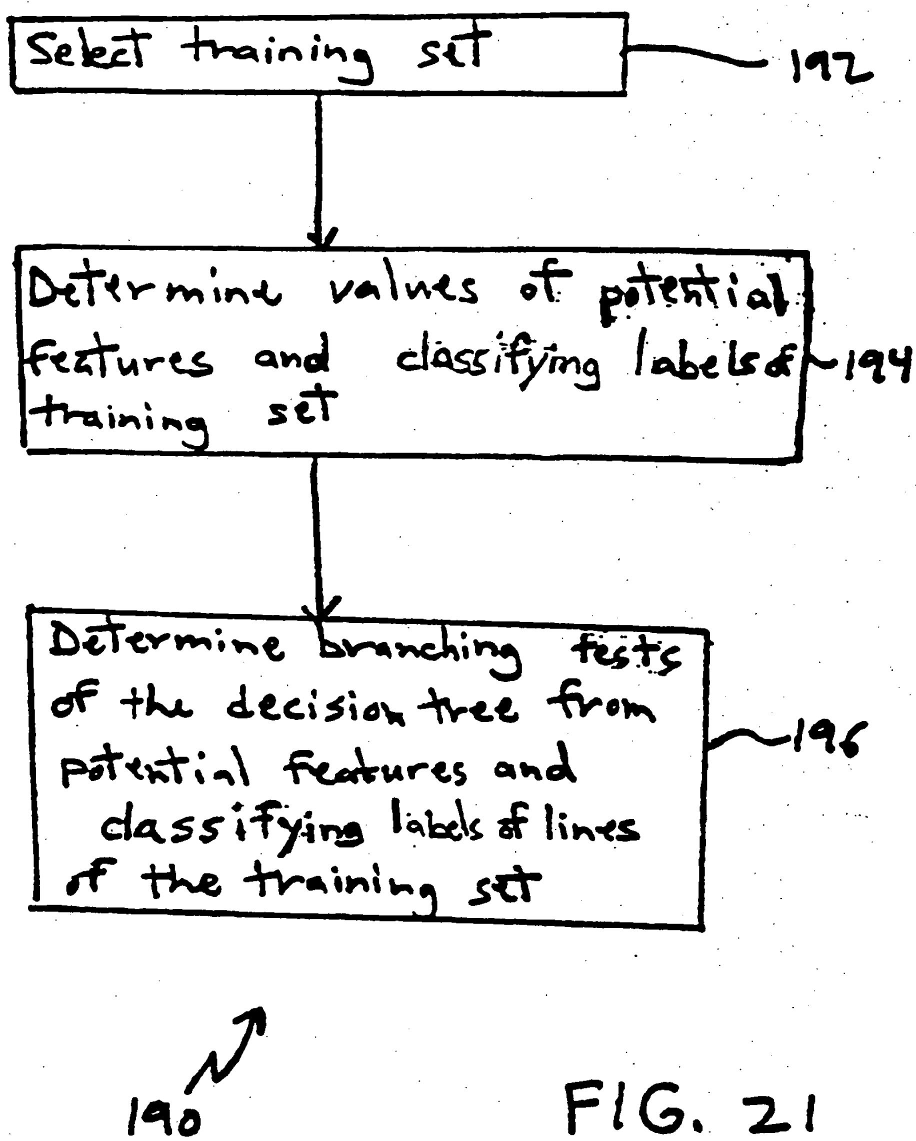

Select training set
192
Determine values of potential features and classifying labels of training set
194
Determine branching tests of the decision tree from potential features and classifying labels of lines of the training set
196
190

FIG. 21

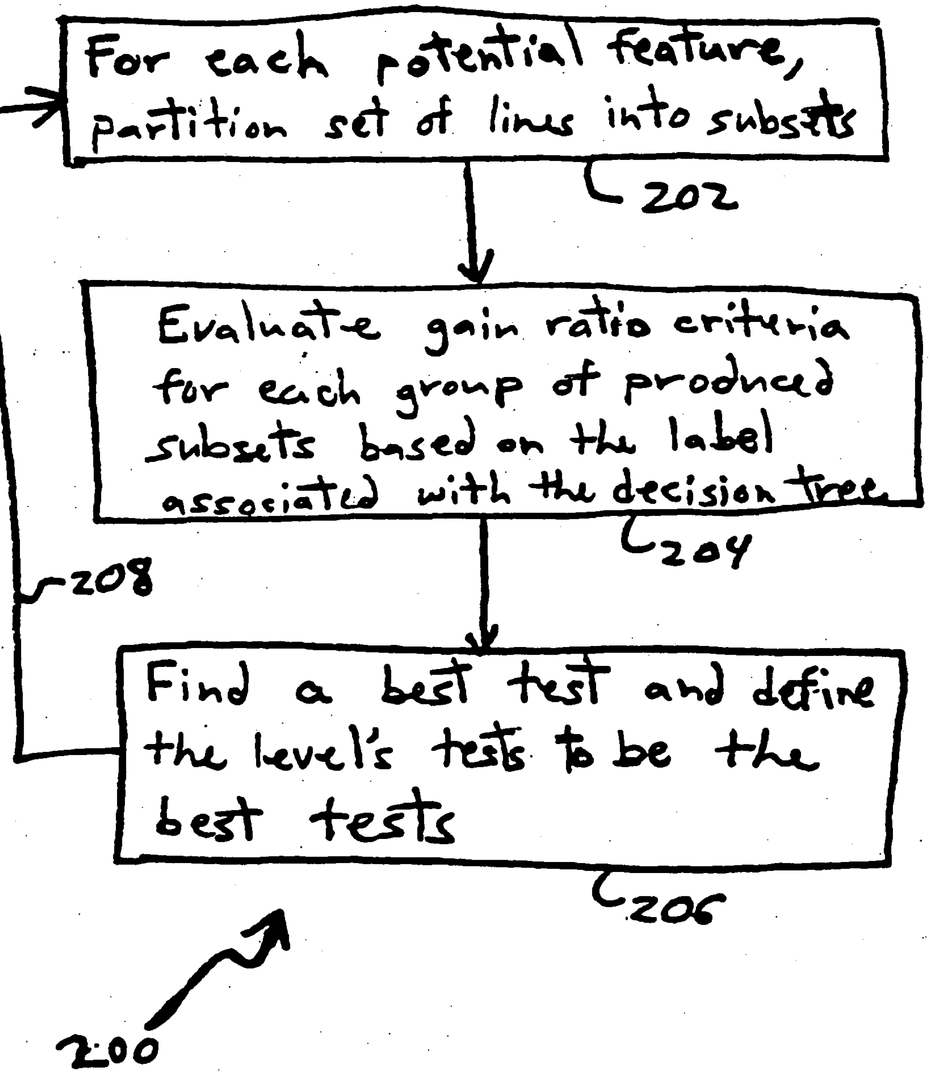

For each potential feature, partition set of lines into subsets
202
Evaluate gain ratio criteria for each group of produced subsets based on the label associated with the decision tree
204
208
Find a best test and define the level's tests to be the best tests
206
200

FIG. 22

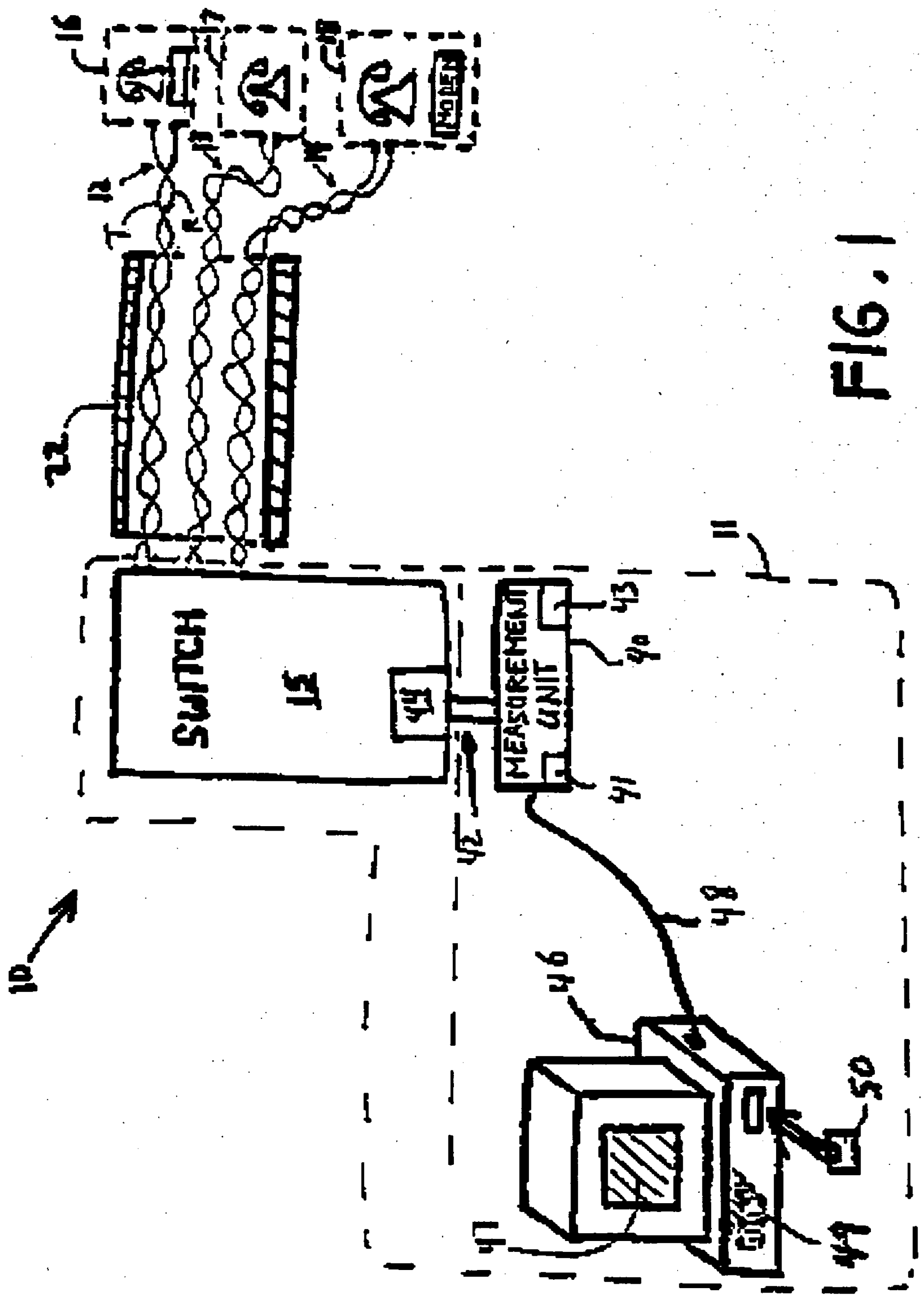

SWITCH
15
44
MEASUREMENT UNIT
MODEM
10
11
16
22
40
41
42
43
46
47
48
49
50

FIG. 1

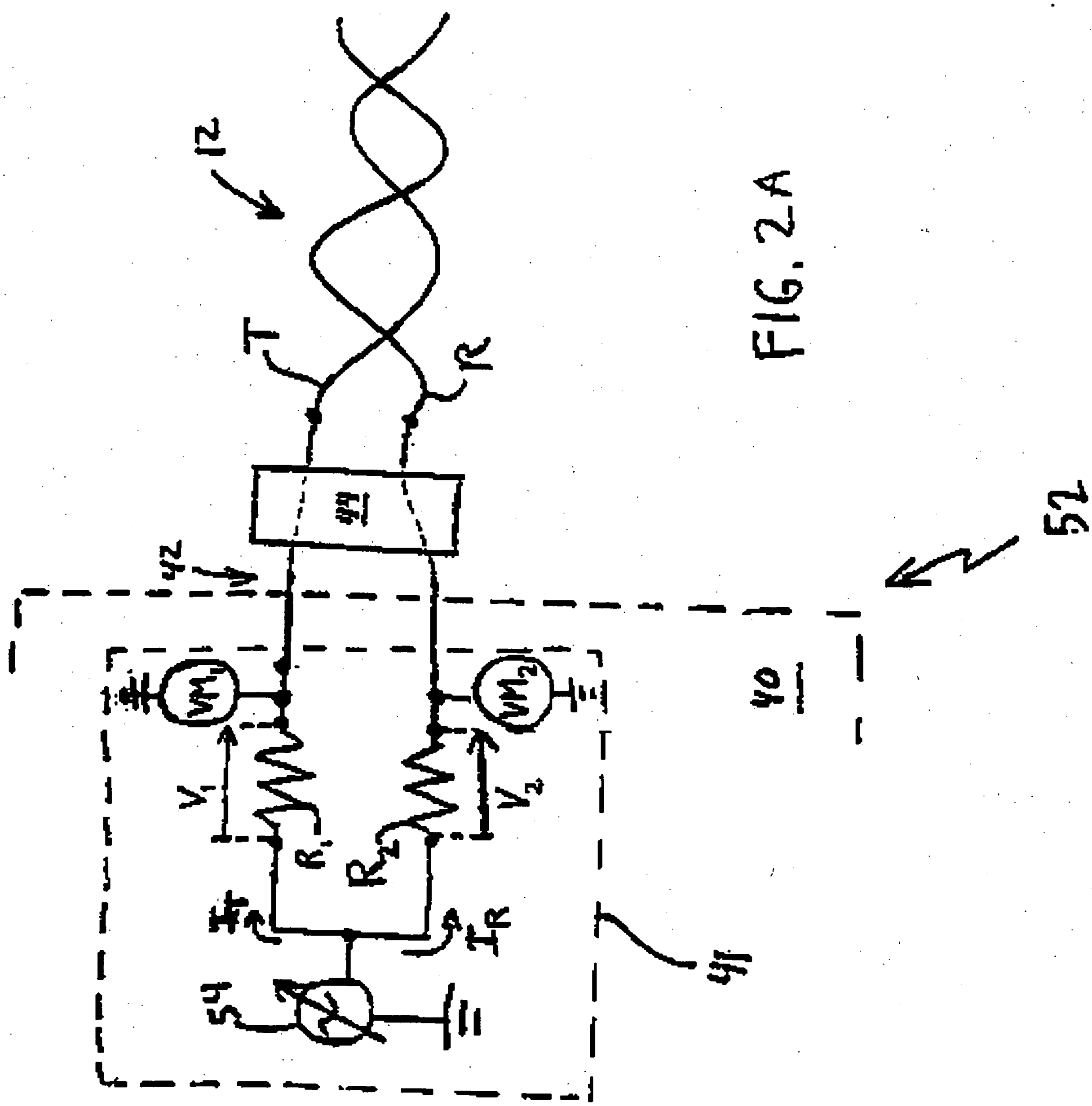


FIG. 2A

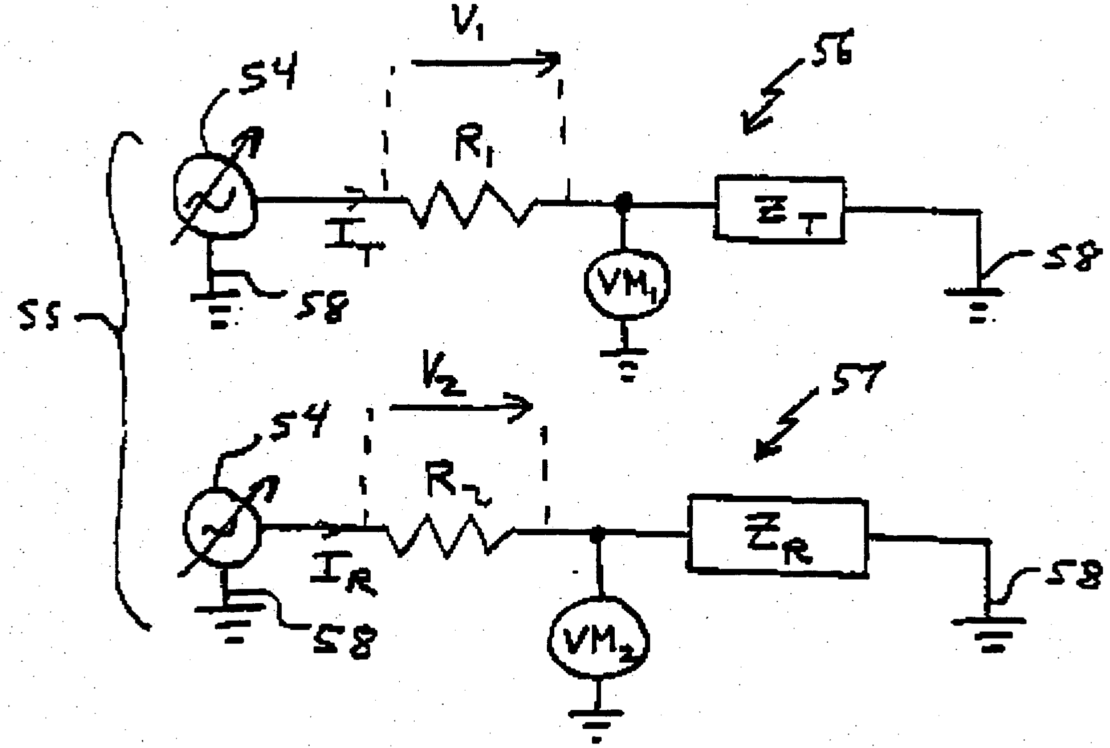


FIG. 2B

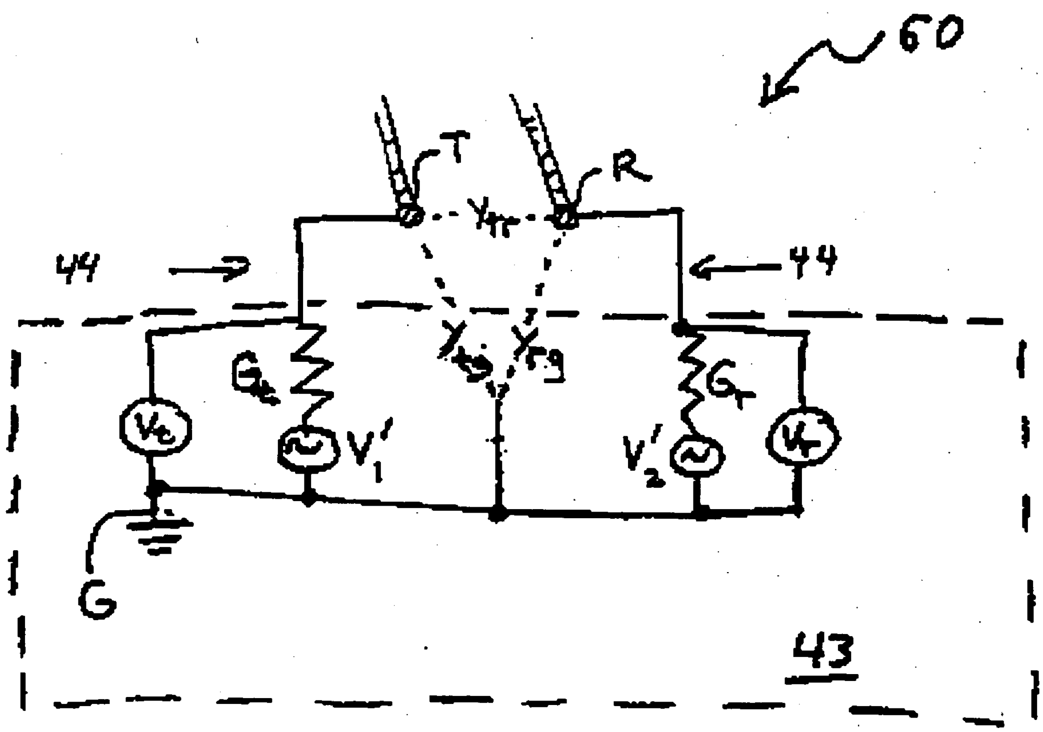


FIG. 2C

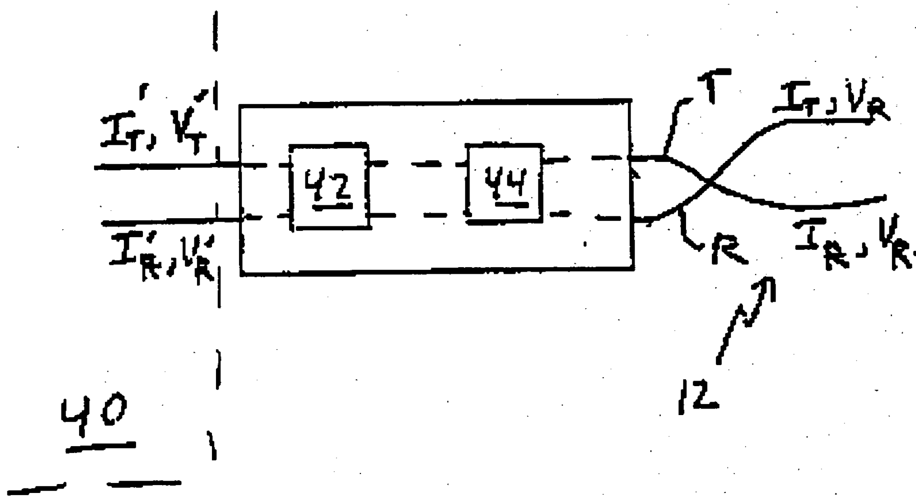


FIG. 3

FIG. 4

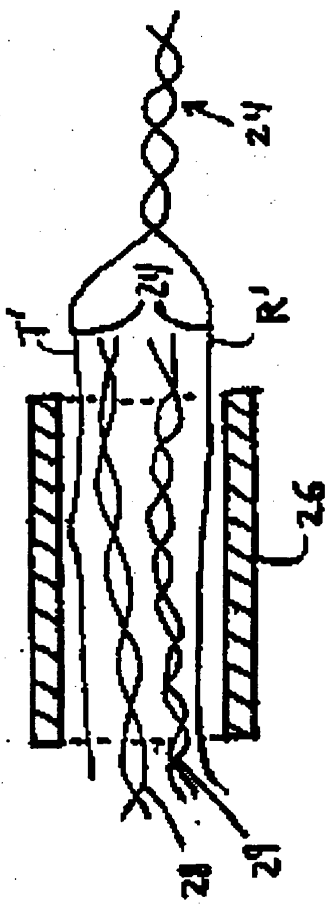
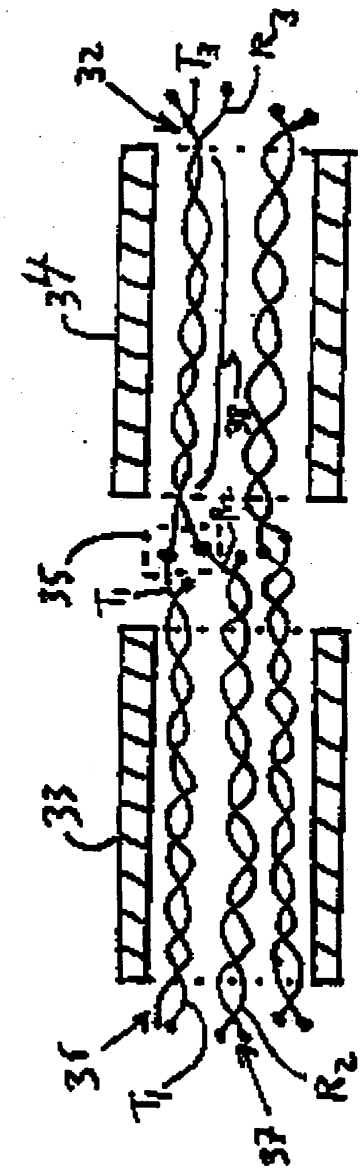


FIG. 5



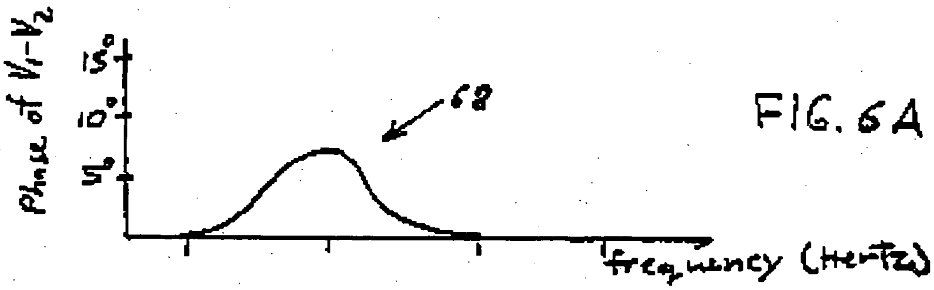

Phase of V_1-V_2
15°
10°
5°
68
frequency (Hertz)

FIG. 6A

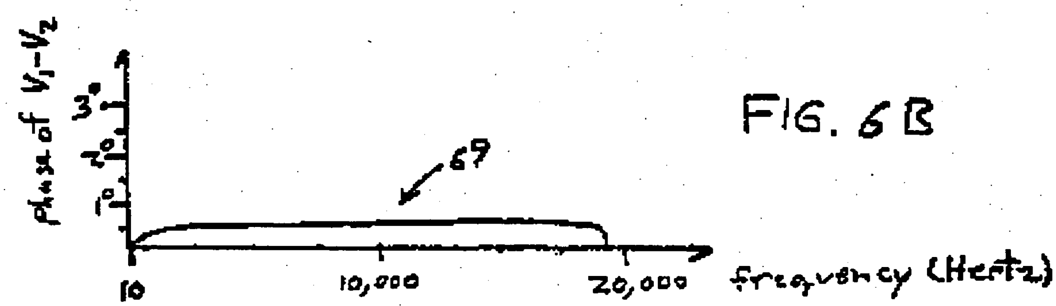

Phase of V_1-V_2
3°
2°
1°
67
10
10,000
20,000
frequency (Hertz)

FIG. 6B

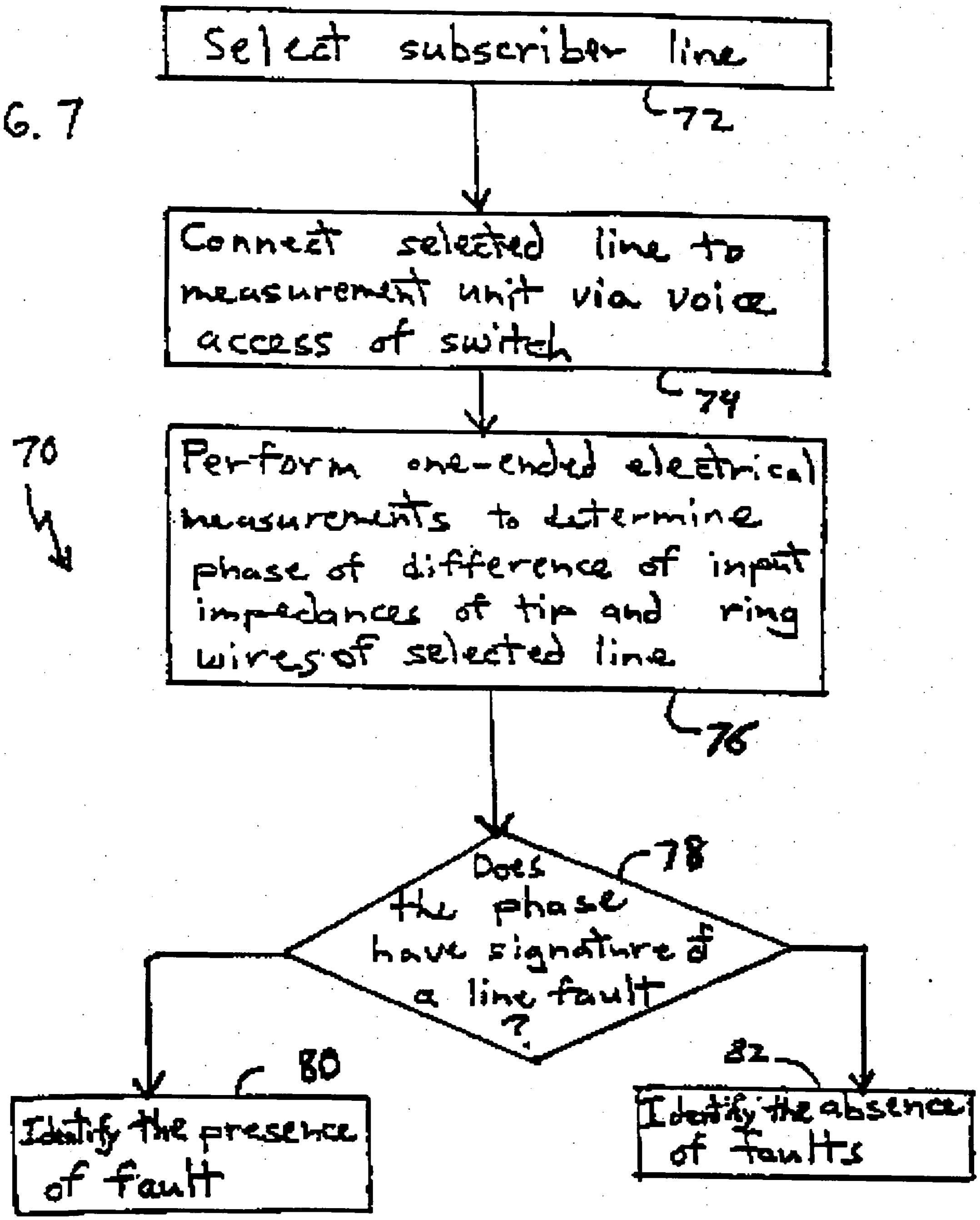

Select subscriber line
72
Connect selected line to measurement unit via voice access of switch
74
70
Perform one-ended electrical measurements to determine phase of difference of input impedances of tip and ring wires of selected line
76
Does the phase have signature of a line fault ?
78
80
Identify the presence of fault
82
Identify the absence of faults

FIG. 7

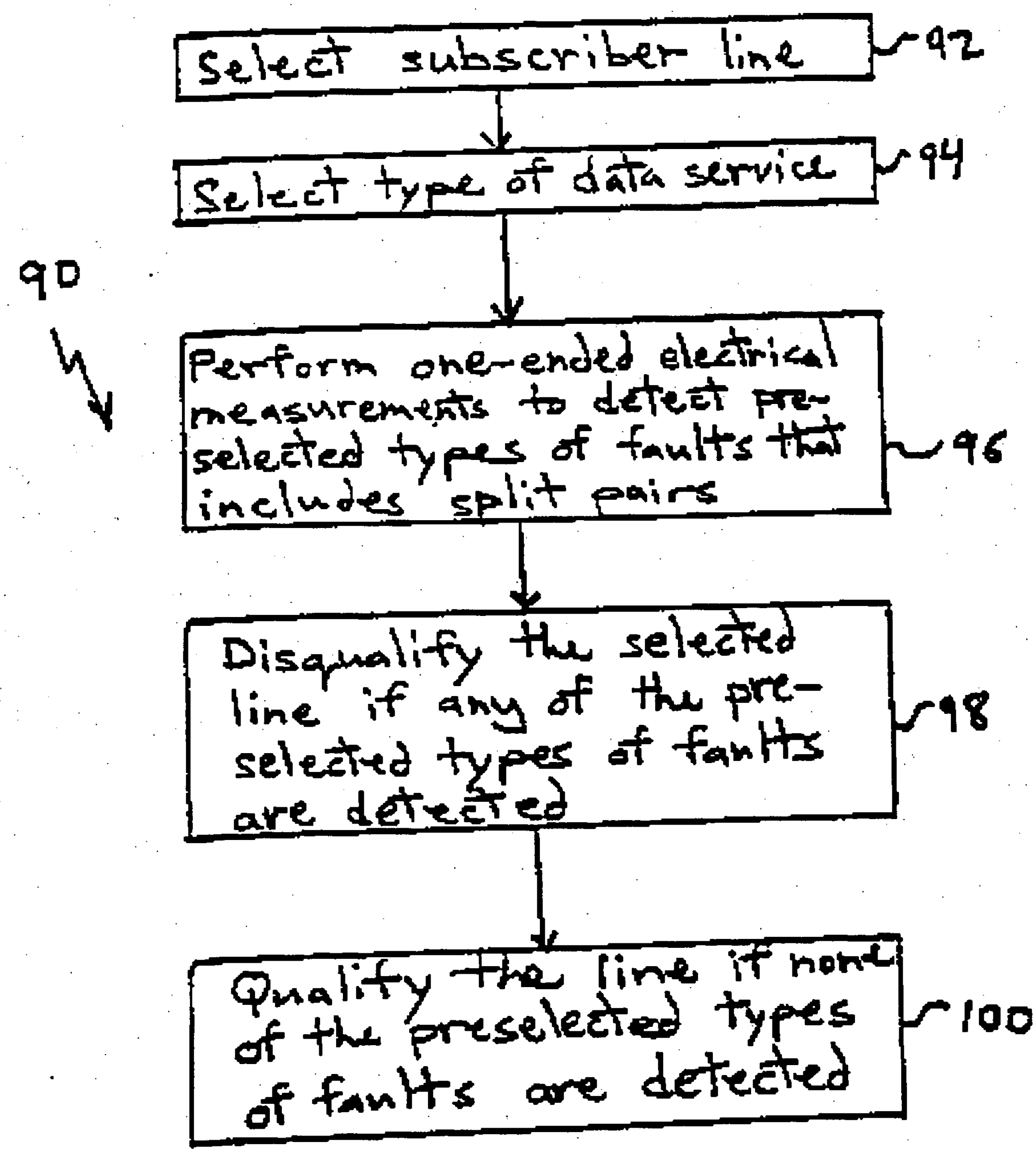

Select subscriber line
92
Select type of data service
94
90
Perform one-ended electrical measurements to detect pre-selected types of faults that includes split pairs
96
Disqualify the selected line if any of the pre-selected types of faults are detected
98
Qualify the line if none of the preselected types of faults are detected
100

FIG. 8

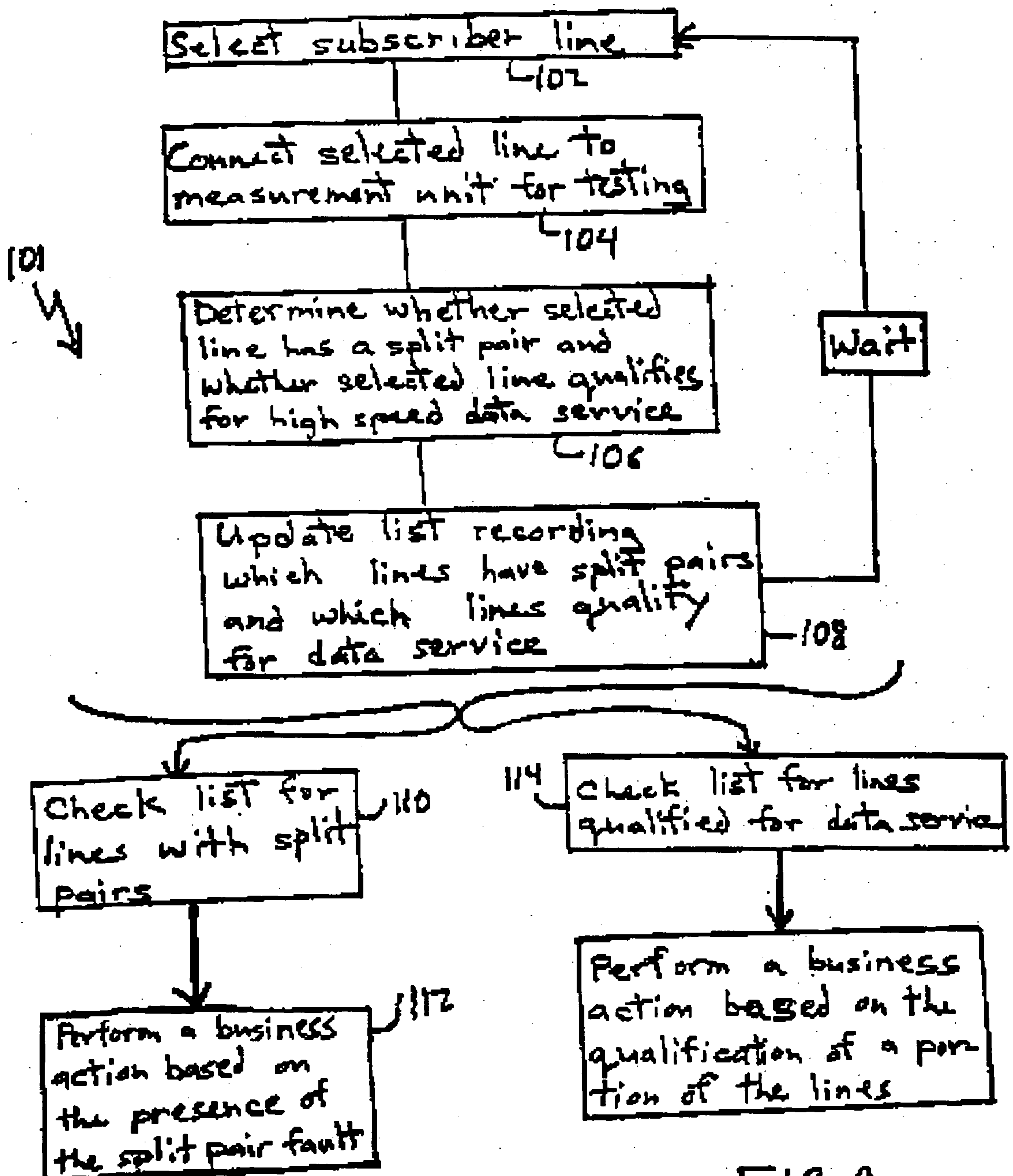

Select subscriber line
102
Connect selected line to measurement unit for testing
104
101
Determine whether selected line has a split pair and whether selected line qualifies for high speed data service
106
Wait
Update list recording which lines have split pairs and which lines quality for data service
108
Check list for lines with split pairs
110
114
check list for lines qualified for data service
Perform a business action based on the presence of the split pair fault
112
Perform a business action based on the qualification of a portion of the lines

FIG. 9

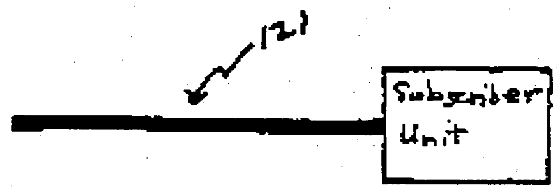


FIG. 10 A

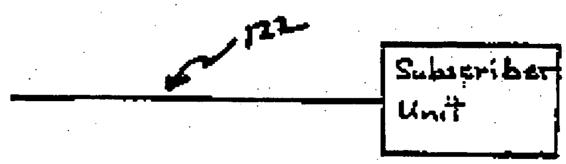


FIG. 10 B

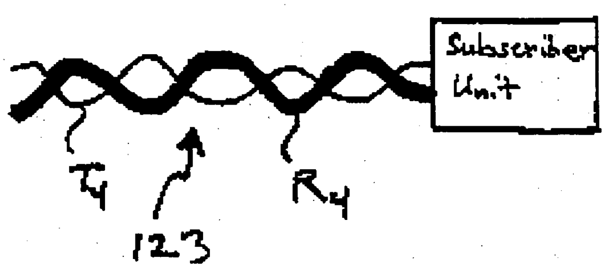


FIG. 10 C

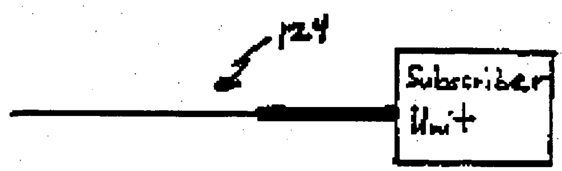


FIG. 10 D

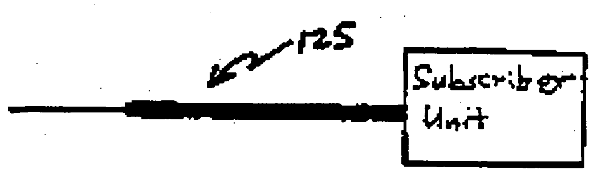


FIG. 10 E

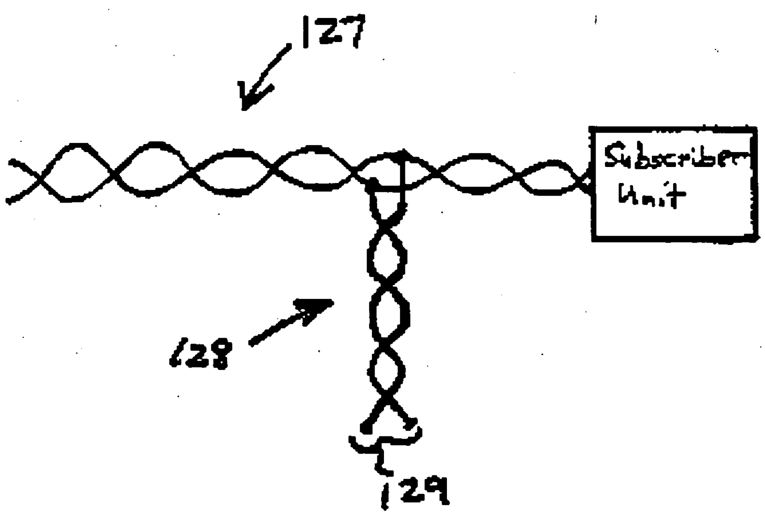


FIG. 11

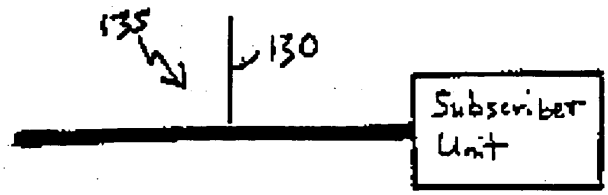


FIG. 12 A

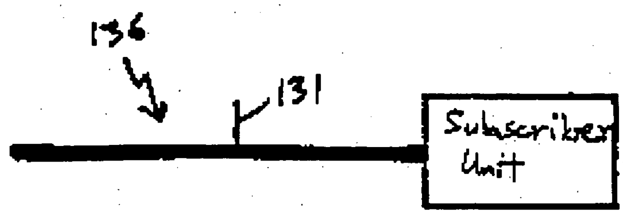


FIG. 12 B

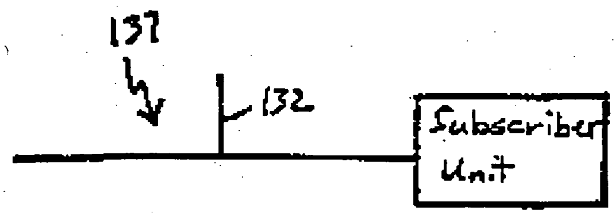


FIG. 12 C

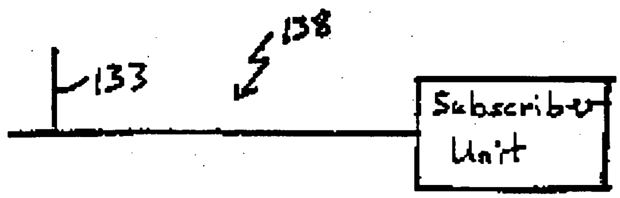


FIG. 12 D

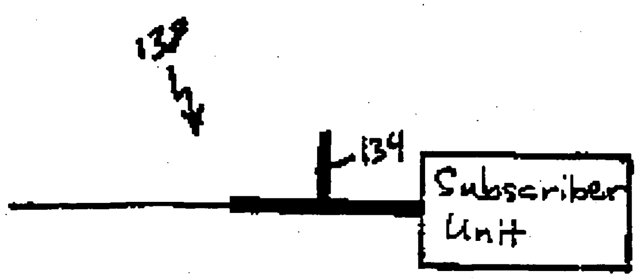


FIG. 12 E

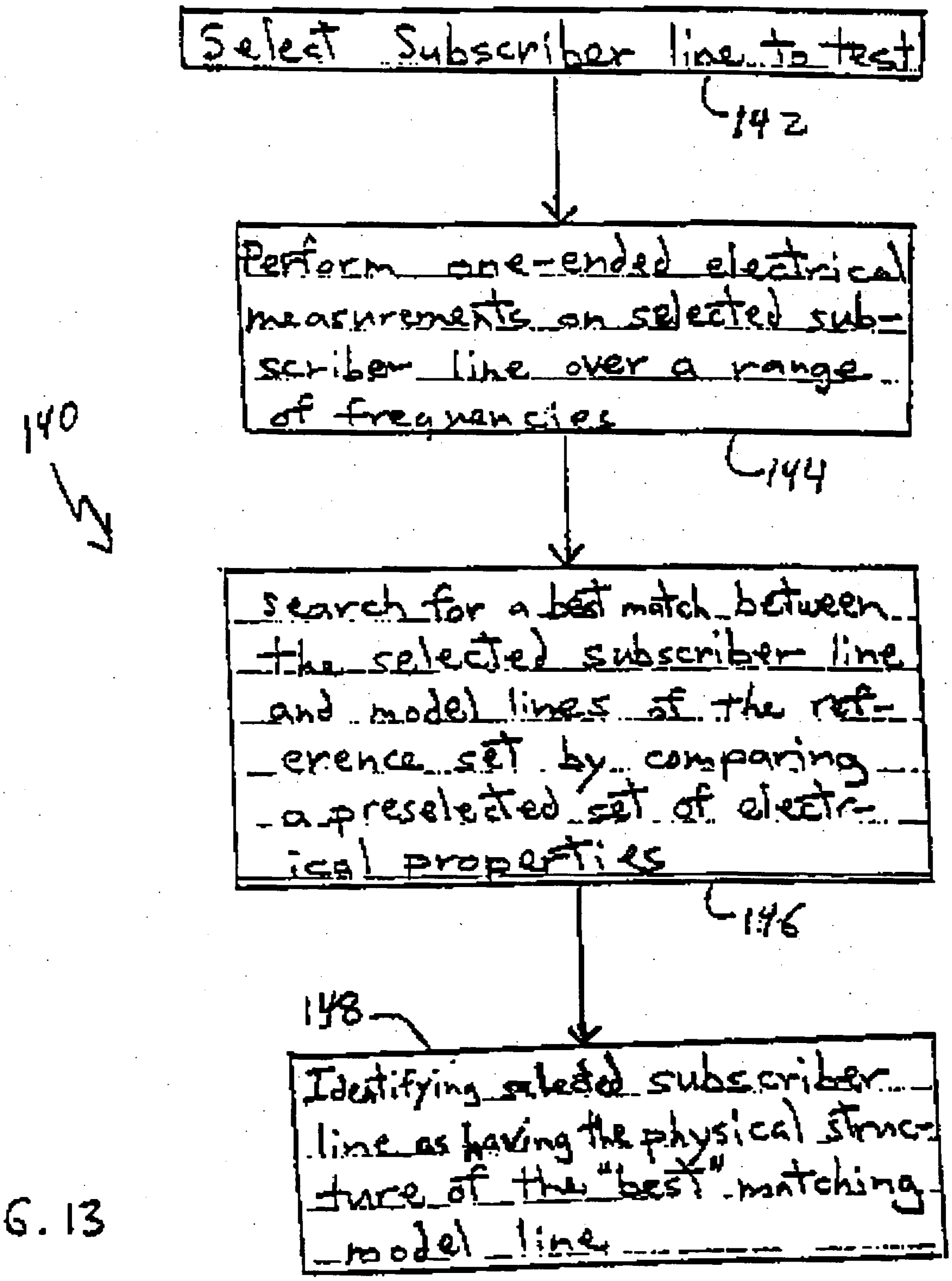

Select Subscriber line to test
142
Perform one-ended electrical measurements on selected subscriber line over a range of frequencies
144
140
search for a best match between the selected subscriber line and model lines of the reference set by comparing a preselected set of electrical properties
146
148
Identifying selected subscriber line as having the physical structure of the "best" matching model line

FIG. 13

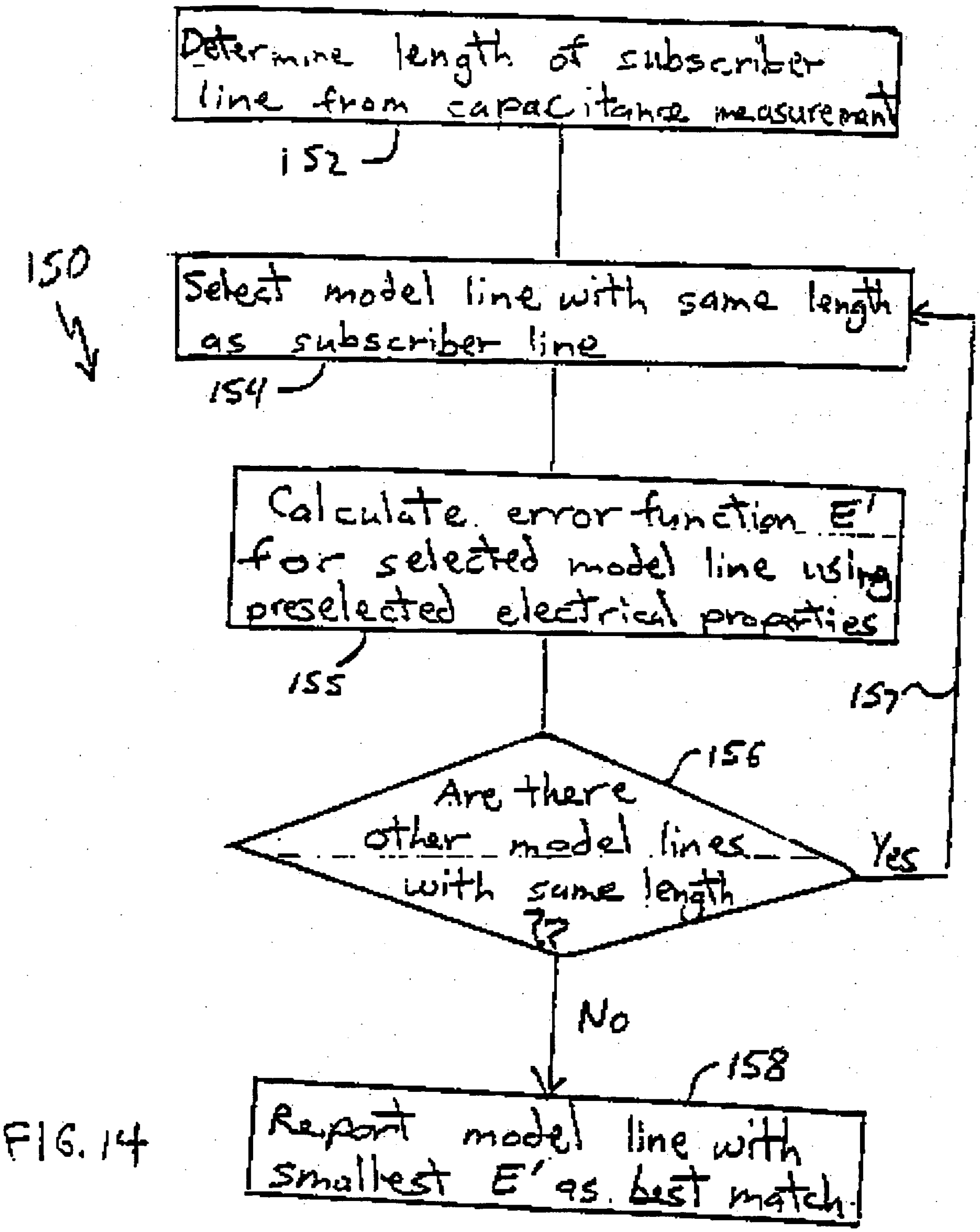

Determine length of subscriber line from capacitance measurement
152
150
Select model line with same length as subscriber line
154
Calculate error function E' for selected model line using preselected electrical properties
155
157
156
Are there other model lines with same length ??
Yes
No
158
Report model line with smallest E' as best match

FIG. 14

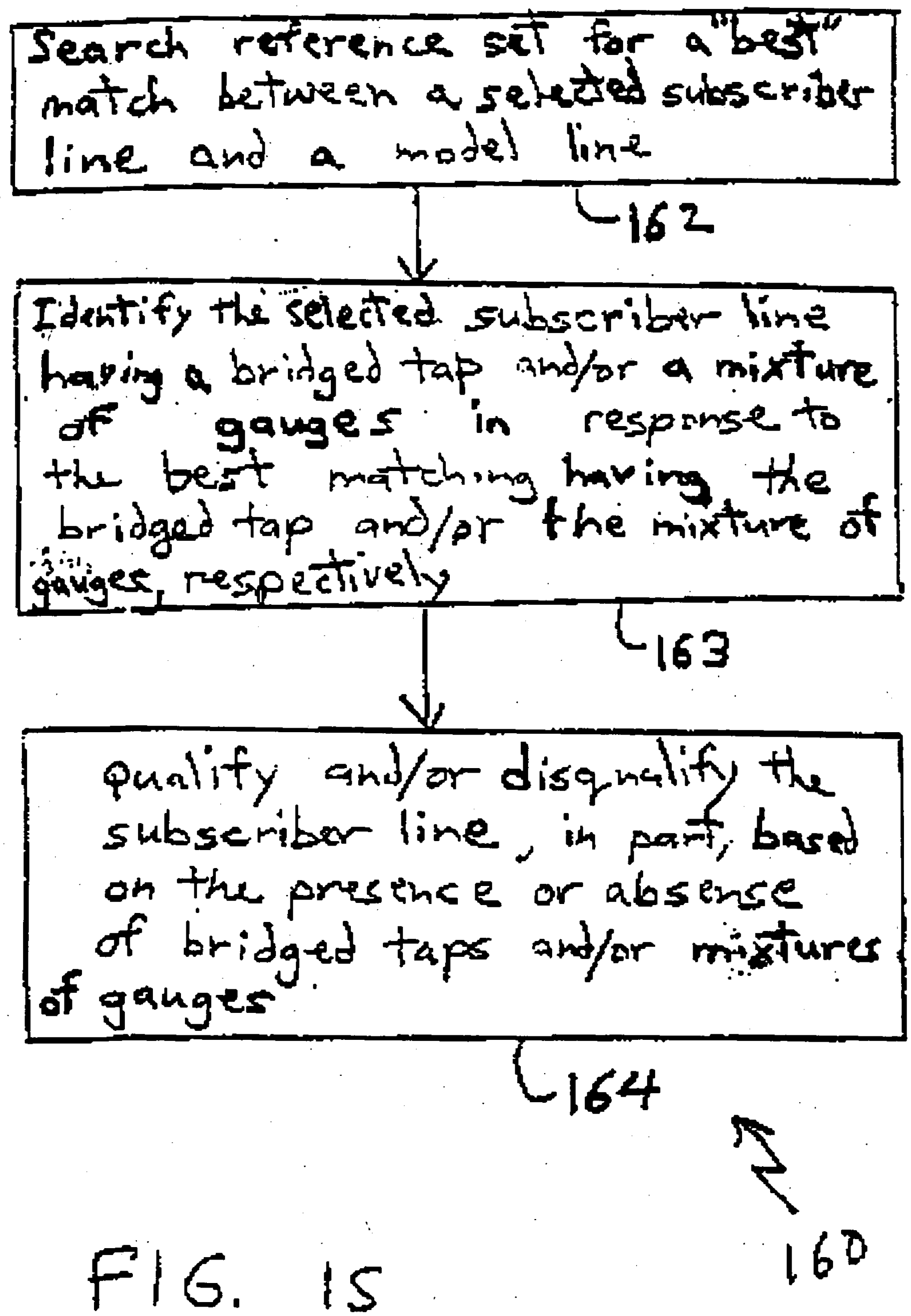

Search reference set for a "best" match between a selected subscriber line and a model line
162
Identify the selected subscriber line having a bridged tap and/or a mixture of gauges in response to the best matching having the bridged tap and/or the mixture of gauges, respectively
163
qualify and/or disqualify the subscriber line, in part, based on the presence or absense of bridged taps and/or mixtures of gauges
164
160

FIG. 15

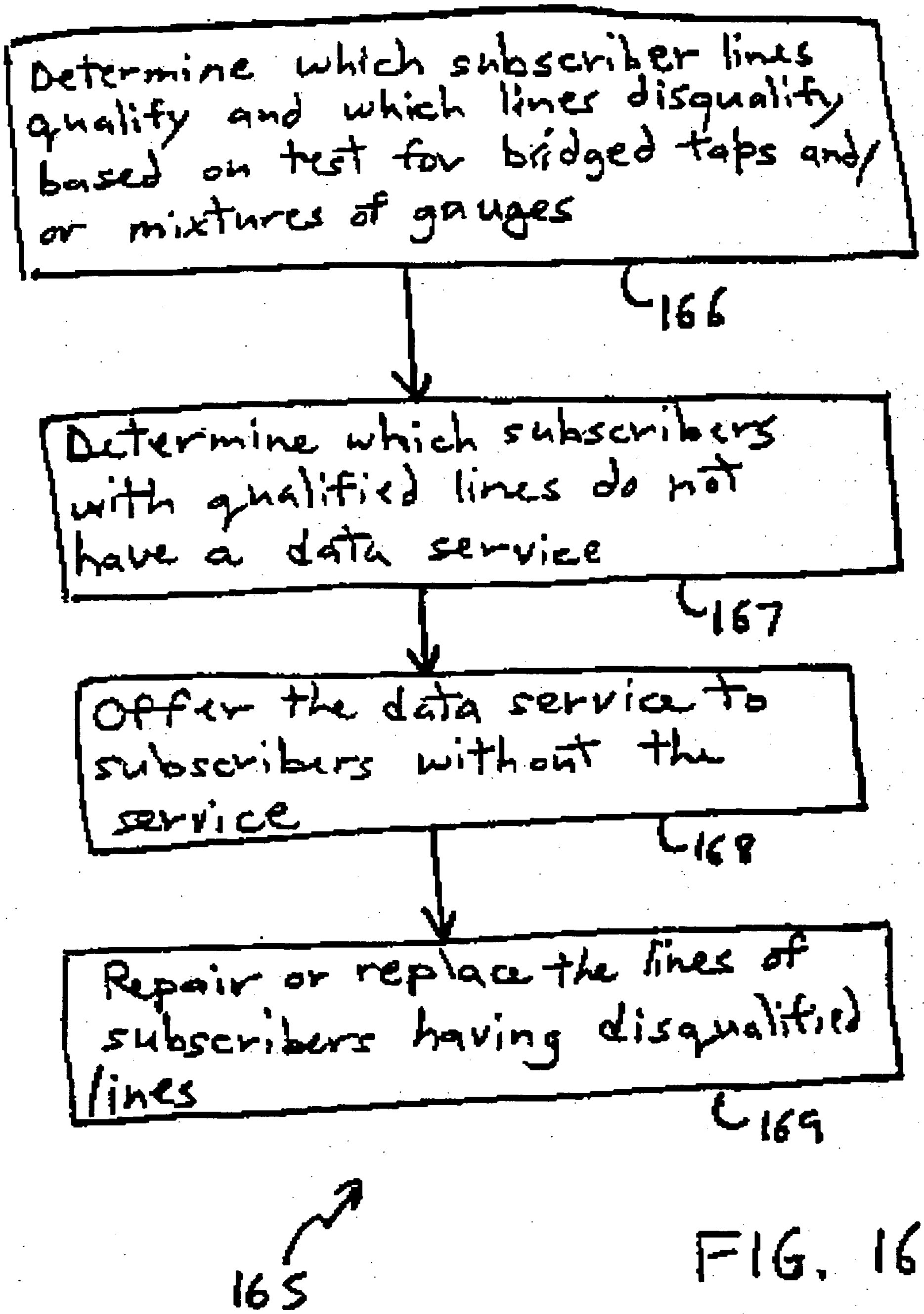

Determine which subscriber lines qualify and which lines disqualify based on test for bridged taps and/or mixtures of gauges
166
Determine which subscribers with qualified lines do not have a data service
167
Offer the data service to subscribers without the service
168
Repair or replace the lines of subscribers having disqualified lines
169
165

FIG. 16

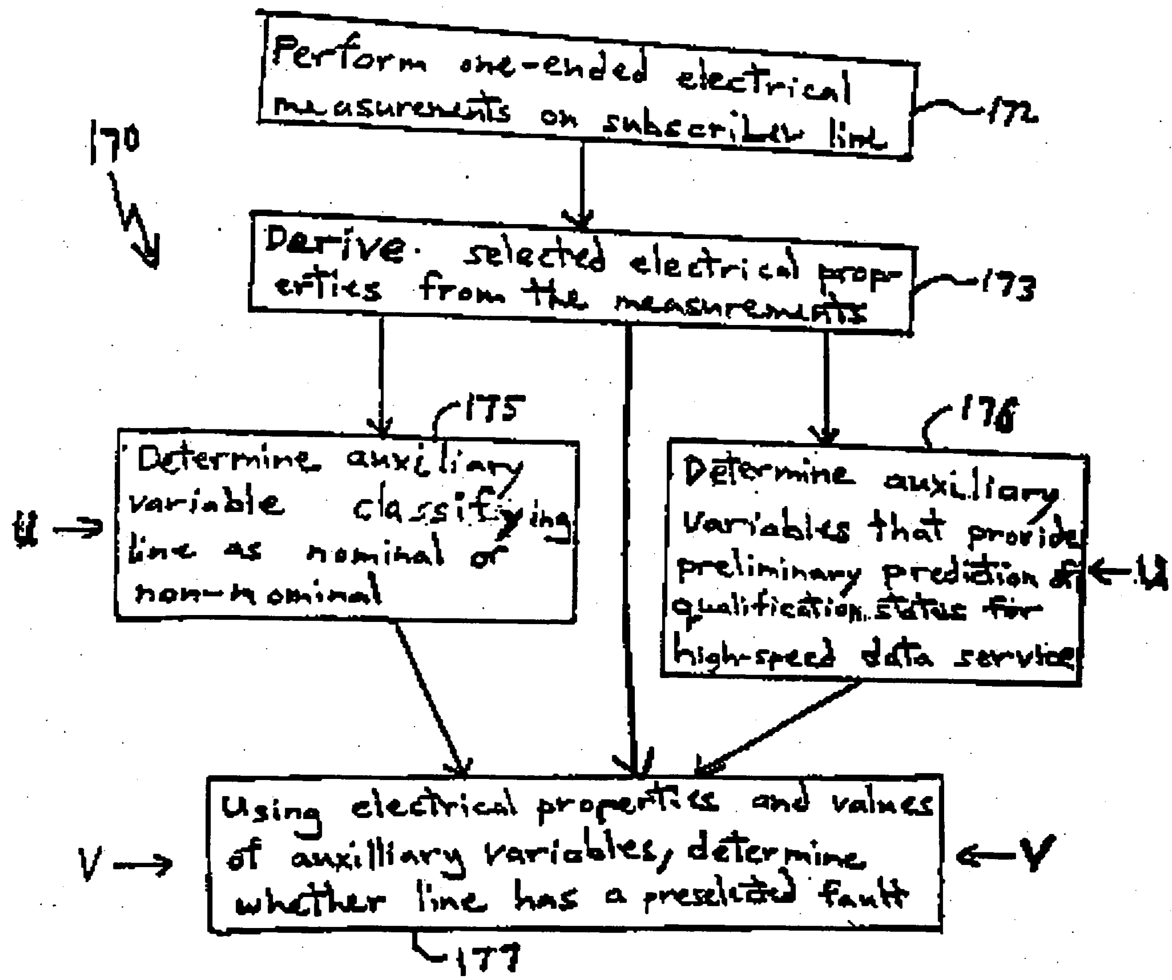

Perform one-ended electrical measurements on subscriber line
172
170
Derive selected electrical properties from the measurements
173
175
Determine auxiliary variable classifying line as nominal or non-nominal
176
Determine auxiliary variables that provide preliminary prediction of qualification status for high-speed data service
U
U
Using electrical properties and values of auxillary variables, determine whether line has a preselected fault
V
V
177

FIG. 17

FIG. 18A

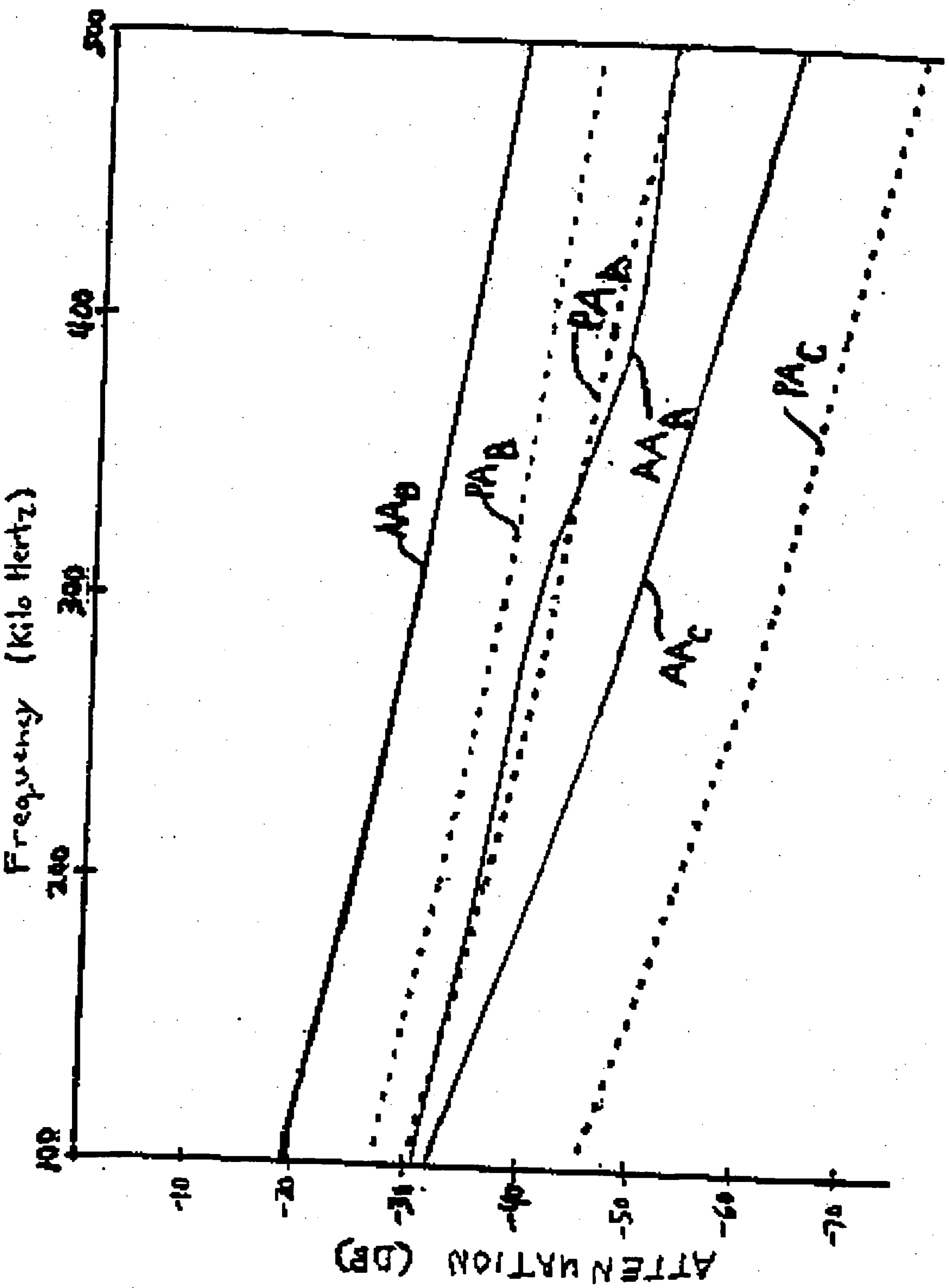
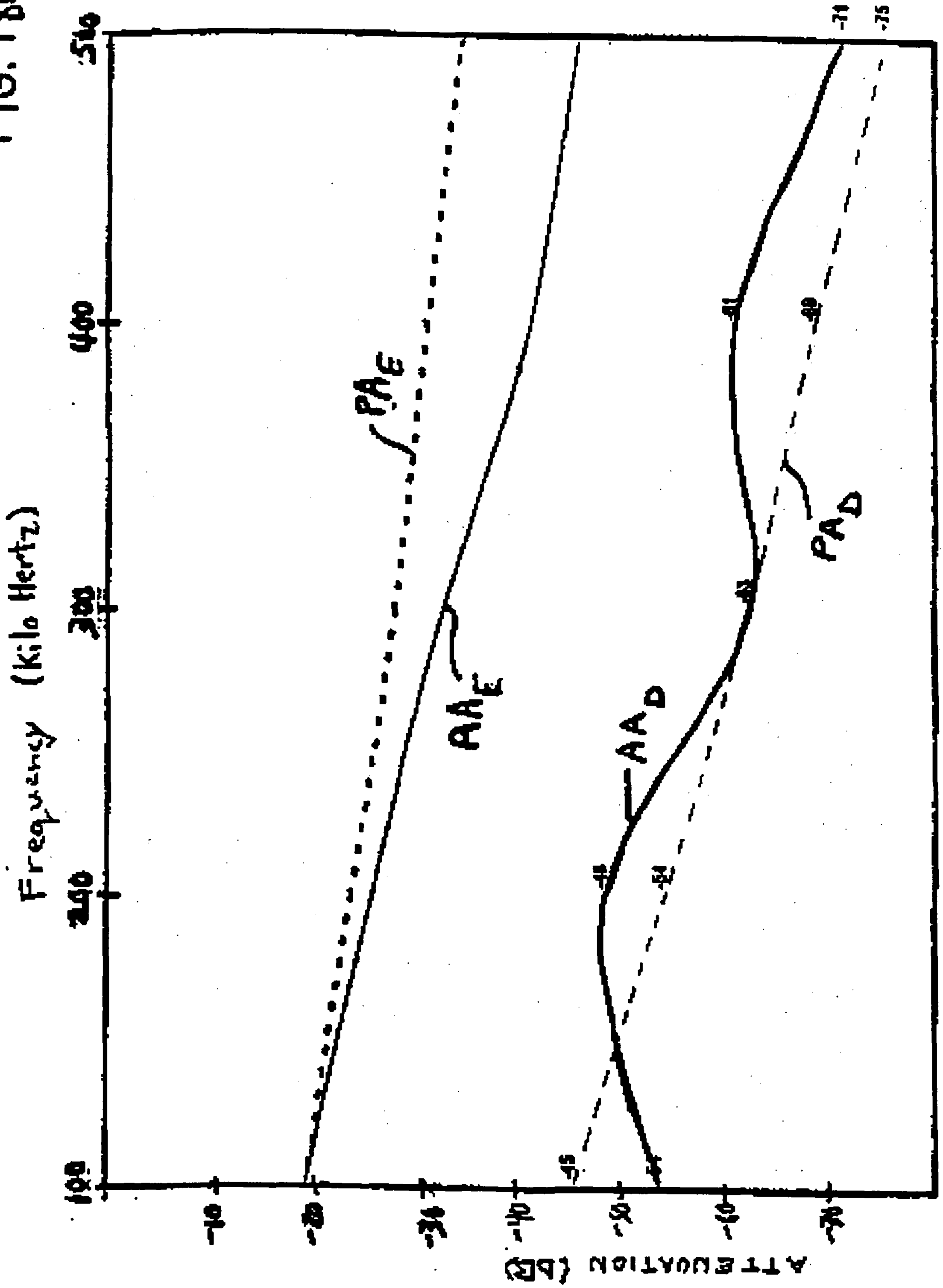

Frequency (Kilo Hertz)
100
200
300
400
500
ATTENUATION (DB)
-10
-20
-30
-40
-50
-60
-70
AA_B
PA_B
PA_A
AA_A
AA_C
PA_C

FIG. 17B


Frequency (Kilo Hertz)
ATTENUATION (dB)
PA_E
AA_E
AA_D
PA_D
100
200
300
400
500
-10
-20
-30
-40
-50
-60
-70

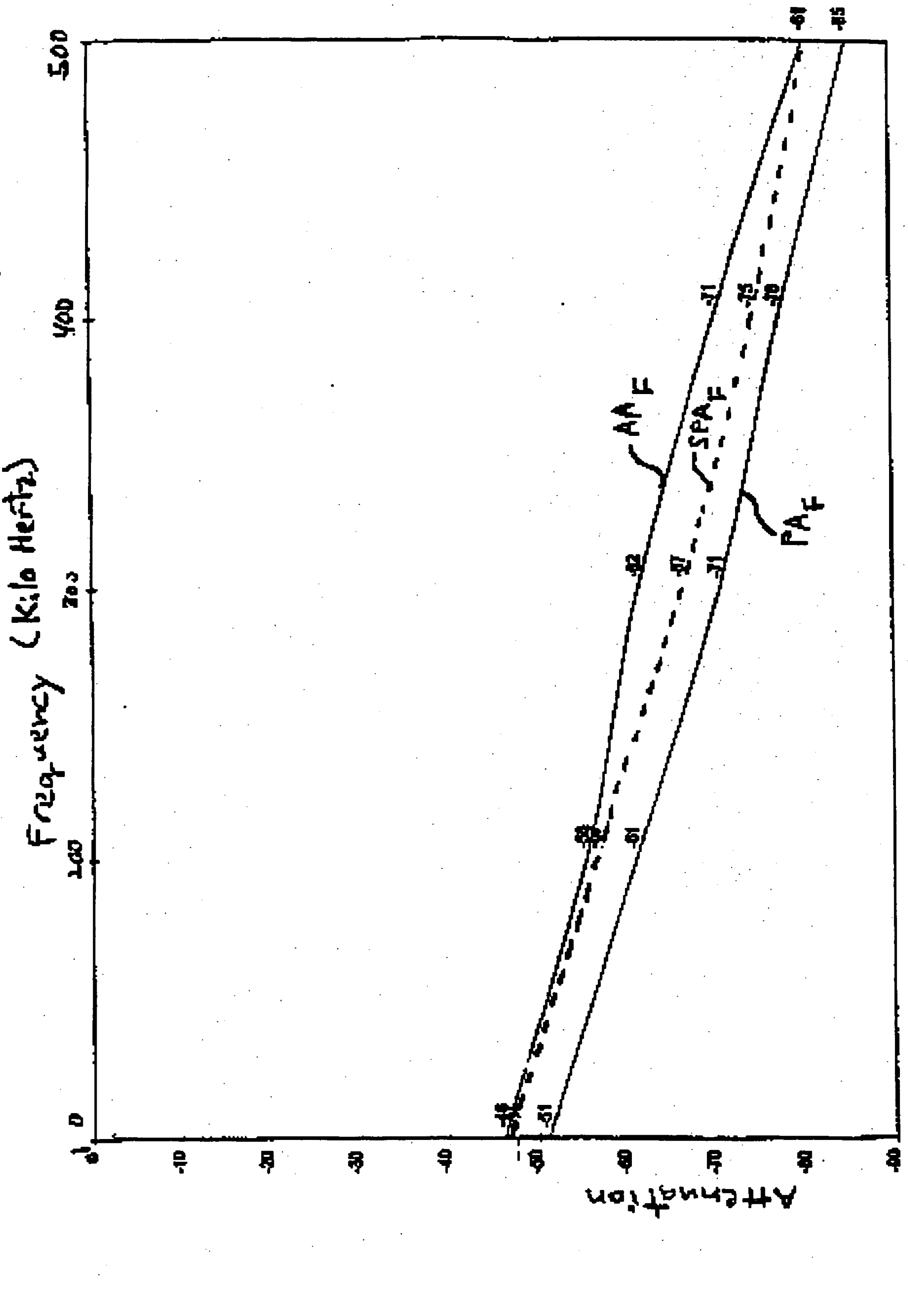

Frequency (Kilo Hertz)
Attenuation
AA_F
SPA_F
PA_F
0
100
200
400
500
0
-10
-20
-30
-40
-50
-60
-70
-80
-90

FIG. 13C

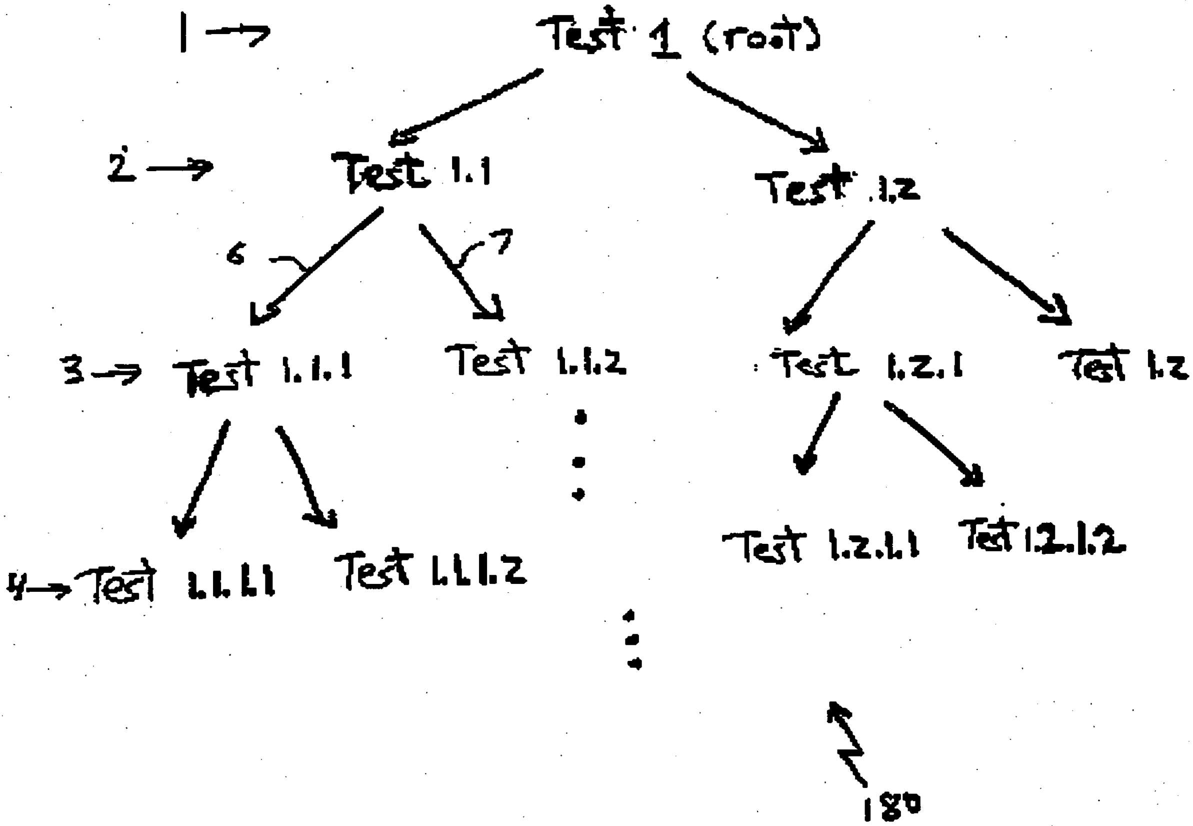
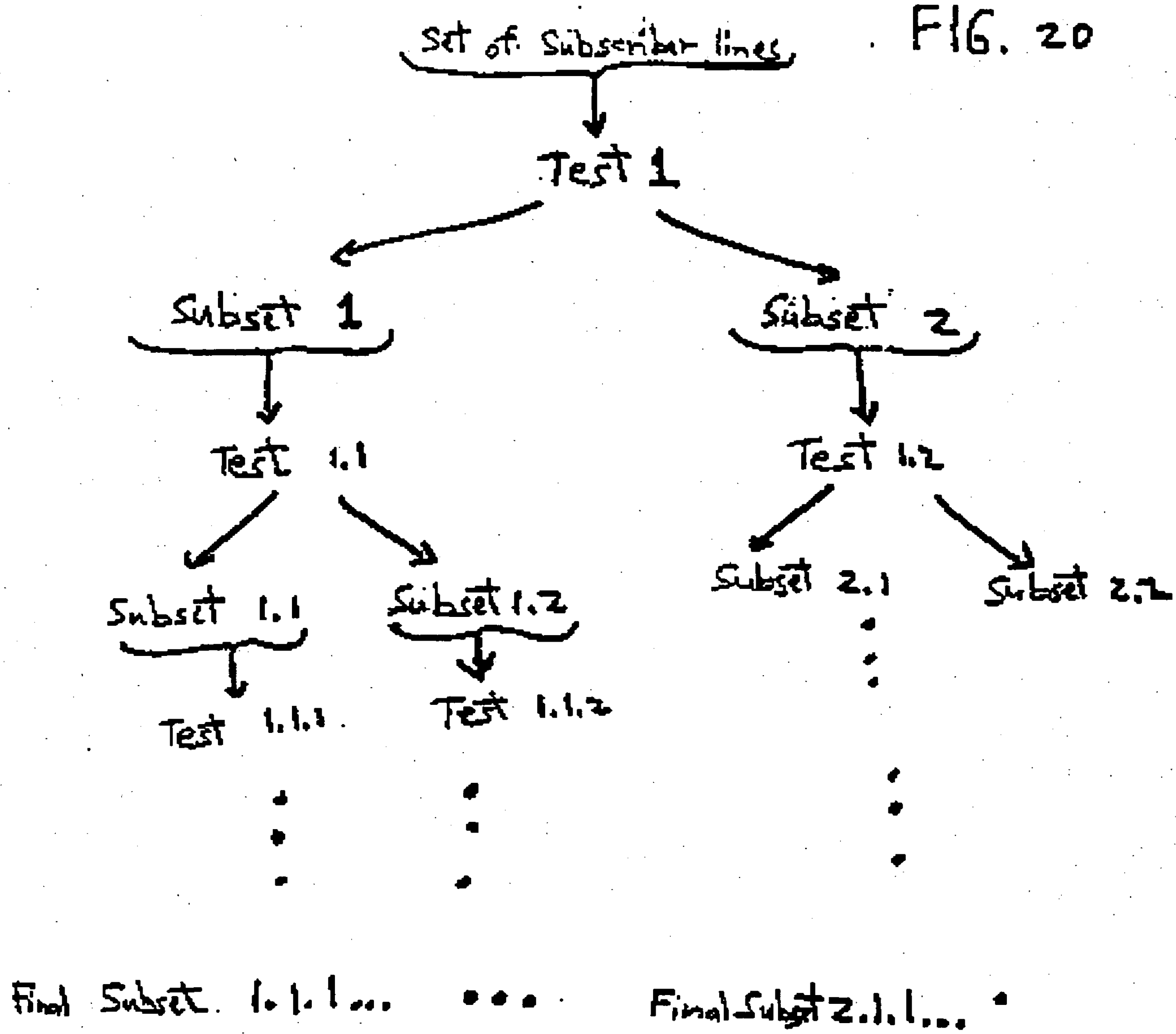

1 →
Test 1 (root)
2 →
Test 1.1
Test 1.2
6
7
3 →
Test 1.1.1
Test 1.1.2
Test 1.2.1
Test 1.2
4 →
Test 1.1.1.1
Test 1.1.1.2
Test 1.2.1.1
Test 1.2.1.2
180

FIG. 19

FIG. 20


Set of Subscriber lines
Test 1
Subset 1
Subset 2
Test 1.1
Test 1.2
Subset 1.1
Subset 1.2
Subset 2.1
Subset 2.2
Test 1.1.1
Test 1.1.2
Final Subset 1.1.1...
Final Subset 2.1.1...

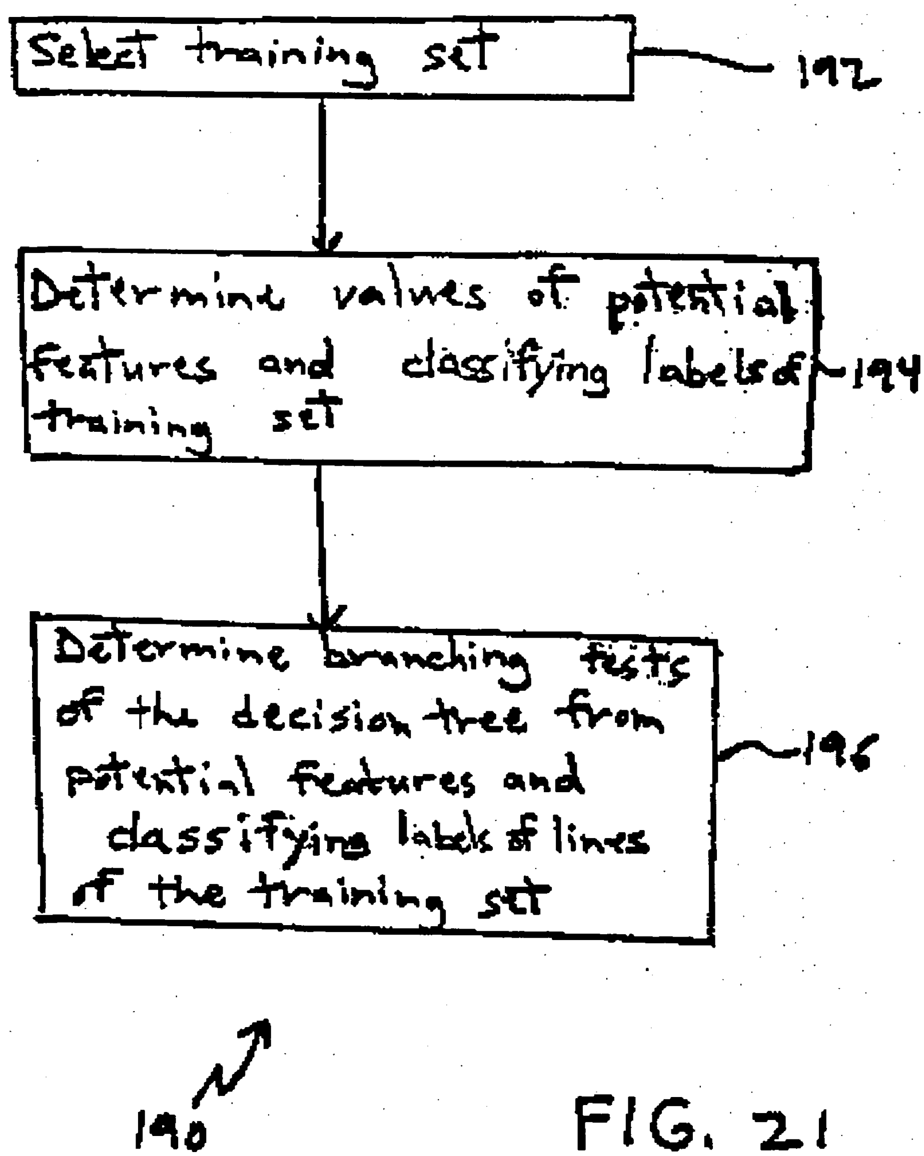

Select training set
192
Determine values of potential features and classifying labels of training set
194
Determine branching tests of the decision tree from potential features and classifying labels of lines of the training set
196
190

FIG. 21

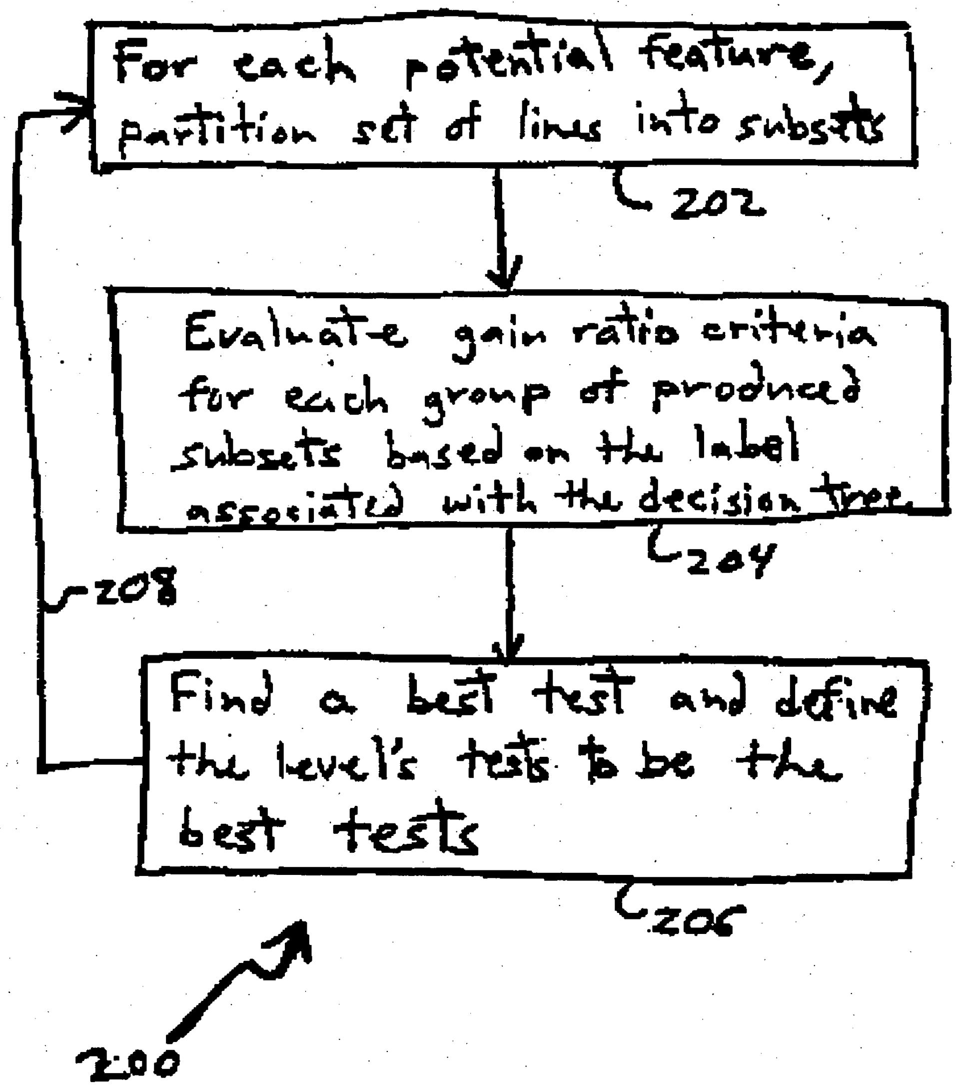

For each potential feature, partition set of lines into subsets
202
Evaluate gain ratio criteria for each group of produced subsets based on the label associated with the decision tree.
204
208
Find a best test and define the level's tests to be the best tests
206
200

FIG. 2Z

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(25) Filing Language: English

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(71) Applicant: TERADYNE, INC. [US/US]; 321 Harrison Avenue, Boston, MA 02118 (US).

(72) Inventors: RUDINSKI, Ilia, L.; 1717 W. Crystal Lane, Mount Prospect, IL 60056 (US). SCHMIDT, Kurt, E.; 6444 W. Brever Road, Burlington, WI 53105 (US).

(74) Agent: WALSH, Edmund, J.; Teradyne, Inc., 321 Harrison Avenue, Boston, MA 02118 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

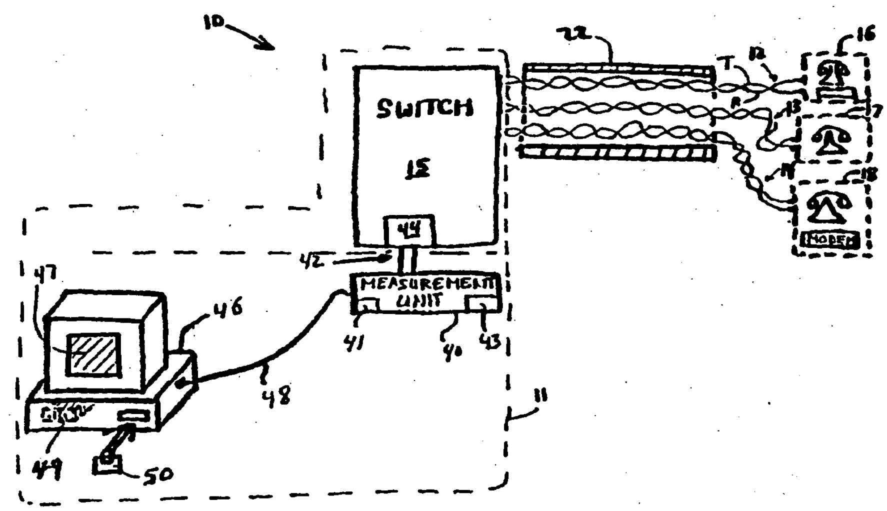
(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

(88) Date of publication of the international search report: 18 January 2001

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: DETERMINING THE PHYSICAL STRUCTURE OF SUBSCRIBER LINES



(57) Abstract: A method determines a structure of a subscriber line. The method includes searching a reference set f r a match between the subscriber line and a model line of the reference set and identifying that the subscriber line has a specific physical structure. The match is based on electrical properties of the lines. The act of identifying is responsive to finding a match with one of the model lines that has the specific physical structure.

WO 00/64130 A3

INTERNATIONAL SEARCH REPORT

Int' 'onal Application No
PCT/US 00/10301

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B3/46

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04M H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 99 03221 A (ADVANCED MICRO DEVICES INC) 21 January 1999 (1999-01-21) page 15, line 28 -page 16, line 24	1,13,22, 30
A	BOETS P ET AL: "THE MODELLING ASPECT OF TRANSMISSION LINE NETWORKS" PROCEEDINGS OF THE INSTRUMENTATION AND MEASUREMENT TECHNOLOGY CONFERENCE,US,NEW YORK, IEEE, vol. -, 12 May 1992 (1992-05-12), pages 137-141, XP000343913 ISBN: 0-7803-0640-6 paragraph '0001!	1,13,22, 30

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 October 2000	10/10/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Cremer, J

1

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int Ional Application No
PCT/US 00/10301

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9903221 A	21-01-1999	EP 0995287 A	26-04-2000

Form PCT/ISA/210 (patent family annex) (July 1992)

BNSDOCID: <WO 0064130A3 I >

(12) UK Patent Application (19) GB (11) 2 303 032 (13) A

(43) Date of A Publication 05.02.1997

(21) Application No 9613602.3

(22) Date of Filing 28.06.1996

(30) Priority Data
(31) 95019065 (32) 30.06.1995 (33) KR

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(51) INT CL^6
H04L 5/06

(52) UK CL (Edition O)
H4P PAQ

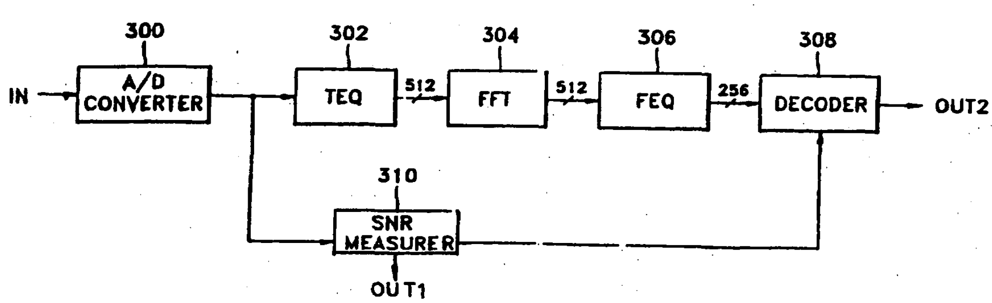
(56) Documents Cited
None

(58) Field of Search
UK CL (Edition O) **H4P PAL PAQ PEM**
INT CL^6 **H04L 5/06 27/34**
ONLINE:WPI

(54) Adaptive bit swapping between channels of a discrete multitone system

(57) An adaptive bit swapping method and device are provided. The method includes the steps of (a) initializing (200) the DMT system to transmit the data via the channel in a steady state; (b) selecting (204) a frame (400) having an inserted sync block from a frame structure of the transmitted data; (c) calculating (210) the signal-to-noise ratios (SNRs) of respective sub-channels of the selected frame; (d) calculating (214) a first difference value between the present representative SNRs calculated in step (c) and the previous representative SNRs of each sub-channel; (e) selecting (216) a maximum value and minimum value among the first difference values of the respective sub-channels; (f) obtaining a second difference value being a difference between the maximum value and the minimum value; (g) determining (218) whether the second difference value is equal to or greater than the predetermined threshold value; and (h) correcting (220) bit and power assigning tables of a transmitter and a receiver if the second difference value is greater than or equal to the threshold value. In addition, the bit and power assigning tables can be corrected accurately since bits and power are swapped using an actually measured SNR.

FIG. 3



GB 2 303 032 A

FIG. 1 (PRIOR ART)

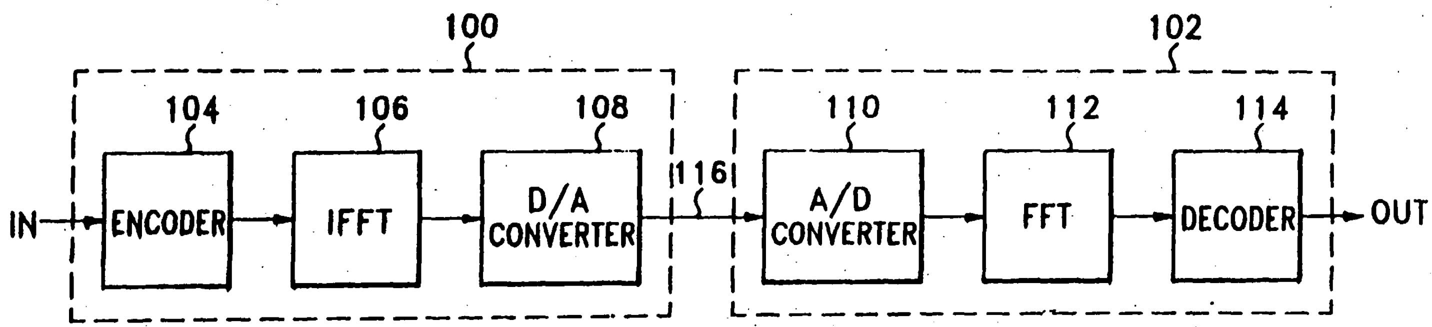


FIG. 2

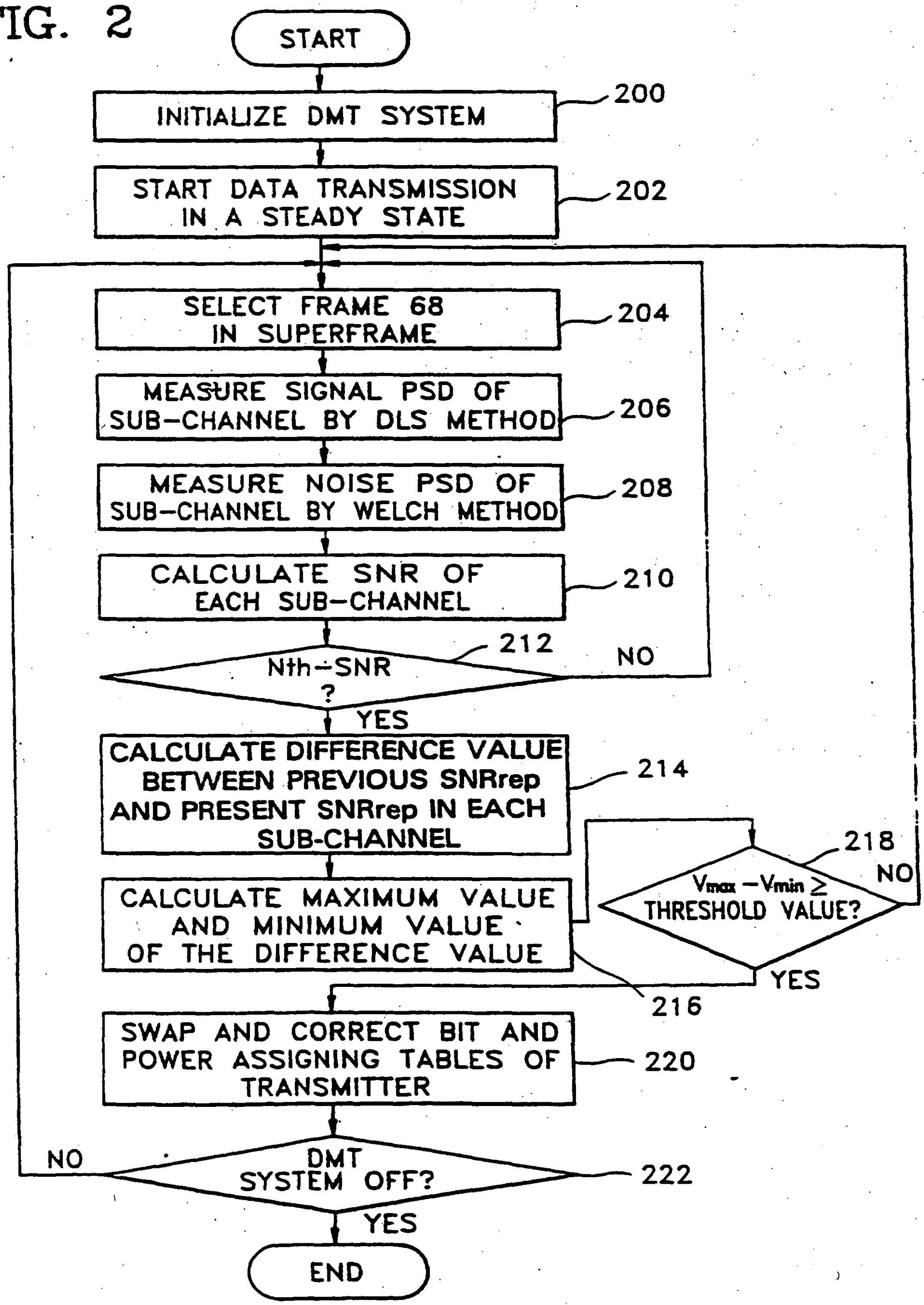

START
INITIALIZE DMT SYSTEM
200
START DATA TRANSMISSION IN A STEADY STATE
202
SELECT FRAME 68 IN SUPERFRAME
204
MEASURE SIGNAL PSD OF SUB-CHANNEL BY DLS METHOD
206
MEASURE NOISE PSD OF SUB-CHANNEL BY WELCH METHOD
208
CALCULATE SNR OF EACH SUB-CHANNEL
210
Nth-SNR ?
212
NO
YES
CALCULATE DIFFERENCE VALUE BETWEEN PREVIOUS SNRrep AND PRESENT SNRrep IN EACH SUB-CHANNEL
214
CALCULATE MAXIMUM VALUE AND MINIMUM VALUE OF THE DIFFERENCE VALUE
216
Vmax - Vmin ≥ THRESHOLD VALUE?
218
NO
YES
SWAP AND CORRECT BIT AND POWER ASSIGNING TABLES OF TRANSMITTER
220
DMT SYSTEM OFF?
222
NO
YES
END

FIG. 3

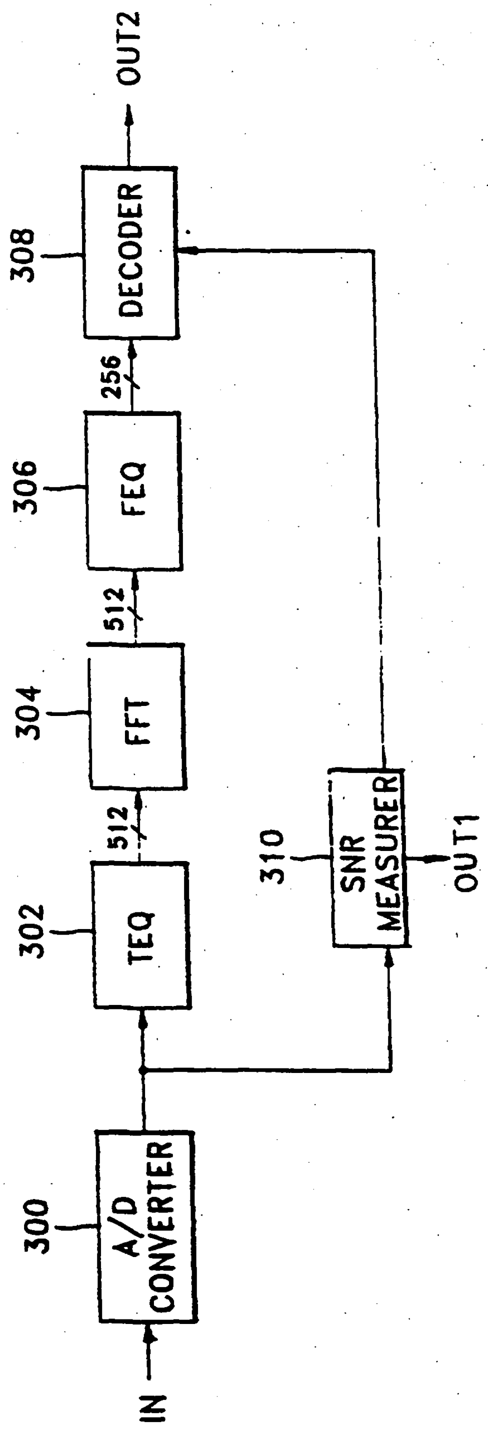
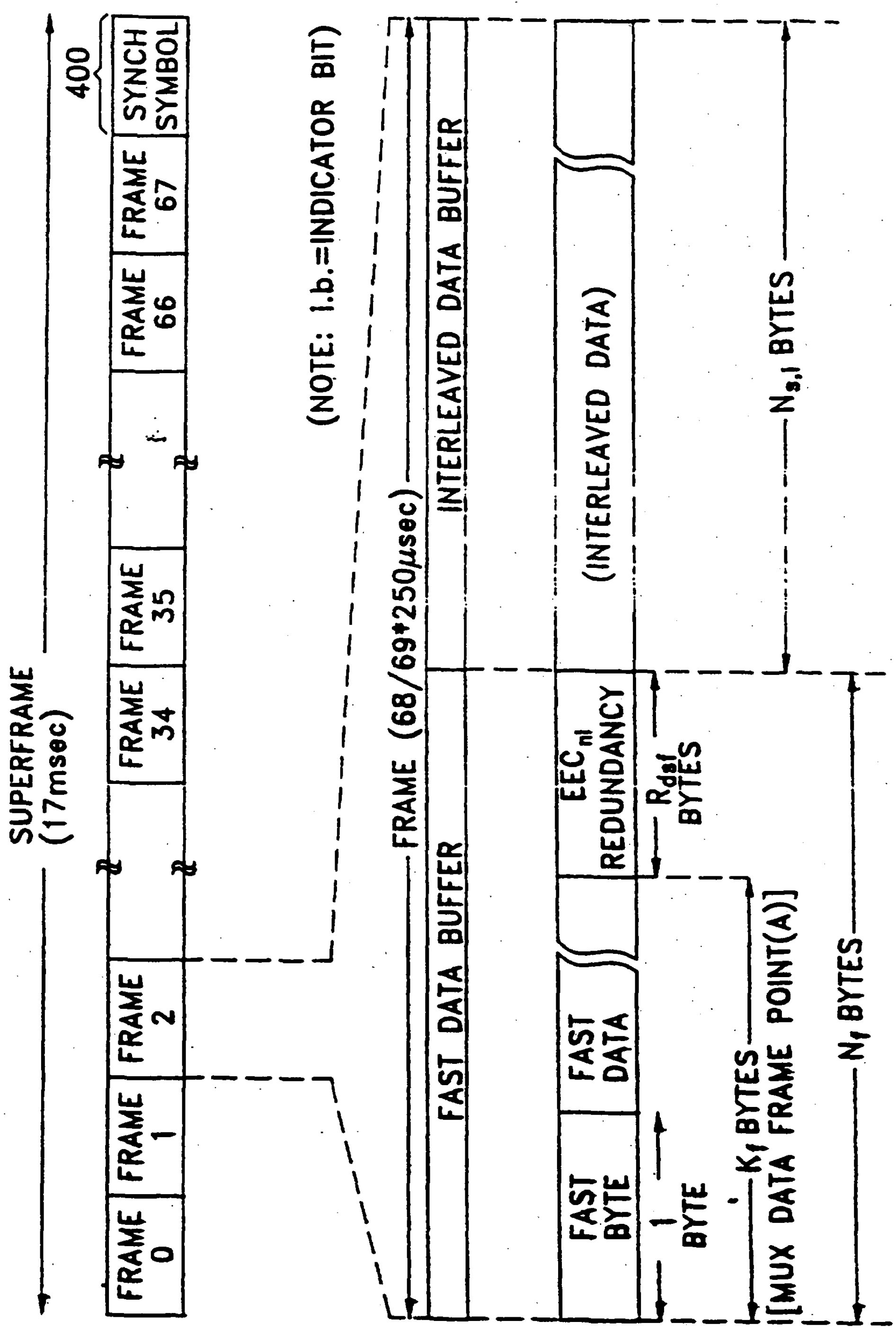

IN
300
A/D CONVERTER
302
TEQ
512
304
FFT
512
306
FEQ
256
308
DECODER
OUT2
310
SNR MEASURER
OUT1

FIG. 4


SUPERFRAME
(17msec)
400
FRAME 0
FRAME 1
FRAME 2
FRAME 34
FRAME 35
FRAME 66
FRAME 67
SYNCH SYMBOL
(NOTE: I.b.=INDICATOR BIT)
FRAME (68/69*250μsec)
FAST DATA BUFFER
INTERLEAVED DATA BUFFER
FAST BYTE
FAST DATA
EEC$_{nl}$ REDUNDANCY
(INTERLEAVED DATA)
1 BYTE
K$_f$ BYTES
R$_{dsf}$ BYTES
[MUX DATA FRAME POINT(A)]
N$_f$ BYTES
N$_{s,l}$ BYTES

ADAPTIVE BIT SWAPPING METHOD AND DEVICE FOR DISCRETE MULTITONE SYSTEM

The present invention relates to a discrete multitone (DMT) system, and more particularly, to an adaptive bit swapping method and device for a DMT system, which adjust the number of bits and power assigned to each sub-channel according to channel characteristics varied during data transmission.

A multicarrier is generally used in a DMT system to use a channel efficiently for transmitting data. Basically in multicarrier modulation, several carrier-modulated waveforms are overlapped to represent an input bit stream. A multicarrier transmission signal is the composite of M independent sub-signals or sub-channels, each having the same bandwidth of 4.3125KHz and respective main frequencies of f_i (i=1, 2, 3,...M). These sub-signals are Quadrature Amplitude Modulation (QAM) signals. When data is transmitted at a high speed via an inferior transmission path such as a copper line, the DMT system enables the data to be transmitted at 6Mbps or above, thus offering a good service. In this DMT system using several carriers, the number of bits and power of each channel depending on its signal-to-noise ratio (SNR) are assigned to each sub-channel in the initialization of the system.

Changing the number of bits and power assigned to each sub-channel according to its SNR, which is varied without an interruption in a data stream in a data transmission mode, is referred to as bit swapping. Bit swapping is used in an Asymmetric Digital Subscriber Line (ADSL) service employing the DMT system to reduce an error probability of transmission data.

Channel characteristics vary gradually with time in most systems, and frequency response characteristics of an ADSL loop vary gradually with temperature. Therefore, a channel model determined in the initialization of a system should be changed according to the frequency response characteristics.

A conventional method for allocating bits to a sub-channel will be described as follows.

A transmitter terminal as well as a receiver terminal by adaption can operate according to the essential concept of a bit allocating method which has been proposed in a dissertation submitted to the Department of Electrical Engineering and the Committee on Graduate Studies of STANFORD University in partial fulfillment of the requirements for the Degree of Doctor of Philosophy, May 1993, entitled "BANDWIDTH OPTIMIZED DIGITAL TRANSMISSION TECHNIQUES FOR SPECTRALLY SHAPED CHANNELS WITH IMPULSE NOISE", by Ronald R. Hunt and P.S. Chow. Details of the bit allocating method there described are as follows:

1. the steady state mean square errors(MSE)'s of all used sub-channels are monitored, where these error values are differences between inputs and outputs of a slicer;

2. it is determined continuously whether the difference between a maximum error value and a minimum error value is a predetermined threshold value (generally

3dB) or above, and if the difference is the threshold value or above, the procedure goes to the subsequent step;

3. the bit number of a value in a bit allocation table for a sub-channel having the maximum error value is decreased by 1, while the bit number of a value in a bit allocation table for a sub-channel having the minimum error value is increased by 1;

4. the minimum error is doubled, while the maximum error is halved;

5. the slicer settings for two sub-channels whose bit values are changed are adjusted; and

6. the bit swapping information is sent back to a transmission part.

The initial number of bits allocated to a sub-channel is determined according to an SNR measured during an initialization in an ADSL DMT system. However, the above bit allocation method exhibits the drawback that an incorrect bit swapping may be performed, since an MSE value may be increased due to an error, such as a burst error when data is examined in a reception part, or a frequency-domain equalizer (FEQ) error which can affect MSE in a steady state.

To circumvent the above problems, it is first object of the present invention to provide an adaptive bit swapping method for a DMT system in which bits allocated to each sub-channel are swapped in a transmission unit according to an actually measured SNR.

It is second object of the present invention to provid an adaptive bit swapping d vice for a DMT system.

To achieve th first object, there is provided an adaptive bit swapping method in a discrete multitone (DMT) system for an asymmetric digital subscriber line (ADSL) which has a transmitter for encoding and converting data to be transmitted via a channel, and a receiver for restoring the transmitted data to the original form by conversion and decoding, said method comprising the steps of: (a) initializing said DMT system to transmit said data via said channel in a steady state; (b) selecting a frame having an inserted sync block from a frame structure of said transmitted data; (c) calculating the signal-to-noise ratios (SNRs) of respective sub-channels of said selected frame; (d) calculating first difference value between the present representative SNRs calculated in step (c) and the previous representative SNRs of each sub-channel; (e) selecting a maximum value and minimum value among the first difference values of said respective sub-channels; (f) obtaining the second difference value between said maximum value and said minimum value; (g) determining whether said second difference value is equal to or greater than the predetermined threshold value; and (h) correcting bit and power assigning tables of a transmitter and a receiver if said second difference value is greater than or equal to said threshold value.

To achieve the second object, there is provided an adaptive bit swapping device functioning as a r ceiver for restoring th transmitted data to the original form by conversion and decoding, said device being included in a discrete multitone (DMT) system for an asymmetric digital subscriber line (ADSL) which has a transmitter for encoding and converting data to be transmitted via a channel, said device comprising: A/D converting means for converting said analogue data signal received via said channel into a digital signal; time-domain equalizing means for receiving said digital signal and reducing a guard band used to remove an interblock interference; fast-Fourier transforming means for receiving the output of said time-domain equalizing means and demodulating said data signal modulated in said transmitter; frequency-domain equalizing means for receiving the output of said fast Fourier transforming means and compensating for a phase error of each sub-channel; SNR measuring means for selecting a frame having an inserted sync block from a frame structure of said transmitted data, calculating the signal-to-noise ratios (SNRs) of respective sub-channels of said selected frame, calculating first difference value between the present representative SNRs calculated above and the previous representative SNRs of each sub-channel, selecting a maximum value and minimum value among the first difference values of said respective sub-channels, obtaining the second difference value between said maximum value and said minimum value, determining whether said second difference value is equal to or greater than the predetermined threshold value and outputting to a transmitter and a receiver the signal used for correcting bit and power assigning tables of a transmitter and a receiver; and decoding means for receiving the outputs of said SNR measuring means and said frequency-domain equalizing means, resetting a slice value, and decoding said reset slice value.

Specific embodiments of the present invention are described in detail below, by way of example, with reference to the attached drawings, in which:

FIG. 1 is a block diagram of a conventional basic DMT system;

FIG. 2 is a flow-chart of a bit swapping method for a DMT system according to an embodiment of the present invention;

FIG. 3 is a block diagram of a receiving unit in a DMT system for performing the method of FIG. 2 according to an embodiment of the present invention; and

FIG. 4 illustrates the structure of a superframe based on "ADSL standards", which is transmitted in a steady state.

An adaptive bit swapping method and device for a DMT system according to an embodiment of the present invention will be described below, with reference to the attached drawings.

A conventional basic DMT system shown in FIG. 1 has a transmitter 100 including an encoder 104, an inverse fast Fourier transformer (IFFT) 106 and a digital/analogue (D/A) converter 108, a receiver 102 including an analogue/digital (A/D) converter 110, a fast Fourier transformer (FFT) 112 and a decoder 114, and a transmission path (a transmission channel or a channel) 116. A DMT system for an ADSL transmits a signal via 256 individual channels each having a 4KHz bandwidth. The encoder 104 of the transmitter 100 in the DMT system shown in FIG. 1 simply receives data sequences via an input terminal IN (the accurate number of bits depends on a data rate and an overhead) and allocates the input data sequences to a multitude of sub-channels. The IFFT 106 produces a plurality of time based samples having several real number values from an encoded value. The D/A converter 108 converts a plurality of the received time based samples into an analogue signal suitable for transmission via a copper line, and transmits the analogue signal to the A/D converter 110 via the transmission path 116.

The receiver 102 performs the operations of the transmitter 100 in a reverse order. The receiver 102 consists of three components for performing time recovery, filtering, and channel check functions, respectively.

An adaptive bit swapping device for a DMT system according to an embodiment of the present invention is shown in Fig.3 and includes an A/D converter 300, a time-domain equalizer (TEQ) 302, an FFT 304, a frequency-domain equalizer (FEQ) 306, a decoder 308, and an SNR measurer 310.

Referring to FIG. 2, showing an algorithm for a bit swapping method for a DMT system according to an embodiment of the present invention, when the DMT system is activated to transmit data, it is initializ d with regard to th channel conditions of the transmitter and receiver, in step 200. The initialization is divided into activation & recognition, transceiver training, and channel analysis & exchange. The initialization in the embodiment of th present invention is especially concerned with channel analysis, since the SNR of each sub-channel of a channel formed between the transmitter and the receiver is measured and the number of bits and power are assigned according to the variation in the measured SNR. When the DMT system is placed in a steady state after the initialization, data transmission begins, in step 202.

FIG. 4 illustrates the structure of a superframe of data transmitted in a steady state, which is determined by "ADSL standards". Referring to FIG. 4, a sync(ronization) symbol 400 used to restore the synchronization of the data without reinitialization when the data are affected by an instantaneous interrupt is inserted in a frame 68 of fram s 0-68.

In step 204, frame 68 alone is selected after step 202 in the embodiment of the present invention, whereas all frames among the 68 frames shown in FIG. 4 are selected to obtain MSEs in the prior art. In step 206, the signal PSD of each sub-channel is measured by a deterministic least sequence (DLS) method, after step 204. The DLS method indicates that known sequence values received from the transmitter via the channel are accumulated and averaged. A channel response free of random noise can be achieved by this method, and the signal PSD of each sub-channel can be achieved by fast Fourier transforming the channel response. In step 208, the noise PSD of each sub-channel is measur d by a Welch method after step 206. After step 208, the SNR of each sub-channel is obtained from the measured signal PSD and noise PSD in step 210. After step 210, it is determined whether the obtained SNR is the Nth SNR of each sub-channel or not in step 212. Here, N is a predetermined number(50~150). Steps 206-210 should be performed repeatedly for series of N sequent superframes because a plurality of sync frames 68, each pattern of which is known, is needed in order to accurately measure the SNR of each sub-channel.

If N SNRs for each sub-channel are obtained, then firstly, the representative SNR(SNR_{rep}) of each sub-channel is obtained by averaging the N SNRs. Then, the difference value(or first difference value) between the presently obtained SNR_{rep} and the previously obtained SNR_{rep} is calculated for each sub-channel. By a method similar to that described above, all first difference values for all sub-channels are obtained in step 214.

The maximum and the minimum values among the first difference values calculated in step 214 are selected in step 216. After step 216, the second difference value between the maximum value and the minimum -value is calculated and it is determined whether the second difference value is a predetermined threshold value(around 3 DB) or not in step 218. If the second difference value is smaller than the threshold value, the procedure fe ds back to step 204, and if it is equal to or gr ater than the threshold value, the bits and power assigned to a corresponding sub-channel in a transmitter are swapped. That is, the number of bit of a sub-channel having a minimum value is assigned to sub-channel having a maximum value. Thus, the corresponding parameters (a bit number and power table) should be changed to enable a receiver to make an accurate decision, in step 220. In step 222, it is determined whether the DMT system is off after step 220. If it is not off, the procedure feeds back to step 204, and if it is off, the bit swapping method of the present invention ends.

Since the bit swapping only takes place once after at least one superframe has been transmitted (17msec is required for one superframe transmission), a long time is required for the bit swapping. However, even though the channel changes during the time required for the bit swapping, this method can be used because a channel changes very slowly, for example by temperature, etc.

Fig.3 shows a device for performing the above-described method. The A/D converter 300 converts an analogue signal received via an input port IN into a digital signal. The TEQ 302 receives the digital signal from the A/D converter 300 and reduces a guard band used to remove an interblock interference (IBI) produced due to characteristics of a DMT system. For this purpose, a finite impulse response filter (FIR) may be used as the TEQ

302. Th FFT 304 receives the signal output from the TEQ 302 and performs a demodulation corresponding to a modulation of the transmitter. Thus, the FFT 304 serves as a demodulator corresponding to the IFFT 106 of FIG. 1. The FEQ 306 is a filter for receiving the output of the FFT 304 and compensating for a phase error of each sub-channel. Meanwhile, the SNR measurer 310 of FIG. 3 receives the output of the A/D converter 300 and performs the steps 204-220 described in Fig.2. The SNR measurer 310 can be achieved in terms of software in a digital signal processor. After processing step 218 shown in Fig.2, the SNR measurer 310 outputs the control signal for bit swapping to the transmitter via an output port OUT1 to correct a bit allocation table at a transmitter, and the measured SNR of each sub-channel is output to the decoder 308. The decoder 308 receives the outputs of the SNR measurer 310 when frame 68 is input, and the output of the FEQ 306 when any frame among frames 0 - 67 is input, decides a slicer value, decodes the reset slicer value, and outputs the decoded value via an output port OUT2.

As described above, in the adaptive bit swapping method and device of embodiments of the present invention in the DMT system, the method for comparing SNRs is added to an SNR measuring method used in a conventional process of initialization. The adaptive bit swapping device selects only frame 68 from each superframe, thereby simplifying a conventional complex hardware construction using all frames. Furthermore, in the adaptive bit swapping method, more accurat swapping information for changing the number of bit and corresponding power can be transmitted to a transmitter than in the conventional method depending on an MSE, since an actually measured SNR value on a frame 68 is used when the assigned bit number and the assigned quantity of power are changed according to a chann l variation.

CLAIMS

1. An adaptive bit swapping method for use in a discrete multitone (DMT) system for an asymmetric digital subscriber line (ADSL) which has a transmitter for encoding and converting data to be transmitted via a channel, and a receiver for restoring the transmitted data to the original form by conversion and decoding, said method comprising the steps of:

(a) initializing said DMT system to transmit said data via said channel in a steady state;

(b) selecting a frame having an inserted sync block from a frame structure of said transmitted data;

(c) calculating the signal-to-noise ratios (SNRs) of respective sub-channels of said selected frame;

(d) calculating first difference values between the present representative SNRs calculated in step (c) and th previous representative SNRs of each sub-channel;

(e) selecting a maximum value and minimum value among the first difference values of said respective sub-channels;

(f) obtaining a second difference value being a difference between said maximum value and said minimum value;

(g) determining whether said second difference value is equal to or greater than a predetermined -threshold value; and

(h) correcting bit and power assigning tables of a transmitter and a receiver if said second difference valu is greater than or equal to said threshold value.

2. An adaptive bit swapping method as claimed in claim 1, wherein said step (a) comprises the steps of:

establishing the initial bits and power values of said DMT system; and

starting a transmission of data in a steady state of said DMT system.

3. An adaptive bit swapping method as claimed in claim 1 or claim 2, wherein said step (c) comprises the steps of;

measuring the signal power spectrum density (PSD) of each sub-channel by a deterministic least sequence (DLS) method;

measuring a noise PSD of each sub-channel by a Welch method; and

calculating said SNR of each sub-channel from said measured signal PSD and said noise PSD.

4. An adaptive bit swapping method as claimed in any of claims 1 to 3, wherein said steps (b) and (c) are performed repeatedly a predetermined number of times, and representative SNR value of each sub-channel are calculated making use of said SNRs if the predetermined number of SNRs is obtained for each sub-channel.

5. An adaptive bit swapping method as claimed in claim 4, wherein said step (c) comprises the step of;

feeding the procedure back to said step (b), if said predetermined number of SNRs of each sub-channel has not been obtained .

6. An adaptive bit swapping method as claimed in any preceding claim, wherein said step (g) comprises the step of;

feeding the procedure back to said step (b), if said second difference value is not greater than or equal to said predetermined threshold value.

7. An adaptive bit swapping device adapted to function as a receiver for restoring transmitted data to its original form by conversion and decoding, said device being adapted for inclusion in a discrete multitone (DMT) system for an asymmetric digital subscriber line (ADSL) which has a transmitter for encoding and converting data to be transmitted via a channel, said device comprising:

A/D converting means for converting said analogue data signal received via said channel into a digital signal;

time-domain equalizing means for receiving said digital signal and reducing a guard band used to remove an interblock interference;

fast-Fourier transforming means for receiving the output of said time-domain equalizing means and demodulating said data signal modulated in said transmitter;

frequency-domain equalizing means for receiving the output of said fast Fourier transforming means and compensating for a phase error of each sub-channel;

SNR measuring means for obtaining the representative SNRs of said respective sub-channels from the output of said A/D converting means using a frame having an inserted sync symbol from a frame structure of transmitted data, calculating a first difference values between the previous representative SNR and present representative SNR for each sub-channel, comparing a threshold value with a second difference value being a difference between maximum and minimum value of said first difference values, and outputting to a transmitter and a receiver the signal us d for correcting a bit allocation table according to the compared result; and

decoding means for receiving the outputs of said SNR measuring means and said frequency-domain equalizing means, resetting a slice value, and decoding said reset slice value.

8. An adaptive bit swapping device adapted to function as a receiver for restoring transmitted data to its original form by conversion and decoding, said device being adapted for inclusion in a discrete multitone (DMT) system for an asymmetric digital subscriber line (ADSL) which has a transmitter for encoding and converting data to be transmitted via a channel, said device comprising:

A/D converting means for converting said analogu data signal received via said channel into a digital signal;

time-domain equalizing means for receiving said digital signal and reducing a guard band used to remove an interblock interference;

fast-Fourier transforming means for receiving the output of said time-domain equalizing means and demodulating said data signal modulated in said transmitter;

frequency-domain equalizing means for receiving the output of said fast Fourier transforming means and compensating for a phase error of each sub-channel;

SNR measuring means for selecting a frame having an inserted sync block from a frame structure of said transmitted data, calculating the signal-to-noise ratios (SNRs) of respective sub-channels of said selected fram , calculating first difference values between the present representative SNRs calculated above and the previous representative SNRs of each sub-channel, selecting a maximum value and minimum value among the first difference values of said respective sub-channels, obtaining a second difference value being a difference between said maximum value and said minimum value, determining whether said second difference value is equal to or greater than the predetermined threshold value, and outputting to a transmitter and a receiver the signal used for correcting bit and power assigning tables of a transmitter and a receiver; and

decoding means for receiving the outputs of said SNR measuring means and said frequency-domain equalizing means, resetting a slice value, and decoding said reset slice value.

9. An adaptive bit swapping device substantially as herein described with reference to Figure 3 with or without reference to Figures 2 and 4.

10. A discrete multitone (DMT) system for an

asymmetric digital subscriber line (ADSL) which has a transmitter for encoding and converting data to be transmitted via a channel, said system comprising an adaptive bit swapping device as claimed in any of claims 7 to 9.

11. An adaptive bit swapping method substantially as herein described with reference to Figure 2 with or without reference to Figures 3 and 4.

The Patent Office

Application N :	GB 9613602.3	**Examiner:**	David Midgley
Claims searched:	1-11	**Date of search:**	22 October 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H4P (PAQ,PAL,PEM)

Int Cl (Ed.6): H04L 5/06,27/34

Other: ONLINE:WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
	NONE	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		

FIG. 1 (PRIOR ART)

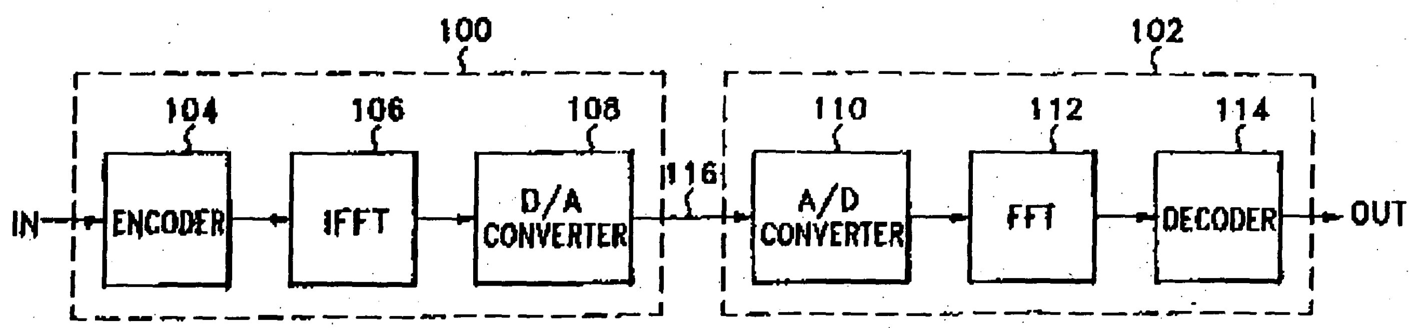


FIG. 2

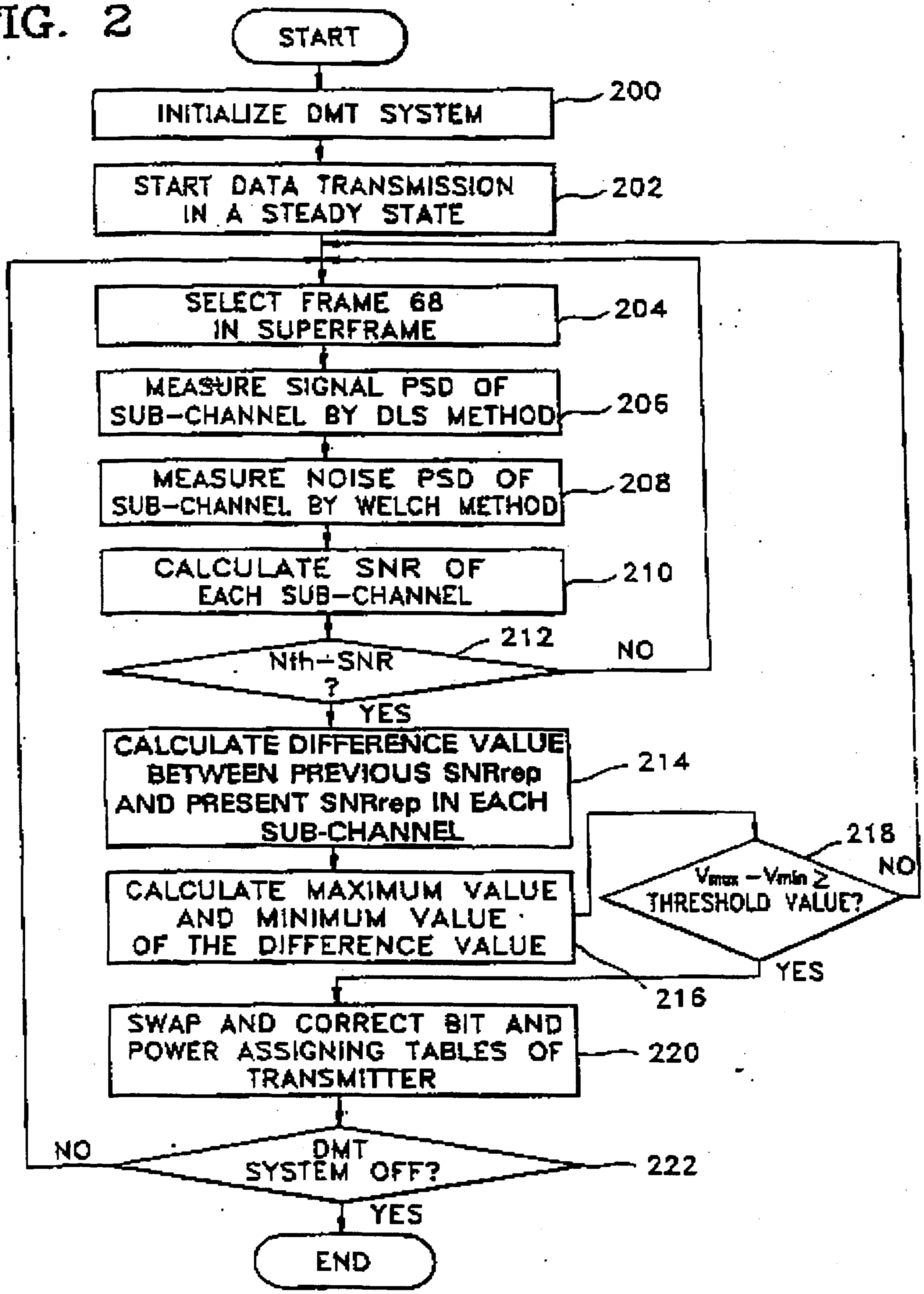

START
INITIALIZE DMT SYSTEM
200
START DATA TRANSMISSION IN A STEADY STATE
202
SELECT FRAME 68 IN SUPERFRAME
204
MEASURE SIGNAL PSD OF SUB-CHANNEL BY DLS METHOD
206
MEASURE NOISE PSD OF SUB-CHANNEL BY WELCH METHOD
208
CALCULATE SNR OF EACH SUB-CHANNEL
210
Nth÷SNR ?
212
NO
YES
CALCULATE DIFFERENCE VALUE BETWEEN PREVIOUS SNRrep AND PRESENT SNRrep IN EACH SUB-CHANNEL
214
CALCULATE MAXIMUM VALUE AND MINIMUM VALUE OF THE DIFFERENCE VALUE
216
Vmax − Vmin ≥ THRESHOLD VALUE?
218
NO
YES
SWAP AND CORRECT BIT AND POWER ASSIGNING TABLES OF TRANSMITTER
220
DMT SYSTEM OFF?
222
NO
YES
END

FIG. 3

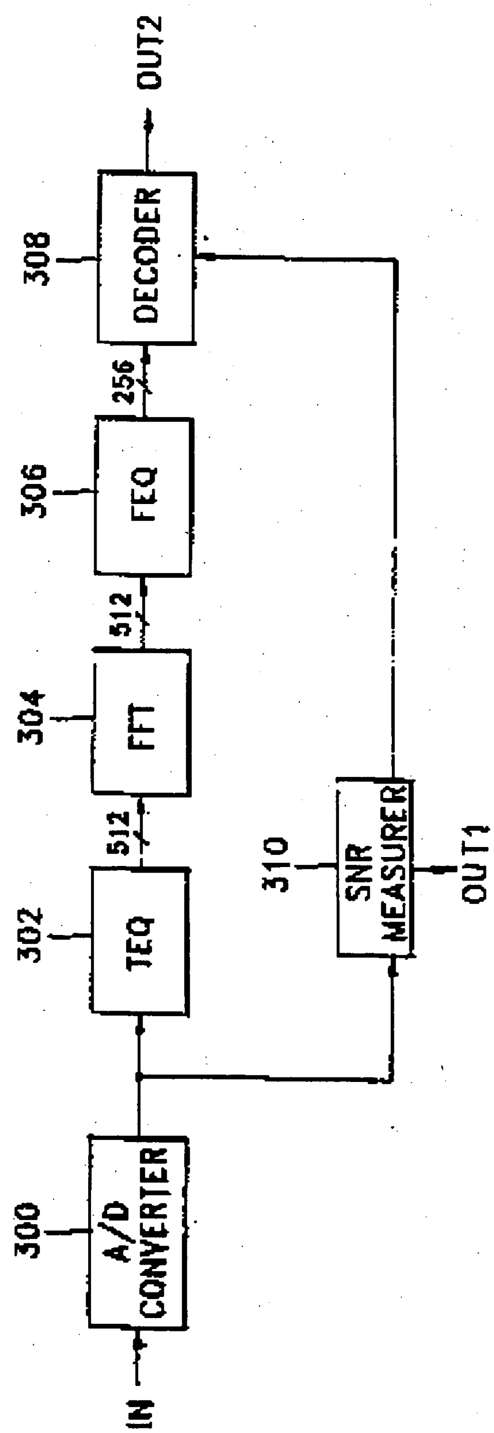
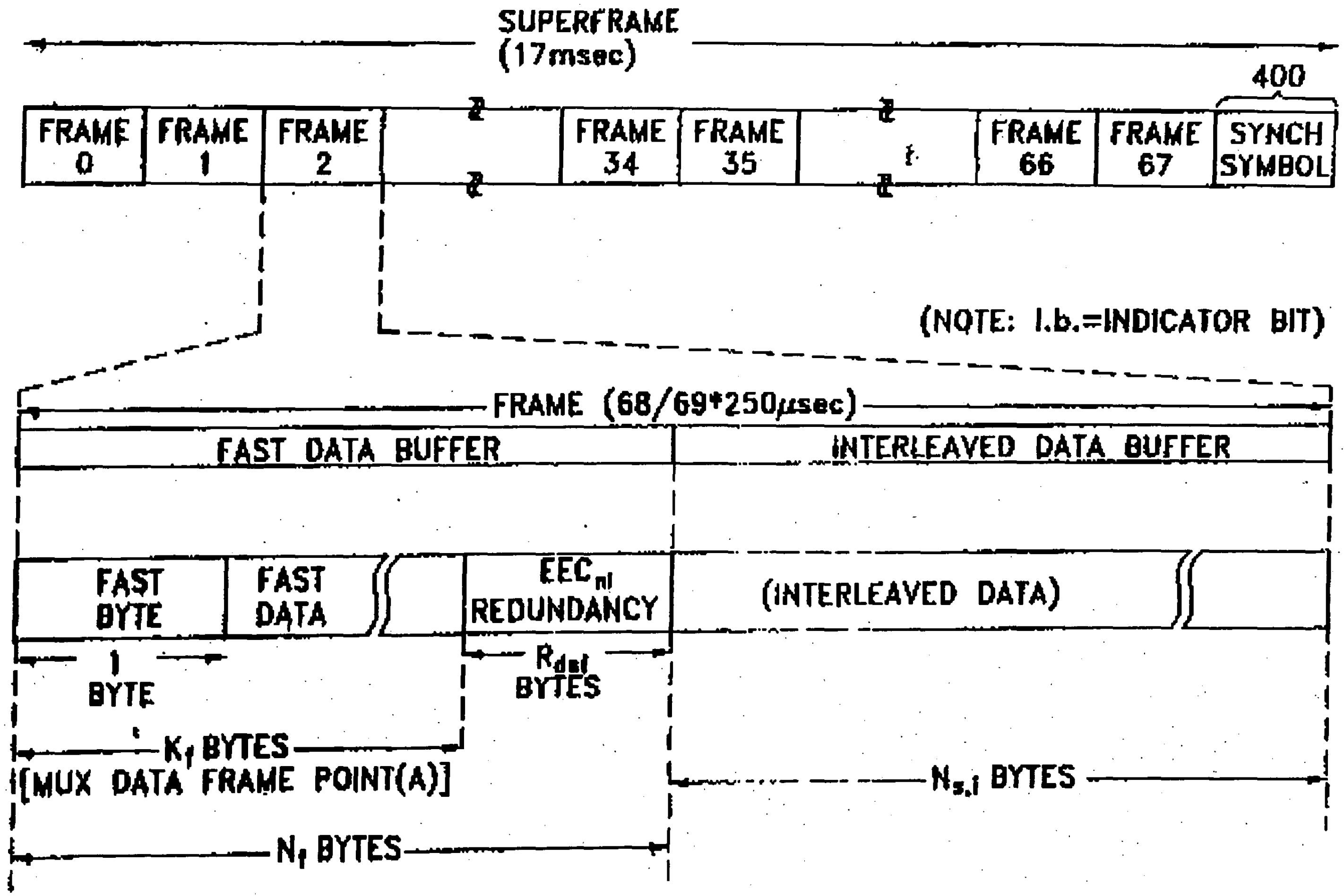

IN
A/D CONVERTER
300
TEQ
302
512
FFT
304
512
FEQ
306
256
DECODER
308
OUT2
SNR MEASURER
310
OUT1

FIG. 4


SUPERFRAME
(17msec)
400
FRAME 0
FRAME 1
FRAME 2
FRAME 34
FRAME 35
FRAME 66
FRAME 67
SYNCH SYMBOL
(NOTE: I.b.=INDICATOR BIT)
FRAME (68/69*250μsec)
FAST DATA BUFFER
INTERLEAVED DATA BUFFER
FAST BYTE
FAST DATA
EEC
REDUNDANCY
(INTERLEAVED DATA)
1 BYTE
R BYTES
K BYTES
[MUX DATA FRAME POINT(A)]
N BYTES