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6

7
8 UNITED STATES DISTRICT COURT
9 FOR THE EASTERN DISTRICT OF CALIFORNIA

10
11 BRANDYWINE COMMUNICATIONS
TECHNOLOGIES, LLC,

12
13 Plaintiff,

14 v.

15 OM NETWORKS D/B/A OMSOFT
TECHNOLOGIES,

16
17 Defendant.

**PLAINTIFF BRANDYWINE
COMMUNICATIONS
TECHNOLOGIES, LLC'S
COMPLAINT FOR PATENT
INFRINGEMENT**

DEMAND FOR JURY TRIAL

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19 Plaintiff Brandywine Communications Technologies, LLC ("Brandywine" or "Plaintiff"),
20 by way of Complaint against the above-named Defendant ("Omsoft" or "Defendant"), alleges the
21 following:

22 **NATURE OF THE ACTION**

23 1. This is an action for patent infringement arising under the Patent Laws of the
24 United States, 35 U.S.C. § 1 *et seq.*

25 **THE PARTIES**

26 2. Plaintiff Brandywine is a limited liability company organized under the laws of the
27 State of Delaware with a place of business at 1612 Mt. Pleasant Road, Villanova, Pennsylvania
28 19085.

1 Robert Earl Scott (collectively the "'657 Inventors"). The '657 Patent has been duly and legally
2 assigned to Brandywine. A copy of the '657 Patent is attached as Exhibit D.

3 12. On November 29, 2005, U.S. Patent No. 6,970,501 (the "'501 Patent"), entitled
4 "Method and Apparatus For Automatic Selection and Operation of a Subscriber Line Spectrum
5 Class Technology," was duly and legally issued by the United States Patent and Trademark Office
6 to inventors Gordon Bremer and Phillip J. Kyees (collectively the "'501 Inventors"). The '501
7 Patent has been duly and legally assigned to Brandywine. A copy of the '501 Patent is attached as
8 Exhibit E.

9 13. On February 22, 2011, U.S. Patent No. 7,894,472 (the "'472 Patent"), entitled
10 "Method and Apparatus For Automatic Selection and Operation of a Subscriber Line Spectrum
11 Class Technology," was duly and legally issued by the United States Patent and Trademark Office
12 to inventors Gordon Bremer and Phillip J. Kyees (collectively the "'472 Inventors"). The '472
13 Patent has been duly and legally assigned to Brandywine. A copy of the '472 Patent is attached as
14 Exhibit F.

15 14. On December 10, 2012, Brandywine sent a letter to Defendant notifying Defendant
16 that it has been infringing the '854, '328, '537, '657, '501, and '472 Patents through the operation of
17 its Digital Subscriber Line ("DSL") business. This letter was sent by certified mail with return
18 receipt requested. Upon information and belief, Defendant has received the letter.

19 **FIRST CLAIM OF RELIEF**

20 **INFRINGEMENT OF U.S. PATENT NO. 5,206,854**

21 **(35 U.S.C. § 271)**

22 15. The allegations set forth in the foregoing paragraphs 1 through 14 are hereby
23 realleged and incorporated herein by reference.

24 16. Upon information and belief, Defendant has infringed one or more claims of the
25 '854 Patent in this judicial district and elsewhere by making, using, selling, and/or offering for sale
26 services and products that infringe and/or perform processes that infringe one or more claims of
27 the '854 Patent ("Accused Services and Products for the '854 Patent").

28 17. Upon information and belief, Defendant's Accused Services and Products for the

1 '854 Patent include but are not limited to Defendant's DSL service and equipment.

2 18. Defendant had actual knowledge of the '854 Patent and its alleged infringement of
3 that patent since at least the time it received Brandywine's December 10, 2012 notice of
4 infringement letter.

5 19. Because of Defendant's infringement of the '854 Patent, Brandywine has suffered
6 damages.

7 **SECOND CLAIM OF RELIEF**

8 **INFRINGEMENT OF U.S. PATENT NO. 5,251,328**

9 **(35 U.S.C. § 271)**

10 20. The allegations set forth in the foregoing paragraphs 1 through 19 are hereby
11 realleged and incorporated herein by reference.

12 21. Upon information and belief, Defendant has infringed one or more claims of the
13 '328 Patent in this judicial district and elsewhere by making, using, selling, and/or offering for sale
14 services and products that infringe and/or perform processes that infringe one or more claims of
15 the '328 Patent ("Accused Services and Products for the '328 Patent").

16 22. Upon information and belief, Defendant's Accused Services and Products for the
17 '328 Patent include but are not limited to Defendant's DSL service and equipment.

18 23. Defendant had actual knowledge of the '328 Patent and its alleged infringement of
19 that patent since at least the time it received Brandywine's December 10, 2012 notice of
20 infringement letter.

21 24. Because of Defendant's infringement of the '328 Patent, Brandywine has suffered
22 damages.

23 **THIRD CLAIM OF RELIEF**

24 **INFRINGEMENT OF U.S. PATENT NO. 5,812,537**

25 **(35 U.S.C. § 271)**

26 25. The allegations set forth in the foregoing paragraphs 1 through 24 are hereby
27 realleged and incorporated herein by reference.

28 26. Upon information and belief, Defendant has infringed and continues to infringe one

1 or more claims of the '537 Patent in this judicial district and elsewhere by making, using, selling,
2 and/or offering for sale services and products that infringe and/or perform processes that infringe
3 one or more claims of the '537 Patent ("Accused Services and Products for the '537 Patent").

4 27. Upon information and belief, Defendant's Accused Services and Products for the
5 '537 Patent include but are not limited to Defendant's DSL service, modems, and equipment.

6 28. Defendant had actual knowledge of the '537 Patent and its alleged infringement of
7 that patent since at least the time it received Brandywine's December 10, 2012 notice of
8 infringement letter.

9 29. Upon information and belief, since at least the time it received Brandywine's
10 December 10, 2012 notice letter, Defendant has committed and continues to commit acts of
11 contributory infringement of the '537 Patent under 35 U.S.C. § 271(c) by providing products,
12 including the Accused Services and Products to others, including but not limited to its customers
13 and partners, knowing or willfully blind to the fact that that these products constitute a material
14 part of the invention, were especially made or especially adapted for use in an infringement of the
15 '537 Patent, and have no substantial non-infringing uses.

16 30. In particular, the Accused Services and Products include DSL modems, which
17 constitute an especially adapted component to receive Defendant's DSL service. These modems
18 are used by Defendant's partners and customers to perform all of the steps recited in one claim of
19 the '537 Patent. These modems have no substantial non-infringing uses at least because they
20 contain components whose only purpose is to practice the claimed method of providing the
21 infringing DSL service. The use of these modems by Defendant's partners and customers
22 constitutes direct infringement of at least one claim of the '537 Patent. Defendant has known or
23 remained willfully blind to these facts since at least the date it received the notice letter from
24 Brandywine notifying Defendant that such activities infringed the '537 Patent.

25 31. Upon information and belief, since at least the time it received Brandywine's
26 December 10, 2012 notice letter, Defendant has induced and continues to induce others to infringe
27 at least one claim of the '537 Patent under 35 U.S.C. § 271(b) by, among other things, and with
28 specific intent or willful blindness, actively aiding and abetting others to infringe, including but

1 not limited to Defendant's partners and customers, whose use of the Accused Services and
2 Products constitutes direct infringement of at least one claim of the '537 Patent.

3 32. In particular, Defendant's actions that aid and abet others such as its partners and
4 customers to infringe include advertising and distributing the Accused Services and Products and
5 providing instruction materials, training, and consulting services regarding the Accused Services
6 and Products. On information and belief, Defendant has engaged in such actions with specific
7 intent to cause infringement or with willful blindness to the resulting infringement because
8 Defendant has had actual knowledge of the '537 Patent and that its acts were inducing its
9 customers to infringe the '537 Patent since at least the date it received the notice letter from
10 Brandywine notifying Defendant that such activities infringed the '537 Patent.

11 33. Despite Brandywine's notice regarding the '537 Patent, Defendant has continued to
12 infringe the '537 Patent. On information and belief, Defendant's infringement has been and
13 continues to be willful.

14 34. Brandywine has been harmed by Defendant's infringing activities.

15 **FOURTH CLAIM OF RELIEF**

16 **INFRINGEMENT OF U.S. PATENT NO. 5,828,657**

17 **(35 U.S.C. § 271)**

18 35. The allegations set forth in the foregoing paragraphs 1 through 34 are hereby
19 realleged and incorporated herein by reference.

20 36. Upon information and belief, Defendant has infringed and continues to infringe one
21 or more claims of the '657 Patent in this judicial district and elsewhere by making, using, selling,
22 and/or offering for sale services and products that infringe and/or perform processes that infringe
23 one or more claims of the '657 Patent ("Accused Services and Products for the '657 Patent").

24 37. Upon information and belief, Defendant's Accused Services and Products for the
25 '657 Patent include but are not limited to Defendant's DSL service, modems, and equipment.

26 38. Defendant had actual knowledge of the '657 Patent and its alleged infringement of
27 that patent since at least the time it received Brandywine's December 10, 2012 notice of
28 infringement letter.

1 39. Upon information and belief, since at least the time it received Brandywine's
2 December 10, 2012 notice letter, Defendant has committed and continues to commit acts of
3 contributory infringement of the '657 Patent under 35 U.S.C. § 271(c) by providing products,
4 including the Accused Services and Products to others, including but not limited to its customers
5 and partners, knowing or willfully blind to the fact that these products constitute a material part of
6 the invention, were especially made or especially adapted for use in an infringement of the '657
7 Patent, and have no substantial non-infringing uses.

8 40. In particular, the Accused Services and Products include DSL modems, which
9 constitute an especially adapted component to receive Defendant's DSL service. These modems
10 are used by Defendant's partners and customers to perform all of the steps recited in one claim of
11 the '657 Patent. These modems have no substantial non-infringing uses at least because they
12 contain components whose only purpose is to practice the claimed method of providing the
13 infringing DSL service. The use of these modems by Defendant's partners and customers
14 constitutes direct infringement of at least one claim of the '657 Patent. Defendant has known or
15 remained willfully blind to these facts since at least the date it received the notice letter from
16 Brandywine notifying Defendant that such activities infringed the '657 Patent.

17 41. Upon information and belief, since at least the time it received Brandywine's
18 December 10, 2012 notice letter, Defendant has induced and continues to induce others to infringe
19 at least one claim of the '657 Patent under 35 U.S.C. § 271(b) by, among other things, and with
20 specific intent or willful blindness, actively aiding and abetting others to infringe, including but
21 not limited to Defendant's partners and customers, whose use of the Accused Services and
22 Products constitutes direct infringement of at least one claim of the '657 Patent.

23 42. In particular, Defendant's actions that aid and abet others such as its partners and
24 customers to infringe include advertising and distributing the Accused Services and Products and
25 providing instruction materials, training, and consulting services regarding the Accused Services
26 and Products. On information and belief, Defendant has engaged in such actions with specific
27 intent to cause infringement or with willful blindness to the resulting infringement because
28 Defendant has had actual knowledge of the '657 Patent and that its acts were inducing its

1 customers to infringe the '657 Patent since at least the date it received the notice letter from
2 Brandywine notifying Defendant that such activities infringed the '657 Patent.

3 43. Despite Brandywine's notice regarding the '657 Patent, Defendant has continued to
4 infringe the '657 Patent. On information and belief, Defendant's infringement has been and
5 continues to be willful.

6 44. Brandywine has been harmed by Defendant's infringing activities.

7 **FIFTH CLAIM OF RELIEF**

8 **INFRINGEMENT OF U.S. PATENT NO. 6,970,501**

9 **(35 U.S.C. § 271)**

10 45. The allegations set forth in the foregoing paragraphs 1 through 44 are hereby
11 realleged and incorporated herein by reference.

12 46. Upon information and belief, Defendant has infringed and continues to infringe one
13 or more claims of the '501 Patent in this judicial district and elsewhere by making, using, selling,
14 and/or offering for sale services and products that infringe and/or perform processes that infringe
15 one or more claims of the '501 Patent ("Accused Services and Products for the '501 Patent").

16 47. Upon information and belief, Defendant's Accused Services and Products for the
17 '501 Patent include but are not limited to Defendant's DSL service, modems, and equipment.

18 48. Defendant had actual knowledge of the '501 Patent and its alleged infringement of
19 that patent since at least the time it received Brandywine's December 10, 2012 notice of
20 infringement letter.

21 49. Upon information and belief, since at least the time it received Brandywine's
22 December 10, 2012 notice letter, Defendant has induced and continues to induce others to infringe
23 at least one claim of the '501 Patent under 35 U.S.C. § 271(b) by, among other things, and with
24 specific intent or willful blindness, actively aiding and abetting others to infringe, including but
25 not limited to Defendant's partners and customers, whose use of the Accused Services and
26 Products constitutes direct infringement of at least one claim of the '501 Patent.

27 50. In particular, Defendant's actions that aid and abet others such as its partners and
28 customers to infringe include advertising and distributing the Accused Services and Products and

1 providing instruction materials, training, and consulting services regarding the Accused Services
2 and Products. On information and belief, Defendant has engaged in such actions with specific
3 intent to cause infringement or with willful blindness to the resulting infringement because
4 Defendant has had actual knowledge of the '501 Patent and that its acts were inducing its
5 customers to infringe the '501 Patent since at least the date it received the notice letter from
6 Brandywine notifying Defendant that such activities infringed the '501 Patent.

7 51. Despite Brandywine's notice regarding the '501 Patent, Defendant has continued to
8 infringe the '501 Patent. On information and belief, Defendant's infringement has been and
9 continues to be willful.

10 52. Brandywine has been harmed by Defendant's infringing activities.

11 **SIXTH CLAIM OF RELIEF**

12 **INFRINGEMENT OF U.S. PATENT NO. 7,894,47**

13 **(35 U.S.C. § 271)**

14 53. The allegations set forth in the foregoing paragraphs 1 through 52 are hereby
15 realleged and incorporated herein by reference.

16 54. Upon information and belief, Defendant has infringed and continues to infringe one
17 or more claims of the '472 Patent in this judicial district and elsewhere by making, using, selling,
18 and/or offering for sale services and products that infringe and/or perform processes that infringe
19 one or more claims of the '472 Patent ("Accused Services and Products for the '472 Patent").

20 55. Upon information and belief, Defendant's Accused Services and Products for the
21 '472 Patent include but are not limited to Defendant's DSL service, modems, and equipment.

22 56. Defendant had actual knowledge of the '472 Patent and its alleged infringement of
23 that patent since at least the time it received Brandywine's December 10, 2012 notice of
24 infringement letter.

25 57. Upon information and belief, since at least the time it received Brandywine's
26 December 10, 2012 notice letter, Defendant has induced and continues to induce others to infringe
27 at least one claim of the '472 Patent under 35 U.S.C. § 271(b) by, among other things, and with
28 specific intent or willful blindness, actively aiding and abetting others to infringe, including but

1 not limited to Defendant's partners and customers, whose use of the Accused Services and
2 Products constitutes direct infringement of at least one claim of the '472 Patent.

3 58. In particular, Defendant's actions that aid and abet others such as its partners and
4 customers to infringe include advertising and distributing the Accused Services and Products and
5 providing instruction materials, training, and consulting services regarding the Accused Services
6 and Products. On information and belief, Defendant has engaged in such actions with specific
7 intent to cause infringement or with willful blindness to the resulting infringement because
8 Defendant has had actual knowledge of the '472 Patent and that its acts were inducing its
9 customers to infringe the '472 Patent since at least the date it received the notice letter from
10 Brandywine notifying Defendant that such activities infringed the '472 Patent.

11 59. Despite Brandywine's notice regarding the '472 Patent, Defendant has continued to
12 infringe the '472 Patent. On information and belief, Defendant's infringement has been and
13 continues to be willful.

14 60. Brandywine has been harmed by Defendant's infringing activities.

15 **PRAYER FOR RELIEF**

16 WHEREFORE, Brandywine respectfully requests that this Court enter judgment for
17 Brandywine and against Defendant as follows:

18 A. An adjudication that Defendant has infringed the '854, '328, '537, '657, '501, and
19 '472 Patents;

20 B. An award of damages to be paid by Defendant adequate to compensate Brandywine
21 for Defendant's past infringement of the above Patents, and any continuing or future infringement
22 through the date such judgment is entered, including interest, costs, expenses and an accounting of
23 all infringing acts including, but not limited to, those acts not presented at trial;

24 C. An order that Defendant pay an ongoing royalty in an amount to be determined for
25 any continued infringement of the above Patents after the date judgment is entered;

26 D. An award of treble damages under 35 U.S.C. § 284;

27 E. A declaration finding this to be an exceptional case, and awarding Brandywine
28 attorney fees under 35 U.S.C. § 285; and

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F. For such further relief at law and in equity as the Court may deem just and proper.

Dated: March 13, 2013

Respectfully submitted,

OWENS TARABICHI LLP



David R. Owens
Owens Tarabichi LLP
Attorneys for Plaintiff
Brandywine Communications Technologies, LLC

DEMAND FOR JURY TRIAL

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Pursuant to Rule 38 of the Federal Rules of Civil Procedure and Rule 38-1 of the Civil Local Rules of the Central District of California, Plaintiff demands a jury trial.

Dated: March 13, 2013

Respectfully submitted,

OWENS TARABICHI LLP



David R. Owens
Owens Tarabichi LLP
Attorneys for Plaintiff
Brandywine Communications Technologies, LLC

Exhibit A



US005206854A

United States Patent [19]
Betts et al.

[11] **Patent Number:** **5,206,854**
 [45] **Date of Patent:** **Apr. 27, 1993**

[54] **DETECTING LOSS OF ECHO CANCELLATION**
 [75] **Inventors:** William L. Betts, St. Petersburg, Fla.;
 Robert A. Day, II, Manalapan, N.J.
 [73] **Assignee:** AT&T Bell Laboratories, Murray Hill, N.J.
 [21] **Appl. No.:** 766,234
 [22] **Filed:** Sep. 24, 1991
 [51] **Int. Cl.⁵** H04B 3/23
 [52] **U.S. Cl.** 372/32.1; 379/410
 [58] **Field of Search** 370/32.1, 14, 27;
 379/406, 410, 411, 3; 371/57.1

[56] **References Cited**
U.S. PATENT DOCUMENTS
 4,707,824 11/1987 Kanemasa 370/32.1
 4,769,808 9/1988 Kanemasa 370/32.1
Primary Examiner—Douglas W. Olms
Assistant Examiner—H. Kizou
Attorney, Agent, or Firm—Henry-T. Brendzel

[57] **ABSTRACT**
 In a full-duplex modem, correlation of an echo estimate signal with an echo-canceled signal is used to determine the presence or absence of a remote signal.

5 Claims, 2 Drawing Sheets

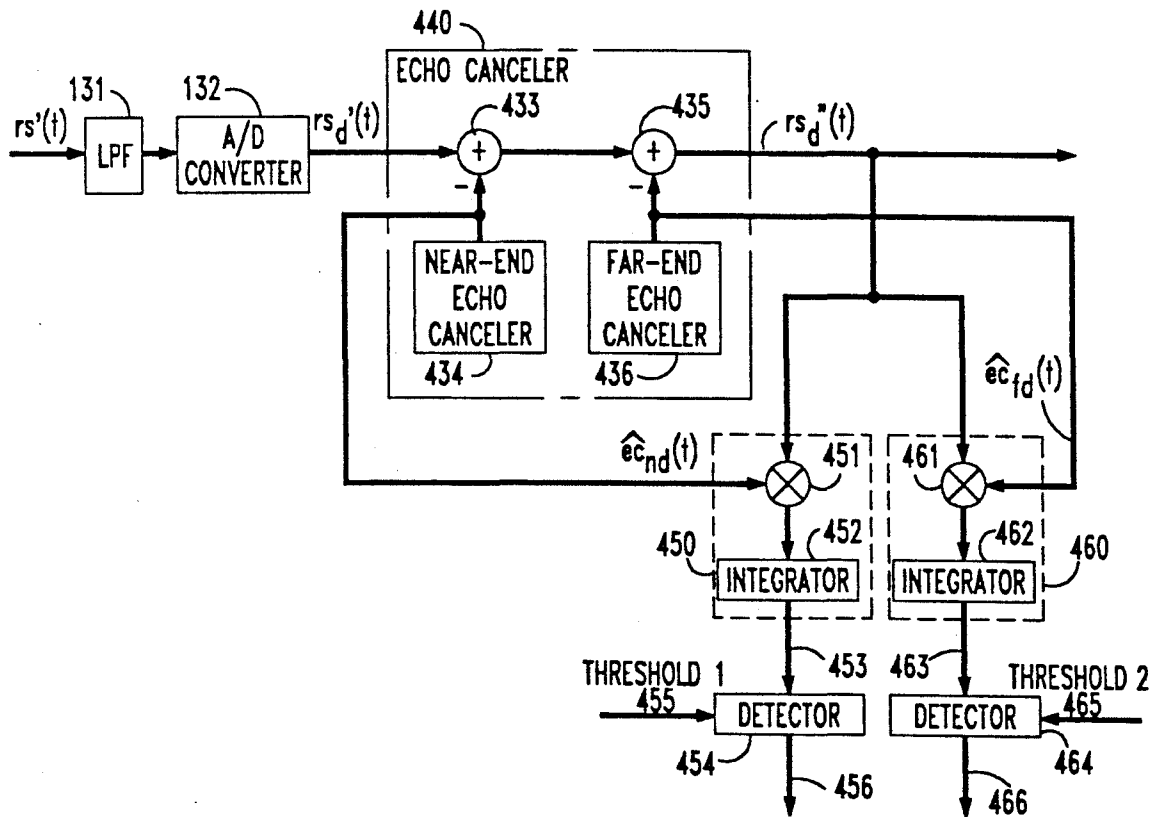


FIG. 1
PRIOR ART

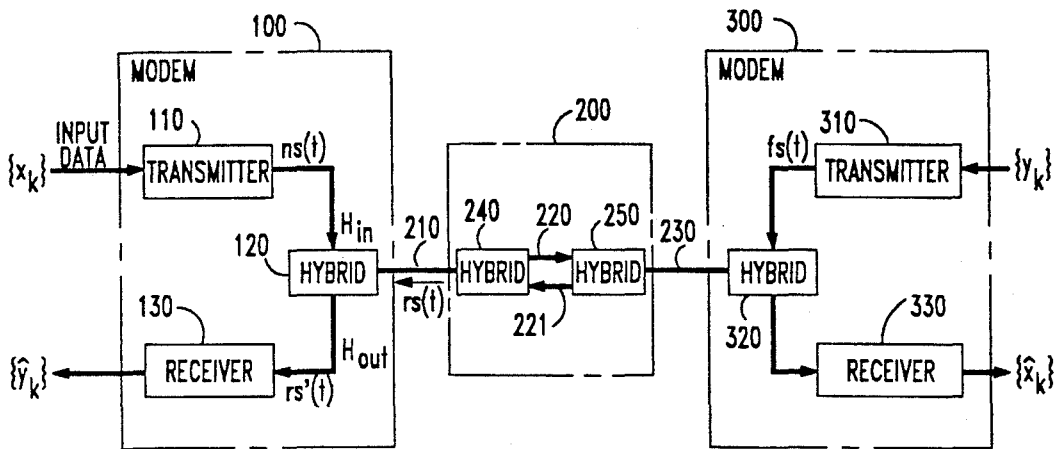


FIG. 2
PRIOR ART

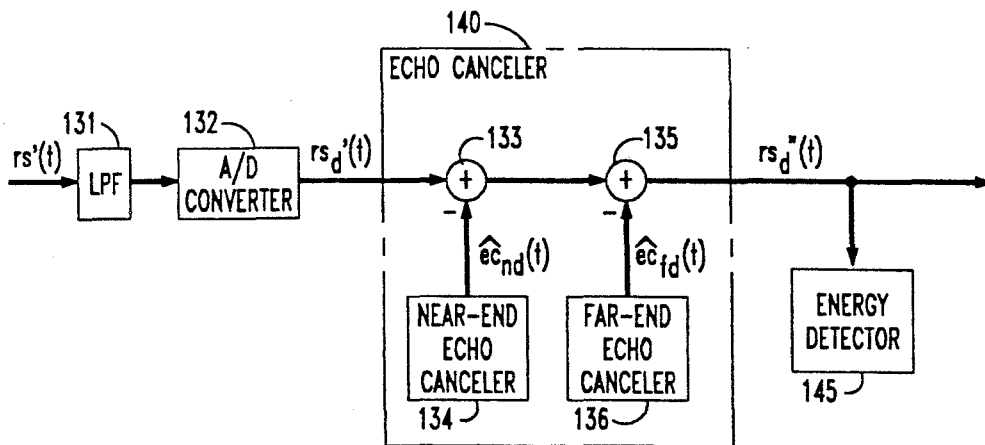


FIG. 3

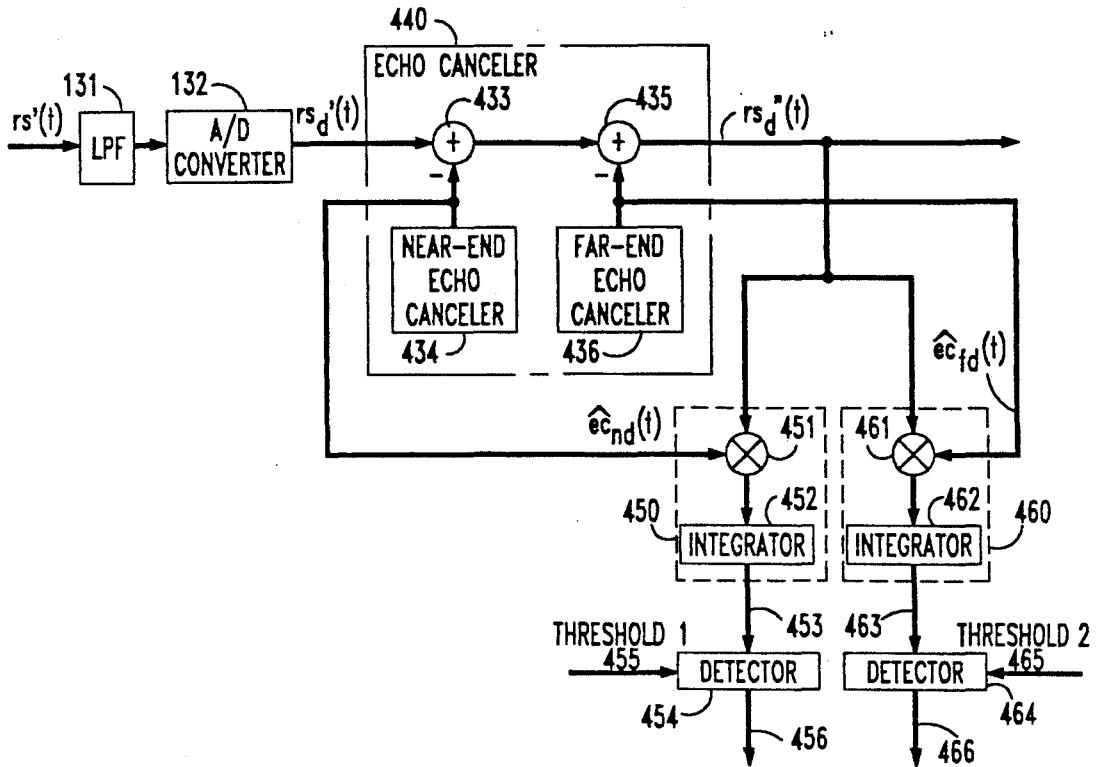
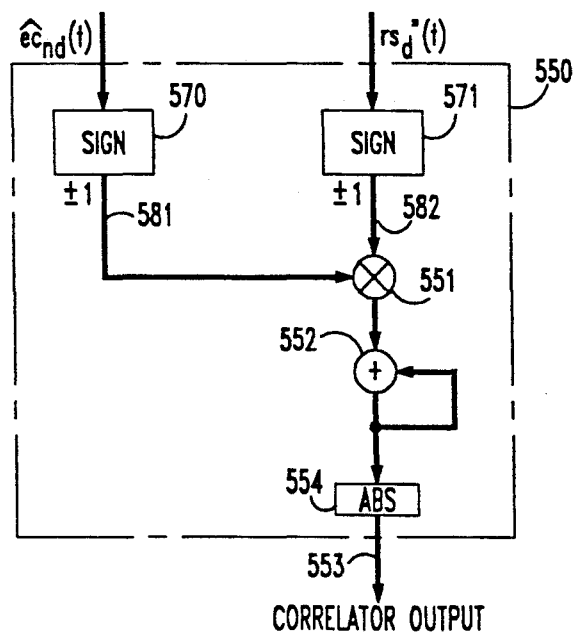


FIG. 4



DETECTING LOSS OF ECHO CANCELLATION

BACKGROUND OF THE INVENTION

The present invention relates to data communication techniques. In particular it relates to the detection of the presence or absence of a remote signal in a modem that uses echo cancellation.

In the field of data communications, it is often advantageous for data traffic to be carried over a single communications channel, e.g., a "two-wire" circuit, in both directions simultaneously between a near-end and a far-end, or remote, modem. This simultaneous, two-way, transmission is known as 'full-duplex' operation. In order to accommodate full-duplex operation, signal energies from both directions of transmission must be superimposed on this single communications channel simultaneously. As a result, some signal energy from each direction of transmission inevitably leaks through to the opposite direction path. This cross-path leakage allows some of a modem's transmitted signal to appear at the input of its own receiver. This undesired leaked-through signal is often referred to as "echo." An echo signal can seriously degrade a modem receiver's performance if not mitigated.

Although the echo cannot simply be filtered, it can be reduced to acceptable levels through the use of an adaptive "echo canceler" within the modem. The echo canceler adaptively synthesizes a replica of the echo, which is then subtracted from the received signal, leaving a substantially echo-free signal. This echo-compensated signal is applied to the modem's data receiver. The echo canceler technique has been so successful that it now is a standard component in most full-duplex high-speed modems.

However, modems which employ an echo cancellation technique have a unique difficulty in reliably detecting the presence and absence of the remote signal. Usually, in an echo-canceling modem, an energy detector is placed after the echo canceler in order to measure the combined energy of the remote signal, noise and residual echo. This type of detector provides an estimate of the remote signal plus noise only as long as the residual or uncanceled echo remains relatively small. However, when the connection to the remote modem is abruptly dropped, the resulting change in impedance of the communications channel to the near-end modem causes the residual echo to increase. As a result, the energy detector detects the energy due to the increased signal level of the residual echo and does not detect the disconnect—even through the remote signal has disappeared. When this happens, a user must manually disconnect the modem before attempting to reestablish the connection.

It should also be noted that a modem's receiver can also use its measure of the mean-squared-error (MSE) between the receiver's estimate of the received data and the receiver's equalizer output as an indicator that the connection to a remote modem has been dropped. For example, when the connection to the remote modem is dropped, the MSE increases. However, in echo-canceling modems it has been observed that the receiver, through influence of the equalizer, carrier recovery and timing recovery circuits, may still "lock-on" to the echo signal notwithstanding that during the disconnect of the remote modem the MSE briefly increased.

SUMMARY OF THE INVENTION

The need to reliably detect the presence or absence of a remote signal in an echo-canceled signal is addressed, in accordance with the invention, by detecting a correlation between an echo estimate signal and the echo-canceled signal. Since the echo estimate signal is derived from a transmitted signal, which is the source of the echo signal, this correlation is effectively between the transmitted signal and the echo-canceled signal and is representative of the amount of residual echo, or transmitted signal, present in the echo-canceled signal. As a result, the degree of correlation determines the presence or absence of a remote signal.

In a preferred embodiment of the invention, the echo-canceled signal is separately correlated to a near-end and far-end echo estimate. A detector is placed at the output of each correlator to signal the correlation between the echo-canceled signal and either the near-end or far-end echo estimate signals.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a block diagram of a full-duplex communication system;

FIG. 2 is a block diagram of a portion of the receiver structure of a prior art modem;

FIG. 3 is a block diagram of a portion of a modem structure embodying the principles of the invention; and

FIG. 4 is another implementation of the correlator shown in FIG. 3.

DETAILED DESCRIPTION

FIG. 1 shows an illustrative full-duplex communication system employing modems to communicate data over a single communications channel. The operation of the various components is well known. In addition, for simplicity, both modems 100 and 300 are assumed to be identical in structure and operation; therefore, only modem 100 will be described in detail hereinbelow.

Modems 100 and 300 both utilize the same frequency band to simultaneously transmit and receive signals, which are representative of their respective input data sequences $\{X_k\}$, $\{y_k\}$, over channel 200. Illustratively, modems 100 and 300 employ quadrature amplitude modulation (QAM).

Channel 200, which is representative of the Public Switched Telephone Network, consists of bidirectional, "two-wire" customer loops 210 and 230 coupled to unidirectional paths 220 and 221, through hybrids 240 and 250. Two-wire loops 210 and 230 are physical pairs of wire, which carry both directions of transmission simultaneously. Unidirectional paths 220 and 221 may or may not be physical pairs of wires, but in any case comprise what is commonly referred to as a "four-wire" path—in essence, dual two-wire paths, each dedicated to one direction of transmission. Hybrids 240 and 250 perform the "four-wire to two-wire conversion" functions, splitting and combining the signals for each direction of transmission. Similarly, hybrids 120 and 320 perform the directional splitting/combining of the signals within modems 100 and 300, respectively.

The input data sequence $\{x_k\}$ to modem 100 is first processed by transmitter 110 to form near-end transmitted signal $n_s(t)$. This signal is representative of the input data sequence to modem 100, and may also include scrambling, redundancy and other forms of encoding. Hybrid 120 couples transmitted signal $n_s(t)$ into two-

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wire loop 210 at input port H_{IN} for transmission to modem 300.

At the same time, far-end modem 300 is similarly transmitting far-end, or remote, signal $fs(t)$. However, the signal received by hybrid 120 is not $fs(t)$ but a version thereof corrupted by (a) various forms of channel-induced distortion including Gaussian noise, intersymbol interference, phase jitter and frequency offset and (b) a so-called far-echo signal $ec_f(t)$ of signal $ns(t)$ caused, for example, by an impedance mismatch at the two-wire loop 230/hybrid 320 interface. The signal received by hybrid 120 is, therefore, signal $rs(t)$, where

$$rs(t) = fs(t) + ec_f(t) + \text{distortion.}$$

Hybrid 120 extracts analog received signal $rs'(t)$ from two-wire loop 210, on output port H_{OUT} . Ideally, the transfer function $u(t)$ from H_{IN} to H_{OUT} would be zero, so that $rs'(t)$ would consist of solely the received signal, i.e., $rs(t)$, from two-wire loop 210. However, in practice, $u(t) \neq 0$, and consequently $rs'(t) = rs(t) + ec_n(t)$. This undesirable signal, $ec_n(t)$, due to the local transmitter, is called 'near-end echo' and represents that portion of the near-end signal energy from $ns(t)$ that leaks through hybrid 120 into receiver 130. Both near-end echo and far-end echo represent sources of interference to a modem receiver and are typically mitigated by corresponding echo cancelers in the receiver.

(Although it will not be discussed in detail in this example, additional echo signals are typically introduced at each four-to-two wire conversion in the system. For example, hybrid 240 may also introduce an echo signal due to an impedance mismatch at the two-wire loop 210/hybrid 240 interface. In what follows, it will be appreciated that the invention applies, with suitable modifications, to any echo signal occurring within the system.)

FIG. 2 shows that portion of receiver 130 that mitigates the effects of echo by including echo cancellation, which is typically performed in the digital domain. Analog received signal $rs'(t)$ is processed and converted by low-pass filter (LPF) 131 and analog-to-digital (A/D) converter 132 to form a digital signal $rs'_d(t)$, where $rs'_d(t) = fs_d(t) + ec_{fd}(t) + \text{distortion}_d + ec_{nd}(t)$ and the subscript d denotes the digital form of a signal. (As used herein, distortion_d is representative of not only the above mentioned forms of channel induced distortion, but also those forms of distortion introduced at respective points of the receiver. For example, at this point in the receiver, distortion_d also includes quantization error due to A/D converter 132.)

Signal $rs'_d(t)$ is then applied to echo canceler 140 and combined through adders 133 and 135 with estimates, or approximations, of the near-end and far-end echo, signal $\hat{ec}_{nd}(t)$ and signal $\hat{ec}_{fd}(t)$, respectively. These echo estimates are provided by near-end echo canceler 134 and far-end echo canceler 136. As known in the prior art, an echo canceler is essentially a filter, whose transfer function is adaptively determined so as to emulate, or estimate, the corresponding "echo path." By passing the transmit symbols through this estimated echo path an echo estimate is derived. The resultant output signal from echo canceler 140 is the echo-canceled received signal $rs''_d(t)$, where

$$rs''_d(t) = fs_d(t) + res_{13} ec_{nd}(t) + res_{ec_{fd}}(t) + \text{distortion}_d.$$

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The signals $res_{13} ec_{nd}(t)$ and $res_{ec_{fd}}(t)$ represent the respective residual echo signal of then ear-end and far-end echo signals, respectively, i.e., $res_{ec_{nd}}(t) = ec_{nd}(t) - \hat{ec}_{nd}(t)$ and $res_{ec_{fd}}(t) = ec_{fd}(t) - \hat{ec}_{fd}(t)$. When the respective echo estimates approximate the actual near-end and far-end echo, then, for all practical purposes, the energy of signal $res_{ec_{nd}}(t) \approx 0$ and the energy of signal $res_{ec_{fd}}(t) \approx 0$. As a result, signal $rs''_d(t)$ is essentially an echo-free signal, which is then processed by the remainder of receiver 130.

In the prior art, this echo-canceled received signal $rs''_d(t)$ is provided to energy detector 145 to determine the presence or absence of the remote signal, i.e., $fs(t)$. However, if there is a disconnect in the near-end echo path, e.g., at the interface between hybrid 120 and two-wire loop 210, of FIG. 1, the resultant impedance change as seen by hybrid 120 causes the near-end echo signal $ec_n(t)$ to change, e.g., increase. Typically, echo canceler 134 uses a very small adaptation step size since a larger step size would limit the amount of cancellation that could be achieved in the presence of the received signal. Consequently, any echo estimate will change very slowly. Therefore, for some time, which can typically be several minutes, following the sudden impedance change, echo estimate signal $\hat{ec}_{nd}(t)$ will continue to mimic the shape, level, and delay of the echo prior to the change and during this time the energy of signal $res_{ec_{nd}}(t)$ is much greater than 0 since $\hat{ec}_{nd}(t)$ no longer approximates $ec_{nd}(t)$. As a result, energy from the near-end residual echo signal is detected by energy detector 145 as representative of the condition that the remote signal is still present-13 when in fact the remote signal has been disconnected. It can typically take a significant amount of time, i.e., on the order of minutes, for near-end echo canceler 134 to eventually approximate the actual near-end echo signal. In the mean time, the modem is left in a state where the modem, and consequently a user, is unaware that the communications connection is lost.

In accordance with this invention, the presence or absence of a remote signal is detected by determining the correlation between the echo estimate and the echo-canceled signal rather than merely measuring the power of the echo-canceled signal. This correlation between the echo estimate signal and the echo-canceled signal is representative of the amount of residual echo present in the echo-canceled signal.

An embodiment of the invention is shown in FIG. 3, which is similar to FIG. 2 except that energy detector 145 is augmented by near-end correlator 450, far-end correlator 460, and detectors 454 and 464. (To simplify the description, energy detector 145 is not shown in FIG. 3). The echo-canceled received signal, $rs''_d(t)$, and the near-end echo estimate signal, $\hat{ec}_{nd}(t)$, are both input to near-end correlator 450. As is known in the art, correlator 450 comprises multiplier 451, which multiplies signals $rs''_d(t)$ and $\hat{ec}_{nd}(t)$, and integrator 452, which integrates the output of multiplier 451. The output of integrator 452, or alternatively correlator 450, is applied to detector 454. The later signals correlation of the near-end echo estimate with the echo-canceled signal when the degree of correlation exceeds a predetermined value, which is representative of a disconnect. For example, detector 454 simply compares the output of correlator 450 to threshold 1, which is provided to detector 454 on lead 455. This predetermined threshold is empirically determined and depends on the modem design and communications channel characteristics.

Similarly, the echo-canceled received signal, $rs''_d(t)$, and the far-end echo estimate signal, $\hat{e}c_{fd}(t)$ are correlated by far-end correlator 460, which provides an output to detector 464. The later compares the degree of correlation of the far-end echo estimate to threshold 2. As is known in the art, the correlators and detectors can be implemented in any number of ways, e.g., by using a digital signal processor (DSP) integrated circuit.

For example, correlator 450 can be designed to implement the following equation: $C_n = \alpha C_{n-1} + \beta rs''_d(t) \hat{e}c_{nd}(t)$. This equation shows that at a time, t , the current output of correlator 450, C_n , is also a function of the previous output of correlator 450, i.e., C_{n-1} . As is known in the art, this equation is representative of a digital low pass filter. The factors α and β are chosen to control the gain of this filtering operation, e.g., to set a unity gain filter, $\alpha=0.99$ and $\beta=0.01$. A similar equation would exist for correlator 460 with substitution of signal $\hat{e}c_{fd}(t)$ for signal $\hat{e}c_{nd}(t)$.

It should be noted that the energies of the echo estimate signal and the echo-canceled received signal can vary over a large range. As a result, the multiplication of these signals will result in a product that varies over a large range, which can make selection of an appropriate threshold difficult. One solution is to make the threshold dependent on the product of the energy in signals $rs''_d(t)$ and $\hat{e}c_{nd}(t)$, i.e., to normalize the threshold to the signal energy. Another solution is use of an alternative implementation of a correlator that is independent of the input signal energies. This is shown in FIG. 4. For simplicity, correlator 550 is described in terms of its operation as the near-end correlator, however, a similar description would apply to the use of correlator 550 as the far-end correlator. Both the near-end echo estimate signal, $\hat{e}c_{nd}(t)$, and the echo-canceled received signal, $rs''_d(t)$, are input to respective elements 570 and 571, of correlator 550. Elements 570 and 571 measure the sign of the respective input signal and provide ± 1 on outputs 581 and 582, respectively. As a result, the output of multiplier 551 is limited to ± 1 . This output is applied to adder 552, which accumulates the output from multiplier 551. If the two signals $\hat{e}c_{nd}(t)$ and $rs''_d(t)$, are not correlated, the output from accumulator 552 will stay close to, i.e., around, a value of zero. On the other hand, if these signals are correlated, the accumulated sum will increase, or decrease if the correlator inputs are 180 degrees out of phase. It should also be noted that even if the echo estimate signal and the echo-canceled received signal are not correlated, the value of the accumulated sum on lead 553 may, over time, drift from zero. This drift is dependent on the actual statistical properties of the echo estimate signal and echo-canceled received signal. As a result, the accumulated sum of adder 552 may also be periodically reset to zero. This accumulated sum is then applied to element 554, which provides the absolute value (abs) of the accumulated sum on correlator output lead 553. The output of correlator 550 is compared to a threshold, as described hereinabove.

The foregoing merely illustrates the principles of the invention and it will thus be appreciated that those skilled in the art will be able to devise numerous alternative arrangements which, although not explicitly described herein, embody the principles of the invention and are within its spirit and scope.

For example, although the invention is described in terms of correlating an echo estimate to the echo-canceled received signal, the presence or absence of a remote signal can also be determined by detecting correlation of the transmitted signal with the echo-canceled received signal.

In addition, although the invention is illustrated herein as being implemented with discrete functional building blocks, e.g., echo cancelers, correlators and detectors, etc., the functions of any one or more of those building blocks can be carried out using one or more appropriate programmed processors.

We claim:

1. A method comprising the steps of receiving a signal, subtracting an echo estimate signal from the received signal to provide an echo-canceled signal, correlating the echo estimate signal with the echo-canceled signal to provide a degree of correlation, and determining the absence of a remote signal by detecting the degree of correlation of the echo estimate signal with the echo-canceled signal.
2. A method of claim 1 wherein the echo estimate signal further comprises a near-end echo estimate signal and a far-end echo estimate signal.
3. Apparatus comprising means for receiving a signal, means for subtracting an echo estimate signal from the received signal to provide an echo-canceled signal, means for correlating the echo estimate signal with the echo-canceled signal to provide a signal representative of the degree of correlation, and means for receiving the signal representative of the degree of correlation to determine the presence or absence of a remote signal.
4. The apparatus of claim 3 wherein the echo estimate signal further comprises a near-end echo estimate signal and a far-end echo estimate signal
5. Modem apparatus comprising means for transmitting a first signal, means for receiving a second signal, echo canceler means to provide an echo estimate signal representative of the first signal, means for combining the echo estimate signal and the second signal to provide an echo-canceled signal, means for correlating the echo estimate signal with the echo-canceled signal to provide a signal representative of the degree of correlation, and means for receiving the signal representative of the degree of correlation to determine the presence or absence of a remote signal.

* * * * *

Exhibit B

United States Patent [19]

[11] **Patent Number:** 5,251,328

Shaw

[45] **Date of Patent:** Oct. 5, 1993

[54] **PREDISTORTION TECHNIQUE FOR COMMUNICATIONS SYSTEMS**

FOREIGN PATENT DOCUMENTS

2225199 5/1990 United Kingdom .

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[21] **Appl. No.:** 630,636

[57] **ABSTRACT**

[22] **Filed:** Dec. 20, 1990

The problem of noise enhancement is eliminated in communications systems by predistorting the amplitude of the transmitted information signal in a manner which compensates for the amplitude distortion introduced in a portion of the communications channel. In the disclosed embodiments, the communications system includes two signal transceivers which communicate with one another through a communications channel. The communications channel includes two-wire subscriber loops adjacent to each signal transceiver with a four-wire transmission path disposed between the subscriber loops. Each transceiver transmits an information signal which, depending on the system noise characteristics, is predistorted to compensate for all or a portion of the amplitude distortion introduced in a subscriber loop adjacent to that signal transceiver. The predistortion necessary to provide such compensation is determined at each transceiver in response to received signals at that transceiver.

[51] **Int. Cl.⁵** H04B 1/38; H04B 1/40

[52] **U.S. Cl.** 455/73; 455/63; 455/69; 455/88; 375/12

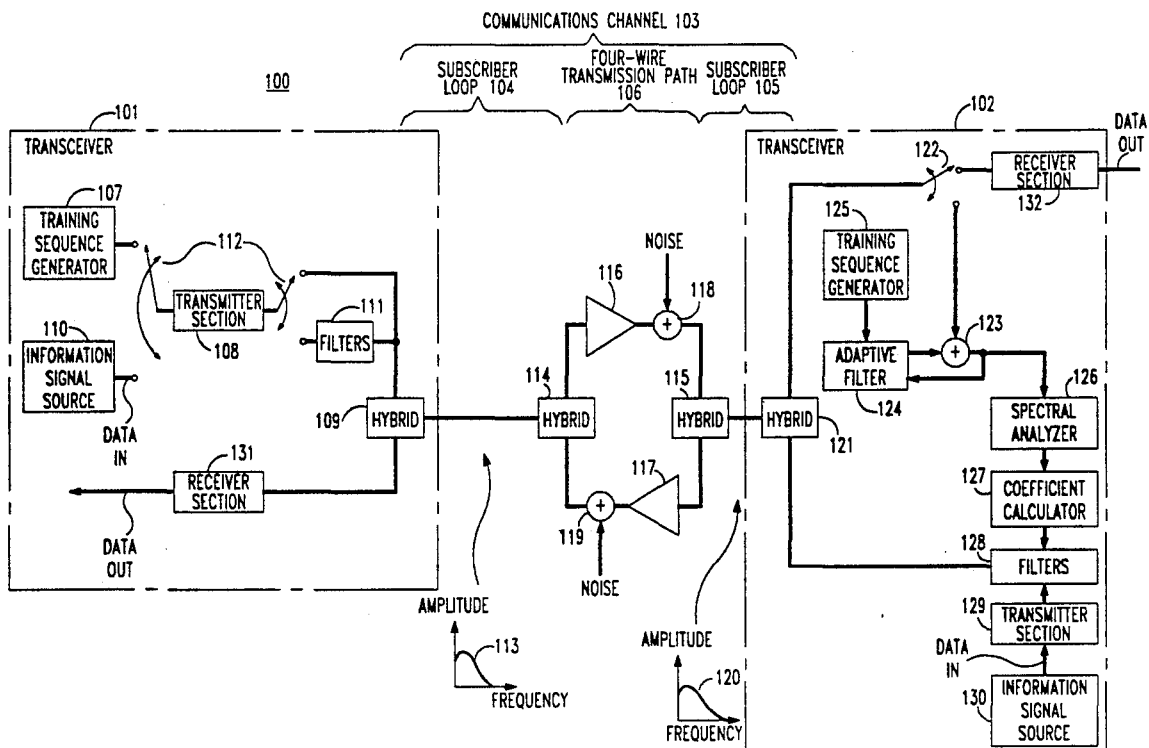
[58] **Field of Search** 455/88, 13.4, 15, 24, 455/63, 69, 116, 127, 73, 67.3, 67.4, 303, 305, 306; 375/12-13, 14, 76

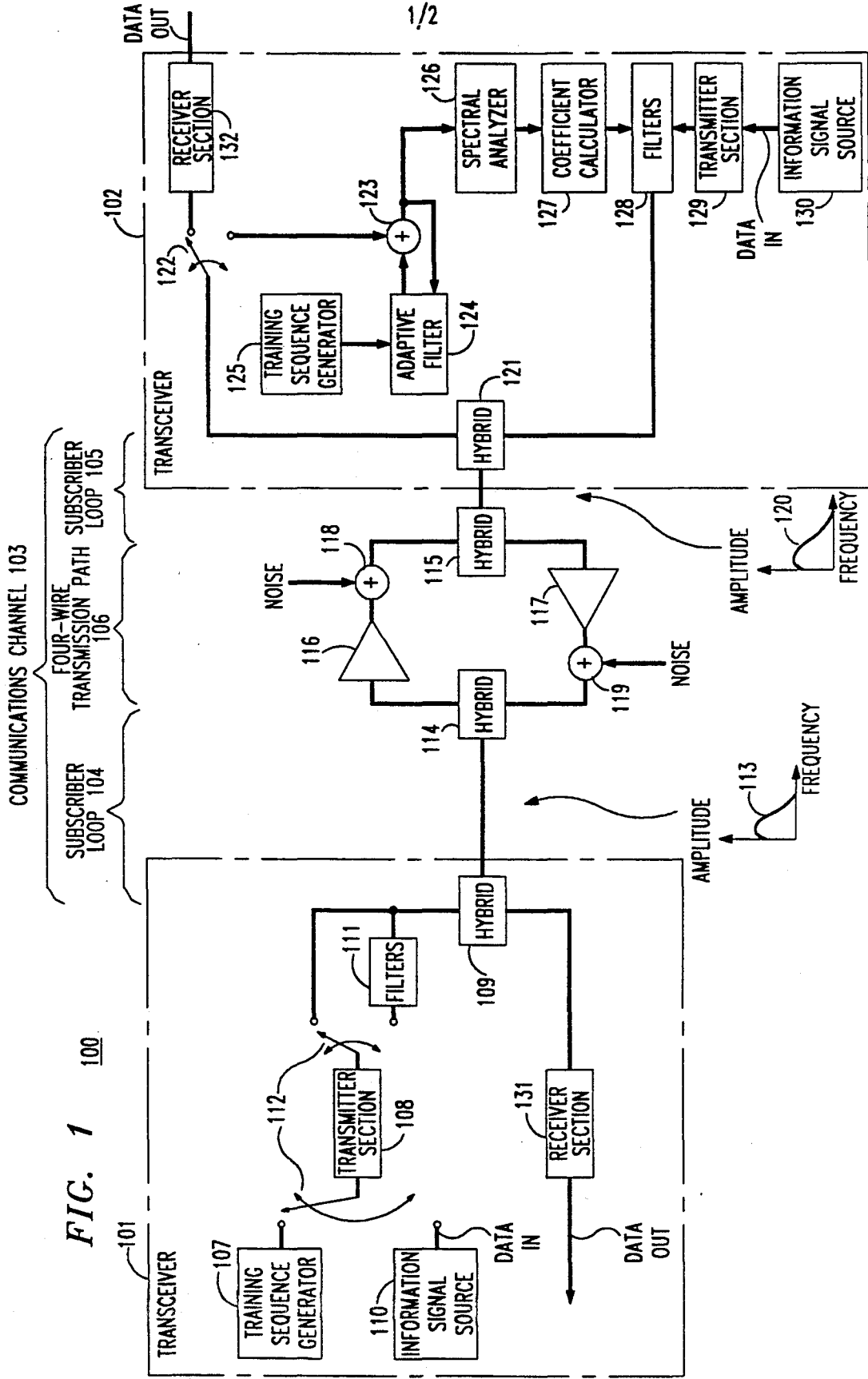
[56] **References Cited**

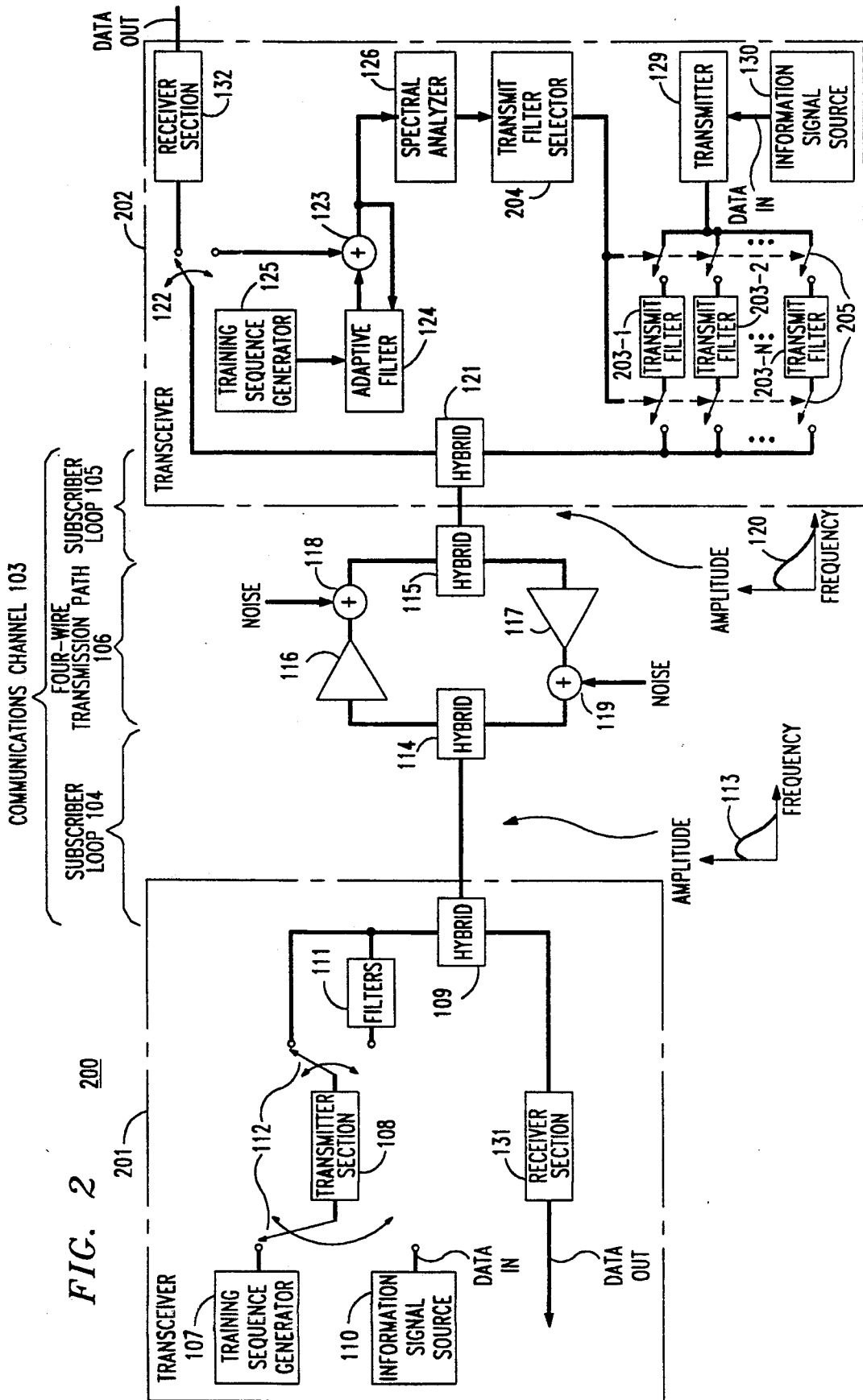
U.S. PATENT DOCUMENTS

3,840,855	10/1974	Ameau et al.	340/146.1 A X
4,441,192	4/1984	Kita et al.	375/14
4,539,583	9/1985	Flamm et al.	358/27
4,561,111	12/1985	Conner	455/63
4,802,236	1/1989	Walczak et al.	455/116
4,890,300	12/1989	Andrews	455/63
4,969,162	11/1990	Karr	375/12

21 Claims, 2 Drawing Sheets







PREDISTORTION TECHNIQUE FOR COMMUNICATIONS SYSTEMS

TECHNICAL FIELD

The present invention relates to communications systems and, more particularly, to a technique for compensating for distortion introduced in a portion of a communications channel.

BACKGROUND OF THE INVENTION

Distortion compensation can be categorized as being either postdistortion or predistortion compensation or a combination of both. Postdistortion compensation is compensation that is provided after distortion is introduced into an information signal while predistortion compensation is compensation for distortion prior to the introduction of the distortion.

In many communications applications, the application of known distortion compensation techniques results in signal noise enhancement. This results from the fact that the information signal is subjected to more distortion than the noise. One example of this is in dial-up modem applications, where the communications channel includes two-wire subscriber loops, each having an associated amplitude versus frequency distortion characteristic, and a four-wire transmission system therebetween. Most of the signal noise is introduced in the four-wire transmission system. Accordingly, any information signal propagating through the communications channel is subjected to amplitude distortion within both subscriber loops while the noise is only subjected to amplitude distortion within one subscriber loop. The process of using linear equalizers to compensate for the distortion to which the information signal has been subjected results in over-equalization or enhancement of the noise signal.

The problem of noise enhancement is not severe for typical voice and low-speed data applications. However, as the data rate increases, such noise enhancement becomes intolerable as it substantially interferes with attainment of required bit error rates. Accordingly, compensation for such noise enhancement is required.

One prior art technique for addressing noise enhancement involves the use of decision feedback equalizers in each receiver to "whiten", i.e., provide a substantially flat amplitude-versus-frequency spectrum for the noise at the equalizer output. The problem with this technique is that a decision feedback equalizer is an inherently complex device to implement and is subject to error propagation. Another technique, known as the "Tomlinson" technique, is to adapt a decision feedback equalizer using a priori known data, thereby eliminating the problem of error propagation, and then transmitting the coefficients of this equalizer to a remote transmitter wherein such coefficients are used to predistort the transmitted signal. The shortcoming of this technique is that it requires the availability of an error-free communications channel for coefficient transmission. Such a channel is not always available when required.

Accordingly, it would be desirable if a distortion compensation technique could be devised which addresses the problem of noise enhancement which did not have the problems of error propagation and did not require an error-free communications channel for coefficient transmission.

SUMMARY OF THE INVENTION

The present invention addresses the above-described problem of noise enhancement and error propagation by predistorting the transmitted information signal without requiring an error-free communications channel to transmit coefficients from one transceiver to another. Broadly speaking, the present invention covers the notion of determining the distortion introduced within a portion of a communications channel between two signal transceivers by processing the received signal at a transceiver and then using the results of this processing to predistort the signal transmitted by that transceiver to compensate for all or a part of the determined amplitude distortion.

In the disclosed embodiment, which pertains to the above-described dial-up modem application, a training sequence of a priori known signals is transmitted from a first transceiver through the communications channel to a second transceiver. An adaptive filter in the receiver of the second transceiver receives this sequence and provides an error signal indicative of the amplitude distortion introduced in the subscriber loop adjacent to the second transceiver. This error signal is spectrally analyzed and the results of this analysis are used to adjust filters in the transmitter of the second transceiver. Such adjustment optimally sets the transmit conditions for communications from the second transceiver to the first by predistorting the transmitted information signal to compensate for all or a portion of the amplitude distortion introduced in the subscriber loop adjacent to the second transceiver. As will be described, the optimum predistortion varies with the system noise characteristics.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a block-schematic diagram of a communications system implementing a first embodiment of the present invention; and

FIG. 2 is a block-schematic diagram of a communications system implementing a second embodiment of the present invention.

DETAILED DESCRIPTION

In the exemplary bidirectional communications system 100 shown in FIG. 1, which incorporates the present invention, transceivers 101 and 102, each incorporated within a dial-up modem (not shown), communicate with one another via communications channel 103. Communications channel 103 includes subscriber loops 104 and 105 which are each a two-wire communications path and are respectively connected to transceivers 101 and 102. Channel 103 also includes a four-wire signal transmission path 106 disposed between the aforesaid subscriber loops. Pursuant to the disclosed embodiment of the present invention, signals received at each transceiver of communications system 100 are processed to determine the amplitude distortion introduced within the adjacent subscriber loop. The determined amplitude distortion is then processed and used to predistort the signals transmitted from the distortion-determining transceiver. For purposes of simplicity, the present invention will be described in reference to determining the predistortion required for signals transmitted from transceiver 102 to transceiver 101 which, depending on the system noise characteristics, compensates for all or a portion of the distortion introduced within subscriber loop 105. Of course, an identical technique can be used

to predistort the signals transmitted from transceiver 101 to transceiver 102 so as to equivalently compensate for the distortion introduced within subscriber loop 104.

To predistort the amplitude of the signal transmitted from transceiver 102 to transceiver 101, the amplitude distortion introduced in subscriber loop 105 must first be determined. To accomplish this, in accordance with the present invention, at each of one or more predetermined time intervals, e.g., during system start-up or "retraining", at least one training sequence is transmitted from transceiver 101 to transceiver 102. Each training sequence, including at least one a priori known signal, is coupled from training sequence generator 107 through the transmitter section 108 of transceiver 101 to hybrid 109 and thence to subscriber loop 104. At other times, an information signal from information signal source 110 is coupled to transmitter section 108 and thence spectrally shaped by filters 111 before being coupled to hybrid 109. Double-pole-double-throw switch 112 provides the selective coupling of either the training sequence or the information signal through the aforementioned apparatus. Hybrid 109 operates in well-known fashion to provide a two-to-four wire signal interface between transceiver 101 and subscriber loop 104. Advantageously, the training sequence provided by training sequence generator 107 has a substantially flat amplitude spectrum over a frequency range greater than that of the information signal after spectral shaping by filters 111. While a variety of training sequences, such as a "chirp" or swept-frequency signal, can provide such a spectrum, a preferable training sequence is a pseudorandom sequence.

Subscriber loop 104 has an associated amplitude-versus-frequency distortion characteristic which selectively attenuates the amplitude of any signal coupled therethrough. This characteristic, designated by reference numerals 113 in FIG. 1, predominantly attenuates the coupled signal at higher frequencies and also attenuates, to a lesser extent, frequencies close to dc due to the characteristics of hybrids 109 and 114. The attenuation characteristic is substantially the same for both directions of transmission over subscriber loop 104.

Four-wire signal transmission path 106 includes a pair of hybrids 114 and 115 and amplifiers 116 and 117. Path 106 can also be symbolically represented as including summing nodes 118 and 119 to reflect the fact that while the amplitude-versus-frequency characteristic of path 106 is substantially flat, most of the noise in communications channel 103 is injected by path 106 into the signal coupled in either transmission direction. This noise can be from a variety of sources, such as quantization noise in digital four-wire systems or thermal noise in analog four-wire systems. Each of hybrids 114 and 115 in path 106 serves as a two-to-four-wire interface for its adjacent subscriber loop and each amplifier provides unidirectional transmission in analog transmission systems and is representative of codecs in digital transmission systems.

After propagating through four-wire transmission path 106, the transmitted signal from transceiver 101 enters subscriber loop 105 and is again subjected to an amplitude-versus-frequency distortion characteristic, designated as 120, which selectively attenuates the amplitude of any coupled signal. Hybrids 115 and 121 have a similar effect on characteristic 120 as their counterparts, i.e., hybrids 109 and 114, have on characteristic 113. Characteristic 120 can be the same or different from characteristic 113 but is typically different due to

the fact that each subscriber loop need not have the same length and that even if the lengths are the same, each subscriber loop can be fabricated using signal conductors having a different loss-per-unit length. However, as noted above with respect to characteristic 113, characteristic 120 is substantially the same for signal transmission in either direction over subscriber loop 105.

Within transceiver 102, the noise and amplitude-distorted signals coupled from subscriber loop 105 pass through hybrid 121. During each predetermined time interval when a training sequence is transmitted from transceiver 101, switch 122 couples the received training sequence to summing node 123. At other times, i.e., at times when the training sequence is not transmitted, switch 122 couples the received information signal originally provided by information signal source 110 to receiver section 132 in transceiver 102. Receiver section 132, which is of conventional design and can incorporate echo-canceling apparatus, recovers the information signal provided by source 110.

The received training sequence includes the noise and amplitude distortion introduced by communications channel 103. Node 123 combines the received training sequence with the output of adaptive filter 124. Filter 124 produces its output in response to a training sequence provided by training sequence generator 125. This training sequence is identical to that provided by training sequence generator 107. The output of node 123 is the "error" signal of the adaptive filter and is coupled back to filter 124 wherein it is used to adjust, in well-known fashion, the tap-weight coefficients therein. Pursuant to the present invention, it is recognized that once filter 124 converges, the output of node 123 or residual error signal represents the noise signal injected in path 106 and coupled through subscriber loop 105. This noise signal has only experienced the amplitude distortion introduced by subscriber loop 105 and can be analyzed to determine distortion characteristic 120, i.e., the amplitude-versus-frequency response of subscriber loop 105. This characteristic can then be analyzed and used to predistort the signal transmitted from transceiver 102 to transceiver 101 in a manner which minimizes the noise enhancement associated with information signals received at transceiver 101. Advantageously, this technique unlike the prior art does not require the transmission of coefficients or equivalent information from transceiver 101 to transceiver 102.

The determination of the predistortion for the transmitted signal from transceiver 102, which compensates for all or a portion of the amplitude distortion introduced in subscriber loop 105, is provided by spectral analyzer 126 and coefficient calculator 127 in response to the output of node 123. Analyzer 126, using well-known techniques, analyzes the output signal at node 123 and determines the characteristic 120 therefrom. By processing this determined characteristic, coefficient calculator 127 generates the coefficients required by transmit filters 128 using well-known procedures for filter design, such as inverse Fourier transforms or the Remez exchange algorithm, to predistort the amplitude of the signal outputted by transmitter section 129. Information signal source 130 provides the information signal to be transmitted by transmitter section 129. This transmitted signal is coupled through communications channel 103, and thence to receiver section 131 in transceiver 101. Receiver section 131 recovers the information signal provided by information signal source 130.

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In certain system applications, it is desirable to predistort the transmitted signal from transceiver 102 based on the exact inverse of the determined distortion characteristic 120. Such processing works well when the noise injected by four-wire transmission path 106 is primarily quantization noise. Such quantization noise is introduced in analog-to-digital signal conversion and vice-versa and is therefore inherent in digital transmission systems. In other applications, where the noise is primarily thermal or white noise, the optimal predistortion is less than that provided by an exact inversion of the determined distortion characteristic 120. Indeed, it has been found that for purely white noise the optimal predistortion is that obtained by using fifty percent of the inverse of the amplitude versus frequency differential of characteristic 120. This optimal white noise predistortion can be readily provided by adjusting the output provided by spectral analyzer 126.

FIG. 2 shows an alternate embodiment of the present invention which functions in a substantially identical manner to FIG. 1 except that any transceiver which predistorts its transmitted signal is designed with a plurality of transmit filters. FIG. 2 shows transceiver 202 with a plurality of transmit filters 203-1 through 203-N, where N is a predetermined integer. Each of the transmit filters has a different predetermined filter characteristic. With this filter arrangement, instead of determining the filter coefficients for a transmit filter, the output of spectral analyzer 126 is processed by transmit filter selector 204 to determine which of transmit filters 203-1 through 203-N provides the optimal amplitude predistortion for signals transmitted from transceiver 102. Again, depending on system noise characteristics, this optimal predistortion can be that which compensates for all or a percentage portion of the amplitude distortion introduced within subscriber loop 105. Once this filter determination is made, the determined filter is serially connected to the output of transmitter portion 127 via multi-pole switch 205. Switch 205 operates in response to control signals provided by transmit filter selector 204.

It should, of course, be understood that, while the present invention has been disclosed in reference to a specifically described embodiment, numerous alternative arrangements will be apparent to those of ordinary skill in the art. For example, while the disclosed embodiments utilize discrete devices, the devices can be implemented using one or more appropriately programmed general-purpose processors or special-purpose integrated circuits or digital processors or an analog or hybrid counterpart of any of these devices. Or, while the present invention has been described with reference to a specific communications application, it is also applicable to other applications wherein the amplitude versus distortion characteristic of a portion of the communications channel is substantially similar for each direction of signal transmission.

I claim:

1. Transceiver apparatus for use in a communications system wherein a communications channel through which a signal is transmitted introduces amplitude distortion, said apparatus comprising means responsive to a received signal from said communications channel for determining substantially less than all of the amplitude distortion introduced within said communications channel, said determining means being designed for determining substantially less than all of the amplitude distortion

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introduced within said communications channel; and means responsive to said determined amplitude distortion for predistorting a transmitted signal from said transceiver.

2. A method for use in a transceiver of a communications system wherein a communications channel through which a signal is transmitted introduces amplitude distortion, said method comprising the steps of determining less than all of the amplitude distortion introduced within said communications channel in response to a signal received from said communications channel using apparatus designed to determine less than all of the amplitude distortion introduced within said communications channel; and predistorting a transmitted signal from said transceiver in response to said determined amplitude distortion.

3. Apparatus for use in a communications system wherein a signal is transmitted through a communications channel including a plurality of serially connected channel sections which introduce amplitude distortion into a transmitted signal including the section adjacent said apparatus, said apparatus comprising means for receiving a training sequence including at least one a priori known signal and means responsive to said received training sequence for determining the amplitude distortion introduced only in the communications channel section adjacent said apparatus.

4. The apparatus of claim 3 further including means responsive to said determined amplitude distortion for predistorting a transmitted signal from said apparatus and wherein said predistorting means predistorts said transmitted signal to compensate for all of said determined amplitude distortion.

5. The apparatus of claim 3 further including means responsive to said determined amplitude distortion for predistorting a transmitted signal from said apparatus and wherein said predistorting means predistorts said transmitted signal to compensate for less than all of said determined amplitude distortion.

6. The apparatus of claim 3 wherein said communications channel includes two subscriber loops and the communications channel section adjacent said apparatus is a subscriber loop.

7. The apparatus of claim 3 wherein said determining means includes an adaptive filter.

8. The apparatus of claim 3 further including means responsive to said determined amplitude distortion for predistorting a transmitted signal from said apparatus and wherein said predistorting means includes a transmit filter.

9. The apparatus of claim 8 wherein said transmit filter has at least one filter coefficient and said determining means determines said filter coefficient.

10. The apparatus of claim 3 further including means responsive to said determined amplitude distortion for predistorting a transmitted signal from said apparatus and wherein said predistorting means includes a plurality of transmit filters.

11. The apparatus of claim 10 wherein said determining means includes means for selecting one of said transmit filters to predistort the amplitude of said transmitted signal.

12. The apparatus of claim 3 wherein said determining means is responsive to said training sequence at least one predetermined time.

13. The apparatus of claim 3 wherein said training sequence is a pseudorandom sequence.

14. The apparatus of claim 3 further including means for generating a second training sequence identical to that transmitted through said communications channel and said determining means includes an adaptive filter which is responsive to said second training sequence.

15. A method for use in a communications system wherein a signal is transmitted from a transmitter through a communications channel to a receiver, said communications channel including a plurality of serially connected channel sections which introduce amplitude distortion into a transmitted signal including the section adjacent said receiver, said method comprising the steps of

receiving a training sequence including at least one a priori known signal and determining the amplitude distortion introduced only in the communications channel section adjacent said receiver in response to said received training sequence.

16. A communications system including first and second signal transceivers interconnected by a communications channel which introduces amplitude distortion in a transmitted signal, said first signal transceiver comprising

means for transmitting a signal through said communications channel, and

said second transceiver comprising

means, responsive to the signal received from said communications channel, for determining substantially less than all of the amplitude distortion introduced within said communications channel, said determining means being designed for determining substantially less than all of the amplitude distortion introduced within said communications channel, and

means for predistorting a transmitted signal in response to said determined amplitude distortion.

17. Transceiver apparatus for use in a communications system in which signals are transmitted from said transceiver apparatus over a communications channel to second transceiver apparatus utilizing adaptive filtering in its receiver section, said channel being of a type which introduces amplitude distortion and noise into said transmitted signals, said channel having a plurality of portions over which said noise does not propagate but which introduce said amplitude distortion, said apparatus comprising

means responsive to a signal received from said communications channel for determining the amplitude distortion introduced into said transmitted signals

within one of said portions of said communications channel, and

means responsive to said determined amplitude distortion for predistorting said transmitted signals in such a way as to compensate for at least a portion of the distortion introduced within said one portion,

whereby enhancement of said noise as the result of adaptive filtering of the signals received by said second transceiver apparatus is reduced.

18. The transceiver apparatus of claim 17 wherein said one portion is directly adjacent to said transceiver apparatus.

19. The transceiver apparatus of claim 17 wherein said signal received from the communications channel represents a predetermined training sequence and wherein said determining means includes

means responsive to that received signal and to a signal generated in said transceiver apparatus that represents said training sequence for generating an error signal which substantially represents only a noise component of that received signal, and means for analyzing said error signal to carry out the amplitude distortion determination.

20. Transceiver apparatus for use in a communications system wherein a communications channel through which a signal is transmitted introduces amplitude distortion in each of a plurality of serially connected communications channel sections, said apparatus comprising

means for determining the amplitude distortion introduced within only one of said communications channel sections in response to a received signal from said communications channel; and

means responsive to said determined amplitude distortion for predistorting a transmitted signal from said transceiver.

21. A method for use in a transceiver of a communications system wherein a communications channel through which a signal is transmitted introduces amplitude distortion in each of a plurality of serially connected communications channel sections, said method comprising the steps of

determining the amplitude distortion introduced within only one of said communications channel sections in response to a signal received from said communications channel; and

predistorting a transmitted signal from said transceiver in response to said determined amplitude distortion.

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Exhibit C

United States Patent [19]
Betts et al.

[11] **Patent Number:** **5,812,537**
 [45] **Date of Patent:** **Sep. 22, 1998**

[54] **ECHO CANCELING METHOD AND APPARATUS FOR DATA OVER CELLULAR**

0667700 A2 8/1995 European Pat. Off. H04M 9/08

OTHER PUBLICATIONS

[75] Inventors: **William Lewis Betts**, St. Petersburg;
Ramon B. Hazen, North Redington
 Beach; **Robert Earl Scott**, Indian
 Rocks Beach, all of Fla.

U.S. application No. 08/137,542, Scott, filed Oct. 18, 1993.
 IEEE Transactions On Communications, vol. COM-26, No.
 5, May 1978, pp. 647-653, authored by Donald L. Dutt-
 weiler, entitled "A Twelve-Channel Digital Echo Canceler".

[73] Assignee: **Paradyne Corporation**, Largo, Fla.

IEEE Journal On Selected Areas In Communications, vol.
 SAC-2, No. 2, Mar. 1984, pp. 297-303, authored by Donald
 L. Duttweiler, C. W. K. Gritton, Kevin D. Kolwicz and Ying
 G. Tao, entitled "A cascadable VLSI Echo Canceller".

[21] Appl. No.: **536,908**

[22] Filed: **Sep. 29, 1995**

[51] **Int. Cl.⁶** **H04B 3/20**

[52] **U.S. Cl.** **370/286; 370/289; 370/292;**
 379/406; 379/410

[58] **Field of Search** 370/291, 290,
 370/289, 286, 465, 295, 210, 292; 379/410,
 392, 406; 381/66, 94, 94.2, 94.3

ICASSP-93, 1993 IEEE International Conference on
 Acoustics, Speech and Signal Processing, Plenary, Special,
 Audio, Underwater Acoustics, VLSI, Neural Networks, vol.
 I of V, Apr. 27-30, 1993, Minneapolis Convention Center,
 Minneapolis, Minnesota, U.S.A. 93-CH3252-4.

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 Kayden, Horstemeyer & Risley, LLP

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,434,438	2/1984	Rzeszewski	348/614
4,464,545	8/1984	Werner	370/286
4,554,417	11/1985	Boyer	370/287
4,621,366	11/1986	Cain et al.	375/222
4,987,569	1/1991	Ling et al.	370/292
5,007,046	4/1991	Erving et al.	370/249
5,007,047	4/1991	Sridhar et al.	370/289
5,131,032	7/1992	Esaki et al.	379/410
5,206,854	4/1993	Betts et al.	370/286
5,263,020	11/1993	Yatsuzuka et al.	370/289
5,610,909	3/1997	Shaw	370/291
5,631,899	5/1997	Duttweiler	370/291

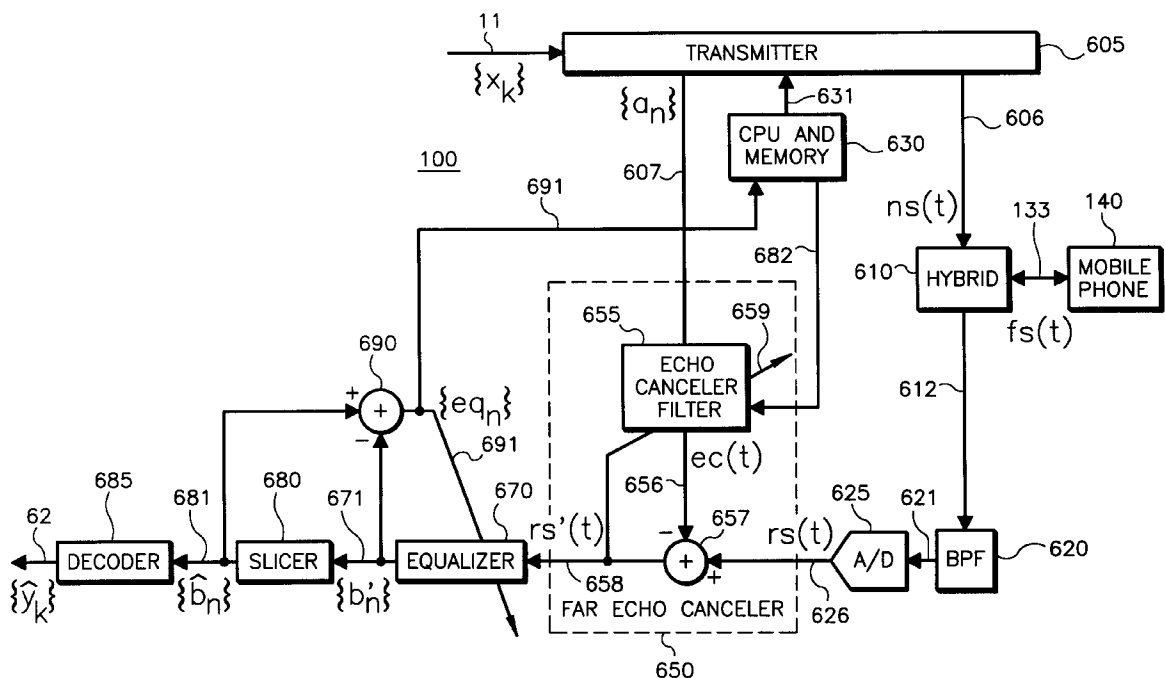
FOREIGN PATENT DOCUMENTS

0111938 B1 6/1984 European Pat. Off. H04B 3/23

[57] **ABSTRACT**

A processor of a cellular modem monitors for the presence of a residual echo signal during a full-duplex portion of a training sequence. In particular, the processor monitors an equalizer error signal during a full-duplex training phase that follows the half-duplex training phase for the echo canceler. If the processor detects a level of the error signal greater than a predefined threshold, the processor presumes the increase in the error signal is due to the presence of a residual echo signal and performs a predefined adjustment of the taps of the corresponding echo canceler of the cellular modem.

25 Claims, 3 Drawing Sheets



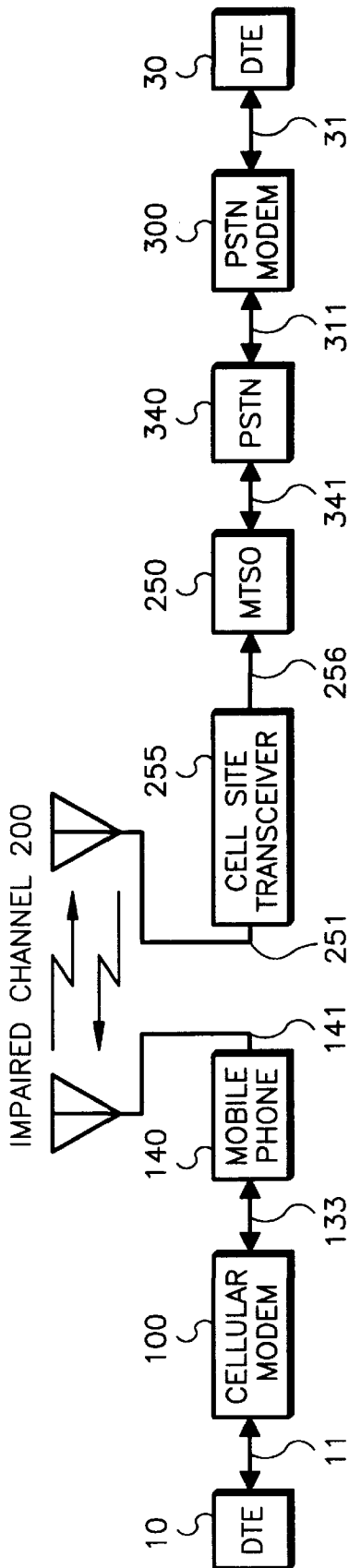


FIG. 1

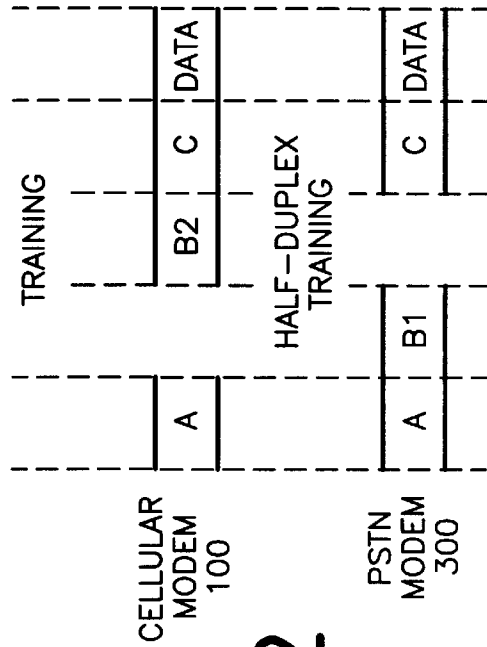
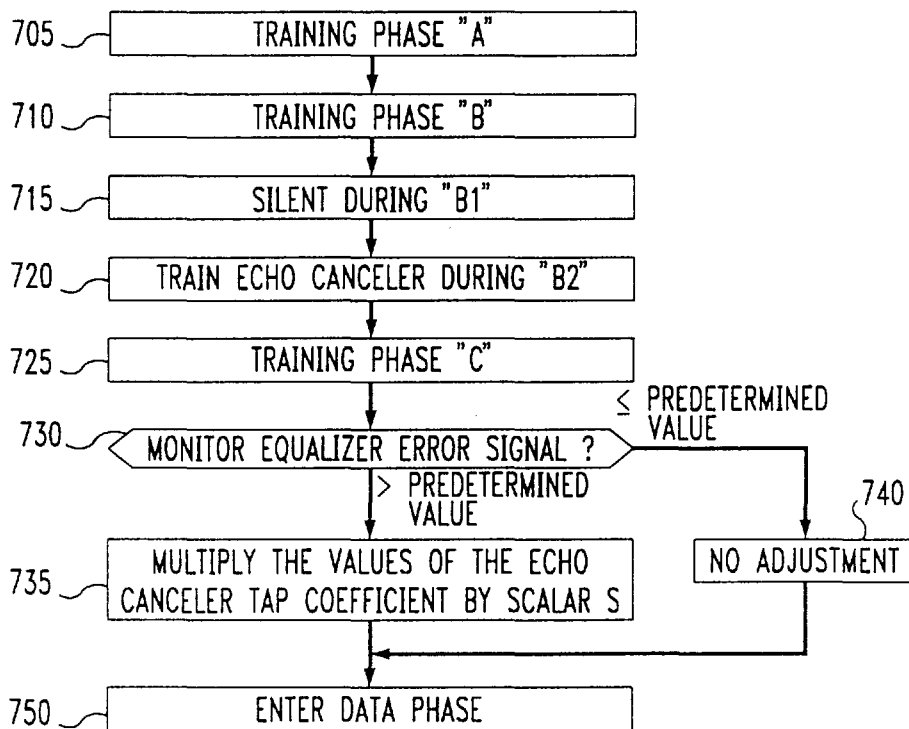


FIG. 2

FIG. 4



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ECHO CANCELING METHOD AND APPARATUS FOR DATA OVER CELLULAR

CROSS-REFERENCE TO RELATED APPLICATIONS

Related subject matter is disclosed in the co-pending commonly assigned, U.S. patent applications of: Betts et al., entitled "Echo Canceling Method and Apparatus for Data Over Cellular," Ser. No. 08/536,916, filed on Sep. 29, 1995; Betts et al., entitled "Echo Canceler Gain Tracker for Cellular Modems," Ser. No. 08/536,917, filed on Sep. 29, 1995.

BACKGROUND OF THE INVENTION

The present invention relates to data communications equipment, e.g., modems, and, more particularly, to echo-canceling modems.

Today, the North American cellular system is predominantly an analog system sometimes referred to as AMPS (Advanced Mobile Phone Service). The corresponding cellular communications channel is sometimes referred to as an "impaired channel" since it is affected by a number of channel impairments like Rayleigh fading, co-channel interference, etc., that increase the error rate and, thus, degrade the overall performance of the mobile connection. This is in contrast to a land-line communications channel, where the predominant impairment is additive white gaussian noise (AWGN). Those in the art have realized that one way to improve data transmission rates in the cellular environment is to use a data protocol that is better suited to combating the effects of the cellular environment over the cellular portion of the data connection. One example of a cellular-oriented protocol is the "Enhanced Throughput Cellular" (ETC) protocol, developed by AT&T Paradyne.

Nevertheless, even with a cellular-oriented protocol, impairments in the cellular channel continue to limit the effective data rate over the cellular channel. For example, reliable, i.e., consistent, data transmission over 9600 bits per second (bps) is difficult to maintain.

SUMMARY OF THE INVENTION

Notwithstanding the above-mentioned impairments present in the cellular channel, we have discovered a non-linearity in the cellular AMPS network that has been affecting the ability to reliably maintain cellular data rates over 9600 bps. In particular, when a cellular modem is performing training with a far-end PSTN modem, the cellular AMPS network distorts a far-end echo signal that is used by the cellular modem to train its echo canceler. We estimate that this distortion of the far-end echo signal occurs in approximately 40% of the AMPS cellular infrastructure. The source of the distortion of the far-end echo signal is due to a non-linear compander in some base-station radios and the half-duplex approach that modems use to train echo cancelers. The result is that the echo canceler of the cellular modem is not properly trained thereby causing a residual echo signal to exist. This residual echo signal limits the maximum cellular data rate to 9600 bps (often, this cellular data rate is reduced to 7200 bps.) Without this residual echo signal, the cellular modem and PSTN modem could often achieve a data rate of 14,400 bps (and even higher in the future).

Therefore, and in accordance with the invention, we have developed a method and apparatus for reducing the residual echo signal, which is effectively caused by the above-

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mentioned distortion of the far-end echo signal during training. In particular, circuitry in a cellular modem detects the presence of a residual echo signal, and, in response thereto, adjusts the taps of the corresponding echo canceler by a predefined amount. As a result, this invention eliminates the incorrect training caused by the distortion of the far-end echo signal, thereby providing the ability to reliably maintain cellular data rates greater than 9600 bps.

In an embodiment of the invention, a processor of the cellular modem monitors an equalizer error signal. In particular, this monitoring occurs in a full-duplex training phase that follows the half-duplex training phase for the echo canceler. If the processor detects a level of the error signal greater than a predefined threshold, the processor presumes the increase in the error signal is due to the presence of a residual echo signal and performs a predefined adjustment of the taps of the corresponding echo canceler of the cellular modem.

This approach has an advantage in that it can work with a standard PSTN modem, i.e., no modification is required in the far-end PSTN modem.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a block diagram of a mobile data communications system embodying the principles of the invention;

FIG. 2 shows an illustrative portion of a training sequence;

FIG. 3 is an illustrative block diagram of modem 100 of FIG. 1 embodying the principles of the invention; and

FIG. 4 is a flow diagram of an illustrative method for use in the modem of FIG. 3.

DETAILED DESCRIPTION

Other than the inventive concept, the elements of FIG. 1 function as in the prior art and will not be described in detail. FIG. 1 shows a block diagram of a mobile data communications system that includes cellular modem 100, which embodies the inventive concept. As shown, cellular modem 100 is coupled to mobile phone 140 for transmitting data signals to, and receiving data signals from, PSTN modem 300 via cell site transceiver 255, impaired channel 200, Mobile Telecommunications Switching Office (MTSO) 250, and PSTN 340. Both cellular modem 100 and PSTN modem 300 are also coupled to respective data terminal equipment (DTE) 10 and 30.

Before describing the inventive concept, the following is a brief overview of the operation of the mobile data communications system of FIG. 1 once a data connection is established, i.e., after training has been completed. A data signal is applied to cellular modem 100, via line 11, from DTE 10 for transmission to PSTN modem 300. Line 11 represents the signaling, electronics, and wiring, for conforming to a DTE/DCE (data communications equipment) interface standard like EIA RS-232. Cellular modem 100 modulates this data signal as is known in the art to, typically, a quadrature amplitude modulated (QAM) signal, which is provided via line 133 to mobile phone 140. Although not necessary to the inventive concept, it is assumed for the purposes of this example that the modem signal is compatible with International Telecommunications Union (ITU) standard V.32 bis. Mobile phone 140 further modulates this transmission signal onto a predefined cellular carrier to provide a cellular data signal to antenna 141. Cell site transceiver 255 receives the cellular data signal via antenna 251 and provides a received modem signal to MTSO 250 for

transmission, via public-switched-telephone network **340**, to a far-end data endpoint as represented by PSTN modem **300** and DTE **30**. Ideally, the data signal received by DTE **30** from PSTN modem **300** is identical to the data signal provided by DTE **10** to cellular modem **100**. Transmission of data signals in the opposite direction, i.e., from DTE **30** to DTE **10** occurs in a like fashion.

However, before establishing a data connection, modems, as known in the art, perform a standard sequence of signaling that is also referred to as hand-shaking or training. This signaling determines such parameters as data rate, modulation to use, and trains, or sets, what is known in the art as filter tap coefficient values for filters like echo cancelers and equalizers, which combat interference and distortion effects caused by the communications channel. As known in the art, the training sequence for an echo canceler is performed half-duplex. Full-duplex training of the echo canceler, while theoretically possible, is not practical from a price/performance viewpoint in the design of data communications equipment.

Since different data communications standards like ITU V.32 bis and ITU V.34 have different training sequences, a generalized representation of a training sequence is illustrated in FIG. 2. It is assumed that cellular modem **100** is the calling modem and that PSTN modem **300** is the answering modem. As shown in FIG. 2, the training sequence is initially full-duplex during phase "A." The latter is followed by a phase "B," which is half-duplex and is additionally divided into two portions: "B1" and "B2". In portion "B1," of phase "B," the called modem, PSTN modem **300**, sends a signal to train the echo canceler of PSTN modem **300** while the cellular modem **100** is silent. Then, in portion "B2," of phase "B," the calling modem, cellular modem **100**, sends a signal to train the echo canceler of cellular modem **100** while the far-end PSTN modem is silent. To complete the description of FIG. 2, after half-duplex training phase "B," both modems enter a subsequent full-duplex training phase "C," which is then followed by a "DATA" phase in which data is actually communicated between the two modems.

During the respective half-duplex training portions of phase "B," each modem uses the returned far-end echo signal to adjust the tap coefficients of its echo canceler. The far-end echo signal is a result of subsequent 4-wire to 2-wire signal conversion within the PSTN, as is known in the art. (It should be noted that other components are also adjusted during training, e.g., equalizer coefficients, etc. However, for the purposes of this example, only the echo canceler training is described.)

In the cellular network, the base station radio—cell site transceiver **255**—performs audio processing. One of the audio processing stages is a compander (not shown). The compander is linear over a given signal range. Unfortunately, we have discovered that some companders are not linear in the signal range of the returned far-end echo signal during the half-duplex training phase. As a result, this non-linearity of the compander results in training the echo canceler of the cellular modem to a distorted far-end echo signal. However, when the cellular modem subsequently goes into full duplex mode, i.e., both transmitting a signal to, and receiving a signal from, the PSTN modem, the received signal level passing through cell site transceiver **255** causes the compander to operate in its linear range. This change in compander operation results in a gain change in the echo path that causes a degradation in echo canceler performance resulting in a large "residual echo" in the cellular modem. In other words, there is a loss of echo cancellation. This

residual echo signal limits the maximum cellular data rate to 9600 bps (often, this cellular data rate is reduced to 7200 bps.) Without this residual echo signal, the cellular modem and PSTN modem could often achieve a data rate of 14,400 bps (and even higher in the future).

This problem can be solved by modems with a four-wire interface at the PSTN-side of the cellular data connection. For example, a cellular network that includes a cellular modem pool, as well as "mu-law" modem pools being installed at customer locations solve this problem. Unfortunately, a large number of cellular users will still be calling 2-wire PSTN modems for the foreseeable future. In addition, this problem could be solved by allowing continued adaptation of the echo canceler during data transmission. However, this adaptation process can be slow. In addition, some modems (as represented by cellular modem **100**) only adapt during the training sequence to conserve hardware requirements, such as memory, and thereby reduce the cost of the data communications equipment.

Therefore, and in accordance with the invention, we have developed a method and apparatus for reducing the residual echo signal, which is effectively caused by the above-mentioned switching between a linear mode of operation and a nonlinear mode of operation of a network compander. In particular, circuitry in a cellular modem detects the presence of a residual echo signal, and, in response thereto, adjusts the taps of the corresponding echo canceler by a predefined amount. As a result, this invention eliminates the incorrect training caused by the distortion of the far-end echo signal, thereby providing the ability to reliably maintain cellular data rates greater than 9600 bps.

In order to facilitate understanding of the inventive concept reference should now be made to FIG. 3, which represents an illustrative block diagram of cellular modem **100**. Except for the inventive concept (discussed below), the structure of cellular modem **100** as illustrated in FIG. 3 is representative of prior art echo-canceling modems and the operation of the various components is well-known.

A binary input data sequence $\{x_k\}$ is provided by DTE **10** to modem **100** on line **11**. This input data sequence is processed by transmitter **605** to form a near-end transmitted signal, $ns(t)$. Illustratively, near-end transmitted signal, $ns(t)$, represents a quadrature amplitude modulated (QAM) signal. The near-end transmitted signal, $ns(t)$, is provided by hybrid **610** to mobile phone **140**, via line **133**. (It should be noted that during training, the binary input sequence is generated by cellular modem **100** as is known in the art. For simplicity, this alternate source of the binary data sequence is not shown.)

Transmitter **605** is under the control of CPU and memory **630**, which is a microprocessor based central processing unit and associated memory for storing program data. It is assumed that transmitter **605** includes an encoder, shaping filter, digital to analog converter, etc., for processing and modulating the input data sequence on line **11** to provide the QAM signal, $ns(t)$, on line **606**. As part of this processing of the input data sequence, transmitter **605** represents the input data sequence as a sequence of complex-valued symbols $\{a_n\}$ at nominal rate $1/T$ symbols per second. (This processing may also include scrambling, redundancy and other forms of encoding.) As can be seen from FIG. 3, this input data sequence is also used by far echo canceler **650** (described below).

Turning now to the other direction of communication, an analog line signal, $fs(t)$, transmitted from a far-end modem, e.g., PSTN modem **300**, is received and is directed to

bandpass filter (BPF) **620**. This signal is referred to as the “far-end data signal,” and utilizes the same frequency band as the transmitted signal, $ns(t)$, i.e., cellular modem **100** is a full-duplex modem. Bandpass filter **620** removes energy outside the signal passband from the far-end data signal **612** to form signal **621**, which is then converted to digital form by analog-to-digital (A/D) converter **625** to form received signal $rs(t)$.

The signal, $fs(t)$, reaching the input of bandpass filter **620** is corrupted by so-called echo signals. Echo signals are typically introduced at each four-to-two wire conversion in the communications system.

The far-end echo signal comprises transmit signal energy from cellular modem **100** which was transmitted towards PSTN modem **300** in the first instance but was reflected back to cellular modem **100** as a result of, for example, an impedance mismatch at a two-to-four wire conversion within PSTN **340**. The received signal, $rs(t)$, provided by A/D converter **625**, thus contains not only energy from the far-end data signal transmitted by PSTN modem **300**, but also energy from the far-end echo signal.

Accurate recovery of the data represented by the far-end data signal requires that the echo energy present in the samples on line **626** be removed. To this end, far-end echo canceler **650** processes received signal $rs(t)$. Far-end echo canceler **650** comprises echo canceler filter **655** and adder **657**. As is known in the art, it is assumed that echo canceler filter **655** compensates for any group delay or frequency translation as necessary. Echo canceler filter **655** forms a far-end echo estimate $ec(t)$, which approximates the actual far-end echo signal present in received signal $rs(t)$. Echo canceler **655** is essentially a filter whose transfer function is adaptively determined so as to emulate the “echo path,” i.e., all filtering operations encountered by the locally transmitted symbol sequence $\{a_n\}$ from transmitter **605** through A/D converter **625**. At adder **657**, $ec(t)$ is subtracted from $rs(t)$ so as to produce, in theory, a substantially echo-free signal **658**, $rs'(t)$. Thus, $rs'(t)$ consists primarily of the far-end signal, plus any noise introduced by the channel and the various receiver elements (e.g., quantization error introduced by analog-to-digital converter **625**).

Further processing of signal $rs'(t)$ is performed by equalizer **670**, which compensates for inter symbol interference introduced by line **133**, mobile phone **140**, impaired channel **200**, etc. Equalizer **670** provides symbol sequence **671**, $\{b'_n\}$ to slicer **680**. The latter operates upon the sequence $\{b'_n\}$ by quantizing the sequence $\{b'_n\}$ to form estimated symbol sequence $\{b''_n\}$. The latter is applied to adder **690** and decoder **685**, which performs a symbol-to-bit mapping function and in turn yields an estimate, $\{b'_{y'_k}\}$, of a binary sequence **62**, $\{y_k\}$, transmitted by the far modem, i.e., PSTN modem **300**.

As noted above, during the above-mentioned half-duplex training phase, echo canceler filter **655** is initially adaptive (as illustrated by line **659**, as is known in the art), and a set of complex echo canceler coefficients, C_i ($0 < i < n$, where n is typically between **100** and **150**) (not shown), are set to an initial set of corresponding values, I_i . Note, since C_i is complex, i.e., multivalued, I_i is a matrix, where i represents each row. That is:

$$C_i = I_i, \quad (0 < i < n). \quad (1)$$

Once the half-duplex training is completed, this set of echo canceler coefficients, C_i , are fixed at these initial values, i.e., no more adaptation takes place. However, as noted above, once full-duplex transmission is begun, the

above-mentioned compander enters its linear range of operation and changes the gain in the echo path. As a result, echo canceler filter **655** is no longer effectively removing the far-echo signal and a large residual echo signal is now present limiting the effective data rate. Therefore, and in accordance with the inventive concept, the quality of the echo canceled signal, $rs'(t)$, is monitored by CPU **630** via line **691**. The latter is simply the error signal used to adapt equalizer **670**. Reference should now be made to FIG. **4**, which represents a first illustrative method in accordance with the inventive concept implemented by cellular modem **100**.

In step **705**, cellular modem **100** enters training, e.g., representative phase “A,” shown in FIG. **2**. Following training phase “A,” cellular modem **100** enters half-duplex training phase “B” in step **710**. In this phase, cellular modem **100** is silent during portion “B1,” as represented by step **715**. After portion “B1,” cellular modem **100** trains its own echo canceler during portion “B2,” as represented by step **720**, during which time PSTN modem **300** is silent. After half-duplex training portion “B2,” cellular modem **100** enters full-duplex training phase “C” in step **725**. In step **730**, cellular modem **100**, e.g., the central processing unit of CPU and memory **630** monitors the equalizer error signal via line **691**. The equalizer error signal is a measure of the “hard errors” occurring in the received data signal. As known in the art, a “hard error” is simply representative of the amount of noise present on each received data symbol. Although these “hard errors” may be recoverable (to a degree) via the use of source and channel encoding techniques, in accordance with the inventive concept, this equalizer error signal is used to indicate, once full-duplex transmission occurs, whether there is an increase in residual echo. In particular, if the compander (not shown) of cell site transceiver **255** has the above-mentioned non-linearity, then—once full-duplex transmission begins—the compander moves into its linear range of operation causing a gain change in the echo path, which results in an increase in the residual echo signal of cellular modem **100**. This increase in the residual echo signal causes more “hard errors” to occur, which results in a corresponding change in the value of the equalizer error signal.

If the value of the equalizer error signal is higher than a predetermined amount, K , then cellular modem **100**, via the central processing unit of CPU and memory **630**, adjusts the above-mentioned initial values of echo canceler coefficients, C_i , by a fixed scalar S in step **735**, via line **682** of FIG. **3**. Line **682** is representative of a data and control bus that allows the central processing unit of CPU and memory **630** to access the values of the tap coefficients of echo canceler filter **655**. As a result, the value of each tap coefficient is now equal to:

$$C_i = I_i(S), \quad (0 < i < n). \quad (2)$$

From experimentation, a value for K is 10% larger than the error signal determined during training, and S can range between 2 to 4 dB. This fixed adjustment of the tap values of the echo canceler coefficients reduces the residual echo signal to compensate for the effects of the compander (not shown) of cell site transceiver **255**. It should be noted that in actuality the central processing unit of CPU and memory **630** is simply reading the current values of the tap coefficients from respective memory locations, performing (in this example) the multiplication, and then writing the new values back to the respective memory locations. This approach does not require additional circuitry (and cost) to perform continued adaptation of the echo canceler during full-duplex

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transmission and can be easily retrofitted into existing modems by a corresponding software change.

On the other hand, if the value of the equalizer error is less than or equal to the predetermined amount, K, then no adjustment of the echo canceler coefficients is performed in step 740.

Independent of whether step 735 or step 740 is performed, cellular modem 100 completes training and enters the "DATA" phase in step 750.

The foregoing merely illustrates the principles of the invention and it will thus be appreciated that those skilled in the art will be able to devise numerous alternative arrangements which, although not explicitly described herein, embody the principles of the invention and are within its spirit and scope.

For example, although the invention is illustrated herein as being implemented with discrete functional building blocks, e.g., an echo canceler, etc., the functions of any one or more of those building blocks can be carried out using one or more appropriate programmed processors, e.g., a digital signal processor.

In addition, although the inventive concept was described in the context of a cellular data connection this invention is applicable to other situations in which electronic equipment distorts the far-end echo signal. In particular, any gain change in the echo path after training the echo canceler causes a degradation in echo canceler performance. For example, it has also been discovered that some digital access arrangement (DAA) hybrids have a time-varying gain that changes the received echo level causing residual echo distortion. Also, although the inventive concept was described in the context of a calling modem, the inventive concept also applies to a called modem.

Finally, the inventive concept is also applicable to an echo canceler that adapts in the data phase, since, typically, the echo canceler adapts too slowly to the changes in the echo signal. Those skilled in the art would realize that although shown in the context of a hybrid, some cellular modems have a four-wire interface to the cellular transceiver.

What is claimed:

1. Data communications equipment apparatus comprising:

an echo canceler for processing an echo-corrupted signal to provide an echo-canceled signal, wherein the echo canceler has a set of tap coefficients, each tap coefficient having an initial value determined during a half-duplex portion of a training sequence;

circuitry for detecting the presence of a residual echo signal in the echo-canceled signal during full-duplex transmission that is subsequent to said half-duplex portion of the training sequence; and

a processor, coupled to the circuitry, for adjusting each initial value of each tap coefficient by a fixed amount when the detected residual echo signal during full-duplex transmission is greater than a predetermined amount.

2. The apparatus of claim 1 wherein the circuitry for detecting the presence of the residual echo signal is an equalizer that provides an error signal which is used by the processor as an indicator of the presence of the residual echo signal.

3. The apparatus of claim 1 wherein the processor performs said adjustment during a full-duplex training phase of the training sequence subsequent to said half-duplex portion of the training sequence.

4. The apparatus of claim 1 wherein the processor performs said adjustment by multiplying each initial value of each tap coefficient by a scalar quantity.

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5. The apparatus of claim 4 wherein the scalar quantity is identical for each tap coefficient.

6. Data communications equipment apparatus comprising:

an echo canceler for processing an echo-corrupted signal to provide an echo-canceled signal, wherein the echo canceler has a set of tap coefficients, each tap coefficient having an initial value;

circuitry for detecting the presence of a residual echo signal in the echo-canceled signal; and

a processor, coupled to the circuitry, for adjusting each initial value of each tap coefficient by a fixed amount when the detected residual echo signal is greater than a predetermined amount during a full-duplex training phase that occurs subsequent to a half-duplex training phase.

7. The apparatus of claim 6 wherein the circuitry for detecting the presence of the residual echo signal is an equalizer that provides an error signal which is used by the processor as an indicator of the presence of the residual echo signal.

8. The apparatus of claim 6 wherein each initial value of the set of tap coefficients of the echo canceler is determined during said half-duplex training phase and wherein the echo canceler is non-adaptive during full-duplex communications.

9. The apparatus of claim 6 wherein the processor performs said adjustment during full-duplex communications in a training phase that occurs subsequent to a half-duplex training phase in which each initial value of the set of tap coefficients of the echo canceler is determined.

10. The apparatus of claim 6 wherein the processor performs said adjustment by multiplying each initial value of each tap coefficient by a scalar quantity.

11. The apparatus of claim 10 wherein the scalar quantity is identical for each tap coefficient.

12. An improved data communications equipment apparatus for receiving a data signal, the apparatus including an echo canceler for processing an echo-corrupted signal to provide an echo-canceled signal, the echo canceler having a set of tap coefficients, each tap coefficient having an initial value, wherein the improvement comprises:

a processor for adjusting each initial value of each tap coefficient by a fixed amount during full-duplex communication which occurs subsequent to a half-duplex training phase for reducing a residual echo signal component of the echo-canceled signal.

13. The apparatus of claim 12 wherein the processor performs said adjustment if an error signal representative of the residual echo signal is greater than a predetermined value.

14. The apparatus of claim 13 wherein the error signal is provided by an equalizer of the data communications equipment apparatus.

15. The apparatus of claim 12 wherein each initial value of the set of tap coefficients of the echo canceler is determined during said half-duplex training phase.

16. The apparatus of claim 12 wherein the processor performs said adjustment during full-duplex communications in a training phase that occurs subsequent to a half-duplex training phase in which each initial value of the set of tap coefficients of the echo canceler is determined and wherein the echo canceler is non-adaptive during full-duplex communications.

17. The appearance of claim 12 wherein the processor performs said adjustment by multiplying each initial value of each tap coefficient by a scalar quantity.

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18. The apparatus of claim 17 wherein the scalar quantity is identical for each tap coefficient.

19. A method for reducing a residual echo signal in data communications equipment apparatus, the data communications equipment comprising an echo cancelor, the method comprising the steps of:

- a) performing a half-duplex training sequence with a far-end data communications equipment apparatus to determine an initial value for each one of a set of tap coefficients of the echo cancelor;
- b) subsequent to the half-duplex training sequence, performing full-duplex transmission with the far-end data communications equipment;
- d) during the subsequent full-duplex transmission, estimating a value of the residual echo signal; and
- e) adjusting the initial value of each one of the set of tap coefficients of the echo cancelor by a fixed amount only if the estimated value of the residual echo signal is greater than a predetermined amount.

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20. The method of claim 19 wherein step d) is performed by using an error signal output of an equalizer of the data communications equipment apparatus.

21. The method of claim 19 wherein the full-duplex transmission of steps d) and e) is performed during a full-duplex training sequence.

22. The method of claim 19 further comprising the step of switching to a data phase after step e).

23. The method of claim 19 wherein the adjustment in step e) is performed by multiplying each initial value of the set of tap coefficients of the echo cancelor by a scalar amount to establish a new set of values for the set of tap coefficients.

24. The method of claim 23 wherein the scalar amount is identical for all tap coefficients of the set.

25. The method of claim 19 wherein the echo cancelor is non-adaptive subsequent to step a).

* * * * *

Exhibit D

United States Patent [19]
Betts et al.

[11] **Patent Number:** **5,828,657**
 [45] **Date of Patent:** **Oct. 27, 1998**

[54] **HALF-DUPLEX ECHO CANCELER TRAINING USING A PILOT SIGNAL** 4,792,940 12/1988 Hiraguchi 370/292
 4,912,758 3/1990 Arbel 379/388
 5,507,033 4/1996 Dolan 375/296
 5,533,048 7/1996 Dolan 375/340

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[21] Appl. No.: **536,916**

[22] Filed: **Sep. 29, 1995**

[51] **Int. Cl.⁶** **H04J 15/00**

[52] **U.S. Cl.** **370/289; 370/269; 370/290;**
370/292; 375/222; 375/231; 375/350; 379/410

[58] **Field of Search** 370/286, 289,
 370/290, 291, 292, 296, 269; 375/296,
 222, 340, 348, 349, 350; 379/388, 410,
 411; 455/43

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,766,589 8/1988 Fisher 370/291

Primary Examiner—Douglas W. Olms
Assistant Examiner—Shick Hom
Attorney, Agent, or Firm—Thomas, Kayden, Horstemeyer
 & Risley

[57] **ABSTRACT**

A far-end modem transmits a “pilot tone” during the time that a near-end modem is training its echo canceler. Correspondingly, the near-end modem is modified to notch, or filter, out this pilot tone from the received signal. The filtered received signal is then used by the near-end modem to train its echo canceler.

6 Claims, 5 Drawing Sheets

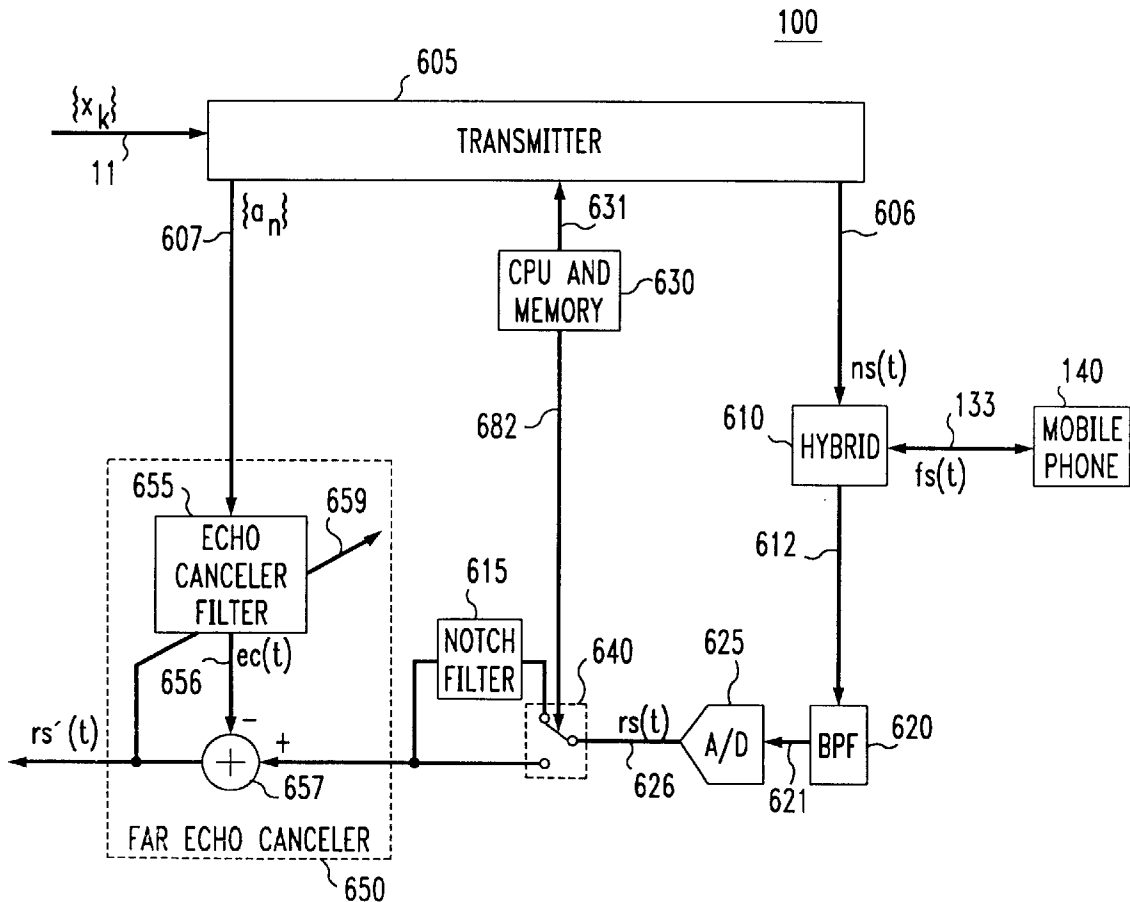


FIG. 1

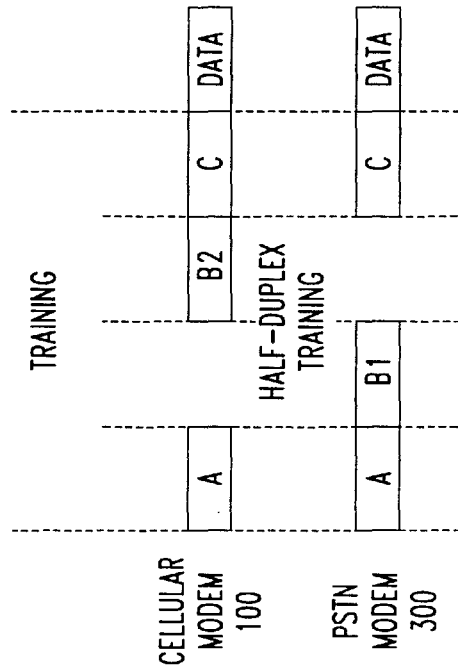
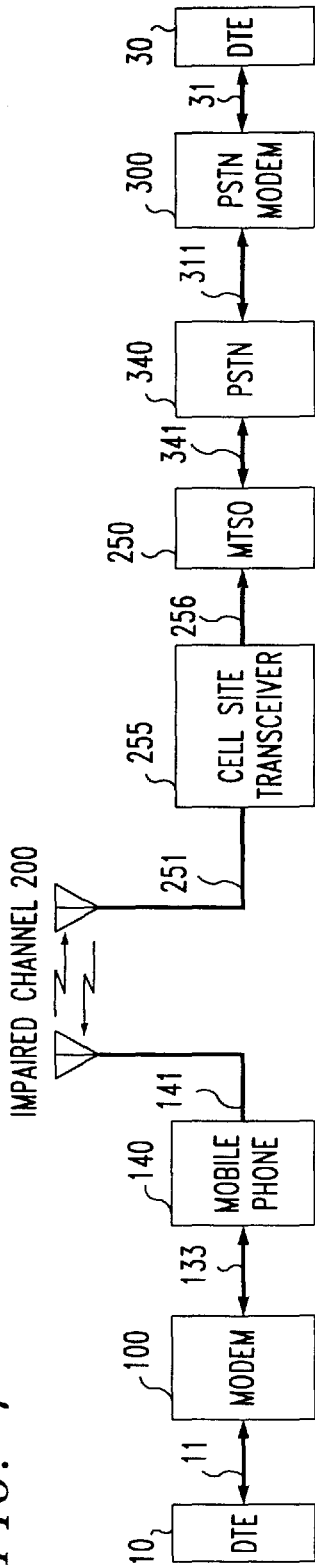


FIG. 2

FIG. 3

CELLULAR ORIGINATING MODEM

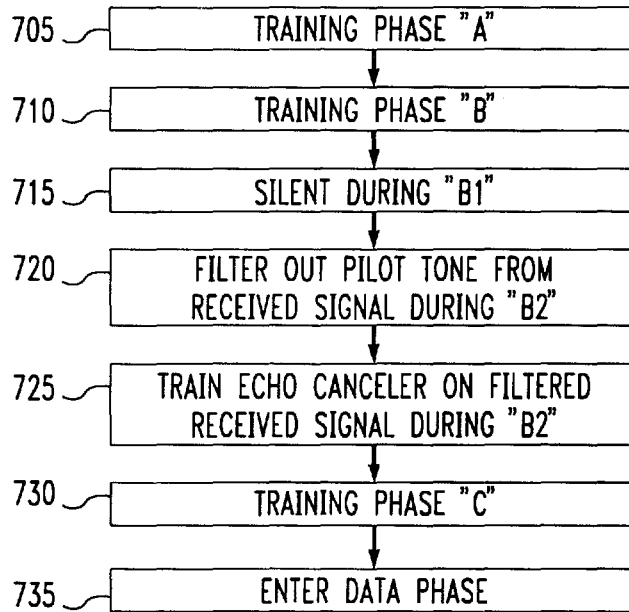


FIG. 4

PSTN ANSWERING MODEM

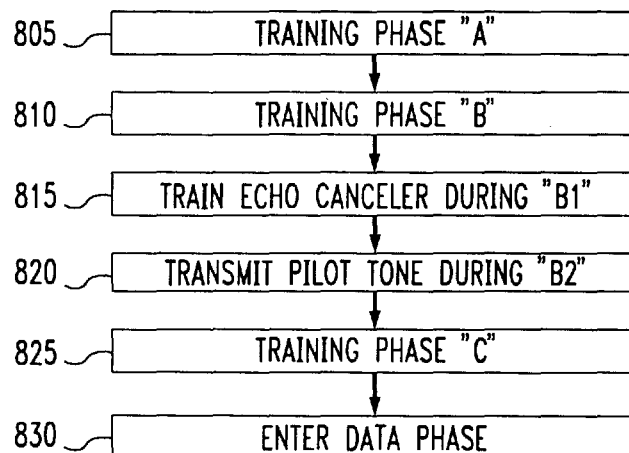


FIG. 7

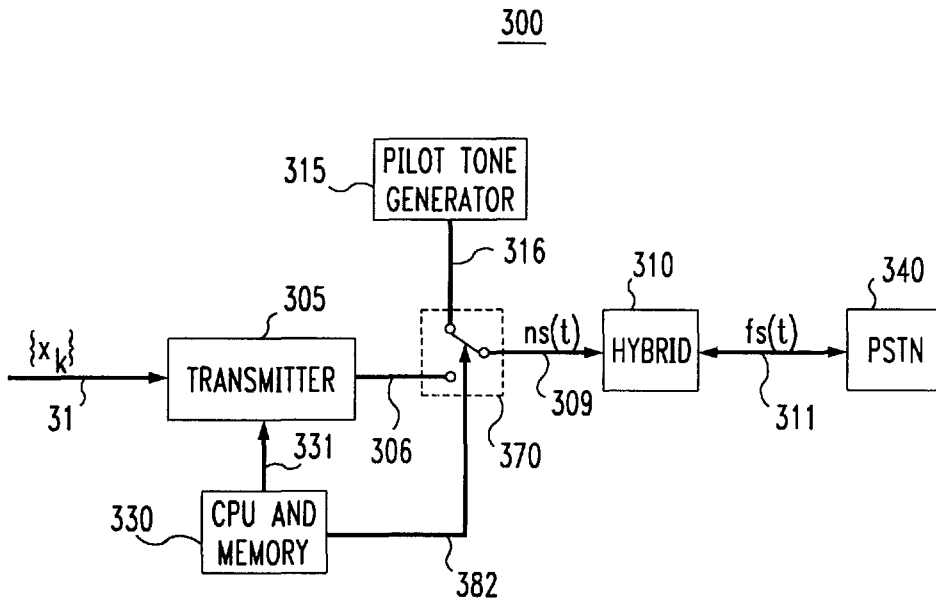


FIG. 8

CELLULAR ANSWERING MODEM

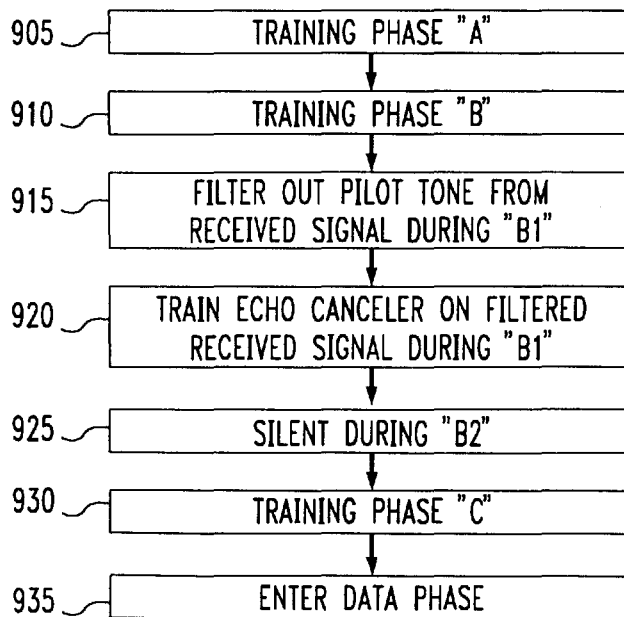


FIG. 9

PSTN ORIGINATING MODEM

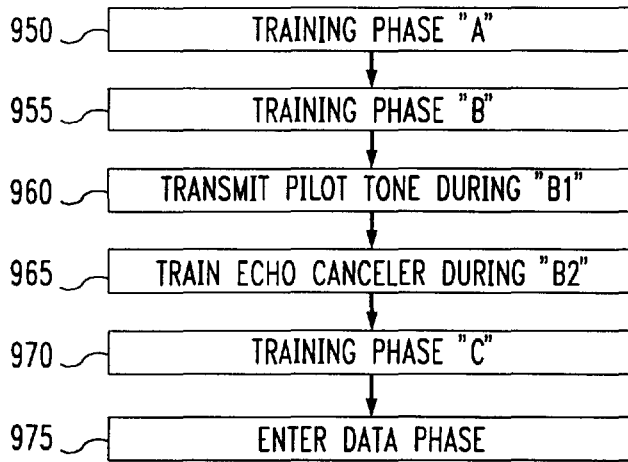
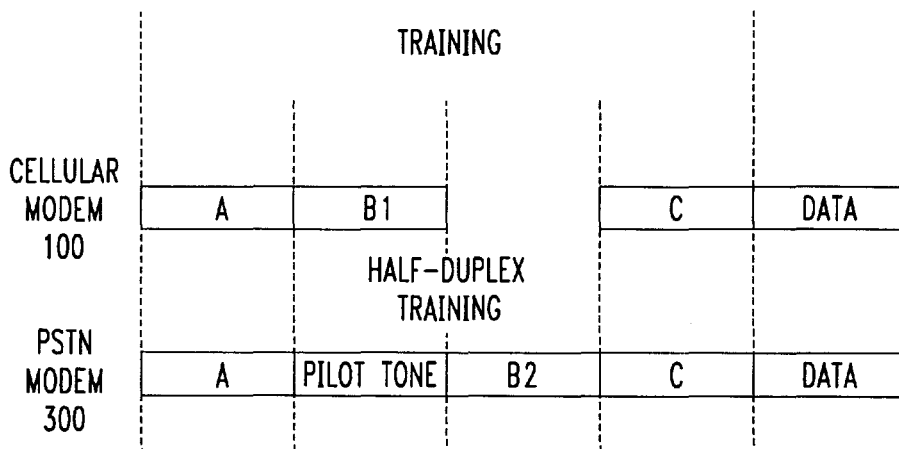


FIG. 10



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HALF-DUPLEX ECHO CANCELER TRAINING USING A PILOT SIGNAL

CROSS-REFERENCE TO RELATED APPLICATIONS

Related subject matter is disclosed in the co-pending commonly assigned, U.S. Patent applications of: Betts et al., entitled "Echo Canceling Method and Apparatus for Data Over Cellular," Ser. No. 08/536,908, filed on Sep. 29, 1995; Betts et al., entitled "Echo Canceler Gain Tracker for Cellular Modems," Ser. No. 08/536,917, filed on Sep. 29, 1995.

BACKGROUND OF THE INVENTION

The present invention relates to data communications equipment, e.g., modems, and, more particularly, to echo-canceling modems.

Today, the North American cellular system is predominantly an analog system sometimes referred to as AMPS (Advanced Mobile Phone Service). The corresponding cellular communications channel is sometimes referred to as an "impaired channel" since it is affected by a number of channel impairments like Rayleigh fading, co-channel interference, etc., that increase the error rate and, thus, degrade the overall performance of the mobile connection. This is in contrast to a land-line communications channel, where the predominant impairment is additive white gaussian noise (AWGN). Those in the art have realized that one way to improve data transmission rates in the cellular environment is to use a data protocol that is better suited to combating the effects of the cellular environment over the cellular portion of the data connection. One example of a cellular-oriented protocol is the "Enhanced Throughput Cellular" (ETC) protocol, developed by AT&T Paradyne.

Nevertheless, even with a cellular-oriented protocol, impairments in the cellular channel continue to limit the effective data rate over the cellular channel. For example, reliable, i.e., consistent, data transmission over 9600 bits per second (bps) is difficult to maintain.

SUMMARY OF THE INVENTION

Notwithstanding the above-mentioned impairments present in the cellular channel, we have discovered a non-linearity in the cellular AMPS network that has been effecting the ability to reliably maintain cellular data rates over 9600 bps. In particular, when a cellular modem is performing training with a far-end PSTN modem, the cellular AMPS network distorts a far-end echo signal that is used by the cellular modem to train its echo canceler. We estimate that this distortion of the far-end echo signal occurs in approximately 40% of the AMPS cellular infrastructure. The source of the distortion of the far-end echo signal is due to a non-linear compander in some base-station radios and the half-duplex approach that modems use to train echo cancelers. The result is that the echo canceler of the cellular modem is not properly trained thereby causing a residual echo signal to exist. This residual echo signal limits the maximum cellular data rate to 9600 bps (often, this cellular data rate is reduced to 7200 bps.) Without this residual echo signal, the cellular modem and PSTN modem could often achieve a data rate of 14,400 bps (and even higher in the future).

Therefore, and in accordance with the invention, we have developed a method and apparatus for reducing the residual

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echo signal, which is effectively caused by the above-mentioned distortion of the far-end echo signal during training. In particular, during the above-mentioned half-duplex training phase a far-end modem does not remain silent but, instead, transmits a pilot tone to the near-end modem during the time that the near-end modem is training its echo canceler. This pilot tone is of a high enough signal level to cause the above-mentioned compander to achieve its linear range. As a result, this invention eliminates the incorrect training caused by the distortion of the far-end echo signal, thereby providing the ability to reliably maintain cellular data rates greater than 9600 bps.

In an embodiment of the invention, the PSTN modem transmits a "pilot tone" during the time that the cellular modem is training its echo canceler. This pilot tone is of a high enough signal level to cause the compander to achieve its linear range. The cellular modem is modified to notch, or filter, out this pilot tone from the received signal. The filtered received signal is then used by the cellular modem to train its echo canceler. Since the above-mentioned compander is now in the same linear range that it will be in when the both modems go into full-duplex mode, the echo canceler is properly trained to the far-echo signal. Residual echo is thus eliminated and the modem can achieve its highest data rate.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a block diagram of a mobile data communications system embodying the principles of the invention;

FIG. 2 shows an illustrative portion of a training sequence;

FIG. 3 is a flow diagram of an illustrative method for use in an originating modem in accordance with the principles of the invention;

FIG. 4 is a flow diagram of an illustrative method for use in an answering modem in accordance with the principles of the invention;

FIG. 5 shows an illustrative portion of a training sequence as modified by the inventive concept;

FIG. 6 is an illustrative block diagram of a portion of cellular modem 100 of FIG. 1 embodying the principles of the invention;

FIG. 7 is an illustrative block diagram of a portion of PSTN modem 300 of FIG. 1 embodying the principles of the invention; and

FIGS. 8-10 show the inventive concept when the cellular modem is the "answering" modem.

DETAILED DESCRIPTION

Other than the inventive concept, the elements of FIG. 1 function as in the prior art and will not be described in detail. FIG. 1 shows a block diagram of a mobile data communications system that includes cellular modem 100, which embodies the inventive concept. As shown, cellular modem 100 is coupled to mobile phone 140 for transmitting data signals to, and receiving data signals from, PSTN modem 300 via cell site transceiver 255, impaired channel 200, Mobile Telecommunications Switching Office (MTSO) 250, and PSTN 340. Both cellular modem 100 and PSTN modem 300 are also coupled to respective data terminal equipment (DTE) 10 and 30.

Before describing the inventive concept, the following is a brief overview of the operation of the mobile data communications system of FIG. 1 once a data connection is established, i.e., after training has been completed. A data signal is applied to cellular modem 100, via line 11, from

DTE 10 for transmission to PSTN modem 300. Line 11 represents the signaling, electronics, and wiring, for conforming to a DTE/DCE (data communications equipment) interface standard like EIA RS-232. Cellular modem 100 modulates this data signal as is known in the art to, typically, a quadrature amplitude modulated (QAM) signal, which is provided via line 133 to mobile phone 140. Although not necessary to the inventive concept, it is assumed for the purposes of this example that the modem signal is compatible with International Telecommunications Union (ITU) standard V.32bis. Mobile phone 140 further modulates this transmission signal onto a predefined cellular carrier to provide a cellular data signal to antenna 141. Cell site transceiver 255 receives the cellular data signal via antenna 251 and provides a received modem signal to MTSO 250 for transmission, via public-switched-telephone network 340, to a far-end data endpoint as represented by PSTN modem 300 and DTE 30. Ideally, the data signal received by DTE 30 from PSTN modem 300 is identical to the data signal provided by DTE 10 to cellular modem 100. Transmission of data signals in the opposite direction, i.e., from DTE 30 to DTE 10 occurs in a like fashion.

However, before establishing a data connection, modems, as known in the art, perform a standard sequence of signaling that is also referred to as hand-shaking or training. This signaling determines such parameters as data rate, modulation to use, and trains, or sets, what is known in the art as filter tap coefficient values for filters like echo-cancelers and equalizers, which combat interference and distortion effects caused by the communications channel. As known in the art, the training sequence for an echo canceler is performed half-duplex. Full-duplex training of the echo canceler, while theoretically possible, is not practical from a price/performance viewpoint in the design of data communications equipment.

Since different data communications standards like ITU V.32bis and ITU V.34 have different training sequences, a generalized representation of a training sequence comprising a number of phases is illustrated in FIG. 2. It is assumed that cellular modem 100 is the calling modem and that PSTN modem 300 is the answering modem. As shown in FIG. 2, the training sequence is initially full-duplex during phase "A." The latter is followed by a phase "B," which is half-duplex and is additionally divided into two portions: "B1" and "B2." In portion "B1," of phase "B," the called modem, PSTN modem 300, sends a signal to train the echo canceler of PSTN modem 300 while the cellular modem 100 is silent. Then, in portion "B2," of phase "B," the calling modem, cellular modem 100, sends a signal to train the echo canceler of cellular modem 100 while the far-end PSTN modem is silent. To complete the description of FIG. 2, after half-duplex training phase "B," both modems enter a subsequent full-duplex training phase "C," which is then followed by a "DATA" phase in which data is actually communicated between the two modems.

During the respective half-duplex training portions of phase "B," each modem uses the returned far-end echo signal to adjust the tap coefficients of its echo canceler. The far-end echo signal is a result of subsequent 4-wire to 2-wire signal conversion within the PSTN, as is known in the art. (It should be noted that other components are also adjusted during training, e.g., equalizer coefficients, etc. However, for the purposes of this example, only the echo canceler training is described.)

In the cellular network, the base station radio—cell site transceiver 255—performs audio processing. One of the audio processing stages is a compander (not shown). The

compander is linear over a given signal range. Unfortunately, we have discovered that some companders are not linear in the signal range of the returned far-end echo signal during the half-duplex training phase. As a result, this non-linearity of the compander results in training the echo canceler of the cellular modem to a distorted far-end echo signal. However, when the cellular modem subsequently goes into full duplex mode, i.e., both transmitting a signal to, and receiving a signal from, the PSTN modem, the received signal level passing through cell site transceiver 255 causes the compander to operate in its linear range. This change in compander operation results in a gain change in the echo path that causes a degradation in echo canceler performance resulting in a large "residual echo" in the cellular modem. In other words, there is a loss of echo cancellation. This residual echo signal limits the maximum cellular data rate to 9600 bps (often, this cellular data rate is reduced to 7200 bps.) Without this residual echo signal, the cellular modem and PSTN modem could often achieve a data rate of 14,400 bps (and even higher in the future).

This problem can be solved by modems with a four-wire interface at the PSTN-side of the cellular data connection. For example, a cellular network that includes a cellular modem pool, as well as "mu-law" modem pools being installed at customer locations solve this problem. Unfortunately, a large number of cellular users will still be calling 2-wire PSTN modems for the foreseeable future. In addition, this problem could be solved by allowing continued adaptation of the echo canceler during data transmission. However, this adaptation process can be slow. Unfortunately, some modems (as represented by cellular modem 100) only adapt during the training sequence to conserve hardware requirements, such as memory, and thereby reduce the cost of the data communications equipment.

Therefore, and in accordance with the invention, we have developed a method and apparatus for reducing the residual echo signal, which is effectively caused by the above-mentioned switching between a linear mode of operation and a nonlinear mode of operation of a network compander. In particular, during the above-mentioned half-duplex training phase a PSTN modem does not remain silent but, instead, transmits a pilot tone to the cellular modem during the time that the cellular modem is training its echo canceler. This pilot tone is of a high enough signal level to cause the above-mentioned compander to achieve its linear range. As a result, this invention eliminates the incorrect training caused by the distortion of the far-end echo signal, thereby providing the ability to reliably maintain cellular data rates greater than 9600 bps.

In order to facilitate understanding of the inventive concept reference should now be made to FIGS. 3 and 4, which represent illustrative methods for use in an originating modem and answering modem, respectively. For the purposes of this description, cellular modem 100 is illustratively the originating modem and PSTN modem 300 is illustratively the answering modem. For simplicity, the steps of dialing (in cellular modem 100), and answering (by PSTN modem 300), are not shown.

First, attention should be directed to FIG. 3. In step 705, cellular modem 100 enters training, e.g., representative phase "A," shown in FIG. 2. Following training phase "A," cellular modem 100 enters half-duplex training phase "B" in step 710. In this phase, cellular modem 100 is silent during portion "B1," as represented by step 715. After portion "B1," cellular modem 100 moves to phase "B2" to train its own echo canceler. In accordance with the inventive

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concept, during phase "B2" cellular modem 100 first filters the received signal in step 720 to remove a pilot tone transmitted by far-end PSTN modem 300 (described below). Then, cellular modem 100 trains its echo cancelers on the filtered received signal in step 725. After half-duplex training portion "B2," cellular modem 100 enters full-duplex training phase "C" in step 730. After completion of training phase "C," cellular modem 100 enters the "DATA" phase in step 735.

Turning now to FIG. 4, corresponding steps are illustrated for PSTN modem 300, the answering modem. In step 805, PSTN modem 300 enters training, e.g., representative phase "A," shown in FIG. 2. Following training phase "A," PSTN modem 300 enters half-duplex training phase "B," in step 810. In portion "B1," PSTN modem 300 trains its own echo canceler in step 815. After portion "B1," PSTN modem enters phase "B2." However, in phase "B2" PSTN modem 300 is not silent, as in the prior art. Instead, PSTN modem 300 transmits a pilot tone to cellular modem 100 in step 820. For example, this pilot tone could illustratively be at a frequency of 300 Hz, at -20 dBm, for the duration of the half-duplex training phase "B2." After half-duplex training portion "B2," PSTN modem 300 discontinues transmission of the pilot tone and enters full-duplex training phase "C" in step 825. After completion of training phase "C," cellular modem 100 enters the "DATA" phase in step 830.

The effect of the methods shown in FIGS. 3 and 4 on the representative training sequence is shown in FIG. 5. In particular, training phase "B2," is no longer half-duplex but full-duplex. However, to avoid the above-mentioned complexities involved with full-duplex training of an echo canceler, cellular modem 100 filters out the pilot tone from the received signal before training its echo canceler. As a result of the above, if the compander (not shown) of cell site transceiver 255 has the above-mentioned non-linearity, then the transmission of the pilot tone by PSTN modem 300 moves the compander into its linear range of operation. This results in the proper training of the echo canceler in cellular modem 100 so that once full-duplex transmission begins there is no gain change in the echo path.

Illustrative embodiments of the invention are shown in FIGS. 6 and 7 for cellular modem 100 and PSTN modem 300, respectively. Except for the inventive concept, the operation of the various components is well-known.

As shown in FIG. 6, a binary input data sequence $\{x_k\}$ is provided by DTE 10 to cellular modem 100 on line 11. This input data sequence is processed by transmitter 605 to form a near-end transmitted signal, $ns(t)$. Illustratively, near-end transmitted signal, $ns(t)$, represents a quadrature amplitude modulated (QAM) signal. The near-end transmitted signal, $ns(t)$, is provided by hybrid 610 to mobile phone 140, via line 133. (It should be noted that during training, the binary input sequence is generated by cellular modem 100 as in known in the art. For simplicity, this alternate source of the binary data sequence is not shown.)

Transmitter 605 is under the control of CPU and memory 630, which is a micro-processor based central processing unit and associated memory for storing program data. It is assumed that transmitter 605 includes an encoder, shaping filter, digital to analog converter, etc., for processing and modulating the input data sequence $\{x_k\}$ on line 11 to provide the QAM signal, $ns(t)$, on line 606. As part of this processing of the input data sequence, transmitter 605 represents the input data sequence as a sequence of complex-valued symbols $\{a_n\}$, at nominal rate $1/T$ symbols per second. (This processing may also include scrambling,

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redundancy and other forms of encoding.) As can be seen from FIG. 3, this input data sequence is also used by far echo canceler 650 (described below). For simplicity, the local echo canceler is not shown.

Turning now to the other direction of communication, an analog line signal, $fs(t)$, transmitted from a far-end modem, e.g., PSTN modem 300, is received by hybrid 610 and is directed to bandpass filter (BPF) 620. This signal is referred to as the "far-end data signal," and utilizes the same frequency band as the transmitted signal, $ns(t)$, i.e., cellular modem 100 is a full-duplex modem. Bandpass filter 620 removes energy outside the signal passband from the far-end data signal, which is then converted to digital form by analog-to-digital (A/D) converter 625 to form received signal $rs(t)$.

The signal, $fs(t)$, reaching the input of bandpass filter 620 is corrupted by so-called echo signals. Echo signals are typically introduced at each four-to-two wire conversion in the communications system.

The far-end echo signal comprises transmit signal energy from cellular modem 100 which was transmitted towards PSTN modem 300 in the first instance but was reflected back to cellular modem 100 as a result of, for example, an impedance mismatch at a two-to-four wire conversion within PSTN 340. The received signal, $rs(t)$, provided by A/D converter 625, thus contains not only energy from the far-end data signal transmitted by PSTN modem 300, but also energy from the far-end echo signal.

In accordance with the principles of the invention, the received signal, $rs(t)$, is applied to switch 640. The latter is under the control of the central processing unit of CPU and memory 630. During training phase "B2," the received signal, $rs(t)$, includes the above-described pilot tone. Therefore, in the above-mentioned step 720 of FIG. 3, the central processing unit of CPU and memory 630 causes the received signal, $rs(t)$, to be applied to notch filter 615 via switch 640. Notch filter 615 is a simple notch filter as known in the art and is designed to remove the above-described pilot tone from the received signal, $rs(t)$. As a result, far echo canceler 650 does not receive the pilot tone and trains on only the far-echo signal present in the received signal, $rs(t)$. After training far echo canceler 650, the central processing unit of CPU and memory 630 controls switch 640, in step 725 of FIG. 3, to remove notch filter 615 from the received signal path and applies received signal $rs(t)$ directly to far echo canceler 650.

Turning now to FIG. 7, an illustrative block diagram of PSTN modem 300 embodying the principles of the invention is shown. A binary input data sequence $\{x_k\}$ is provided by DTE 30 to PSTN modem 300 on line 31. This input data sequence is processed by transmitter 305 to form a near-end transmitted signal, $ns(t)$. Illustratively, near-end transmitted signal, $ns(t)$, represents a quadrature amplitude modulated (QAM) signal. The near-end transmitted signal, $ns(t)$, is provided by hybrid 310 to PSTN 340, via line 311. (It should be noted that during training, the binary input sequence is generated by PSTN modem 300 as in known in the art. For simplicity, this alternate source of the binary data sequence is not shown.)

Transmitter 305 is under the control of CPU and memory 330, which is a microprocessor based central processing unit and associated memory for storing program data. It is assumed that transmitter 305 includes an encoder, shaping filter, digital to analog converter, etc., for processing and modulating the input data sequence on line 31 to provide the QAM signal, $ns(t)$, on line 306. As part of this processing of

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the input data sequence, transmitter **305** represents the input data sequence as a sequence of complex-valued symbols $\{a_n\}$, at nominal rate $1/T$ symbols per second. (This processing may also include scrambling, redundancy and other forms of encoding.)

In accordance with the principles of the invention, PSTN modem **300** includes a means for generating the above-mentioned pilot tone, i.e., pilot tone generator **315** and switch **370**. During training phase "B2," PSTN modem **300** transmits this pilot tone to cellular modem **100**. In particular, during the above-mentioned step **820**, the central processing unit of CPU and memory **330** controls switch **370**, via line **382**, to apply the pilot tone for transmission to cellular modem **100**. After training phase "B2" has ended, the central processing unit of CPU and memory **330** controls switch **370** to apply the output signal from transmitter **305** to hybrid **310**. As a result, PSTN modem **300** is not silent during the half-duplex portion of the training signal as in the prior art.

It should be noted that although an illustrative switch is shown in FIGS. **6** and **7** for the purposes of description, those in the art would realize that modifications to corresponding algorithms in a digital signal processor (not shown) would be equivalent. For example, in FIG. **7** transmitter **305** represents a digital signal processor that is programmed to provide corresponding handshaking signaling. As a result, to implement this inventive concept, transmitter **305** is simply reprogrammed to generate the above-mentioned pilot tone during training phase "B2." Further, it should be noted that although the invention was described in the context of a called, or answering, modem providing the pilot tone, the inventive concept also applies to a calling, or originating, modem providing the pilot tone to the answering modem, which now filters out the pilot tone to train its echo canceler. This case is illustrated in FIGS. **8-10**.

The foregoing merely illustrates the principles of the invention and it will thus be appreciated that those skilled in the art will be able to devise numerous alternative arrangements which, although not explicitly described herein, embody the principles of the invention and are within its spirit and scope.

For example, although the invention is illustrated herein as being implemented with discrete functional building blocks, e.g., an echo canceler, etc., the functions of any one or more of those building blocks can be carried out using one or more appropriate programmed processors, e.g., a digital signal processor.

In addition, although the inventive concept was described in the context of a cellular data connection this invention is applicable to the PSTN network. Also, although the invention was described in the context of using a pilot tone, other signals can be used so long as the signal causes the above-mentioned compander to enter the linear range of operation and the receiver can appropriately cancel this signal before

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training its echo canceler. Those skilled in the art would realize that although shown in the context of a hybrid, some cellular modems have a four-wire interface to the cellular transceiver. In addition, it should be realized that the above-described inventive concept could be selectively enabled by a user via use of the well-known "AT-command set."

What is claimed:

1. Data communications equipment apparatus comprising:

10 an echo canceler that is trained during an echo-canceler training phase of a half duplex training sequence with a far-end data communications equipment while the communication channel is operating in a linear mode; and

15 a filter that filters a received signal during the echo-canceler training phase to remove a pilot signal transmitted by the far-end data communications equipment before application of the received signal to the echo canceler to train the echo canceler on an echo signal component thereof.

2. The apparatus of claim **1** comprising transmitter circuitry that transmits a training signal during the half-duplex training phase to act as a source for the echo signal.

25 **3.** A method for training an echo canceler during a training sequence of a data connection, the method comprising the steps of:

transmitting a training signal to far-end data communications equipment;

30 receiving, during a half-duplex training sequence, a signal that comprises an echo signal of the training signal and a pilot signal transmitted by the far-end communications equipment;

filtering the received signal to remove the pilot signal to provide a filtered signal; and

35 training the echo canceler on the filtered signal while the communications channel is operating in a linear mode.

4. The method of claim **3** wherein the pilot signal is a tone.

40 **5.** A method for training an echo canceler during a training sequence of a data connection, the method comprising the steps of:

performing a half-duplex training sequence with an opposite data communications equipment that includes the step of transmitting a pilot signal during that portion of said half-duplex training sequence in which the opposite data communications equipment trains its echo canceler while the communication channel is operating in a linear mode; and

50 communicating data in a data phase of the data connection subsequent to said half-duplex training sequence.

6. The method of claim **5** wherein the pilot signal is a tone.

* * * * *

Exhibit E

(12) **United States Patent**
Bremer et al.

(10) **Patent No.:** **US 6,970,501 B1**
(45) **Date of Patent:** **Nov. 29, 2005**

(54) **METHOD AND APPARATUS FOR
AUTOMATIC SELECTION AND OPERATION
OF A SUBSCRIBER LINE SPECTRUM CLASS
TECHNOLOGY**

5,781,617 A * 7/1998 McHale et al. 379/93.14
5,812,786 A * 9/1998 Seazholtz et al. 709/233
5,828,748 A * 10/1998 Akhteruzzaman 379/399.01
5,912,895 A * 6/1999 Terry et al. 370/445

(75) Inventors: **Gordon Bremer**, Clearwater, FL (US);
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* cited by examiner

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Assistant Examiner—Pankaj Kumar

(74) *Attorney, Agent, or Firm*—Thomas, Kayden,
Horstemeyer & Risley LLP

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

(57) **ABSTRACT**

The present invention provides a communication device, such as a modem, that is capable of detecting whether it is capable of operating in a mode that is compatible with one or more of the Spectrum Management Classes. The modem automatically selects a mode of operation that is compliant with one or more of the Spectrum Management Classes. The communication device also determines whether it is capable of operating in multiple modes that are compliant with multiple Spectrum Management Classes, and is capable of selecting the modes of operation that optimize the performance of the communication device. Furthermore, the communication device is capable of determining when it is not capable of operating in a mode that is compliant with at least one of the Spectrum Management Classes and which prevents operation of itself upon determining that it is not capable of operating in a mode that is compliant with at least one of the Spectrum Management Classes.

(21) Appl. No.: **09/573,518**

(22) Filed: **May 17, 2000**

Related U.S. Application Data

(60) Provisional application No. 60/134,590, filed on May 17, 1999.

(51) **Int. Cl.**⁷ **H04B 1/38**

(52) **U.S. Cl.** **375/222; 375/220; 375/377;**
379/93.01

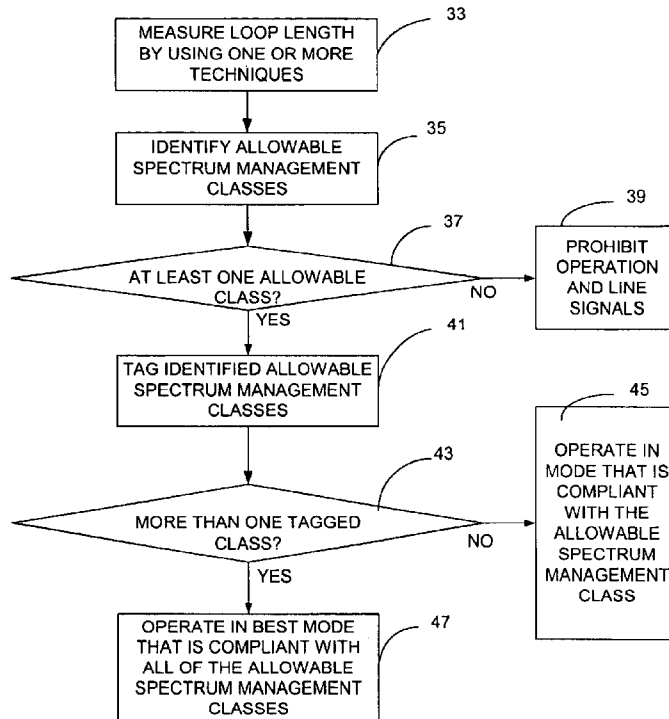
(58) **Field of Search** 375/219, 220,
375/221, 222; 379/27.01, 1.01, 93.01

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,636,037 A * 6/1997 Saitoh 358/442

13 Claims, 4 Drawing Sheets



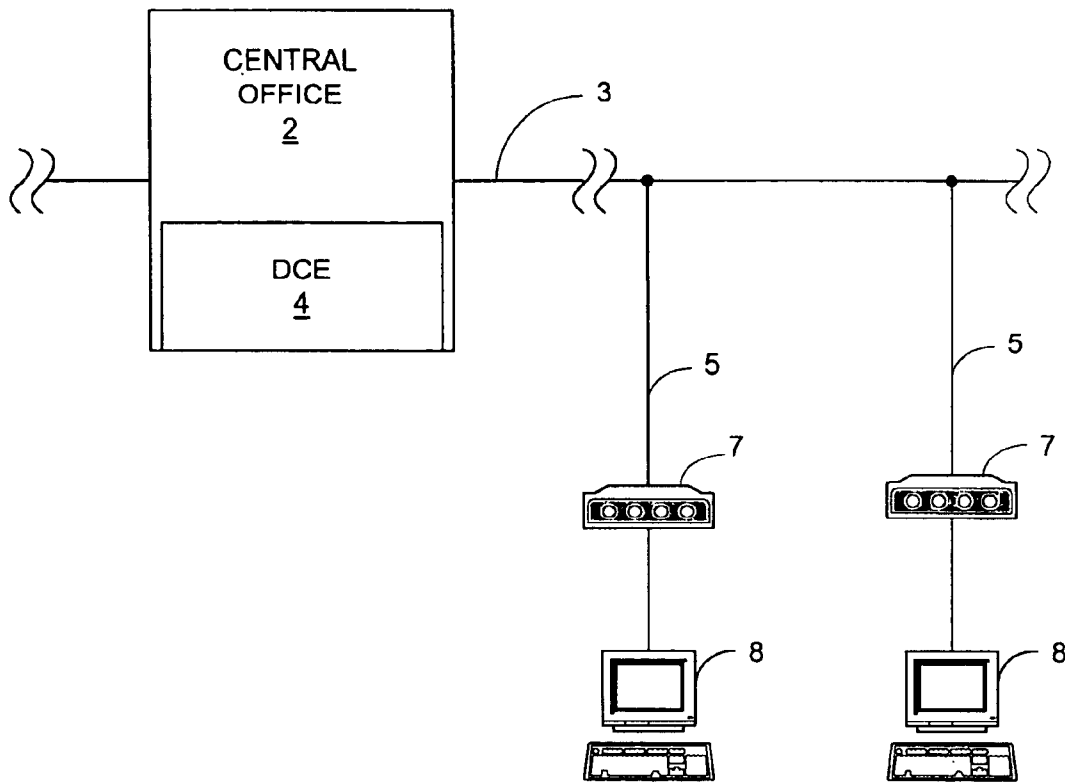


Fig. 1

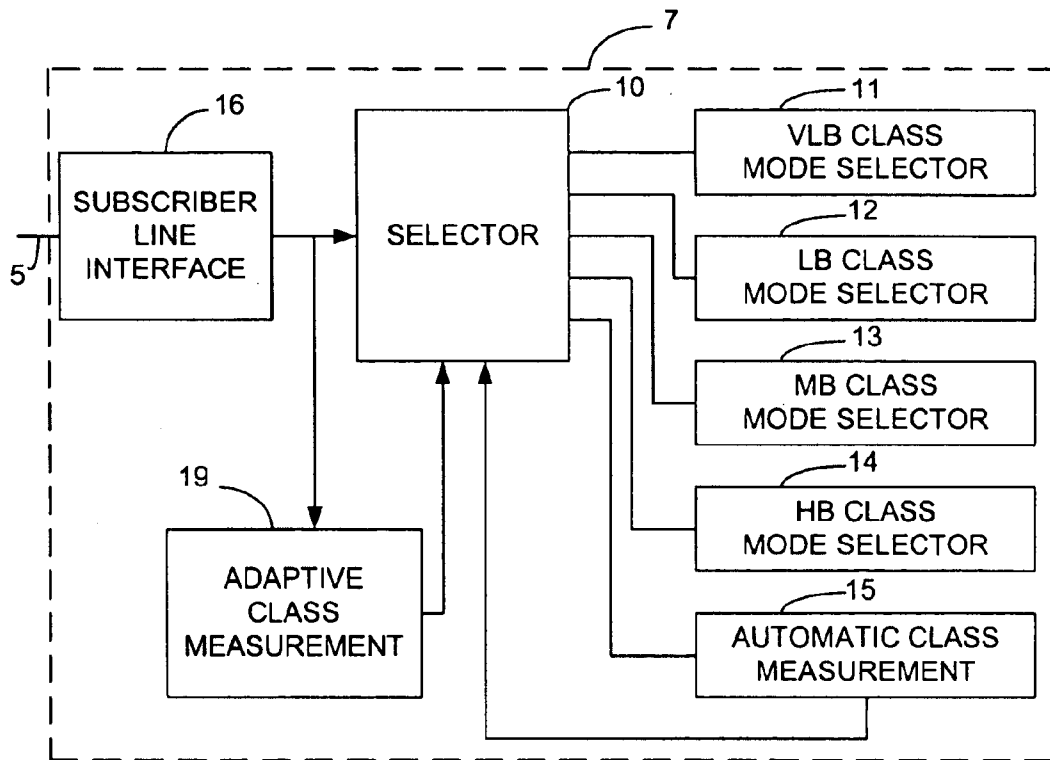


Fig. 2

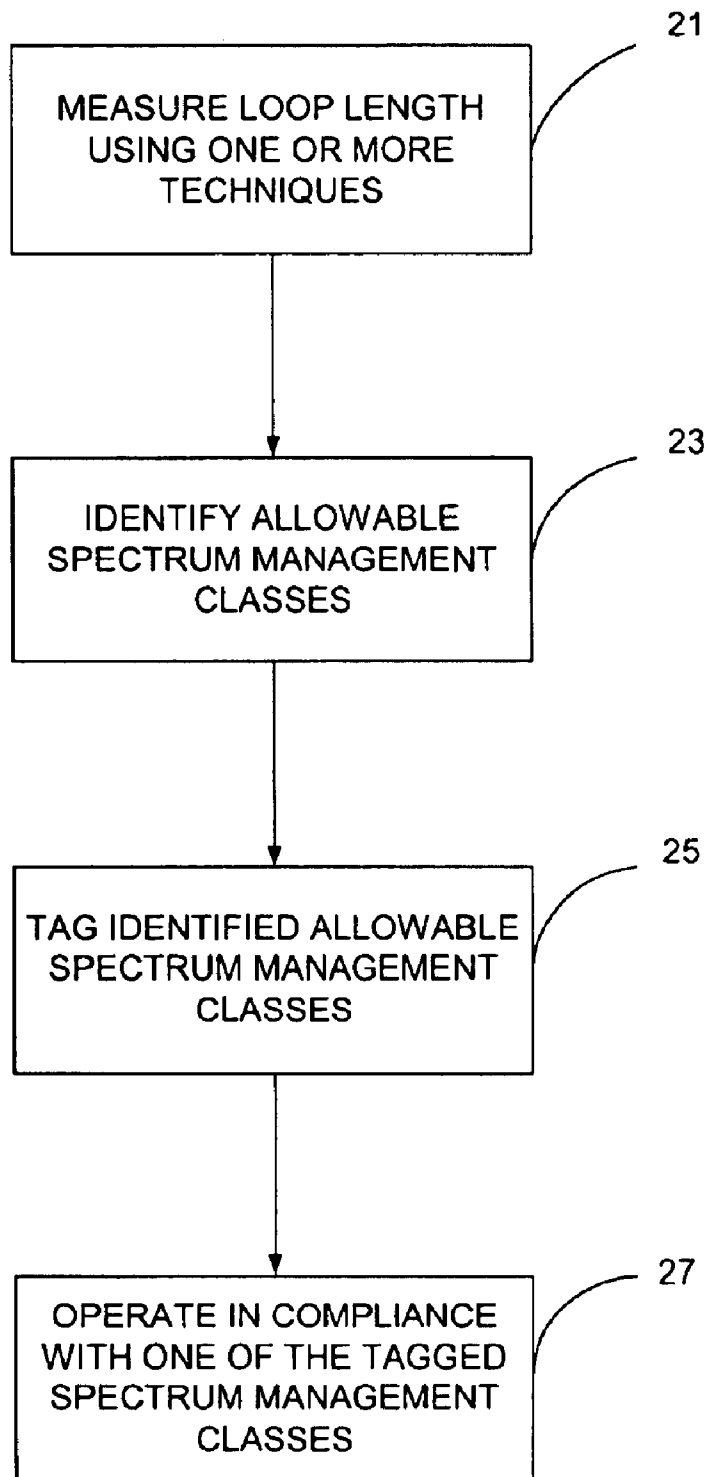


Fig. 3

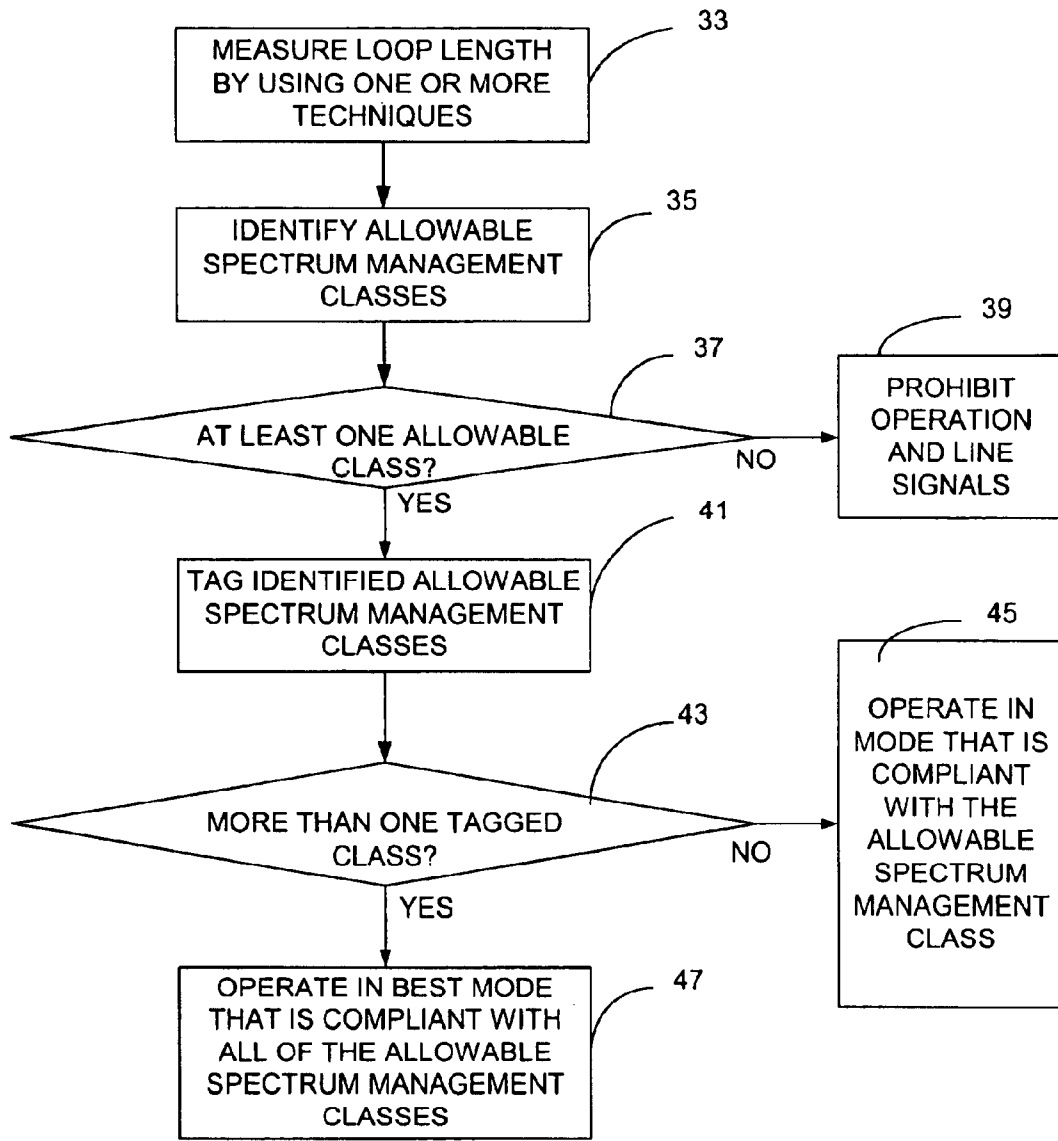


Fig. 4

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**METHOD AND APPARATUS FOR
AUTOMATIC SELECTION AND OPERATION
OF A SUBSCRIBER LINE SPECTRUM CLASS
TECHNOLOGY**

This application claim benefit of No. 60/134,590 filed May 17, 1999.

TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to a method and apparatus for automatically selecting a subscriber line Spectrum Management Class technology mode of operation for communication over metallic subscriber loop cables. More particularly, the present invention relates to a communication device that automatically detects which of a plurality of Spectrum Management Classes the communication device is capable of operating in and selects a mode of operation that is compatible with one or more of the Spectrum Management Classes.

BACKGROUND OF THE INVENTION

The American National Standard for Telecommunications is developing a standard that sets forth spectrum management requirements and recommendations for the administration of services and technologies that use metallic subscriber loop wire pairs, commonly referred to as subscriber loops. The goal of the standard is to administer the loop plant in a way that provides spectral compatibility for services and technologies that use pairs in the same cable binder. The standard is particularly directed to minimizing the potential for cross-talk interference in twisted pair subscriber loop cables that are shared by multiple service providers (carriers). In situations where multiple service providers utilize twisted pairs in the same loop binders, services and technologies may interfere with each other if they are deployed in an uncontrolled manner. The standard provides spectrum management requirements and deployment recommendations for the administration of services and technologies in such an environment in a way that prevents or minimizes such deleterious effects.

The Spectrum Management Classes address (1) transmit signal power spectral density (PSD) requirements, (2) transmit signal average power requirements, (3) transverse balance requirements, (4) deployment restrictions based upon the subscriber loop characteristics, and (5) loop assignment guidelines. A communication device or system that meets all of the applicable requirements for one of the spectrum management classes is deemed to be in conformance with the standard. If a communication device or system does not meet all of the requirements associated with at least one of the spectrum management classes, the communication device or system is deemed to be non-compliant with the standard.

It would be desirable to provide a communication device, such as a digital subscriber line (DSL) modem, for example, that is capable of operating in a manner that is compatible with one or more of the spectrum management classes. It would also be desirable to provide a communication device that is capable of automatically detecting which of the spectrum management classes it is capable of operating in and of automatically selecting a mode of operation that is compatible with one of the spectrum management classes. Furthermore, it would be desirable to provide such a communication device that could detect when it is capable of operating in a mode that is compatible with more than one of these classes and that would automatically select a mode

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of operation that is compatible with the class that optimizes performance of the communication device. It would also be desirable to provide such a communication device that could detect when it is no longer capable of operating in a mode that is compatible with at least one of the spectrum management classes and which would prevent operation of the communication device when such a determination is made.

Although it is generally known for certain DSL modems and subscriber line technologies to have automatic and adaptive algorithms that seek to optimize performance, it is not known to provide a modem that detects compatibility with one or more spectrum management classes of the aforementioned standard and that selects the appropriate or best mode of operation based on that determination. For example, algorithms that automatically select transmit spectrum bandwidths and/or bandwidth locations are known. These algorithms are utilized to optimize performance in accordance with the ITU V.34 standard. The ITU V.34 standard also provides for adaptive equalizers and echo-cancelers.

Another type of automatic algorithm provided for by the ITU V.34 standard, which is often referred to as an auto-rating algorithm, provides for modifying a data transmission rate of a modem to allow the highest data rate possible to be utilized in the presence of certain line impairments. However, this algorithm is not truly "adaptive" because it is necessary to temporarily disrupt communication while the rate change is being accomplished. An auto-rate algorithm that is utilized with Multiple Virtual Lines (MVL) technology is known, which was developed by the assignee of the present application. The MVL auto-rating algorithm enables the rate change to be accomplished without disrupting communication. Therefore, the MVL auto-rating algorithm is adaptive.

Although the aforementioned algorithms seek to optimize performance, they do not take into account restrictions on transmit bandwidth and/or transmit power level or other types of restrictions that are in effect on a particular subscriber line on which they operate. These are examples of the types of restrictions that must be met in order to comply with the spectrum management classes defined in the standard. Therefore, these algorithms are not suitable for automatically selecting an appropriate mode of operation that is in compliance with one of the spectrum management classes.

A feature known as Spectrum Manager is used with Etherloop modems, which are marketed by a company known as Elastic Networks. Etherloop modems base the use of transmit spectrum on the presence or absence of other devices in the binder, i.e., on the presence or absence of other devices communicating on the same copper pair. Etherloop modems correlate an allowable use of spectrum to the length of the loop to which the modem is connected. The etherloop modem adjusts its usage of transmit spectrum based on a detection of cross-talk caused by other DSL systems in the binder.

However, the Etherloop modem does not adjust its use of spectrum based on loop parameters required for spectrum management class compliance. Furthermore, when an Etherloop modem is operating properly, it will, under many circumstances, select modes of operation that are not in compliance with the aforementioned spectrum management classes. Also, Etherloop modem adjustments are based on a measurement of transient conditions and other conditions that are difficult to measure. It is not based on measurement parameters that are directly related to the deployment rules associated with the spectrum management classes.

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Accordingly, a need exists for a communication device, such as a modem, that is capable of detecting whether it is capable of operating in a mode that is compatible with one or more of the spectrum management classes and which automatically selects a mode of operation that is compliant with one of the spectrum management classes. A need also exists for such a communication device that is capable of determining whether it is capable of operating in multiple modes that are compliant with multiple spectrum management classes and which is capable of selecting the mode of operation that optimizes the performance of the communication device. A need also exists for such a communication device that is capable of determining when it is not capable of operating in a mode that is compliant with at least one of the spectrum management classes and which prevents operation of itself upon determining that it is not capable of operating in a mode that is compliant with at least one of the spectrum management classes.

SUMMARY OF THE INVENTION

The present invention provides a communication device, such as a modem, that is capable of detecting whether it is capable of operating in a mode that is compatible with one or more of the spectrum management classes and which automatically selects a mode of operation that is compliant with one of the spectrum management classes. The communication device determines whether it is capable of operating in multiple modes that are compliant with multiple spectrum management classes and which is capable of selecting the mode of operation that optimizes the performance of the communication device. The communication device is also capable of determining when it is not capable of operating in a mode that is compliant with at least one of the spectrum management classes and which prevents operation of itself upon determining that it is not capable of operating in a mode that is compliant with at least one of the spectrum management classes.

These and other aspects and advantages of the present invention will become apparent from the following discussion, drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram illustrating a portion of the system in which the method and apparatus of the present invention may be implemented.

FIG. 2 is a block diagram illustrating the apparatus of the present invention in accordance with one exemplary embodiment.

FIG. 3 is a flow chart representing an example of the manner in which the present invention can be used to determine whether one or more Spectrum Management Classes are available for communicating over the loop 3 and subscriber line 5 shown in FIG. 1.

FIG. 4 is a flow chart demonstrating the method of the present invention in accordance with one exemplary embodiment, wherein the parameter being measured to determine the best mode of modulation is loop length.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides a Network Access Provider (NAP) Test Feature that enables one or more tests to be performed to determine which of multiple transceivers of a data communication equipment (DCE) device should be operating over a subscriber loop. The test(s) of the NAP test

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feature are utilized in accordance with the preferred embodiment of the present invention to determine which spectrum management class or classes a DCE device may operate in over the subscriber loop. It should be noted that the tests of the NAP Test Feature of the present invention are not limited to being used to determine which spectrum management class or classes a communication device may operate in on a subscriber loop. The present invention is capable of being utilized to determine the appropriate spectrum management class or classes defined in the aforementioned American National Standard for Telecommunications, although the present invention is not limited to being utilized for this purpose.

FIG. 1 is a block diagram illustrating the loop plant 3 that connects a central office (CO) 2 to several different subscriber premises, each of which comprises a DCE device 7 (e.g., an xDSL modem) and data terminal equipment (DTE) 8 (e.g., one or more computers). The CO 2 comprises at least one DCE 4 that is compatible with the DCEs 7 located at the subscriber premises. The loop plant represented by the line 3 is comprised of one or more twisted copper pairs, as is well known in the industry. The subscriber lines 5 are also twisted copper pairs that connect the subscriber premises to the loop plant 3. The subscriber lines 5 are normally viewed as being part of the loop plant 3. In accordance with the present invention, one or more tests are performed to determine the operating capability of the DCEs 4 and/or 7 located, respectively, at the CO 2 and at the subscriber premises. The DCE 4 located at the CO 2 preferably is an xDSL modem having similar or identical functional capabilities as those of the DCEs 7 located at the subscriber premises, which, as stated above, preferably are also xDSL modems.

By performing these test(s), one or more Spectrum Management Classes that the DCEs 4 and/or 7 are capable of operating in can be determined. FIG. 2 is a block diagram illustrating the apparatus of the present invention in accordance with one exemplary embodiment. The apparatus preferably is comprised in an xDSL modem, which is represented by each of the DCEs 4 and 7 shown in FIG. 1. Each of the DCEs 4 and 7 comprises four transceivers 11, 12, 13 and 14, which are available for connection, one at a time, to the subscriber line 5 via a selector 10 and the subscriber line interface 16.

Instead of one of the transceivers being connected to the subscriber line 5 at a particular time, the selector 10 can instead connect the Automatic Class Measurement device 15 to the subscriber loop 5 via the subscriber line interface 16. The Automatic Class Measurement device 15 is capable of performing certain tests to determine which of the transceivers 11, 12, 13 or 14 should be connected to the subscriber line 5. Once this determination has been made, the Automatic Class Measurement device 15 notifies the selector 10 as to which transceiver is to be connected. The manner in which this determination is made will be discussed below in detail with respect to the NAP tests of the present invention.

Connection of the appropriate transceiver to the subscriber line 5 enables the modem 7 to communicate with the DCE 4 located at the CO 2 within the determined Spectrum Management Class dictated by the physical characteristics of the subscriber line 5 (e.g., loop length, gauge, etc.). Once the appropriate transceiver has been connected, the Adaptive Class Measurement device 19 monitors the subscriber line 5 and determines whether the connected transceiver of the modem 7 is currently capable of communicating with the CO 2 within the particular Spectrum Management Class. If not, the transceiver is then taken out of service and the

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transceiver that is most appropriate for communicating within the current Spectrum Management Class with the DCE 4 of the central office 2 is connected to the subscriber loop 5 via the selector 10 and subscriber line interface 16. The manner in which the Adaptive Class Measurement device 19 performs these tasks will be discussed below with reference to the NAP tests of the present invention.

In the exemplary embodiment shown in FIG. 2, a transceiver is provided for four Spectrum Management Classes, namely, very low band symmetric (VLB) Class, the low band symmetric (LB) Class, the mid band symmetric (MB) Class and the high band symmetric (HB) Class. Upon measurement by the Automatic Class Measurement device 15 of the loop length and/or other loop parameters defined by the Spectrum Management Class deployment rules, the Spectrum Management Class or Classes that correspond to the measured parameters are identified as Allowable Classes. This measurement by the Automatic Class Measurement device 15 will occur automatically whenever a modem incorporating the invention is placed into service and powered on.

As stated above, at other times the Adaptive Class Measurement device 19 will measure parameters in an adaptive background manner to determine whether or not the Allowable Classes have changed. Both of the devices 15 and 19 are configured to be capable of controlling the selector 10 to connect the appropriate transceiver of the DCE 7 to the subscriber line 5. Furthermore, the Adaptive Class Measurement device 19 is capable of removing the currently connected transceiver from service and causing the most appropriate transceiver to be connected. The Adaptive Class Measurement device 19 preferably is configured to perform some or all of the loop qualification NAP testing capabilities described below in detail. Preferably, the communication device 1 at the CO 2 and the DCE 7 at the subscriber premises are configured to cooperate with each other in performing these tests. However, as discussed below, at least some of the tests may be performed by the DCE 4 at the CO 2 without a DCE 7 being located at the subscriber premises, and vice versa.

The Adaptive Class Measurement device 19 performs the tests necessary to determine the Spectrum Management Class or Classes for which the subscriber line 5 is qualified. It may then further determine from test results which compliant transceiver will provide best performance. In accordance with one aspect of the present invention, Pre-qualification Test(s) are performed to permit preliminary Class identification to be ascertained by the communication device 1 of the CO without the necessity of a subscriber premises test device (e.g., a DSL modem configured to cooperate with the communication device 1 during the test(s)). The Pre-qualification Test(s) permit more accurate Class identification to be performed from the CO 2 when being utilized in conjunction with a premises test device (e.g., a DSL modem 7).

FIG. 3 is a flow chart representing an example of the manner in which the present invention can be used to determine whether one or more Spectrum Management Classes are available for communicating over the loop 3 and subscriber line 5. This flow chart applies to situations where the determination is made with and without the premises test device, which is represented by the DSL modem 7. In this example, the loop length is measured to determine the available Spectrum Management Class or Classes, as indicated by block 21. The Allowable Spectrum Management Class or Classes are then identified at the CO 2 by the communication device 1 and/or at the subscriber premises

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by the modem 7. Preferably, the allowable Spectrum Management Class or Classes are tagged, as indicated by block 25. The most appropriate transceiver of the modem 7 is then selected and connected to the subscriber line 5 via selector 10 and subscriber line interface 16.

When the Automatic Class Measurement device 15 of the modem 7 is determining the allowable Spectrum Management Class or Classes, it will cause the selector 10 to select the appropriate transceiver for connection to the subscriber line 5. If the communication device 1 at the CO 2 is making the determination, it will send a command to the modem 7, once the modem 7 has been placed in operation, to cause the appropriate transceiver to be selected. The modem 7 will then operate in compliance with one of the allowable Spectrum Management Classes, as indicated by block 27.

In-Service Tests of the NAP test feature of the present invention are performed by the Adaptive Class Measurement device 19. This aspect of the present invention permits continual monitoring to determine and select the transceiver corresponding to the most appropriate Spectrum Management Class. If none of the transceivers 11, 12, 13, 14 and are capable of operating in compliance with the available Spectrum Management Class or Classes, the Adaptive Class Measurement device 19 will cause the modem 7 to cease operating.

Loop length or reach is a prime parameter used in establishing the allowable Spectrum Management Class. Measurement of this parameter can be made during In-Service Tests. The aforementioned ANSI standardized deployment rules for identifying the available Spectrum Management Class or Classes are not yet finalized and, even once finalized, are always subject to change. Therefore, rather than describing the manner in which the non-finalized rules may be applied to determine the allowable, or available, Spectrum Management Classes, the basic NAP tests of the present invention will be described and examples of the manner in which they can be applied to determine allowable Spectrum Management Classes will be provided.

The subscriber line 3/5 is comprised of a wire pair connecting the DCE 4 located at the CO 2 to the DCE 7 located at the subscriber premise. The pair may be comprised of, for example, a single wire gauge, typically AWG 24 or AWG 26. Alternatively, the pair may be of mixed gauge with some lengths of one gauge and some lengths of another gauge. The subscriber loop may have bridged taps attached to the wire pair at one or more points. Depending on the detailed Spectrum Management Class deployment rule definition of "reach", the parameters to be tested may vary. The following example is representative of the manner in which "reach" can be determined, but variations can be accommodated by the test methods of the present invention, as will be understood by those skilled in the art in view of the discussion provided herein. The following example assumes that the "reach" test is performed by either DCE 7 or DCE 4. It should also be noted that the "reach" test could also be determined by a device external to the DCEs 7 and 4, even a device manufactured by a manufacturer other than the manufacturer of the DCEs 4 and 7. The "reach" determination could then be entered into the Adaptive Class Measurement device 19, by a service technician, for example.

For exemplary purposes, it will be assumed that the standardized deployment rule definition of "reach" is the "equivalent length of an AWG 26 wire pair for the measured end-to-end loss vs. frequency, irrespective of any bridged taps. For this case, it is necessary to measure the end-to-end

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loss while identifying and discounting any effect of any bridged taps. The loss vs. frequency of an AWG 26 wire pair at any reach is well known. Therefore, if a determination is made that no bridged taps are present, a direct loss vs. frequency measurement can be compared with known AWG 26 reach tables and the loop reach can be determined from those tables. This method of determining reach is suitable even if the actual wire gauge is not AWG 26, or is of mixed gauge, because the deployment rule is only directed to determining "equivalent" length. Unfortunately, if no a priori information on bridged taps is available, bridged taps must be identified by the test and either compensated for by the testing signals or compensated for in the interpretation of the loss vs. frequency data, or both. The manner in which this determination is made will now be described.

A bridged tap at or very near one end of the loop, which is the typical case, is readily discoverable and quantifiable by test equipment at that end. The bridged tap creates a frequency dependent impedance that is a function of the length of the bridged tap. For example, the impedance associated with the bridged tap is typically lowest at a frequency of about 150 kHz/B, where B is the length of the bridged tap in kilofeet. A typical test signal generator with a non-zero output impedance, say 100 ohms, would be expected to transmit a signal that has a small loss vs. frequency variation when no bridged tap is present. However, since the bridged tap will normally introduce a lower impedance at the frequency identified above, the length of the bridged taps can be deduced by measuring at a test signal generator the signal level placed on to the wire pair.

The objective of this test is to disregard effects of bridged taps. Two approaches may be used to achieve this. The first approach is to set the test generator output impedance near zero so that the low impedance caused by the bridged tap is substantially inconsequential. The second is to equalize the transmit test signal. In both cases, the transmit test signal loss vs. frequency variation will be substantially negligible. By using either of these approaches at each end of the loop, a determination can be made as to (1) whether a bridged tap is present at either or both ends of the loop, and (2) the length of any bridged taps that are present. These determinations can then be used to overcome the influence of the taps on the end-to-end loss vs. frequency measurements.

Once the effect of bridged taps at or near the ends of the subscriber loop has been mitigated, end-to-end loss vs. frequency data can be obtained in each direction. However, it remains possible that bridged taps far from either end of the loop are present. It is probably not possible to accurately account for all such bridged taps in this manner. However, since the large majority of bridged taps are near one end of the loop and the large majority are less than 1000 ft from one end of the loop, restricting the loss vs. frequency to frequencies well below 150 kHz assures that the desired reach calculation of this example can be achieved.

Measurement of loop reach may be accomplished by transmitting from one end of the loop, such as from the CO 2, a signal with a known spectral content and measuring at the other end, such as at the DEC 7, the level at various frequencies across the frequency band of interest. Such a signal can be a swept sine wave as is used in classical spectrum analyzers or other test signals, which are well known in the art. By knowing the spectral content of the transmitted signal and of the received signal, the loss vs. frequency characteristics of the of the test signal over the channel can be determined, as will be understood by those skilled in the art. The same test can be performed to make this determination in both directions.

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It should be noted that, if a loop is classed at, for example, Spectrum Management Class LB, it is also useable for Class VLB DSLs since Class VLB falls within the requirements of Class LB. The test would then be to measure performance parameters and select the best modulation method that is compliant with both Class VLB and Class LB. This is demonstrated by the flow chart of FIG. 4. The example demonstrated in the flow chart of FIG. 4 assumes that the parameter being measured to determine the best mode of modulation is loop length. Therefore, loop length is measured, as indicated by block 33 to determine the allowable Spectrum Management Classes, as indicated by block 35.

Once the allowable Spectrum Management Classes, if any, have been identified, a determination is made as to whether any allowable Spectrum Management Classes exists, as indicated by block 37. If not, operation in the current modulation mode and line signals are prohibited, as indicated by block 39. If at least one allowable Spectrum Management Class has been identified, the allowable Spectrum Management Class(es) is tagged, as indicated by block 41. A determination is then made as to whether more than one allowable Class was identified, as indicated by block 43. If only one allowable Class has been identified, then the Adaptive Class Measurement device 19 causes the selector to select the transceiver (11, 12, 13, 14) corresponding to the mode of operations that is compliant with the Allowable Spectrum Management Class, as indicated by block 45.

If more than one allowable Class has been identified, then the Adaptive Class Measurement device 19 causes the selector 10 to select the transceiver (1, 12, 13, 14) corresponding to the best mode of operations that is compliant with each of the allowable Spectrum Management Class, as indicated by block 47. The following table lists classes of tests that are provided in accordance with the present invention. Each class of tests may be performed without a prerequisite performance of any other class of tests. That is, each class has a test set that provides results without need to perform other. Those skilled in the art will understand the manner in which these tests are performed.

Class	Test Name	
Pre-Qualification Tests	Premises modem not Operational POTS Available Loading Coils Present POTS Splitter Present Loop Length Prediction On/Off Hook Interfering POTS Activity DSL/CO Average Noise* DSL/CO Impulse Noise* DSL/CO Noise Spectrum* DSL/CO Crosstalk Type* DSL/CO Tonal Interferences* DCE Performance Prediction*	Note: Tests with an *** may be performed and reported for both on/off-hook states. But test operator has no control over premises.
Qualification Tests	Premises modem Operational POTS Available Loading Coils Present POTS Splitter Present Loop Length Estimate Downlink Loop Characteristic, or DLC Uplink Loop Characteristic, or ULC On/Off Hook Phone Filter Present Interfering POTS Activity CO/DLC Non-Linear Distortion*	Note: Tests with an *** are performed and reported for both on/off-hook states. Test operator may have control over premises.

-continued

Class	Test Name	
	Premises Non-Linear Distortion*	
	DSL/CO Average Noise*	
	Premises Average Noise*	
	DSL/CO Impulse Noise*	
	Premises Impulse Noise*	
	DSL/CO Noise Spectrum*	
	Premises Noise Spectrum*	
	DSL/CO Crosstalk Type*	
	Premises Crosstalk Type*	
	DSL/CO Tonal Interferences*	
	Downstream Data Rate*	
	Upstream Data Rate*	
In-Service Tests	1. Premises modem Operational	Note: Tests with an "*" are performed and reported for both on/off-hook states. Test operator has control over premises.
	2. On/Off Hook	
	3. Downstream Data Rate*	
	4. Upstream Data Rate*	
	5. Downstream Block Test*	
	6. Upstream Block Test*	
	7. Downstream User Byte Count*	
	8. Upstream User Byte Count*	
	9. Downstream Data Efficiency*	
	10. Upstream Data Efficiency*	
	11. POTS State Change Count	
	12. Retrain Count	
	13. CO/DLC Receive Level	
	14. Premises Receive Level	
	15. CO/DLC Receive Ratio	
	16. Premises Receive Ratio	
Service User Tests	1. Modem Service Available	Note: Tests with an "*" are performed and reported for both on/off-hook states. Test operator has control over premises.
	2. On/Off Hook	
	3. Downstream Data Rate*	
	4. Upstream Data Rate*	
	5. Downstream Block Test*	
	6. Upstream Block Test*	

The Pre-Qualification Tests involve testing from a CO without a modem (i.e., a DSL modem) at the subscriber premises. Alternatively, the Pre-Qualification Tests could be performed by the modem located at the subscriber premises without the need for cooperation by the modem located at the CO. The accuracy of some of these tests is limited due to the absence of known termination and DCE equipment at the premises or at the CO. For purposes of explanation, it will be assumed that the Pre-Qualification Tests are to be performed by the modem located at the CO. The first objective of these tests is to estimate, prior to any premises installation, the likelihood that a modem, if installed at the subscriber premises, will perform according to the proposed service offering. The second objective of these tests is to identify impairments that may limit performance of the modem once installed at the subscriber premises.

The Qualification Tests involve testing from a modem at a CO in conjunction with a modem located at the subscriber premises, but with the premises modem service being disrupted or disabled. Each multipoint premises modem can be individually tested, if desired. The accuracy of these tests is high due to the use of the premises modem equipment in conjunction with the testing equipment located at the CO (DCE 4 shown in FIG. 1). The first objective of these tests is to establish premises modem performance compared to the proposed service offering. The second objective is to identify impairments that may limit the performance of the premises modem.

The In-Service Tests involve testing from a CO modem concurrent with and without interfering with normal service provided by the premises modem. Each premises modem can be individually tested, if desired. The accuracy of these tests is high. The first objective of these tests is to measure the premises modem performance according to the proposed

service offering. A second objective is to report impairments that may lead to either performance improvements or the offering of higher performance services.

The Premises User Tests provide test results at a premises modem concurrent with normal operational service of the modem, i.e., without interrupting service provided by the premises modem. Each multipoint premises modem can be individually tested, if desired. The accuracy of these tests is high. The first objective of these tests is to provide information to the service user to permit direct assessment of performance from the premises modem to the CO without contacting the service provider. The second objective is to identify performance limiting impairments or attached POTS devices within the premises. Each multipoint premises modem can be individually tested, if desired.

It should be noted that although the modem located at the subscriber premises has been discussed only in terms of preferably being an xDSL modem, this is not a requirement of the present invention. However, the present invention preferably is directed to providing xDSL services between subscriber premises and a CO. The services are provided by a network service provider (NSP). Therefore, the CO DCE 4 and the DCEs 7 preferably are xDSL modems. The assignee of the present application has invented technology for implementation in xDSL modems known as multiple virtual line (MVL) technology. MVL DSL modems are capable of being utilized at a subscriber premise to enable multiple DTE devices, such as a facsimile machine and a personal computer, to operate simultaneously and communicate over a single telephone line coupling the subscriber premise to the CO. The present invention may be implemented in various types of DCE devices, including various xDSL modems and MVL xDSL modems.

Those skilled in the art will understand the manner in which these tests can be performed. Therefore, no further discussion of the manner in which any of these tests can be performed will be provided herein in the interest of brevity. Preferably, the tests of the present invention are implemented in software in the modem located at the subscriber premises, as well as in the modem located at the CO. As stated above, some tests are performed solely by the modem 4 located at the CO whereas others are performed solely by the modem 7 located at the subscriber premise. Others are performed in part by the subscriber premises modem 7 and in part by the modem 4 located at the CO 2. Therefore, only the code that is needed at those locations will need to be installed at those locations. It is desirable, but not required, to have the test software reside permanently in the same software codes used for operation of modems implementing xDSL and MVL/xDSL technology. In other words, either the test code itself, or modem operational code including the test code, would be selected, rather than loaded, to perform the testing routines. One reason for this is that some modem with which the present invention could be implemented may have difficulty running test software while simultaneously running multiple operational modem codes.

Therefore, the manner in which the test software is implemented may depend on the type of modem with which it is to be implemented. With respect to MVL technology, which was developed by the assignee of the present application, it is desirable for the test software to reside without change in progressive releases of MVL, even new classes of MVL technology are released. One reason for this is to maintain permanence of test results so that data collected in the past can be deemed to be reliable. Another reason is to provide independence of test code releases from operational code releases.

Preferably, test signal transmissions are generic so that received data can be (1) immediately analyzed, and (2) stored for later analysis, perhaps by analysis programs not yet in existence. It is also desirable for the test signal transmission (digital to analog writes) and test signal reception (analog to digital reads) to have rather short, finite lengths commensurate with memory and backhaul data capacities of the modem hardware (DSP and DSLAM hardware, respectively). In the case where the subscriber premise modem utilizes MVL/xDSL technology, it may be desirable for as much signal analysis as possible to be performed outside of the MVL operational system. That is, while the xDSL/MVL modem will generate and receive test signals upon command, the raw data received should be analyzed outside of this system by, for example, a personal computer (PC) so that performance of the MVL tasks is not limited by processing of the received test signal.

One possible architecture of the present invention will now be described with reference to a modem incorporating xDSL/MVL technology. It will be assumed that the tests are limited to tests that are not run in the MVL operational mode. The tests listed above can be categorized into either the operational mode or the test mode. Preferably, every MVL software code set would have both some MVL operating software and the Test Software of the present invention. When instructed, the Test Software would be enabled and test parameters would be loaded that would select the transmitted test signals, the cadence of these signals, and the capture of these signals. The Test Software would have a test signal generation capability (i.e., a digital-to-analog (D/A) write at the sample rate) and a test signal reception capability (i.e., an analog-to-digital (A/D) read at the sample rate). In all cases, the D/A writes and the A/D reads would occur simultaneously (including null D/A generation). A single counter would identify and label the transmit and receive sample pairs.

The test signal generations would be accomplished by one or more algorithms capable of generating periodic waveforms, including pseudo-random periodic waveforms. The objective here would be to utilize very small program space and very small data memory space. Each algorithm can have a parameters set, or the parameter set may be loaded from an external source. Loading the parameters from an external source provides great flexibility and use of test signals not yet known.

It should be noted that the present invention has been described with reference to preferred embodiments, but that the present invention is not limited to those embodiments. It should also be noted that, although the present invention preferably is implemented in software, the present invention may also be implemented solely in hardware, if so desired. If implemented in software, the software is not limited to being stored on any particular type of storage device. A suitable storage device for this purpose may be, for example, a magnetic storage medium, such as a magnetic disk, a solid state storage medium, such as random access memory (RAM) or read only memory (ROM), or an optical storage medium, such as an optical compact disk ROM (CD ROM). Therefore, the present invention is not limited with respect to the type of computer-readable medium employed for storing the software. Those skilled in the art will understand that various modifications may be made to the embodiments and features discussed above without deviating from the spirit and scope of the present invention.

What is claimed is:

1. An apparatus comprising:

a modem connected to a subscriber loop, the modem being capable of operating in one or more modes that

are compatible with one or more spectrum management classes defined by a standard, each spectrum management class defining power spectral density (PSD) requirements, the modem being configured to automatically select a mode that is compatible with at least one of the spectrum management classes;

a plurality of transceivers, each transceiver corresponding to one of the modes, wherein the modem electrically couples a corresponding transceiver to the subscriber loop upon selecting one of the modes;

a selector, the selector selecting one of the transceivers to be electrically coupled to the subscriber loop; and

an Automatic Class Measurement device in communication with the selector, the Automatic Class Measurement device being configured to automatically select a mode that is compatible with at least one of the spectrum management classes and to cause the selector to select one of the transceivers to be electrically coupled to the subscriber loop.

2. The apparatus of claim **1**, wherein the modem is further configured to detect when the modem is not capable of operating in a mode that is compatible with at least one of the spectrum management classes, and to prevent data transmission and reception upon such detection.

3. The apparatus of claim **1**, wherein the modem is further configured to automatically select a mode that is compatible with at least one of the spectrum management classes by measuring subscriber loop length.

4. The apparatus of claim **1**, further comprising:

an Adaptive Class Measurement device in communication with the selector, the Adaptive Class Measurement device being configured to adaptively determine whether a current mode is not compatible with at least one of the spectrum management classes and to prevent data transmission and reception upon such determination.

5. An apparatus comprising:

a modem connected to a subscriber loop, the modem being capable of operating in one or more modes that are compatible with one or more spectrum management classes defined by a standard, each spectrum management class defining power spectral density (PSD) requirements, the modem being configured to measure characteristics of the subscriber loop, the modem being further configured to automatically select, based on the measured characteristics, a mode that is compatible with at least one of the spectrum management classes;

a plurality of transceivers, each transceiver corresponding to one of the modes, wherein the modem electrically couples the corresponding transceiver of the modem to the subscriber loop upon selecting a mode;

a selector, the selector selecting one of the transceivers to be electrically coupled to the subscriber loop; and

an Automatic Class Measurement device in communication with the selector, the Automatic Class Measurement device being configured to automatically select a mode that is compatible with at least one of the spectrum management classes and to cause the selector to select one of the transceivers to be electrically coupled to the subscriber loop.

6. The apparatus of claim **5**, further comprising:

an Adaptive Class Measurement device in communication with the selector, the Adaptive Class Measurement device being configured to adaptively determine whether a current mode of the modem is not compatible with at least one of the spectrum management classes and to prevent line signaling on such a determination.

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7. The system of claim 5, wherein the modem provides a subscriber service, and the modem determines which of the spectrum management classes are compatible with the subscriber loop by performing a qualification test which disrupts the subscriber service.

8. The system of claim 5, wherein the modem provides a subscriber service, and the modem determines which of the spectrum management classes are compatible with the subscriber loop by performing a qualification test without interfering with the subscriber service.

9. The system of claim 5, wherein the modem, upon the determination of which of the spectrum management classes are compatible with the subscriber loop, automatically selects one of the modes that is compatible with one of the determined spectrum management classes.

10. The system of claim 5, wherein the modem is configured to detect when the modem is not capable of operating in a mode that is compatible with at least one of the determined spectrum management classes and to prevent data transmission and reception upon such detection.

11. The system of claim 5, wherein the modem is configured to determine which of the spectrum management classes are compatible with the subscriber loop by measuring subscriber loop length.

12. A system for communicating over a subscriber loop, the system comprising:

a first modem located at a subscriber premise, the first modem being capable of operating in one or more modes that are compatible with one or more spectrum management classes defined by a standard, each spectrum management class defining power spectral density (PSD) requirements;

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a second modem located at a central office, the second modem being capable of operating in one or more modes that are compatible with one or more of the spectrum management classes;

a subscriber loop electrically coupling the first modem to the second modem wherein the first and second modems cooperate with each other to determine which of the spectrum management classes are compatible with the subscriber loop;

a plurality of transceivers, each transceiver corresponding to one of the compatible modes, wherein the modem electrically couples a corresponding transceiver to the subscriber loop upon selecting one of the modes;

a selector, the selector selecting one of the transceivers to be electrically coupled to the subscriber loop; and

an Automatic Class Measurement device in communication with the selector, the Automatic Class Measurement device being configured to automatically select a mode that is compatible with at least one of the spectrum management classes and to cause the selector to select one of the transceivers to be electrically coupled to the subscriber loop.

13. The system of claim 12, further comprising:

an Adaptive Class Measurement device in communication with the selector, the Adaptive Class Measurement device being configured to adaptively determine whether a current mode is not compatible with least one of the spectrum management classes and to prevent data transmission and reception upon such determination.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,970,501 B1
DATED : November 29, 2005
INVENTOR(S) : Bremer et al.

Page 1 of 1


It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 8,

Line 32, delete "1" and replace with -- 11 --.

Signed and Sealed this

Seventh Day of March, 2006

A handwritten signature in black ink on a light gray dotted background. The signature reads "Jon W. Dudas" in a cursive style.

JON W. DUDAS

Director of the United States Patent and Trademark Office

Exhibit F



(12) **United States Patent**
Bremer et al.

(10) **Patent No.:** **US 7,894,472 B2**
 (45) **Date of Patent:** ***Feb. 22, 2011**

(54) **METHOD AND APPARATUS FOR
 AUTOMATIC SELECTION AND OPERATION
 OF A SUBSCRIBER LINE SPECTRUM CLASS
 TECHNOLOGY**

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Philip J. Kyees, Largo, FL (US)

(73) Assignee: **Brandywine Communications
 Technologies, LLC**, Villanova, PA (US)

(*) Notice: Subject to any disclaimer, the term of this
 patent is extended or adjusted under 35
 U.S.C. 154(b) by 898 days.

This patent is subject to a terminal dis-
 claimer.

5,812,786 A	9/1998	Seazholtz et al.	395/200.63
5,828,748 A	10/1998	Akhteruzzaman	379/399
5,838,724 A *	11/1998	Cole et al.	375/222
5,912,895 A	6/1999	Terry et al.	370/445
6,061,392 A *	5/2000	Bremer et al.	375/222
6,226,322 B1 *	5/2001	Mukherjee	375/229
6,389,062 B1 *	5/2002	Wu	375/222
6,404,806 B1 *	6/2002	Ginesi et al.	375/222
6,415,005 B2 *	7/2002	Koga et al.	375/347
6,647,058 B1 *	11/2003	Bremer et al.	375/222
6,693,957 B1 *	2/2004	Wingrove et al.	375/222
6,700,927 B1 *	3/2004	Esliger et al.	375/222

(Continued)

(21) Appl. No.: **11/074,029**

(22) Filed: **Mar. 7, 2005**

(65) **Prior Publication Data**

US 2005/0147158 A1 Jul. 7, 2005

Related U.S. Application Data

(63) Continuation of application No. 09/573,518, filed on
 May 17, 2000, now Pat. No. 6,970,501.

(60) Provisional application No. 60/134,590, filed on May
 17, 1999.

(51) **Int. Cl.**
H04J 3/16 (2006.01)

(52) **U.S. Cl.** **370/465; 370/252; 375/130;**
 375/222

(58) **Field of Classification Search** 375/222;
 709/223, 220; 455/453; 370/465

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,636,037 A	6/1997	Saitoh	358/442
5,781,617 A	7/1998	McHale et al.	379/93.14

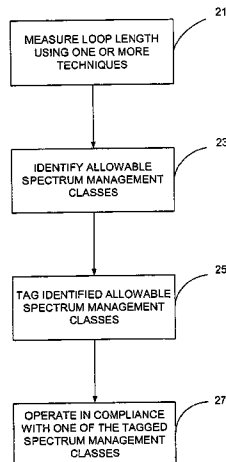
Primary Examiner—Donald L Mills

(74) *Attorney, Agent, or Firm*—Thomas, Kayden,
 Horstemeyer & Risley, LLP

(57) **ABSTRACT**

The present invention provides a communication device, such as a modem, that is capable of detecting whether it is capable of operating in a mode that is compatible with one or more of the Spectrum Management Classes. The modem automatically selects a mode of operation that is compliant with one or more of the Spectrum Management Classes. The communication device also determines whether it is capable of operating in multiple modes that are compliant with multiple Spectrum Management Classes, and is capable of selecting the modes of operation that optimizes the performance of the communication device. Furthermore, the communication device is capable of determining when it is not capable of operating in a mode that is compliant with at least one of the Spectrum Management Classes and which prevents operation of itself upon determining that it is not capable of operating in a mode that is compliant with at least one of the Spectrum Management Classes.

22 Claims, 4 Drawing Sheets



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U.S. PATENT DOCUMENTS			
6,751,254	B1 *	6/2004	Palm 375/222
6,765,957	B2 *	7/2004	Palm 375/222
6,775,840	B1 *	8/2004	Naegel et al. 725/111
6,970,501	B1 *	11/2005	Bremer et al. 375/222
2005/0147158	A1 *	7/2005	Bremer et al. 375/222

* cited by examiner

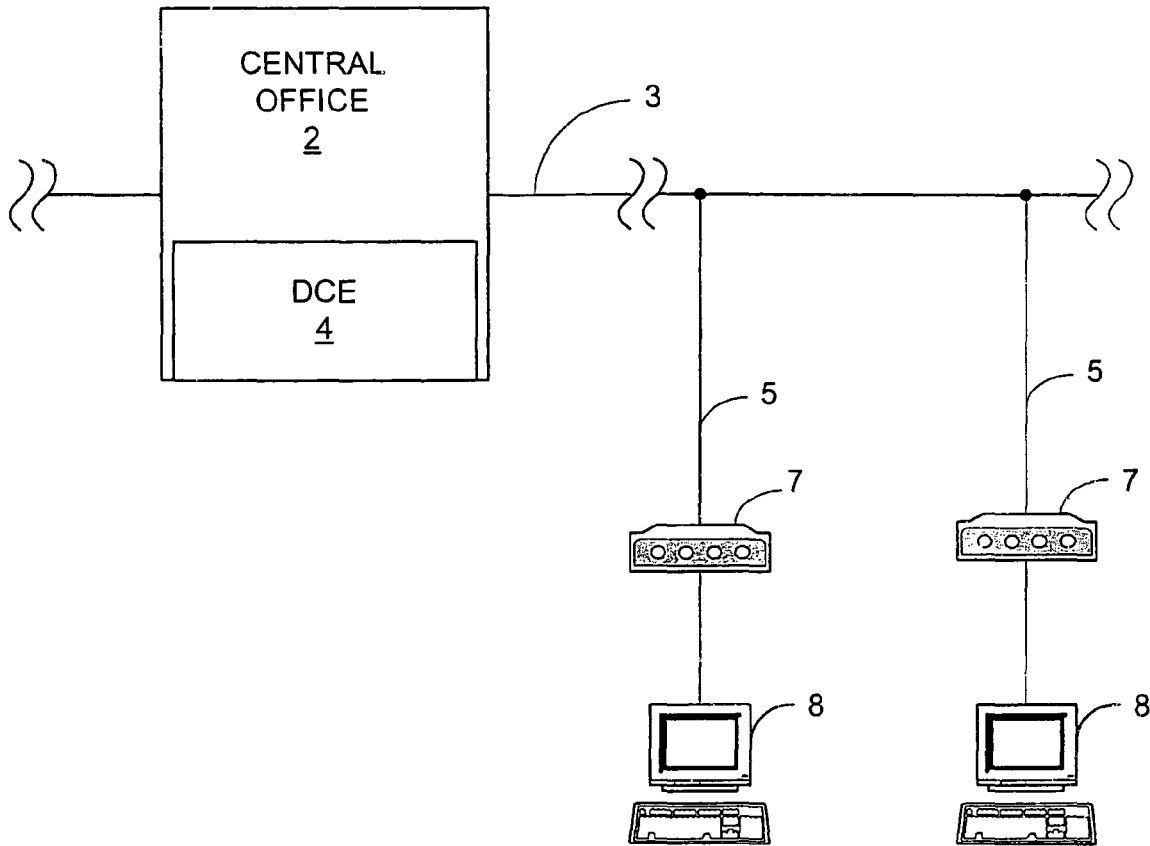


Fig. 1

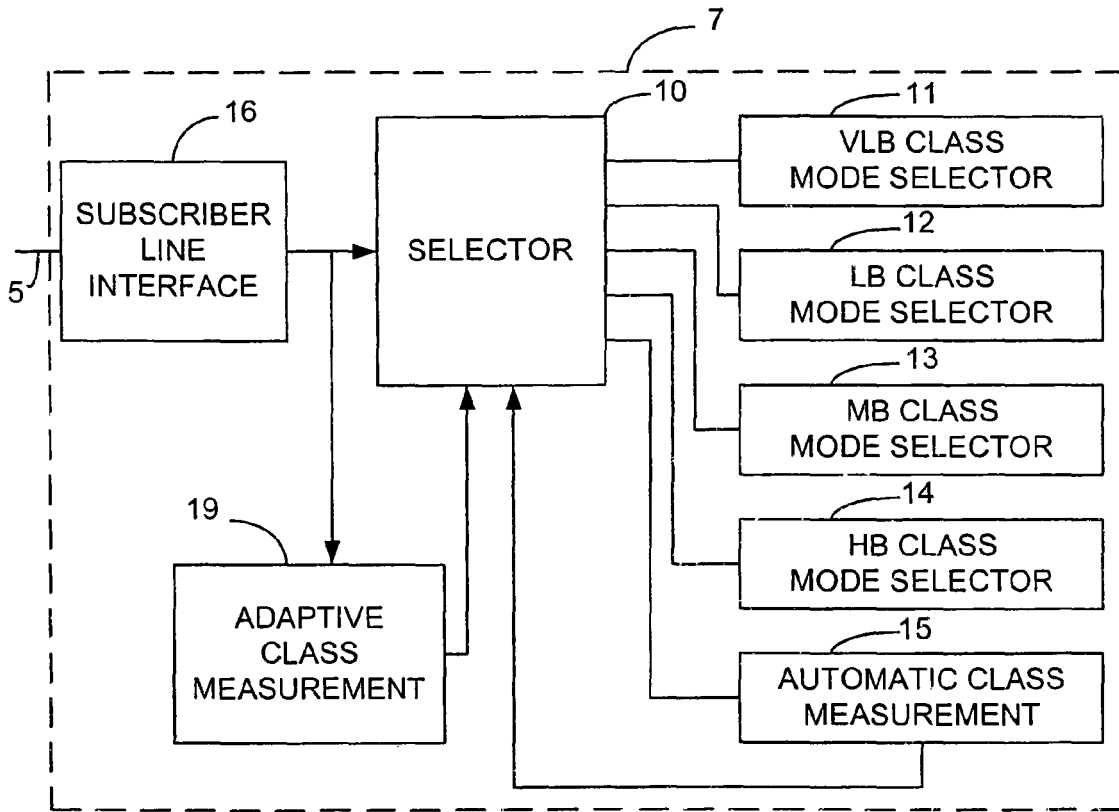


Fig. 2

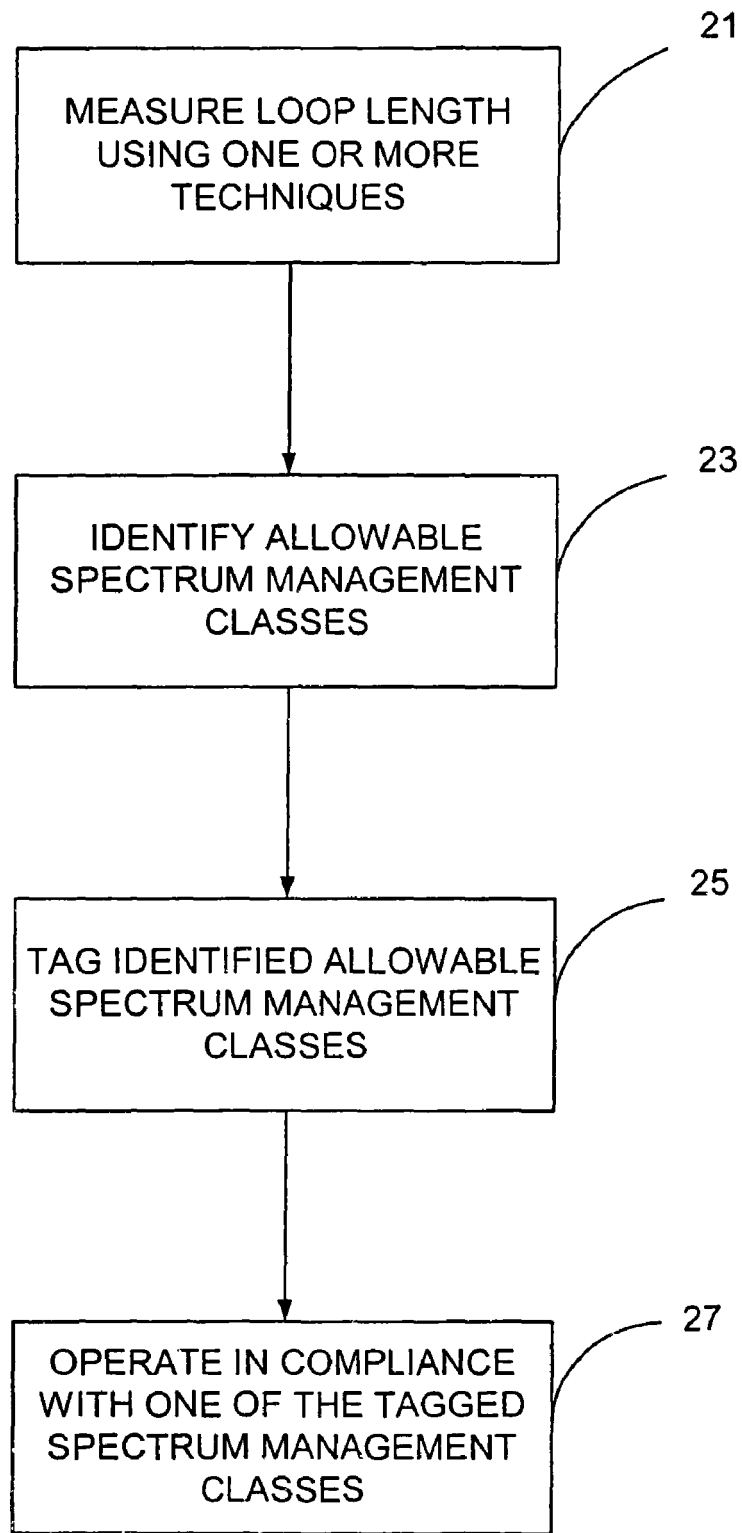


Fig. 3

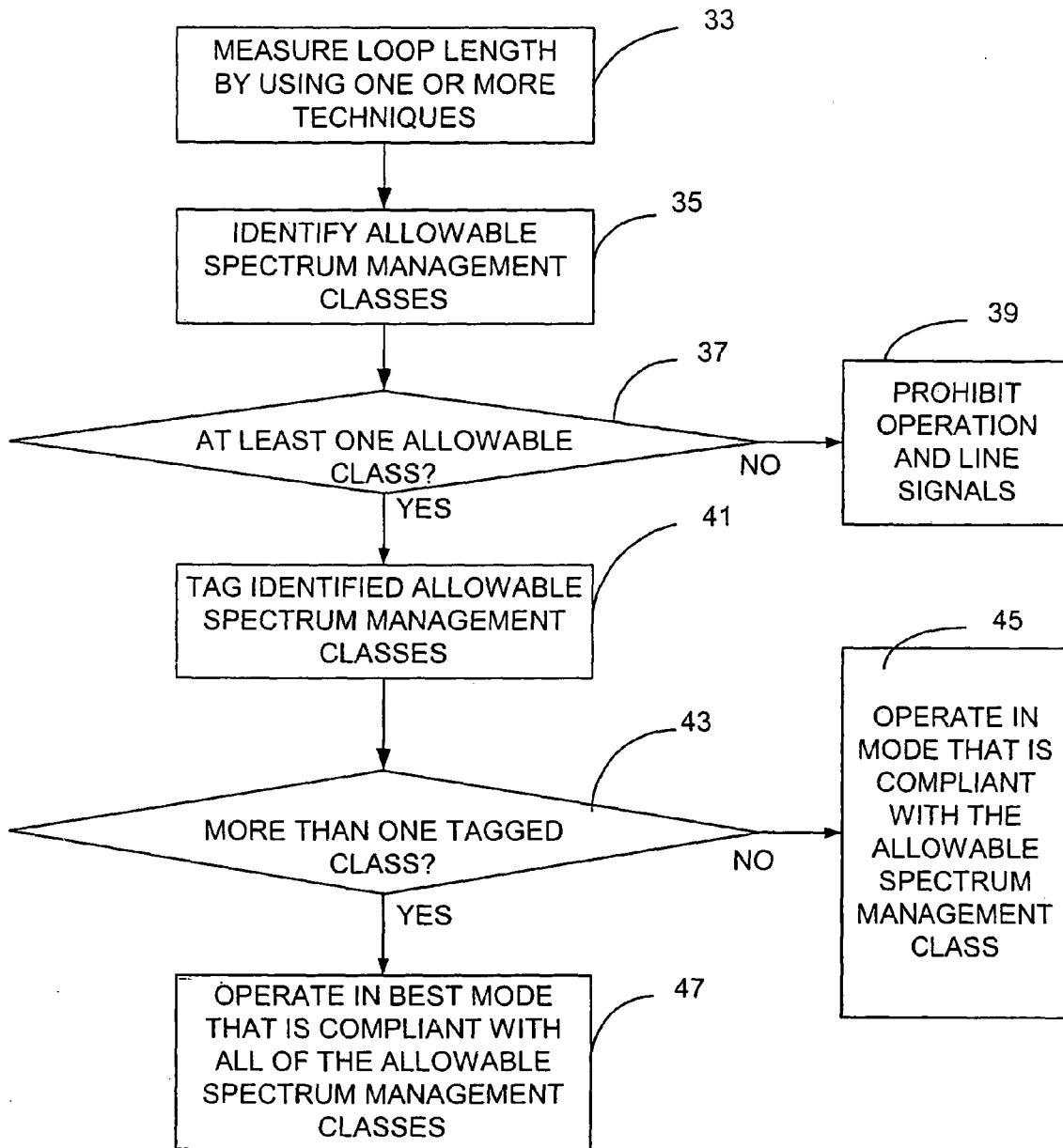


Fig. 4

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**METHOD AND APPARATUS FOR
AUTOMATIC SELECTION AND OPERATION
OF A SUBSCRIBER LINE SPECTRUM CLASS
TECHNOLOGY**

CROSS-REFERENCE TO RELATED
APPLICATIONS

This application is a continuation of application Ser. No. 09/573,518, filed May 17, 2000, now U.S. Pat. No. 6,970,501 which claims the benefit of U.S. Provisional Application No. 60/134,590, filed May 17, 1999. These applications are entirely incorporated herein by reference.

TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to a method and apparatus for automatically selecting a subscriber line Spectrum Management Class technology mode of operation for communication over metallic subscriber loop cables. More particularly, the present invention relates to a communication device that automatically detects which of a plurality of Spectrum Management Classes the communication device is capable of operating in and selects a mode of operation that is compatible with one or more of the Spectrum Management Classes.

BACKGROUND OF THE INVENTION

The American National Standard for Telecommunications is developing a standard that sets forth spectrum management requirements and recommendations for the administration of services and technologies that use metallic subscriber loop wire pairs, commonly referred to as subscriber loops. The goal of the standard is to administer the loop plant in a way that provides spectral compatibility for services and technologies that use pairs in the same cable binder. The standard is particularly directed to minimizing the potential for cross-talk interference in twisted pair subscriber loop cables that are shared by multiple service providers (carriers). In situations where multiple service providers utilize twisted pairs in the same loop binders, services and technologies may interfere with each other if they are deployed in an uncontrolled manner. The standard provides spectrum management requirements and deployment recommendations for the administration of services and technologies in such an environment in a way that prevents or minimizes such deleterious effects.

The Spectrum Management Classes address (1) transmit signal power spectral density (PSD) requirements, (2) transmit signal average power requirements, (3) transverse balance requirements, (4) deployment restrictions based upon the subscriber loop characteristics, and (5) loop assignment guidelines. A communication device or system that meets all of the applicable requirements for one of the spectrum management classes is deemed to be in conformance with the standard. If a communication device or system does not meet all of the requirements associated with at least one of the spectrum management classes, the communication device or system is deemed to be non-compliant with the standard.

It would be desirable to provide a communication device, such as a digital subscriber line (DSL) modem, for example, that is capable of operating in a manner that is compatible with one or more of the spectrum management classes. It would also be desirable to provide a communication device that is capable of automatically detecting which of the spectrum management classes it is capable of operating in and of automatically selecting a mode of operation that is compat-

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ible with one of the spectrum management classes. Furthermore, it would be desirable to provide such a communication device that could detect when it is capable of operating in a mode that is compatible with more than one of these classes and that would automatically select a mode of operation that is compatible with the class that optimizes performance of the communication device. It would also be desirable to provide such a communication device that could detect when it is no longer capable of operating in a mode that is compatible with at least one of the spectrum management classes and which would prevent operation of the communication device when such a determination is made.

Although it is generally known for certain DSL modems and subscriber line technologies to have automatic and adaptive algorithms that seek to optimize performance, it is not known to provide a modem that detects compatibility with one or more spectrum management classes of the aforementioned standard and that selects the appropriate or best mode of operation based on that determination. For example, algorithms that automatically select transmit spectrum bandwidths and/or bandwidth locations are known. These algorithms are utilized to optimize performance in accordance with the ITU V.34 standard. The ITU V.34 standard also provides for adaptive equalizers and echo-cancelers.

Another type of automatic algorithm provided for by the ITU V.34 standard, which is often referred to as an auto-rating algorithm, provides for modifying a data transmission rate of a modem to allow the highest data rate possible to be utilized in the presence of certain line impairments. However, this algorithm is not truly "adaptive" because it is necessary to temporarily disrupt communication while the rate change is being accomplished. An auto-rate algorithm that is utilized with Multiple Virtual Lines (MVL) technology is known, which was developed by the assignee of the present application. The MVL auto-rating algorithm enables the rate change to be accomplished without disrupting communication. Therefore, the MVL auto-rating algorithm is adaptive.

Although the aforementioned algorithms seek to optimize performance, they do not take into account restrictions on transmit bandwidth and/or transmit power level or other types of restrictions that are in effect on a particular subscriber line on which they operate. These are examples of the types of restrictions that must be met in order to comply with the spectrum management classes defined in the standard. Therefore, these algorithms are not suitable for automatically selecting an appropriate mode of operation that is in compliance with one of the spectrum management classes.

A feature known as Spectrum Manager is used with Etherloop modems, which are marketed by a company known as Elastic Networks. Etherloop modems base the use of transmit spectrum on the presence or absence of other devices in the binder, i.e., on the presence or absence of other devices communicating on the same copper pair. Etherloop modems correlate an allowable use of spectrum to the length of the loop to which the modem is connected. The Etherloop modem adjusts its usage of transmit spectrum based on a detection of cross-talk caused by other DSL systems in the binder.

However, the Etherloop modem does not adjust its use of spectrum based on loop parameters required for spectrum management class compliance. Furthermore, when an Etherloop modem is operating properly, it will, under many circumstances, select modes of operation that are not in compliance with the aforementioned spectrum management classes. Also, Etherloop modem adjustments are based on a measurement of transient conditions and other conditions that are difficult to measure. It is not based on measurement param-

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eters that are directly related to the deployment rules associated with the spectrum management classes.

Accordingly, a need exists for a communication device, such as a modem, that is capable of detecting whether it is capable of operating in a mode that is compatible with one or more of the spectrum management classes and which automatically selects a mode of operation that is compliant with one of the spectrum management classes. A need also exists for such a communication device that is capable of determining whether it is capable of operating in multiple modes that are compliant with multiple spectrum management classes and which is capable of selecting the mode of operation that optimizes the performance of the communication device. A need also exists for such a communication device that is capable of determining when it is not capable of operating in a mode that is compliant with at least one of the spectrum management classes and which prevents operation of itself upon determining that it is not capable of operating in a mode that is compliant with at least one of the spectrum management classes.

SUMMARY OF THE INVENTION

The present invention provides a communication device, such as a modem, that is capable of detecting whether it is capable of operating in a mode that is compatible with one or more of the spectrum management classes and which automatically selects a mode of operation that is compliant with one of the spectrum management classes. The communication device determines whether it is capable of operating in multiple modes that are compliant with multiple spectrum management classes and which is capable of selecting the mode of operation that optimizes the performance of the communication device. The communication device is also capable of determining when it is not capable of operating in a mode that is compliant with at least one of the spectrum management classes and which prevents operation of itself upon determining that it is not capable of operating in a mode that is compliant with at least one of the spectrum management classes.

These and other aspects and advantages of the present invention will become apparent from the following discussion, drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram illustrating a portion of the system in which the method and apparatus of the present invention may be implemented.

FIG. 2 is a block diagram illustrating the apparatus of the present invention in accordance with one exemplary embodiment.

FIG. 3 is a flow chart representing an example of the manner in which the present invention can be used to determine whether one or more Spectrum Management Classes are available for communicating over the loop 3 and subscriber line 5 shown in FIG. 1.

FIG. 4 is a flow chart demonstrating the method of the present invention in accordance with one exemplary embodiment, wherein the parameter being measured to determine the best mode of modulation is loop length.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides a Network Access Provider (NAP) Test Feature that enables one or more tests to be performed to determine which of multiple transceivers of a

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data communication equipment (DCE) device should be operating over a subscriber loop. The test(s) of the NAP test feature are utilized in accordance with the preferred embodiment of the present invention to determine which spectrum management class or classes a DCE device may operate in over the subscriber loop. It should be noted that the tests of the NAP Test Feature of the present invention are not limited to being used to determine which spectrum management class or classes a communication device may operate in on a subscriber loop. The present invention is capable of being utilized to determine the appropriate spectrum management class or classes defined in the aforementioned American National Standard for Telecommunications, although the present invention is not limited to being utilized for this purpose.

FIG. 1 is a block diagram illustrating the loop plant 3 that connects a central office (CO) 2 to several different subscriber premises, each of which comprises a DCE device 7 (e.g., an xDSL modem) and data terminal equipment (DTE) 8 (e.g., one or more computers). The CO 2 comprises at least one DCE 4 that is compatible with the DCEs 7 located at the subscriber premises. The loop plant represented by the line 3 is comprised of one or more twisted copper pairs, as is well known in the industry. The subscriber lines 5 are also twisted copper pairs that connect the subscriber premises to the loop plant 3. The subscriber lines 5 are normally viewed as being part of the loop plant 3. In accordance with the present invention, one or more tests are performed to determine the operating capability of the DCEs 4 and/or 7 located, respectively, at the CO 2 and at the subscriber premises. The DCE 4 located at the CO 2 preferably is an xDSL modem having similar or identical functional capabilities as those of the DCEs 7 located at the subscriber premises, which, as stated above, preferably are also xDSL modems.

By performing these test(s), one or more Spectrum Management Classes that the DCEs 4 and/or 7 are capable of operating in can be determined. FIG. 2 is a block diagram illustrating the apparatus of the present invention in accordance with one exemplary embodiment. The apparatus preferably is comprised in an xDSL modem, which is represented by each of the DCEs 4 and 7 shown in FIG. 1. Each of the DCEs 4 and 7 comprises four transceivers 11, 12, 13 and 14, which are available for connection, one at a time, to the subscriber line 5 via a selector 10 and the subscriber line interface 16.

Instead of one of the transceivers being connected to the subscriber line 5 at a particular time, the selector 10 can instead connect the Automatic Class Measurement device 15 to the subscriber loop 5 via the subscriber line interface 16. The Automatic Class Measurement device 15 is capable of performing certain tests to determine which of the transceivers 11, 12, 13 or 14 should be connected to the subscriber line 5. Once this determination has been made, the Automatic Class Measurement device 15 notifies the selector 10 as to which transceiver is to be connected. The manner in which this determination is made will be discussed below in detail with respect to the NAP tests of the present invention.

Connection of the appropriate transceiver to the subscriber line 5 enables the modem 7 to communicate with the DCE 4 located at the CO 2 within the determined Spectrum Management Class dictated by the physical characteristics of the subscriber line 5 (e.g., loop length, gauge, etc). Once the appropriate transceiver has been connected, the Adaptive Class Measurement device 19 monitors the subscriber line 5 and determines whether the connected transceiver of the modem 7 is currently capable of communicating with the CO 2 within the particular Spectrum Management Class. If not,

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the transceiver is then taken out of service and the transceiver that is most appropriate for communicating within the current Spectrum Management Class with the DCE 4 of the central office 2 is connected to the subscriber loop 5 via the selector 10 and subscriber line interface 16. The manner in which the Adaptive Class Measurement device 19 performs these tasks will be discussed below with reference to the NAP tests of the present invention.

In the exemplary embodiment shown in FIG. 2, a transceiver is provided for four Spectrum Management Classes, namely, very low band symmetric (VLB) Class, the low band symmetric (LB) Class, the mid band symmetric (MB) Class and the high band symmetric (HB) Class. Upon measurement by the Automatic Class Measurement device 15 of the loop length and/or other loop parameters defined by the Spectrum Management Class deployment rules, the Spectrum Management Class or Classes that correspond to the measured parameters are identified as Allowable Classes. This measurement by the Automatic Class Measurement device 15 will occur automatically whenever a modem incorporating the invention is placed into service and powered on.

As stated above, at other times the Adaptive Class Measurement device 19 will measure parameters in an adaptive background manner to determine whether or not the Allowable Classes have changed. Both of the devices 15 and 19 are configured to be capable of controlling the selector 10 to connect the appropriate transceiver of the DCE 7 to the subscriber line 5. Furthermore, the Adaptive Class Measurement device 19 is capable of removing the currently connected transceiver from service and causing the most appropriate transceiver to be connected. The Adaptive Class Measurement device 19 preferably is configured to perform some or all of the loop qualification NAP testing capabilities described below in detail. Preferably, the communication device 1 at the CO 2 and the DCE 7 at the subscriber premises are configured to cooperate with each other in performing these tests. However, as discussed below, at least some of the tests may be performed by the DCE 4 at the CO 2 without a DCE 7 being located at the subscriber premises, and vice versa.

The Adaptive Class Measurement device 19 performs the tests necessary to determine the Spectrum Management Class or Classes for which the subscriber line 5 is qualified. It may then further determine from test results which compliant transceiver will provide best performance. In accordance with one aspect of the present invention, Pre-qualification Test(s) are performed to permit preliminary Class identification to be ascertained by the communication device 1 of the CO without the necessity of a subscriber premises test device (e.g., a DSL modem configured to cooperate with the communication device 1 during the test(s)). The Pre-qualification Test(s) permit more accurate Class identification to be performed from the CO 2 when being utilized in conjunction with a premises test device (e.g., a DSL modem 7).

FIG. 3 is a flow chart representing an example of the manner in which the present invention can be used to determine whether one or more Spectrum Management Classes are available for communicating over the loop 3 and subscriber line 5. This flow chart applies to situations where the determination is made with and without the premises test device, which is represented by the DSL modem 7. In this example, the loop length is measured to determine the available Spectrum Management Class or Classes, as indicated by block 21. The Allowable Spectrum Management Class or Classes are then identified at the CO 2 by the communication device 1 and/or at the subscriber premises by the modem 7. Preferably, the allowable Spectrum Management Class or

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Classes are tagged, as indicated by block 25. The most appropriate transceiver of the modem 7 is then selected and connected to the subscriber line 5 via selector 10 and subscriber line interface 16.

When the Automatic Class Measurement device 15 of the modem 7 is determining the allowable Spectrum Management Class or Classes, it will cause the selector 10 to select the appropriate transceiver for connection to the subscriber line 5. If the communication device 1 at the CO 2 is making the determination, it will send a command to the modem 7, once the modem 7 has been placed in operation, to cause the appropriate transceiver to be selected. The modem 7 will then operate in compliance with one of the allowable Spectrum Management Classes, as indicated by block 27.

In-Service Tests of the NAP test feature of the present invention are performed by the Adaptive Class Measurement device 19. This aspect of the present invention permits continual monitoring to determine and select the transceiver corresponding to the most appropriate Spectrum Management Class. If none of the transceivers 11, 12, 13, 14 and 15 are capable of operating in compliance with the available Spectrum Management Class or Classes, the Adaptive Class Measurement device 19 will cause the modem 7 to cease operating.

Loop length or reach is a prime parameter used in establishing the allowable Spectrum Management Class. Measurement of this parameter can be made during In-Service Tests. The aforementioned ANSI standardized deployment rules for identifying the available Spectrum Management Class or Classes are not yet finalized and, even once finalized, are always subject to change. Therefore, rather than describing the manner in which the non-finalized rules may be applied to determine the allowable, or available, Spectrum Management Classes, the basic NAP tests of the present invention will be described and examples of the manner in which they can be applied to determine allowable Spectrum Management Classes will be provided.

The subscriber line 3/5 is comprised of a wire pair connecting the DCE 4 located at the CO 2 to the DCE 7 located at the subscriber premise. The pair may be comprised of, for example, a single wire gauge, typically AWG 24 or AWG 26. Alternatively, the pair may be of mixed gauge with some lengths of one gauge and some lengths of another gauge. The subscriber loop may have bridged taps attached to the wire pair at one or more points. Depending on the detailed Spectrum Management Class deployment rule definition of "reach", the parameters to be tested may vary. The following example is representative of the manner in which "reach" can be determined, but variations can be accommodated by the test methods of the present invention, as will be understood by those skilled in the art in view of the discussion provided herein. The following example assumes that the "reach" test is performed by either DCE 7 or DCE 4. It should also be noted that the "reach" test could also be determined by a device external to the DCEs 7 and 4, even a device manufactured by a manufacturer other than the manufacturer of the DCEs 4 and 7. The "reach" determination could then be entered into the Adaptive Class Measurement device 19, by a service technician, for example.

For exemplary purposes, it will be assumed that the standardized deployment rule definition of "reach" is the "equivalent length of an AWG 26 wire pair for the measured end-to-end loss vs. frequency, irrespective of any bridged taps." For this case, it is necessary to measure the end-to-end loss while identifying and discounting any effect of any bridged taps. The loss vs. frequency of an AWG 26 wire pair at any reach is well known. Therefore, if a determination is made that no

bridged taps are present, a direct loss vs. frequency measurement can be compared with known AWG 26 reach tables and the loop reach can be determined from those tables. This method of determining reach is suitable even if the actual wire gauge is not AWG 26, or is of mixed gauge, because the deployment rule is only directed to determining “equivalent” length. Unfortunately, if no priori information on bridged taps is available, bridged taps must be identified by the test and either compensated for by the testing signals or compensated for in the interpretation of the loss vs. frequency data, or both. The manner in which this determination is made will now be described.

A bridged tap at or very near one end of the loop, which is the typical case, is readily discoverable and quantifiable by test equipment at that end. The bridged tap creates a frequency dependent impedance that is a function of the length of the bridged tap. For example, the impedance associated with the bridged tap is typically lowest at a frequency of about 150 kHz/B, where B is the length of the bridged tap in kilofeet. A typical test signal generator with a non-zero output impedance, say 100 ohms, would be expected to transmit a signal that has a small loss vs. frequency variation when no bridged tap is present. However, since the bridged tap will normally introduce a lower impedance at the frequency identified above, the length of the bridged taps can be deduced by measuring at a test signal generator the signal level placed on to the wire pair.

The objective of this test is to disregard effects of bridged taps. Two approaches may be used to achieve this. The first approach is to set the test generator output impedance near zero so that the low impedance caused by the bridged tap is substantially inconsequential. The second is to equalize the transmit test signal. In both cases, the transmit test signal loss vs. frequency variation will be substantially negligible. By using either of these approaches at each end of the loop, a determination can be made as to (1) whether a bridged tap is present at either or both ends of the loop, and (2) the length of any bridged taps that are present. These determinations can then be used to overcome the influence of the taps on the end-to-end loss vs. frequency measurements.

Once the effect of bridged taps at or near the ends of the subscriber loop has been mitigated, end-to-end loss vs. frequency data can be obtained in each direction. However, it remains possible that bridged taps far from either end of the loop are present. It is probably not possible to accurately account for all such bridged taps in this manner. However, since the large majority of bridged taps are near one end of the loop and the large majority are less than 1000 ft from one end of the loop, restricting the loss vs. frequency to frequencies well below 150 kHz assures that the desired reach calculation of this example can be achieved.

Measurement of loop reach may be accomplished by transmitting from one end of the loop, such as from the CO 2, a signal with a known spectral content and measuring at the other end, such as at the DEC, the level at various frequencies across the frequency band of interest. Such a signal can be a swept sine wave as is used in classical spectrum analyzers or other test signals, which are well known in the art. By knowing the spectral content of the transmitted signal and of the received signal, the loss vs. frequency characteristics of the of the test signal over the channel can be determined, as will be understood by those skilled in the art. The same test can be performed to make this determination in both directions.

It should be noted that, if a loop is classed at, for example, Spectrum Management Class LB, it is also useable for Class VLB DSLs since Class VLB falls within the requirements of Class LB. The test would then be to measure performance

parameters and select the best modulation method that is compliant with both Class VLB and ClassLB. This is demonstrated by the flow chart of FIG. 4. The example demonstrated in the flow chart of FIG. 4 assumes that the parameter being measured to determine the best mode of modulation is loop length. Therefore, loop length is measured, as indicated by block 33 to determine the allowable Spectrum Management Classes, as indicated by block 35.

Once the allowable Spectrum Management Classes, if any, have been identified, a determination is made as to whether any allowable Spectrum Management Classes exists, as indicated by block 37. If not, operation in the current modulation mode and line signals are prohibited, as indicated by block 39. If at least one allowable Spectrum Management Class has been identified, the allowable Spectrum Management Class (es) is tagged, as indicated by block 41. A determination is then made as to whether more than one allowable Class was identified, as indicated by block 43. If only one allowable Class has been identified, then the Adaptive Class Measurement device 19 causes the selector 10 to select the transceiver (11, 12, 13, 14) corresponding to the mode of operations that is compliant with the Allowable Spectrum Management Class, as indicated by block 45. If more than one allowable Class has been identified, then the Adaptive Class Measurement device 19 causes the selector 10 to select the transceiver (11, 12, 13, 14) corresponding to the best mode of operations that is compliant with each of the allowable Spectrum Management Class, as indicated by block 47. The following table lists classes of tests that are provided in accordance with the present invention. Each class of tests may be performed without a prerequisite performance of any other class of tests. That is, each class has a test set that provides results without need to perform other. Those skilled in the art will understand the manner in which these tests are performed.

Class	Test Name	
40 Pre- Qualification Tests	Premises modem not Operational POTS Available Loading Coils Present POTS Splitter Present Loop Length Prediction On-Off Hook	Note: Tests with an “*” may be performed and report for both on/off-hook states.
45	Interfering POTS Activity DSL/CO Average Noise* DSL/CO Impulse Noise* DSL/CO Noise Spectrum* DSL/CO Crosstalk Type* DSL/CO Tonal Interferences* DCE Performance Prediction*	
50 Qualification Tests Note: each multipoint premises DSL modem may be individually tested.	Premises modem Operational POTS Available Loading Coil Present POTS Splitter Present Loop Length Downlink Loop Characteristic, or DLC Uplink Loop Characteristic, or ULC On/Off Hook Phone Filter Present Interfering POTS Activity CO/DLC Non-Linear Distortion* Premises Non-Linear Distortion* DSL/CO Average Noise* Premises Average Noise* DSL/CO Impulse Noise* Premises Impulse Noise*	But test operator has no control over premises. Note: Test with an “*” are performed and report for both on/off-hook states.
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-continued

Class	Test Name	
In-Service Tests	DSL/CO Noise Spectrum*	
	Premises Noise Spectrum*	
	DSL/CO Crosstalk Type*	
	Premises Crosstalk Type*	
	DSL/CO Tonal Interferences*	
	Downstream Data Rate*	
	Upstream Data Rate*	
	Premises modem Operation On/Off Hook	Note: Tests with an “*” are performed and reported for both on/off-hook states.
	Downstream Data Rate*	Test operator has control over premises.
	Upstream Data Rate*	
	Downstream Block Test*	
	Upstream Block Test*	
	Downstream User Byte Count*	
	Upstream User Byte Count*	
	Downstream Data Efficiency*	
	Upstream Data Efficiency*	
	POTS State Change Count Retrain Count	
CO/DLC Receive Level		
Premises Receive Level		
CO/DLC Receive Ratio		
Premises Receive Ratio		
Service User Tests	Modem Service Available On/Off Hook	Note: Tests with an “*” are performed and reported for both on/off-hook states.
	Downstream Data Rate*	Test operator has control over premises.
	Upstream Data Rate*	
	Downstream block Test*	
	Upstream Block Test*	

The Pre-Qualification Tests involve testing from a CO without a modem (i.e., a DSL modem) at the subscriber premises. Alternatively, the Pre-Qualification Tests could be performed by the modem located at the subscriber premises without the need for cooperation by the modem located at the CO. The accuracy of some of these tests is limited due to the absence of known termination and DCE equipment at the premises or at the CO. For purposes of explanation, it will be assumed that the Pre-Qualification Tests are to be performed by the modem located at the CO. The first objective of these tests is to estimate, prior to any premises installation, the likelihood that a modem, if installed at the subscriber premises, will perform according to the proposed service offering. The second objective of these tests is to identify impairments that may limit performance of the modem once installed at the subscriber premises.

The Qualification Tests involve testing from a modem at a CO in conjunction with a modem located at the subscriber premises, but with the premises modem service being disrupted or disabled. Each multipoint premises modem can be individually tested, if desired. The accuracy of these tests is high due to the use of the premises modem equipment in conjunction with the testing equipment located at the CO (DCE 4 shown in FIG. 1). The first objective of these tests is to establish premises modem performance compared to the proposed service offering. The second objective is to identify impairments that may limit the performance of the premises modem.

The In-Service Tests involve testing from a CO modem concurrent with and without interfering with normal service provided by the premises modem. Each premises modem can be individually tested, if desired. The accuracy of these tests is high. The first objective of these tests is to measure the premises modem performance according to the proposed service offering. A second objective is to report impairments that may lead to either performance improvements or the offering of higher performance services.

The Premises User Tests provide test results at a premises modem concurrent with normal operational service of the modem, i.e., without interrupting service provided by the premises modem. Each multipoint premises modem can be individually tested, if desired. The accuracy of these tests is high. The first objective of these tests is to provide information to the service user to permit direct assessment of performance from the premises modem to the CO without contacting the service provider. The second objective is to identify performance limiting impairments or attached POTS devices within the premises. Each multipoint premises modem can be individually tested, if desired.

It should be noted that although the modem located at the subscriber premises has been discussed only in terms of preferably being an xDSL modem, this is not a requirement of the present invention. However, the present invention preferably is directed to providing xDSL services between subscriber premises and a CO. The services are provided by a network service provider (NSP). Therefore, the CO DCE 4 and the DCEs 7 preferably are xDSL modems. The assignee of the present application has invented technology for implementation in xDSL modems known as multiple virtual line (MVL) technology. MVL DSL modems are capable of being utilized at a subscriber premise to enable multiple DTE devices, such as a facsimile machine and a personal computer, to operate simultaneously and communicate over a single telephone line coupling the subscriber premise to the CO. The present invention may be implemented in various types of DCE devices, including various xDSL modems and MVL xDSL modems.

Those skilled in the art will understand the manner in which these tests can be performed. Therefore, no further discussion of the manner in which any of these tests can be performed will be provided herein in the interest of brevity. Preferably, the tests of the present invention are implemented in software in the modem located at the subscriber premises, as well as in the modem located at the CO. As stated above, some tests are performed solely by the modem 4 located at the CO whereas others are performed solely by the modem 7 located at the subscriber premise. Others are performed in part by the subscriber premises modem 7 and in part by the modem 4 located at the CO 2. Therefore, only the code that is needed at those locations will need to be installed at those locations. It is desirable, but not required, to have the test software reside permanently in the same software codes used for operation of modems implementing xDSL and MVL/xDSL technology. In other words, either the test code itself, or modem operational code including the test code, would be selected, rather than loaded, to perform the testing routines. One reason for this is that some modem with which the present invention could be implemented may have difficulty running test software while simultaneously running multiple operational modem codes.

Therefore, the manner in which the test software is implemented may depend on the type of modem with which it is to be implemented. With respect to MVL technology, which was developed by the assignee of the present application, it is desirable for the test software to reside without change in progressive releases of MVL, even new classes of MVL technology are released. One reason for this is to maintain permanence of test results so that data collected in the past can be deemed to be reliable. Another reason is to provide independence of test code releases from operational code releases.

Preferably, test signal transmissions are generic so that received data can be (1) immediately analyzed, and (2) stored for later analysis, perhaps by analysis programs not yet in existence. It is also desirable for the test signal transmission (digital to analog writes) and test signal reception (analog to

digital reads) to have rather short, finite lengths commensurate with memory and backhaul data capacities of the modem hardware (DSP and DSLAM hardware, respectively). In the case where the subscriber premise modem utilizes MVL/xDSL technology, it may be desirable for as much signal analysis as possible to be performed outside of the MVL operational system. That is, while the xDSL/MVL modem will generate and receive test signals upon command, the raw data received should be analyzed outside of this system by, for example, a personal computer (PC) so that performance of the MVL tasks is not limited by processing of the received test signal.

One possible architecture of the present invention will now be described with reference to a modem incorporating xDSL/MVL technology. It will be assumed that the tests are limited to tests that are not run in the MVL operational mode. The tests listed above can be categorized into either the operational mode or the test mode. Preferably, every MVL software code set would have both some MVL operating software and the Test Software of the present invention. When instructed, the Test Software would be enabled and test parameters would be loaded that would select the transmitted test signals, the cadence of these signals, and the capture of these signals. The Test Software would have a test signal generation capability (i.e., a digital-to-analog (D/A) write at the sample rate) and a test signal reception capability (i.e., an analog-to-digital (A/D) read at the sample rate). In all cases, the D/A writes and the A/D reads would occur simultaneously (including null D/A generation). A single counter would identify and label the transmit and receive sample pairs.

The test signal generations would be accomplished by one or more algorithms capable of generating periodic waveforms, including pseudo-random periodic waveforms. The objective here would be to utilize very small program space and very small data memory space. Each algorithm can have a parameters set, or the parameter set may be loaded from an external source. Loading the parameters from an external source provides great flexibility and use of test signals not yet known.

It should be noted that the present invention has been described with reference to preferred embodiments, but that the present invention is not limited to those embodiments. It should also be noted that, although the present invention preferably is implemented in software, the present invention may also be implemented solely in hardware, if so desired. If implemented in software, the software is not limited to being stored on any particular type of storage device. A suitable storage device for this purpose may be, for example, a magnetic storage medium, such as a magnetic disk, a solid state storage medium, such as random access memory (RAM) or read only memory (ROM), or an optical storage medium, such as an optical compact disk ROM (CD-ROM). Therefore, the present invention is not limited with respect to the type of computer-readable medium employed for storing the software. Those skilled in the art will understand that various modifications may be made to the embodiments and features discussed above without deviating from the spirit and scope of the present invention.

What is claimed is:

1. A method comprising:
measuring subscriber loop characteristics;
identifying a first allowable class corresponding to the measured subscriber loop characteristics, where the allowable class is chosen from a group of predefined spectrum management classes
selecting an operating transceiver from a group of transceivers within a device, where each transceiver is con-

figured to communicate in a respective at least one of the predefined spectrum management classes, and where the selected operating transceiver is configured to communicate in the first allowable class; and
enabling the operating transceiver.
2. The method of claim 1, wherein each spectrum management class defines transmit power requirements.
3. The method of claim 1, wherein each spectrum management class defines transmit power spectral density (PSD) requirements.
4. The method of claim 1, wherein the spectrum management classes are defined by a standard.
5. The method of claim 1, further comprising:
determining that the selected operating transceiver is not currently compatible with the first allowable class; and
ceasing line signaling upon such determination.
6. The method of claim 1, further comprising:
determining that the selected operating transceiver is not currently compatible with the first allowable class; and
identifying a second allowable class corresponding to the measured subscriber loop characteristics; and
selecting a transceiver that is compatible with the second allowable class.
7. The method of claim 1, further comprising:
determining which one of the transceivers optimizes performance;
selecting the one transceiver that optimizes performance.
8. A computer-readable medium containing a program designed to perform the steps of:
performing a test on a subscriber loop coupled to the communication device; and
determining, responsive to the test, whether at least one of a group of transceivers within a device is currently compatible with at least one of a plurality of predefined spectrum management classes;
selecting an operating transceiver from the group of transceivers, where each transceiver is configured to communicate in a respective at least one of the predefined spectrum management classes, and where the selected operating transceiver is configured to communicate in the first allowable class; and
enabling the operating transceiver.
9. The computer-readable medium of claim 8, wherein each spectrum management class defines transmit power requirements for the modem.
10. The computer-readable medium of claim 8, wherein the spectrum management classes are defined by a standard.
11. The computer-readable medium of claim 8, the program further designed to perform the step of determining that none of the transceivers is currently compatible with any of the spectrum management classes, and to refrain from data transmission and reception upon such determination.
12. The computer-readable medium of claim 8, the program further designed to perform the step of measuring characteristics of the subscriber loop.
13. The computer-readable medium of claim 12, the program further designed to perform the step of automatically selecting, based on the measured characteristics, one of the transceivers that is compatible with at least one of the spectrum management classes.
14. The computer-readable medium of claim 12, wherein the measured characteristic is loop length.
15. A device, comprising:
a group of transceivers that are each compatible with a respective at least one of a predefined spectrum management classes; and

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a modem coupled to a subscriber loop, the modem capable of operating with the group of transceivers, wherein each spectrum management class defines transmit power requirements to which the modem must adhere in order to be compatible with the class, wherein the modem is configured to determine whether at least one of the transceivers is currently compatible with at least one of the spectrum management classes and configured to select an operating transceiver from the group of transceivers, and where the selected operating transceiver is configured to communicate in the first allowable class.

16. The modem of claim **15**, wherein each spectrum management class defines transmit power spectral density (PSD) requirements.

17. The modem of claim **15**, wherein the spectrum management classes are defined by a standard.

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18. The modem of claim **15**, the modem further configured to automatically select one of the transceivers that is compatible with at least one of the spectrum management classes.

19. The modem of claim **15**, wherein the modem is further configured to determine that none of the transceivers is currently compatible with any of the spectrum management classes, and to refrain from data transmission and reception upon such determination.

20. The modem of claim **15**, wherein the modem is further configured to measure subscriber loop length.

21. The modem of claim **15**, wherein the modem is further configured to measure characteristics of the subscriber loop.

22. The modem of claim **21**, wherein the modem is further configured to automatically select, based on the measured characteristics, one of the transceivers that is compatible with at least one of the spectrum management classes.

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