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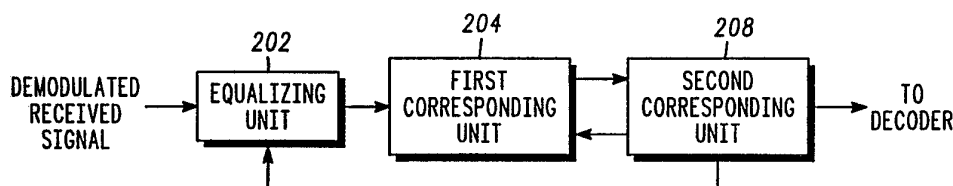
(57) Abstract

A device and method utilize a linear feedback/feedforward configuration to estimate and cancel a listener echo wherein equalizer (202) and listener echo cancellation (204 and 208) units are jointly updated, allowing determination of an error signal once (204 and 208), in place of the former method of separate error signal determination for each of an equalizer and a listener echo canceller. An improved phase-correction scheme is utlized to compensate the frequency offset in the listener echo. The relationship between the listener echo and talker far echo is utilized to facilitate the listener echo cancellation.

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DEVICE AND METHOD FOR LINEAR LISTENER ECHO CANCELLATION

5   Field of the Invention

This invention relates generally to synchronous digital information transmission systems, and more particularly, to echo cancellation in such transmission systems.

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Background

Data communication equipment (DCE) such as modems are generally utilized to transmit and receive data over a
15   communication channel. High speed modems typically use bandwidth-efficient modulation schemes such as quadrature modulation. In such a system that utilizes binary data, the data is first mapped into a sequence of complex signal points or symbols selected from a constellation with a finite number
20   of points. A real-valued transmitted signal is utilized to carry information about this complex sequence.

One category of DCEs, often referred to as full-duplex modems, is capable of transmitting and receiving simultaneously over a two-wire communication link such as a
25   telephone channel in the general switched telephone network. On such a two-wire telephone channel, hybrid couplers are commonly used to perform two to four wire conversions which separate the data transmission in both directions. Due to imperfect impedance matching at the hybrid couplers, data
30   transmission separations are not ideal. Thus, there exist echoes that interfere with normal data transmission. Such echoes may be divided into two categories: a talker echo and a listener echo. The talker echo signal, generated by an outgoing signal from a local modem's transmitter, typically includes a

near echo component and a far echo component. The near echo is generated by hybrids in the local modem and a near-end telephone central office, and the far echo signal is mainly generated by hybrids in a remote central telephone office and a

5 remote modem. The far echo signal is delayed in time relative to the near echo signal since it travels a round trip around the telephone channel. The far echo signal may also be corrupted by a frequency offset in the telephone network. The listener echo signal, in contrast, is generated by a data signal from the

10 remote modem's transmitter. The overall channel that the listener echo signal passes through can be viewed as a cascade of the channel that a normal received data signal passes through and an extra channel that includes the round trip telephone trunk and two trans-hybrid paths on both sides of

15 the trunk, as is illustrated in FIG. 1. The listener echo signal is delayed in time with respect to the normal received data signal since it travels an extra round trip around the telephone network. Both the talk far echo delay and the listener echo delay are about equal to the telephone trunk round trip delay,

20 and hence are nearly equal to each other.

Similar to the talker far echo signal corruption, the listener echo signal may also be corrupted by a frequency offset, often designated as phase roll, thereby complicating cancellation of that echo signal. Thus, phase correction

25 circuitry is needed to track and correct phase variations in the echo.

The listener echo total frequency offset substantially consists of a sum of two components. The first component corresponds to the normal received data frequency offset,

30 while the second component corresponds to the frequency offset of the listener echo relative to the normal received data signal, which is substantially equal to the talker far echo frequency offset. Further, the second component is substantially equal to a sum of the normal data frequency

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offsets in the transmission and the reception directions,
typically being smaller than the first component and a total
frequency offset.

Most existing two-wire full-duplex high-speed modems
5   come equipped with an adaptive talker echo canceller that is
capable of nearly eliminating the talker echoes, including the
near and the far talker echoes. The listener echo is often much
weaker than the normal received data signal. The ratio
between the normal received data signal and the listener echo
10   signal is substantially computed as the total signal loss by the
round trip telephone trunk and trans-hybrid losses on both
sides of the telephone trunk. When this ratio is much greater
than the required signal-to-noise ratio (SNR), the listener echo
signal has little effect on the reception of the remote data.
15   However, as the quality of the telephone network improves, the
signal loss by the telephone trunk may be reduced, and thus the
ratio between the normal received data signal and the listener
echo signal may also be reduced. As a result, the listener echo
signal may become a problem, especially for very high-speed
20   modems which may require a higher SNR to obtain reliable
reception. In this case, elimination of the listener echo signal
becomes necessary.

In the prior art listener echo cancellers have been
implemented as a special form decision feedback equalizer. A
25   detected data signal from an output of a decision device, after
an appropriate delay corresponding to a listener echo delay, is
fed back to a transversal filter whose coefficients are
adaptively adjusted such that the filter's output, after
correcting a total phase variation caused by a total frequency
30   offset in the listener echo signal, becomes an estimate of the
listener echo signal. This estimate is then typically
subtracted from a phase-corrected equalizer output before it
is sent to the decision device. Such a structure has two
potential problems. First, as is the case for a conventional

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decision feedback equalizer, decision errors in the decision
device may cause error propagation. Second, to obtain a more
reliable decision, complex decision algorithms, such as a
Viterbi decoding algorithm, are generally employed. A
5   relatively long decision delay may be required for such a
decoding algorithm. If the listener echo delay is shorter than
this decision delay, the decision will not be readily available
for the listener echo canceller. In addition, a major drawback
is that a relationship between the listener echo signal and the
10 talker far echo signal is typically disregarded, forcing
estimation of the listener echo bulk delay by an extensive
search scheme. Prior art compensates the total frequency
offset using a simple first-order phase-locked loop (PLL).
Thus, as is known in the art, an inherent compensation error by
15 such a first-order PLL is proportional to the frequency offset
to be compensated.

Hence, there is a need for a listener echo signal canceller
that eliminates the problem of decision error propagation and
that is not limited by decision delay, that utilizes information
20 obtained for the talker far echo cancellation, and that
improves phase correction.

Summary of the Invention

25   A device and method are set forth for minimizing a
listener echo signal interference in a substantially
demodulated, where desired, communication signal received
over a channel having simultaneous transmission and
reception. The device comprises at least a listener echo
30 canceller for reducing a listener echo interference in a digital
communication system having a selected sampling interval,
and having a sampled input and a sampled output, said sampled
input comprising substantially at least a sum of a desired
signal and a listener echo interference, and said sampled

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output being substantially free of listener echo interference, said listener echo canceller comprising at least: a bulk delay line means, operably coupled to receive and store at least one sample of one of: the sampled input and the sampled output of

5   said listener echo canceller, to provide a bulk delay line output; an adaptive listener echo interference estimator means, operably coupled to receive the bulk delay line output, for generating an estimate of the l 'ener echo interference; and an interference cancelling mear operably coupled to

10 receive the sampled input of the lis ᵑer echo canceller and the estimate of the listener echo interference, for substantially subtracting said estimate of the listener echo interference from said input of the listener echo canceller.

15   Brief Description of the Drawings

        FIG. 1 illustrates how a near echo, a far echo, and a listener echo are formed in a local modem/remote modem system as is known in the art.

20   FIG. 2A is a block diagram of a first embodiment of a device of the present invention.

        FIG. 2B is a block diagram of a second embodiment of a device of the present invention.

        FIG. 2C is a block diagram of a third embodiment of a

25 device of the present invention; FIG. 2D and 2E are block diagrams of underlying exemplary first and second operation modes, respectively, of the third embodiment of the device of the present invention; 2D sets forth a block diagram of the device of the present invention in an exemplary data receiving

30 linear feedback mode; 2E sets forth a block diagram of the device of the present invention in an exemplary reference directed training mode.

FIG. 3 is a block diagram setting forth an exemplary embodiment of the linear feedback configuration implementation of the device of the present invention.

FIG. 4 is a block diagram setting forth an exemplary
5 embodiment of the linear feedforward configuration implementation of the device of the present invention.

FIG. 5 is a block diagram setting forth an exemplary embodiment of the listener echo estimator of FIGs. 3 and 4.

FIG. 6 is block diagram of a local modem and a remote
10 modem with precoding as is known in the art.

FIG. 7 is an exemplary embodiment of a device of the present invention having a linear feedback configuration with precoding.

FIG. 8 is an exemplary embodiment of a device of the
15 present invention having a linear feedforward configuration with precoding.

FIG. 9 is a block diagram of setting forth exemplary embodiments of a listener echo phase estimating unit (LEPE), a listener echo phase-locked loop unit (LEPLL), a listener echo
20 phase correcting unit (LEPC), and a listener echo phase correction inverse unit (LEPC)I of FIGs. 3 and 4.

FIG. 10 is a block diagram setting forth exemplary embodiments of a received data phase estimating unit (RDPE), a received data phase-locked loop unit (RDPLL), a received data
25 phase correcting unit (RDPC), and a received data phase correction inverse unit (RDPCI) of FIGs. 3 and 4.

FIG. 11 is a block diagram setting forth an exemplary embodiment of a modem that includes a listener echo cancelling device in accordance with the present invention.

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Detailed Description of a Preferred Embodiment

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The present invention provides a device and method for an equalizer that includes a listener echo cancellation system that is stable, typically linear, and has a listener echo cancellation residual error that converges to a global

5   minimum. In the present invention, the listener echo phase correction means needs to compensate only the listener echo frequency offset relative to the received data signal, which is typically smaller than the listener echo total frequency offset and easier to compensate. The present invention also utilizes

10   a fact that such a frequency offset component is substantially equal to a talker far echo frequency offset, an estimate of which is typically available for far echo cancellation. In addition, the present invention utilizes a further fact, that the listener echo bulk delay relative to the received data signal is

15   substantially equal to the talker far echo bulk delay relative to the near echo that is usually available for far echo cancellation. Further, an equalizer and a listener echo canceller are jointly updated to allow determination of an error signal only once, more efficiently than in the past where

20   a separate error signal was determined for each of the equalizer and the listener echo canceller.

FIG. 2A is a block diagram of a first embodiment of the present invention, illustrating a feedback implementation of a listener echo canceller (LECR). An interference cancelling unit

25   (201), operably coupled to receive a sampled input to the listener echo canceller and an estimate of a listener echo interference from an adaptive listener echo interference estimator unit (203), substantially subtracts the estimate of the listener echo interference from the sampled input to

30   provide a listener echo corrected output. The LECR of FIG. 2A further includes a bulk delay line unit (205), operably coupled to receive the listener echo corrected output, for providing a bulk delay line output to the listener echo interference

estimator unit. Further description of a typical listener echo estimator unit and a bulk delay line unit are set forth below.

FIG. 2B is a block diagram of a second embodiment of the present invention, illustrating a feedforward implementation

5   of a listener echo canceller (LECR). An interference cancelling unit (211), operably coupled to receive a sampled input to a listener echo canceller and an estimate of a listener echo interference from an adaptive listener echo interference estimator unit (209), substantially subtracts the estimate of

10   the listener echo interference from the sampled input to provide a listener echo corrected output. The LECR of FIG. 2B further includes a bulk delay line unit (207), operably coupled to receive the sampled input, for providing a bulk delay line output to the listener echo interference estimator unit.

15   Further description of a typical listener echo estimator unit and a bulk delay line unit are set forth below.

FIG. 2C is a block diagram of a third embodiment of a device of the present invention for minimizing a listener echo signal interference in a substantially demodulated, equalized

20   communication signal received over a channel having simultaneous transmission and reception. The device comprises at least: an equalizing unit (202), a first correcting unit (204), and a second correcting unit (208). The equalizing unit (202) receives the demodulated, where desired,

25   communication signal and provides an equalized signal to the first correcting unit (204). The first correcting unit (204), operably coupled to the equalizing unit (202) and to the second correcting unit (208), at least receives the equalized signal from the equalizing unit (202), provides a listener echo

30   estimate with a proper phase correction utilizing a phase-tracking device, corrects the equalized signal in accordance with that listener echo estimate, and provides a first corrected signal to the the second correcting unit (208). The second correcting unit (208) is operably coupled to the first

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correcting unit (204) and is configured substantially for providing a phase correction to the first corrected signal, outputting a second corrected signal to the decoder, providing an error signal to the equalizing unit (202) for updating the
5 equalizer coefficients and to the first correcting unit (204) for updating the listener echo estimator coefficients, and, where desired, providing a reference signal to the first correcting unit (204) in the reference directed training mode for training the listener echo estimator and the phase-tracking
10 device.

FIG. 2D and 2E are basic signal-path block diagrams of underlying exemplary first and second operation modes, respectively, of the third embodiment of the device of the present invention. An error signal provided by a second
15 correcting unit (224) to the equalizer unit (210) and to the first correcting unit (212) for updating the equalizer unit (210) and listener echo estimator coefficients is not illustrated. FIG. 2D sets forth a block diagram of the device of the present invention in an exemplary data receiving linear
20 feedback implementation wherein an input to a listener echo estimator (220) is provided via a linear feedback configuration. An equalizer unit EQ (210) is coupled to receive a demodulated communication signal. The first correcting unit (212) is operably coupled to the equalizer unit
25 (210) and to the second correcting unit (224), and comprises a listener echo estimator LEE (220) with a switch S1 (222) for selecting an input signal to the LEE (220) in different operation modes, a listener echo phase correction unit LEPC (216) and a combining unit (214) that substantially obtains a
30 difference between the equalized demodulated communication signal and the phase-corrected listener echo estimate for providing a first corrected signal to the second correcting unit (224). The second correcting unit (224) includes a received data phase correction unit (226) to provide phase correction to

the first corrected signal from the first correcting unit (212) and output the second corrected signal u to a decoder. In FIG. 2D, the device is in a communication data receiving mode. The switch S1 (222) selects z, an output of the combining unit

5 (214) as an input to the LEE (220). Hence, the first correcting unit (212) operates in a linear feedback mode.

FIG. 2E sets forth a block diagram of the device of the present invention in an exemplary linear feedback listener echo cancelling implementation with a reference-directed

10 training mode. In such an operation mode, a switch S2 (232) in the second correcting unit (224) selects a reference signal as signal v, the reference signal being a predetermined data signal transmitted by a remote modem in a reference-directed training period and being known by a local modem receiver.

15 Signal v is phase-rotated in a received data phase correction inverse unit RDPCI (230) that performs an inverse operation of that of a received data phase correction unit RDPC (226), the RDPCI unit (230) outputting signal d. Signal d is selected by the switch S1 (222) in the first correcting unit (212) as an

20 input to the LEE (220).

FIG. 3 is a block diagram setting forth an exemplary embodiment of a linear feedback configuration implementation of the device of the present invention. The device minimizes listener echo signal interference in a substantially

25 demodulated, where desired, communication signal received over a channel having simultaneous transmission and reception, the device comprising at least: an equalizing unit (302), operably coupled to receive the demodulated, where desired, communication signal, for substantially providing an

30 equalized signal; a first correcting unit (304), operably coupled to the equalizing unit (302) and to a second correcting unit (308), and being configured for at least: receiving the equalized signal; determining at least a phase-corrected listener echo estimate; and combining the equalized signal

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with the phase-corrected listener echo estimate to provide at
least a first corrected signal; wherein the second correcting
unit (308) is operably coupled to the first correcting unit
(304) and to the equalizing unit (302), and is configured

5   substantially for at least: receiving the first corrected signal,
providing a phase correction to the first corrected signal to
generate a second corrected signal that is output to a decoder,
providing an error signal to the equalizing unit (302) for
updating coefficients of the equalizing unit (302) and to the

10   first correcting unit (304) for updating coefficients of the LEE
(320), and providing, where a reference-directed training mode
is selected, a reference signal as an input signal to the LEE
(320) in the first correcting unit (304).

       In the exemplary embodiment of the linear feedback

15   configuration implementation, FIG. 3, the first correcting unit
(304) comprises at least: a primary combining unit (310),
operably coupled to the equalizing unit (302) and to a listener
echo phase correcting unit LEPC (316) that provides at least a
phase-corrected listener echo estimate e_L, for substantially

20   obtaining a difference between an equalized signal q and the
phase-corrected listener echo estimate e_L, being the first
corrected signal z; a first switching unit S1 (322), operably
coupled to the primary combining unit (310) and to a second
correcting unit (308), for selecting, as desired, one of:

25   for a data receiving mode, substantially a linear
feedback signal z that is substantially an equalized, listener
echo estimate corrected signal, and
            for a reference-directed training mode, a phase-rotated
reference signal d;

30   a listener echo estimating unit LEE (320) having LEE
coefficients, being operably coupled to the first switching unit
(S1) for utilizing the selected signal to determine a first
listener echo estimate and operably coupled to a listener echo
phase correction inverse unit LEPCI (318) that provides a

rotated error signal, for utilizing the rotated error signal to update the LEE coefficients; wherein the listener echo phase correction unit LEPC (316) is operably coupled to the listener echo estimating unit LEE (320) and to a listener echo phase-

5 locked loop unit LEPLL (314) for providing a phase correction to the listener echo estimate and for generating a phase-corrected listener echo estimate e_L to the primary combining unit (310) and is responsive to a controlled input of the LEPLL (314); and a listener echo phase error determining unit LEPE

10 (312), operably coupled to the equalizing unit and to the listener echo phase correcting unit LEPC (316), for utilizing at least the equalized signal q and the phase-corrected listener echo estimate e_L to provide a listener echo phase error θ to the LEPLL (314); wherein the listener echo phase-locked loop unit

15 LEPLL (314) is operably coupled to the listener echo phase error determining unit LEPE (312) for tracking a correct phase of a listener echo based at least on θ and for providing a phase correction ψ to the LEPC (316) and to the LEPCI (318); and wherein the listener echo phase correction inverse unit LEPCI

20 (318) is operably coupled to the listener echo phase-locked loop unit LEPLL (314) and to the second correcting unit (308) that provides the error signal ε, for substantially rotating the error signal ε from the second correcting unit in accordance with the LEPLL phase correction ψ to provide a rotated error

25 signal η for updating coefficients of the LEE (320).

In the above embodiment the second correcting unit typically comprises at least: a received data phase correcting unit RDPC (324) , operably coupled to the first correcting unit (304) and to a received data phase-locked loop unit RDPLL

30 (330) , for substantially providing a data signal phase correction to the first corrected signal z and utilizing that data phase correction to generate a second corrected signal u for outputting to a decoder; a preliminary decision unit (PD) (328), operably coupled to the received data phase correcting

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unit RDPC (324), for generating an output signal w in
accordance with the second corrected signal u, w being a
preliminary estimate of a data signal transmitted by a remote
modem; a second switching unit (S2), operably coupled to the

5   preliminary decision unit PD (328) and to a reference signal
unit (REFERENCE) having at least a reference signal, for
selecting one of: for a data receiving mode, the preliminary
decision output signal w, and for a reference-directed
training mode, a pre-determined reference signal r, as a

10   decision signal v; a received data phase error unit RDPE (328),
operably coupled to the received data phase correcting unit
RDPC (324) and to the second switching unit S2 (336), for
substantially determining a received data phase error α in
accordance with signals u and v; a received data phase-locked

15   loop unit RDPLL (330), operably coupled to the received data
phase correcting unit RDPC (324) and to a received data phase
correction inverse unit RDPCI (332), for substantially tracking
a phase of a received data signal and providing a phase
correction estimate $\phi(n)$ to the RDPC (324) and to the RDPCI

20   (332) in accordance with α; the received data phase correction
inverse unit RDPCI (332) being operably coupled to the
received data phase-locked loop unit RDPLL (330) and to the
second switching unit S2 (336), for performing an inverse
operation of the RDPC to provide a phase rotation on decision

25   signal v that generates a rotated decision signal d; and a
second combining unit (334), operably coupled to the received
data phase correction inverse unit and to the first correcting
unit, for substantially subtracting the first corrected signal z
from d to provide an error signal $\epsilon(n)$ to the equalizing unit

30   (302) for updating equalizer unit coefficients and to the first
correcting unit (304) for updating LEE coefficients after phase
rotation in the LEPCI. The second combiner is typically an
adder.

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FIG. 4 is a block diagram setting forth an exemplary
embodiment of a linear feedforward configuration
implementation of the device of the present invention. The
exemplary embodiment in FIG. 4 is similar to that in FIG. 3,
5   except that the first switching unit S1 (420) selects the
equalized signal q instead of the first corrected signal z as the
input to the LEE (422). Thus, in this exemplary embodiment, an
equalizing unit (402) is utilized also, and the first correcting
unit (404) comprises at least: a first adding unit (418),
10   operably coupled to the equalizing unit (402) and to a listener
echo phase correcting unit LEPC (416) that provides at least a
phase-corrected listener echo estimate, for substantially
obtaining a difference between the equalized signal and that
listener echo estimate, being the first corrected signal; a
15   switching unit S3 (420), operably coupled to the equalizing
unit (402) and to the second correcting unit (408), wherein the
second correcting unit (408) provides a rotated reference
signal, for selecting, as desired, one of: the equalized signal,
and the rotated reference signal, as a selected signal; a
20   listener echo estimating unit LEE (422) having LEE
coefficients, operably coupled to the switching unit S3 (420)
for utilizing the selected signal to determine a listener echo
estimate, and to a listener echo phase correction inverse unit
LEPCI (414) that provides a rotated error signal, for utilizing
25   the rotated error signal to update the LEE coefficients;
wherein the listener echo phase correcting unit LEPC (416) is
operably coupled to the listener echo estimating unit LEE
(422) and to a listener echo phase-locked loop unit LEPLL (412)
that provides a listener echo phase correction estimate, for
30   substantially rotating the listener echo estimate of the LEE in
accordance with the listener echo phase correction estimate
to determine at least a phase-corrected listener echo
estimate; a listener echo phase error determining unit LEPE
(410), operably coupled to the equalizing unit (402) and to the

listener echo phase correcting unit LEPC   (416), for utilizing
the equalized signal and the listener echo estimate to provide
a listener echo phase error; wherein the listener echo phase-
locked loop unit LEPLL (412) is operably coupled to the listener

5   echo phase error determining unit LEPE (410), for utilizing the
listener echo phase error to provide a listener echo phase
correction estimate; and wherein the listener echo phase
correction inverse unit LEPCI (430) is operably coupled to the
listener echo phase-locked loop unit LEPLL (412) and to the

10   second correcting unit (408) that provides an error signal, for
substantially utilizing the listener echo phase correction
estimate and the second correcting unit error signal for
providing a rotated error signal for updating the listener echo
estimating unit. The second correcting unit (408) typically is

15   substantially that described above.
          The equalizing unit, having equalizing coefficients, is
implemented utilizing known techniques. Typically a baseband
adaptive equalizer may be used where an input is a
demodulated baseband signal, as is illustrated in the FIGs.

20   described above. A passband adaptive equalizer may be used
where an input is a modulated passband signal. In the latter
case, a demodulator follows the equalizer. A least mean square
(LMS) algorithm is typically used for updating the coefficients
of the equalizer.

25   The listener echo estimating unit LEE in FIGs. 3 and 4
(320, 422) is further illustrated in FIG. 5. Typically, the LEE
includes at least: a bulk delay line (BD) (502), operably coupled
to the first switching unit S1 (322, 420), for providing a delay
substantially in accordance with B_L, a listener echo bulk delay

30   relative to a received data signal; and an adaptive transversal
filter (504), operably coupled to BD (502),   whose coefficients
are $a_k(n)$, where k = 0, 1, 2, ..., M-1, where M is a number of
taps in the transversal filter unit, and whose output is
substantially

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$$p(n) = \sum_{k=0}^{M-1} g(k + n + BL)a_k(n),$$ where n is a discrete time

index and g() is input from the first switching unit. The delay BL, where desired, is substantially determined by a talker far echo delay measuring method, based on the proposition that,

5   both the listener echo delay and the talker far echo delay being actually substantially equal to a communication round trip delay, the said delays are substantially equal to each other.

Devices such as modems may include trellis precoding technique, where desired, as illustrated in FIG. 6, wherein a

10   local modem A communicates with a remote modem B. Thus, in another embodiment, illustrated in FIG. 7, of a linear feedback listener echo canceller of the present invention wherein precoding is utilized, there is further included a noise prediction filter NPF (702), operably coupled between the

15   equalizing unit (302) and the first correcting unit (304), to receive and filter the demodulated, equalized received communication signal, so that a spectrum of noise in the demodulated, equalized communication signal is whitened; and an inverse noise prediction filter NPF^{-1} (704), operably

20   coupled between the second correcting unit (308) and the equalizing unit (302), for filtering an error signal $\varepsilon(n)$ of the second correcting unit to provide an adjusted error for updating equalizer coefficients.

Similarly, in an embodiment, illustrated in FIG. 8, of a

25   linear feedforward listener echo canceller of the present invention where trellis precoding is utilized, a noise prediction filter NPF (802) and an inverse noise prediction filter NPF^{-1} (804) are included in a fashion similar to that described above for FIG. 7.

30   The listener echo cancelling device of the present invention is typically implemented in a modem utilized for communicating with a remote device in both directions over a channel, described as above.

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Exemplary determinations described above are more particularly set forth below, wherein the following terminology is utilized: an equalized signal is q(n), n being the discrete time index; a rotated error signal is η(n); a phase-corrected listener echo estimate is $e_L(n)$; a first corrected signal is z(n); a first listener echo estimate is p(n); and an error signal is ε (n); a received communication signal phase error is α(n); a received communication signal phase correction estimate is φ(n); a remote transmitted communication signal estimate is v(n), being one of: a known reference signal r(n) for selection of a reference-directed training mode, and a preliminary decision of the remote transmitted communication signal communication signal w(n); a phase-rotated decision signal is d(n);

The phase-corrected listener echo estimate is substantially of a form: $e_L(n) = p(n)e^{j\psi(n)}$, where n is a discrete time index, p(n) is a first listener echo estimate, and ψ(n) is a listener echo phase correction estimate. The first corrected signal z(n) is substantially determined as a difference between q(n) and $e_L(n)$: $z(n) = q(n) - e_L(n)$, where q(n) is the equalized signal.

An exemplary embodiment of a phase correcting device in the first correcting unit is set forth in FIG. 9, wherein the units LEPE (902), LEPLL (904) and LEPCI (906) are included. The LEPE (920) determines a listener echo phase error θ(n), a phase difference between the equalized signal q(n) and the phase-corrected listener echo estimate $e_L(n)$, utilizing a typical method of determining phase differences between two signals as is known in the art (for example, as in U.S. Patent No. 4,813,073 and in U.S. Patent No. 4,987,569):

$$\theta(n) \approx \frac{e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)}{|q(n)||e_L(n)|},$$

where e_{Lr} and e_{Li} are the real and imaginary parts, respectively, of $e_L(n)$, and q_r and q_i are the real and imaginary parts, respectively, of the equalized signal q(n).

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The exemplary embodiment of the LEPE (902), FIG. 9, includes a first device (910) that provides a real part $q_r(n)$, an imaginary part $q_i(n)$, and a magnitude of $q(n)$ and a second device (912) that provides a real part $e_{Lr}(n)$, an imaginary part

5    $e_{Li}(n)$, and a magnitude of $e_L(n)$, first and second multipliers (914, 916) operably coupled to the first and second devices, for providing the products $e_{Li}(n)q_r(n)$ and $e_{Lr}(n)q_i(n)$, a first adder (920) operably coupled to the first and second multipliers substantially determines a difference $e_{Li}(n)q_r(n)$ -

10   $e_{Lr}(n)q_i(n)$, a third multiplier (918) operably coupled to the first device and to the second device provides $|q(n)||e_L(n)|$, and a first divider (922) provides $\theta(n)$.

With the configuration in the present invention, the LEPC unit compensates only the listener echo frequency offset

15   relative to the received data signal, which is generally much smaller than the total frequency offset, making compensation easier to achieve.

In this embodiment the listener echo phase locked loop LEPLL (980) is implemented as a typical second order digital

20   phase locked loop as is known in the art, for example, as described in U.S. Patent No. 4,813,073 and U.S. Patent No. 4,987,569, wherein a listener echo frequency offset relative to the received data signal f_L and a listener echo correction $\psi(n)$ are determined recursively utilizing the listener echo

25   phase error $\theta(n)$ obtained in the LEPE:

a phase-locked loop of the first correcting unit determines an estimate of f_L and a phase correction estimate for $p(n+1)$, wherein,

$$f_L(n+1) = f_L(n) + b_1\theta(n), \text{ and}$$

30   $$\psi(n+1) = \psi(n) + b_2\theta(n) + b_3f_L(n+1),$$

where b_1, b_2, and b_3 are constants that determine a phase-locked loop characteristic.

Based on the proposition that f_L is substantially equal to a talker far echo frequency offset f_F, as soon as an estimate of

f_F is available, for example, using the method described in U.S. Patent No. 4,987,569, that estimate of f_F may be utilized to initialize an estimate of f_L in the LEPLL. This initialization scheme facilitates an initial convergence of the LEPLL.

5   In the exemplary embodiment illustrated in FIG. 9, the listener echo phase-locked loop LEPLL (980) includes at least a third multiplier (928), operably coupled to first divider (922) of the LEPE (902) that multiplies the listener echo phase error $\theta(n)$ by a first constant b_1 to provide $b_1\theta(n)$, a fourth

10   multiplier (936), coupled to the first divider (922) of the LEPE (902), that multiplies $\theta(n)$ by a second constant b_2 to provide $b_2\theta(n)$, a second adder (930), operably coupled to the third multiplier (928) and to a first delay unit (932), that substantially adds $b_1\theta(n)$ to a current estimate of f_L to

15   provide an updated estimate of f_L which is then stored in the first delay unit (932), and is multiplied by a third constant b_3 utilizing a fifth multiplier (934) that is operably coupled to the second adder (930) to provide a fifth multiplier output. A third adder (938), operably coupled to receive the fifth

20   multiplier output and $b_2\theta(n)$ is utilized for adding same to $b_2\theta(n)$ to provide a third adder output. A fourth adder (940), operably coupled to receive the third adder output and a second delay unit (942) output, is utilized to add the third adder output to a current value of $\psi(n)$ to generate an updated value

25   of $\psi(n)$ that is stored in the second delay unit (942) and is further transmitted to the LEPC (904) and to the LEPCI (906). The second delay unit is operably coupled to provide the current value of $\psi(n)$ to the fourth adder (940).

A second approach (not shown) may also be used to

30   implement the LEPLL. $\psi(n)$ is determined based on the sign of $q(n)$, $s(n)$:

$$s(n) = \text{sign}[q(n)] = \text{sign}\,[e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)],$$

defining $s(n) = 1$ for $e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n) > TH$,

$s(n) = -1$ for $e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n) < -TH$, and

20

$$s(n) = 0;$$

otherwise, where TH is a small predetermined positive threshold value; and determining

$$f_L(n + 1) = f_L(n) + d_1 s(n), \text{ and}$$

5 $$\psi(n+1) = \psi(n) + d_2 s(n) + b_3 f_L(n + 1),$$

where d_1 and d_2 are selected constants and $f_L(n)$, where desired, is initialized using a talker far echo frequency offset estimate to facilitate an initial convergence. The second approach is computationally more efficient than the first

10 approach. An initial convergence utilizing the second approach is facilitated by an appropriate initialization scheme using the talker far echo frequency offset estimate.

An exemplary embodiment of the LEPC (904), utilized to determine $e_L(n)$, is set forth in FIG. 9, wherein, upon input of

15 $\psi(n)$ from the LEPLL (908), a first unit (1ST EXP) (924) for providing powers of e provides $e^{j\psi(n)}$ to a sixth multiplier (925) that is operably coupled to the 1ST EXP (924) and to receive $p(n)$, for substantially multiplying $e^{j\psi(n)}$ and $p(n)$ to obtain $e_L(n)$: $e_L(n) = p(n)e^{j\psi(n)}$.

20 An exemplary embodiment of the LEPCI (906), utilized to determine $\eta(n)$, is set forth in FIG. 9, wherein, upon input of $\psi(n)$ from the LEPLL (908), a second unit (2ND EXP) (926) for providing powers of e provides $e^{-j\psi(n)}$ to a seventh multiplier (927) that is operably coupled to the 2ND EXP (924)

25 and to receive $\varepsilon(n)$, for substantially multiplying $e^{-j\psi(n)}$ and $\varepsilon(n)$ to obtain $\eta(n)$: $\eta(n) = \varepsilon(n)e^{-j\psi(n)}$.

$\eta(n)$ is utilized to update the listener echo estimator (LEE) coefficients, typically according to an LMS-type algorithm:

30 $$a_k(n+1) = a_k(n) + \delta\eta(n) \, g(n+B_L+ k), \, k = 0, 1, ..., M-1, \text{ where } \delta$$
is a small adaptation constant and M is a number of taps in the LEE.

Received data phase correction may be implemented using known phase correction techniques (for example, as

described in U.S. Patent No. 4,813,073). An exemplary
embodiment of a received data phase error determining unit
(RDPE) (1002), a received data phase-locked loop (RDPLL)
(1008), a received data phase correction unit (RDPC)(1004),

5   and a received data phase correction inverter unit (RDPCI)
(1006) of FIGs. 3 and 4 is set forth in FIG. 10. The RDPE
(1002) is utilized to determined a phase error $\alpha(n)$ using
signals v(n) and u(n) such that:

$$\alpha(n) \approx \frac{v_r(n)u_i(n) - u_r(n)v_i(n)}{|v(n)|^2},$$

10   where $v_r(n)$ and $v_i(n)$ are real and imaginary parts,
respectively, of v(n), and $u_r(n)$ and $u_i(n)$ are real and imaginary
parts, respectively, of u(n). A third device (1010) provides a
real part $v_r(n)$, an imaginary part $v_i(n)$, and a magnitude of
v(n), and a second device (1012) provides a real part $u_r(n)$, an

15   imaginary part $u_i(n)$, and a magnitude of u(n), eighth and ninth
multipliers (1014, 1016) operably coupled to the first and
second devices, provide the products $u_i(n)v_r(n)$ and $u_r(n)v_i(n)$, a
fifth adder (1018), operably coupled to the eighth and ninth
multipliers, substantially determines a difference $u_i(n)v_r(n)$ -

20   $u_r(n)v_i(n)$, a square unit (1020) operably coupled to the third
device, provides $|v(n)|^2$, and a second divider (1022) operably
coupled to the square unit (1020) provides $\alpha(n)$. Alternatively,
a prestored table of $1/|v(n)|^2$ may be employed, allowing
replacement of the second divider (1022) by a look-up table

25   together with an associated multiplier.

In the above embodiment, the received data phase-locked
loop RDPLL (1008) is implemented as a typical second-order
digital phase-locked loop as, for example, in U.S. Patent No.
4,813,073, wherein an estimate of a received data frequency

30   offset f_D and a received data phase correction $\phi(n)$ are
determined recursively utilizing the received data phase error
$\alpha(n)$ obtained in the RDPE (1002), substantially as set forth
below:

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$$fD(n+1) = fD(n) + c_1 \alpha(n); \text{ such that}$$

$$\phi(n + 1) = \phi(n) + c_2 \alpha(n) + c_3 fD(n+1) \ ,$$

5   where c_1, c_2, and c_3 are constants that determine a desired phase-locked loop characteristic.

In the exemplary embodiment, FIG. 10, a received data phase error determining unit RDPE (1002), a received data phase-locked loop RDPLL (1008), a received data phase

10   correcting unit RDPC (1004), and an RDPCI (1006) of FIGs. 3 and 4 are included. The RDPLL (1008) includes at least a tenth multiplier (1028), operably coupled to a second divider (1022) of the RDPE (1002) that multiplies the phase error $\alpha(n)$ by a fourth constant c_1 to provide $c_1 \alpha(n)$, an eleventh multiplier

15   (1036), coupled to the second divider (1022) of the RDPE (1002), that multiplies $\alpha(n)$ by a fifth constant c_2 to provide $c_2 \alpha(n)$, a sixth adder (1030), operably coupled to the tenth multiplier (1028) and to a third delay unit (1032), that substantially adds $c_1 \alpha(n)$ to a current estimate of fD to

20   provide an updated estimate of fD which is then stored in the third delay unit (1032), and is multiplied by a sixth constant c_3 utilizing a twelfth multiplier (1034) that is operably coupled to the sixth adder (1030) to provide a twelfth multiplier output. A seventh adder (1038), operably coupled to

25   receive the twelfth multiplier output and $c_2 \alpha(n)$, is utilized for adding same to $c_2 \alpha(n)$ to provide a seventh adder output. A eighth adder (1040), operably coupled to receive the seventh adder output and a fourth delay unit (1042) output, is utilized to add the seventh adder (1038) output to a current value of

30    $\phi(n)$ to generate an updated value of $\phi(n)$ that is stored in the fourth delay unit (1042) and is further transmitted to the RDPC (1004) and to the RDPCI (1006). The fourth delay unit (1042) is operably coupled to provide the current value of $\phi(n)$ to the eighth adder (1040).

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An exemplary embodiment of the RDPC (1004), utilized to determine u(n) is set forth in FIG. 10, wherein, for an input of $\phi(n)$, a third unit 3RD EXP (1024) for providing powers of e provides $e^{j\phi(n)}$ and a thirteenth multiplier (1025), operably

5   coupled to the third unit 3RD EXP (1024) and to receive an input z(n), substantially multiplies $e^{j\phi(n)}$ times z(n) to obtain u(n): $u(n) = z(n)e^{j\phi(n)}$.

An exemplary embodiment of the RDPCI (1006), utilized to determine d(n) is set forth in FIG. 10, wherein, for an input

10 of $\phi(n)$, a fourth unit 4TH EXP (1026) for providing powers of e provides $e^{-j\phi(n)}$ and a fourteenth multiplier (1027), operably coupled to the fourth unit 4TH EXP (1026) and to receive v(n), substantially multiplies $e^{-j\phi(n)}$ times v(n) to obtain d(n): $d(n) = v(n)e^{-j\phi(n)}$.

15   d(n) is utilized to determine the error signal
$$\varepsilon(n) = d(n) - z(n),$$
which in turn is used to update the equalizer coefficients, typically according to the LMS algorithm. d(n) is also sent to the first correcting unit for updating the LEE coefficients

20 after phase rotation in the LEPCI.

The method of the present invention (not illustrated) for minimizing a listener echo signal interference in a substantially demodulated, where desired, equalized communication signal received over a channel having

25 simultaneous transmission and reception, the method comprising at least the steps of: receiving the demodulated, where desired, communication signal, for substantially providing an equalized signal utilizing an equalizing unit; determining at least a first listener echo estimate; providing

30 an appropriate phase correction to the first listener echo estimate in a listener echo estimating unit; and combining the equalized signal with the phase-corrected listener echo estimate to provide at least a first corrected signal; selecting an appropriate signal in a different operational mode for the

listener echo estimation; providing at least an error signal for updating the equalizing unit and listener echo estimating unit coefficients; providing a phase correction to the first corrected signal to generate a second corrected signal, and

5   outputting substantially the second corrected signal, the second corrected signal being a listener echo corrected and phase corrected communication signal.

The method typically further includes one of the following two approaches:

10   including at least the steps of: substantially obtaining a difference between the equalized signal and the phase-corrected listener echo estimate, being the first corrected signal; selecting, as desired, one of: the first corrected signal, and a phase-rotated reference signal, as a first selected

15   signal; utilizing the first selected signal to determine a first listener echo estimate; providing a phase correction to the listener echo estimate and substantially obtaining a phase-corrected listener echo estimate; utilizing an equalized signal and the phase-corrected listener echo estimate to provide a

20   listener echo phase error; utilizing the listener echo phase error to provide a listener echo phase correction estimate; providing an error signal and substantially rotating the error signal based on the listener echo phase correction estimate to obtain a rotated error signal for updating the listener echo

25   estimation; and

including at least the steps of: providing at least the phase-corrected listener echo estimate and substantially obtaining a difference between the equalized signal and the phase-corrected listener echo estimate, being the first

30   corrected signal; selecting, as desired, one of: the equalized signal, and a phase-rotated reference signal, as a selected signal; utilizing this second selected signal to determine a first listener echo estimate; providing to the first listener echo estimate a phase correction and substantially obtaining a

phase-corrected listener echo estimate; utilizing the equalized signal and the phase-corrected listener echo estimate to provide a listener echo phase error; utilizing the listener echo phase error to provide a listener echo phase

5   correction estimate; providing an error signal and substantially rotating the error signal based on the listener echo phase correction estimate to obtain a rotated error signal for updating the listener echo estimate.

In addition to utilization of one of the two approaches

10   set forth above, the method of the present invention typically further includes at least the steps of: substantially determining a data phase correction and utilizing that data phase correction to provide a second corrected signal, being substantially a listener echo corrected, phase corrected

15   communication signal; providing a preliminary decision signal as a preliminary estimate of the data signal transmitted by a remote modem; selecting, as desired, one of: the preliminary decision signal and a known reference signal as a second selected signal; substantially providing a received data phase

20   correction estimate; providing a phase-rotation to the second selected signal to obtain a rotated decision signal; and substantially subtracting the first corrected signal from the rotated decision signal to obtain an error signal for equalization unit and listener echo estimating unit adaptation.

25   Also, the method of the present invention generally includes at the least the following steps: utilizing a bulk delay unit to provide a delay substantially in accordance with a listener echo bulk delay B_L; and utilizing a transversal filter unit whose coefficients are $a_k(n)$, where $k = 0, 1, 2, ..., M-1$,

30   where M is a number of taps in the transversal filter unit, and whose output is substantially

$$p(n) = \sum_{k=0}^{M-1} g(k + n + B_L)a_k(n),$$ where n is a discrete time index and g() is an output of the first switching unit. B_L is,

where desired, substantially determined by a selected talker far echo ranging method.

Exemplary determinations of the listener echo estimate $e_L(n)$, the listener echo phase correction estimate $\psi(n)$, the first corrected signal $z(n)$, the rotated error input $\eta(n)$, the received communication signal phase correction estimate $\phi(n)$, the data phase corrected communication signal $u(n)$, the rotated decision signal $d(n)$, and related values are understood to be in correspondence with the determinations described for the device as described above.

Alternatively, the method of the present invention may be selected to include the steps of: utilizing a noise prediction filter (NPF) receive and filter the equalized signal, so that a noise spectrum of the equalized signal is whitened; and utilizing an inverse noise prediction filter (NPF^{-1}) for filtering an error signal from the second correcting unit to provide a filtered error signal for updating equalizer coefficients.

Clearly, in a preferred embodiment, the device of the present invention may be utilized in a modem. An exemplary modem utilizing the present invention is shown in FIG. 11. Such a modem typically has a talker echo cancelling device, the modem being utilized for communicating information with a remote device in both directions over a channel, the modem comprising at least: a transmission unit (1102), operably coupled to receive the information to be communicated, for preparing an analog signal which carries that information for transmission; a hybrid coupling unit (1104), operably coupled to the transmission unit and to a receiving unit (1106), for transmitting the analog signal and for receiving another analog signal from a remote device; a talker echo estimating unit (1108), operably coupled to the transmission unit (1102), for providing at least a talker echo estimate to the receiving unit (1106); and the receiving means (1106), operably coupled to

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the talker echo estimating unit (1108) and to the hybrid
coupling unit (1104), for recovering information from the
analog signal transmitted by the remote device.

    The transmission means typically comprises at least: an
5   encoding unit (1110), operably coupled to receive information,
for providing an encoded data signal; a modulating unit (1112),
operably coupled to the encoding unit (1110), for providing a
modulated encoded signal; a transmission (TX) filtering unit
(1114), operably coupled to the first modulating unit (1112),
10   for providing a modulated, filtered transmission digital signal
at a desired sampling rate; a digital-to-analog converting unit
(D/A) (1116), operably coupled to the transmission filtering
unit (1114), for converting the modulated filtered
transmission digital signal to an analog signal to provide to
15   the hybrid coupling unit (1104). The receiving unit (1106)
typically comprises: an analog-to-digital converting unit (A/D)
(1118), operably coupled to the hybrid coupling unit (1104), for
converting received analog signals to digital signals at a
preselected sampling rate; a first combining unit (1120),
20   operably coupled to the talker echo estimating unit (1108) and
to the A/D unit (1118), for combining the received digital
signal and the talker echo estimate to provide a first talker
echo corrected signal; a rate converting unit (1122), where
desired, operably coupled to the first combining unit (1120),
25   for converting the first talker echo corrected signal, being
sampled at a transmitter sampling clock, to a second talker
echo corrected signal, being sampled at a desired receiver
sampling clock; a demodulation unit (DEMOD)(1124), operably
coupled to the rate converting unit (1122) for providing a
30   demodulated second talker echo corrected signal; a receiving
(RX) filtering unit (1126), operably coupled to the
demodulation unit (1124), to receive the demodulated signal,
for filtering the demodulated second talker echo corrected
signal; an equalizing unit (1128), operably coupled to the

receiving filtering unit (1126), for providing an equalized, demodulated, filtered, second talker echo corrected signal; a listener echo cancelling unit LEC (1130), operably coupled to the equalizing unit (1128), for providing a listener echo

5   corrected, equalized, demodulated, filtered, second talker echo corrected signal; and a decoding unit (1132), operably coupled to the listener echo correcting unit (1142), for decoding the listener echo corrected, equalized, demodulated, filtered, second talker echo corrected signal to recover, substantially,

10   the received information transmitted by the remote modem.

Typically, in the embodiment illustrated in FIG. 11, the talker echo estimating unit (1108) includes at least: a near echo correcting unit (NEC)(1134), operably coupled to the modulator (1112) and to the first combining unit (1120), for

15   providing a near echo estimate as is known in the art; a bulk delaying unit (BD)(1136), operably coupled to the modulator (1112), for providing a desired bulk delay; a far echo correcting unit (FEC) (1138), typically including a phase-correcting unit to compensate a far echo frequency offset,

20   operably coupled to the bulk delaying means (1136), for providing a phase-corrected far echo estimate as is known in the art; a second combining unit (1140), operably coupled to the near echo correcting unit (1134) and to the far echo correcting unit (1138), for combining the near echo estimate

25   and the phase-corrected far echo estimate to provide at least the first talker echo estimate to the first combining unit (1120).

In the embodiment illustrated in FIG. 11, the listener echo correcting unit (1130) typically comprises at least: a

30   first correcting unit, operably coupled to the equalizing unit and to a second correcting unit , and being configured for at least: receiving the equalized, demodulated, filtered, second talker echo corrected signal; determining at least a listener echo estimate; and combining the equalized, demodulated,

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filtered, talker echo corrected signal with the listener echo estimate to provide at least a first corrected signal; wherein the second correcting means is operably coupled to the first correcting means and to the equalizing means, and is

5   configured substantially for at least: providing at least a phase correction to the first corrected signal to generate and output substantially a second corrected signal that is an equalized, listener echo-corrected, and phase-corrected communication signal; providing at least an error signal to the

10 equalizing means for adjusting an equalization process of the equalizing means, and to the first correcting means for adjusting the listener echo estimate; providing at least a rotated reference signal in reference-directed training mode for facilitating an initial training in a listener echo

15 estimation. The listener echo cancelling unit of the modem is configured substantially as described above, and functions substantially as described above.

Although exemplary embodiments are described above, it will be obvious to those skilled in the art that many

20 alternations and modifications may be made without departing from the invention. Accordingly, it is intended that all such alterations and modifications be included within the spirit and scope of the invention as defined in the appended claims.

We claim:

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Claims:

1.   A listener echo canceller (LECR) for reducing a listener
echo interference in a digital communication system having a
5   selected sampling interval, and having a sampled input and a
sampled output, said sampled input comprising substantially
at least a sum of a desired signal and a listener echo
interference, and said sampled output being substantially free
of listener echo interference, said listener echo canceller
10   comprising at least 1A-1C:
         1A)   a bulk delay line means, operably coupled to receive
and store at least one sample of one of: the sampled input and
the sampled output of said listener echo canceller, to provide a
bulk delay line output;
15   1B)   an adaptive listener echo interference estimator
means, operably coupled to receive the bulk delay line output
to generate an estimate of the listener echo interference; and
         1C)   an interference cancelling means, operably coupled
to receive the sampled input of the listener echo canceller and
20   the estimate of the listener echo interference, for
substantially subtracting said estimate of the listener echo
interference from said input of the listener echo canceller.

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2. The LECR of claim 1, wherein said adaptive listener echo interference estimator means further includes at least:

a set of filter coefficients and a tapped delay line, operably coupled to receive and store samples of said bulk
5 delay line output; and

wherein the said estimate of the listener echo interference is related to a weighted combination of the stored samples of said bulk delay line output such that the weighting is determined by the filter coefficients, and the
10 said filter coefficients are adaptively adjusted to produce the estimate of said listener echo interference.

3. The LECR of claim 1, wherein the said bulk delay line output is one of 3A-3B:
15 3A) the sampled input of the LECR, delayed by a selected number of sampling intervals; and

3B) the sampled output of the LECR, delayed by a selected number of sampling intervals;

wherein said selected number of sampling intervals is non-
20 zero.

4. The LECR of claim 1, wherein said adaptive listener echo interference estimator means further includes compensating means, operably coupled to receive the sampled input of the
25 LECR and to receive a phase-corrected listener echo estimate, for compensating a frequency offset in the said estimate of the listener echo interference, and, where selected, wherein the means for compensating the frequency offset includes at least 4A-4C:
30 4A) a phase-error estimating means, operably coupled to receive the sampled input of the LECR and to receive a phase-corrected listener echo estimate, for substantially generating a phase error that is substantially a phase

difference between the estimate of the listener echo estimate and the said input of the LECR;

   4B)   a phase-locked loop, operably coupled to receive the said phase error, for substantially generating a phase
5 correction estimate; and

   4C)   a phase-correction means, operably coupled to receive the phase correction estimate, for substantially generating a phase-corrected listener echo estimate.

5.   A device for minimizing a listener echo signal interference in a substantially demodulated, where desired, communication signal received over a channel having simultaneous transmission and reception, the device

5   comprising at least 5A-5B:

5A)   equalizing means, operably coupled to receive the demodulated, where desired, communication signal, for substantially providing an equalized signal;

5B)   a first correcting means, operably coupled to the

10   equalizing means and to a second correcting means, and being configured for at least 5B1-5B3:

5B1)   receiving the equalized signal;

5B2)   determining at least a listener echo estimate; and

15   5B3)   combining the equalized signal with the listener echo estimate to provide at least a first corrected signal;

wherein the second correcting means is operably coupled to the first correcting means and to the equalizing means, and

20   is configured substantially for at least 5B4-5B6:

5B4)   providing at least a phase correction to the first corrected signal to generate and output substantially a second corrected signal that is an equalized listener echo corrected and phase-corrected communication signal;

25   5B5)   providing at least an error signal to the equalizing means for adjusting an equalization process of the equalizing means and to the first correcting means for adjusting the listener echo estimation; and

5B6)   providing at least a rotated reference signal

30   in reference-directed training mode for facilitating an initial training of a listener echo estimation.

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6. The device of claim 5, wherein the first correcting means comprises at least 6A-6C:

6A) primary adding means, operably coupled to the equalizing means and to a listener echo estimating means

5 together with a listener echo phase correcting means that provide at least a phase-corrected listener echo estimate, for substantially obtaining a difference between the equalized signal and that listener echo estimate, being the first corrected signal;

10 6B) listener echo estimating means, operably coupled to one of 6B1-6B2:

6B1) the primary adding means in a linear feedback configuration, and

6B2) the equalizing means in a linear

15 feedforward configuration;

and further being operably coupled to the second correcting means, for utilizing:

6B3) in a data-receiving mode, one of 6B3a-

20 6B3b:

6B3a) the first corrected signal, and

6B3b) the equalized signal;

and

6B4) in a reference-directed training

25 mode, the rotated reference signal;

to determine a first listener echo estimate;

6C) listener echo phase error determining means, operably coupled to the listener echo phase correcting means and one of:

30 6C1) in the data-receiving mode, the preliminary decision means, and

6C2) in the reference-directed training mode, a reference signal means,

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for substantially determining a listener echo phase error;

wherein the listener echo phase-locked loop means is operably coupled to the listener echo phase error determining means for utilizing the listener echo phase error to provide a listener echo phase correction estimate; and

wherein the listener echo phase correction inverse means is operably coupled to the listener echo phase-locked loop means and to the second correcting means that provides an error signal, for substantially utilizing the listener echo phase correction estimate and the second correcting means error signal for providing a rotated error signal for updating the listener echo estimating means,

6D) and, where selected, one of 6D1-6D2:

6D1) further including that the listener echo estimating means includes at least 6D1a-6D1b:

6D1a) a bulk delay line unit, operably coupled to the second correcting means,

and further being operably coupled to one of 6D1a-6D1b:

6D1a1) in the linear feedback configuration, the primary adding means, and

6D1a2) in a linear feedforward configuration, the equalizing means,

for providing a delay substantially in accordance with a listener echo bulk delay B_L; and

6D1b) an adaptive transversal filter unit, operably coupled to bulk delay line unit, whose coefficients are $a_k(n)$, where $k = 0, 1, 2, ..., M-1$, where M is a number of taps in the transversal filter unit, and whose output is substantially

$$p(n) = \sum_{k=0}^{M-1} g(k + n + B_L)a_k(n),$$ where n is a discrete time index and g() is input to the bulk delay line unit, wherein,

where selected, BL is substantially determined by a talker far
echo ranging method,

6D2) further including that the second correcting
5 means of 5B comprises at least 6D2a-6D2e:

6D2a) received data phase correcting
means, operably coupled to the first correcting means and to a
received data phase-locked loop means, for substantially
determining a data phase correction and utilizing that data
10 phase correction to provide a data phase corrected
communication signal;

6D2b) preliminary decision means,
operably coupled to the received data phase correcting means,
for providing a preliminary estimate of the communication
15 signal transmitted by a remote modem;

6D2c) received data phase error
determining means, operably coupled to the received data
phase correcting means and to one of 6D2c1-6D2c2:

6D2c1) in the data-receiving mode, the
20 preliminary decision means, and

6D2c2) in the reference-directed
training mode, the reference signal means,
for substantially determining a received data phase error α;

6D2d) received data phase-locked loop
25 means, operably coupled to the received data phase correcting
means and to a received data phase correction inverse means,
for substantially providing the received data phase correction
estimate $\phi(n)$; the received data phase correction inverse
means being operably coupled to the received data phase-
30 locked loop means and to one of 6D2d1-6D2d2:

6D2d1) the preliminary decision means,
and

6D2d2) the reference signal means,
to provide a rotated decision signal;

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6D2e) a combiner, operably coupled to the received data phase correction inverse means and to the first correcting means, for substantially subtracting the first corrected signal from the rotated decision signal to provide an

5   error signal $\varepsilon(n)$,

6E) and, where selected, in addition to 6D, further including one of 6E1-6E2:
6E1) at least:
10   6E1a) a noise prediction filter (NPF), operably coupled between the equalizing means and the first correcting means to receive and filter the equalized signal, so that a noise spectrum of the equalized signal is whitened; and
6E1b) an inverse noise prediction filter
15   (NPF^{-1}), operably coupled between the second correcting means and the equalizing means, for filtering the error signal from the second correcting means to provide a filtered error signal for updating equalizer coefficients, and
6E2) the phase-corrected listener echo estimate is
20   substantially of a form: $e_L(n) = p(n)e^{j\psi(n)}$, where n is a discrete time index, $p(n)$ is the first listener echo estimate, and $\psi(n)$ is a listener echo phase correction estimate,
6F) and, where selected, in addition to 6E, one of 6F1 and 6F2:
25   6F1) further including that $\psi(n)$ is determined utilizing one of 6F1a-6F1b:
6F1a) substantially utilizing a listener echo phase error $\theta(n)$ where

$$\theta(n) \approx \frac{e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)}{|q(n)||e_L(n)|} ,$$

30   where e_{Lr} and e_{Li} are the real and imaginary parts, respectively, of $e_L(n)$, and q_r and q_i are the real and imaginary parts, respectively, of the equalized signal $q(n)$; and

further including that a listener echo phase-locked loop of the first correcting unit determines an estimate of the

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listener echo frequency offset component $f_L(n)$ and a phase correction estimate $\psi(n)$ for correcting the phase of the signal $p(n)$, wherein:

$$f_L(n+1) = f_L(n) + b_1\theta(n), \text{ and}$$

5 $$\psi(n+1) = \psi(n) + b_2\theta(n) + b_3 f_L(n+1),$$

where b_1, b_2, and b_3 are constants that determine a phase-locked loop characteristic, and $f_L(n)$ may be initialized using a talker far echo frequency offset estimate to facilitate an initial convergence; and

10   6F1b)   substantially by determining, a sign of $\theta(n)$, denoted as $s(n)$:

$$s(n) = \text{sign}[e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)],$$

defining $s(n) = 1$ for $e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n) > TH,$

$$s(n) = -1 \text{ for } e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n) < TH, \text{ and}$$

15             $s(n) = 0$ otherwise, where TH is a small predetermined positive threshold value;

and determining $f_L(n+1) = f_L(n) + d_1 s(n)$, and

$$\psi(n+1) = \psi(n) + d_2 s(n) + b_3 f_L(n+1), \text{ where } d_1 \text{ and } d_2 \text{ are}$$

selected constants and $f_L(n)$, an estimate of the listener echo

20 frequency offset component, may be initialized using a talker far echo frequency offset estimate to facilitate an initial convergence,

                                       6F2)   wherein the first corrected signal, $z(n)$, is substantially of a form:

25             $z(n) = q(n) - e_L(n)$, where $q(n)$ is the equalized signal,

                                       6G)   and, where selected, in addition to 6F2, further including that the rotated error   input, $\eta(n)$ is substantially of a form:

$$\eta(n) = \varepsilon(n)e^{-j\psi(n)}, \text{where } \varepsilon(n) \text{ is the error signal from the}$$

30 second correcting means,

                                       6H)   and, where selected, in addition to 6G, further including that $\phi(n)$ is substantially determined utilizing a received communication signal data phase error α where:

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$$\alpha(n) \approx \frac{v_r(n)u_i(n) - u_r(n)v_i(n)}{|v(n)|^2}$$; which is substantially used

to estimate a frequency offset of a received communication
signal $f_D(n)$ and the received data phase correction estimate
$\phi(n)$, such that substantially:

5

$$f_D(n+1) = f_D(n) + c_1\alpha(n); \text{ and}$$

$$\phi(n + 1) = \phi(n) + c_2\alpha(n) + c_3 f_D(n+1) \ ,$$

where u(n) is substantially the first corrected signal further
10   phase-corrected by $\phi(n)$, u_r and u_i are the real and imaginary
parts, respectively, of u(n), v_r and v_i are the real and
imaginary parts, respectively, of v(n), and c_1, c_2, and c_3 are
constants that determine a desired phase-locked loop
characteristic for a phase-locked loop having an input $\alpha(n)$,
15   6I)   and, where selected, in addition to 6H, further
including that the second corrected signal, u(n), is
substantially of a form:

$$u(n) = z(n)e^{j\phi(n)} \ ,$$ n being the discrete time index and z(n)
being the first corrected signal,
20   6J)   and, where selected, in addition to 6I, further
including that a rotated decision signal d(n) is substantially of
a form:

$$d(n) = v(n)e^{-j\phi(n)},$$ n being the discrete time index, and
v(n) being the reference signal r(n) for selection of a reference
25   directed training mode and being a preliminary decision output
for selection of a communication signal receiving mode.

7.   A modem having a linear listener echo cancelling device, the modem being utilized for communicating information with a remote device in both directions over a channel, the modem comprising at least:

5   transmission means, operably coupled to receive the information to be communicated, for preparing an analog signal carrying that information for transmission;

        hybrid coupling means, operably coupled to the transmission means and to a receiving means, for transmitting
10   the analog signal and for receiving another analog signal from a remote device;

        talker echo estimating means, operably coupled to the transmission means, for providing at least a talker echo estimate to the receiving means; and

15   the receiving means, operably coupled to the talker echo estimating means and to the hybrid coupling means, for recovering information from the analog signal transmitted by the remote device, said receiving means including one of:

        a linear feedback listener echo canceller, and

20   a linear feedforward listener echo canceller, for reducing a listener echo interference.

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8.   The modem of claim 7, wherein the transmission means includes one of 8A-8D:

    8A)   at least:

        8A1) encoding means, operably coupled to receive the information to be communicated, for providing an encoded data signal;

        8A2)   modulation means operably coupled to the encoding means, for providing a modulated signal; and

        8A3)   transmission filtering means, operably coupled to the modulation means, for providing a modulated filtered transmission data signal at a desired sampling rate; and

        8A4)   digital-to-analog converting means, operably coupled to the transmission filtering means, for converting the modulated filtered transmission data signal to an analog signal,

    8B)   wherein the talker echo estimating means includes at least:

        talker far echo delay estimating means for estimating a talker far echo delay; and

        wherein the listener echo correcting means substantially comprises a bulk delay line whose length is determined by the estimated talker far echo delay, for reducing the listener echo interference,

    8C)   wherein the talker echo estimating means includes at least:

        a far-end echo frequency offset determining means, for estimating a far-end echo frequency offset; and

        wherein the listener echo correcting means comprises a frequency offset phase-correcting means for correcting frequency offset in the listener echo estimate, said phase-correcting means further including at least a phase-locked loop having an initial value determined at least by the far-end talker echo frequency offset estimate,

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8D) wherein the receiving means includes at least 8D1-
8D8:

8D1) analog-to-digital converting means, operably
coupled to the hybrid coupling means, for converting received
5 analog signals to digital signals at a preselected sampling
rate;

8D2) first combining means, operably coupled to
the talker echo estimating means and to the analog-to-digital
converting means, for combining the received digital signal
10 and the talker echo estimate to provide a first talker echo
corrected signal;

8D3) rate converting means, where desired,
operably coupled to the first combining means, for converting
the first talker echo corrected signal, being sampled at a
15 transmitter sampling clock, to a second talker echo corrected
signal, being sampled at a desired receiver sampling clock;

8D4) demodulation means, operably coupled to the
rate converting means, for providing a demodulated talker echo
corrected signal;

20 8D5) receiving filtering means, operably coupled
to the demodulation means, for filtering the demodulated
talker echo corrected signal;

8D6) equalizing means, operably coupled to the
receiving filtering means, for providing an equalized,
25 demodulated filtered talker echo corrected signal;

8D7) listener echo cancelling means, operably
coupled to the equalizing means, for providing a substantially
listener echo corrected, equalized, demodulated, filtered
talker echo corrected signal; and

30 8D8) decoding means, operably coupled to the
listener echo cancelling means, for substantially decoding the
listener echo corrected, equalized, demodulated, filtered,
talker echo corrected signal to provide received information,

8E) and wherein, where selected, the listener echo cancelling means of 8D7 comprises at least a first correcting means, operably coupled to the equalizing means and to a second correcting means, and being configured for at least:

5   8E1) receiving the equalized signal;

        8E2) determining at least a listener echo estimate; and

        8E3) combining the equalized signal with the listener echo estimate to provide at least a first corrected

10 signal;

wherein the second correcting means is operably coupled to the first correcting means and to the equalizing means, and is configured substantially for at least:

        8E4) providing at least a phase correction to the

15 first corrected signal to generate and output substantially a second corrected signal that is an equalized, listener echo-corrected, and phase-corrected communication signal;

        8E5) providing at least an error signal to the equalizing means for adjusting an equalization process of the

20 equalizing means, and to the first correcting means for adjusting the listener echo estimate; and

        8E6) providing at least a rotated reference signal in reference-directed training mode for facilitating an initial training in a listener echo estimation,

25   8F) and wherein, where selected, in addition to 8E, one of 8F1-8F5:

        8F1) wherein the first correcting means comprises at least 8F1a-8F1c:

        8F1a) an adding means, operably coupled to

30 the equalizing means and to a listener echo estimating means together with a listener echo phase-correcting means that provide at least a phase-corrected listener echo estimate, for substantially obtaining a difference between the equalized

signal and that listener echo estimate, being the first
corrected signal;

8F1b)   listener echo estimating means,
operably coupled to operably coupled to the second correcting
means, and further being operably coupled to one of 8Fb1-8Fb2:

8F1b1)   the primary adding means in a
linear feedback configuration, and

8F1b2)   the equalizing means in a linear
feedforward configuration;

for utilizing:

in a data-receiving mode, one of:

the first corrected signal, and

the equalized signal;

and

in a reference-directed training mode,

the rotated reference signal;
to determine a first listener echo estimate;

8F1c)   listener echo phase error determining
means, operably coupled to the listener echo phase correcting
means and one of:

8F1c1)   in the data-receiving mode, the
preliminary decision means, and

8F1c2)   in the reference-directed
training mode, a reference signal means,
for substantially determining a listener echo phase error;

wherein the listener echo phase-locked loop means is
operably coupled to the listener echo phase error determining
means for utilizing the listener echo phase error to provide a
listener echo phase correction estimate; and

wherein the listener echo phase correction inverse
means is operably coupled to the listener echo phase-locked
loop means and to the second correcting means that provides
an error signal, for substantially utilizing the listener echo
phase correction estimate and the second correcting means

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error signal for providing a rotated error signal for updating
the listener echo estimating means,

8F2) further including that the second correcting
means comprises at least 8F2a-8F2e:

5   8F2a)   a received data phase correcting
means, operably coupled to the first correcting means and to a
received data phase-locked loop means, for substantially
determining a data phase correction and utilizing that data
phase correction to provide a data phase corrected

10   communication signal;

8F2b)   a preliminary decision means,
operably coupled to the received data phase correcting means,
for providing a preliminary estimate of the communication
signal transmitted by a remote modem;

15   8F2c)   received data phase error
determining means, operably coupled to the received data
phase correcting means and to one of:

8F2c1)   in the data-receiving mode, the
preliminary decision means, and

20   8F2c2)   in the reference-directed
training mode, the reference signal means,
for substantially determining a received data phase error α;

8F2d)   received data phase-locked loop
means, operably coupled to the received data phase correcting

25   means and to a received data phase correction inverse means,
for substantially providing a received data phase correction
estimate $\phi(n)$;

the received data phase correction i. verse means being
operably coupled to the received data phase-locked loop means

30   and to one of:

8F2d1)   the preliminary decision means,
and

8F2d2)   the reference signal means,
to provide a rotated decision signal;

8F2e) a combiner, operably coupled to the received data phase correction inverse means and to the first correcting means, for substantially subtracting the first corrected signal from the rotated decision signal to provide an
5 error signal $\varepsilon(n)$,

8F3) wherein the first corrected signal, $z(n)$, is substantially of a form:

$z(n) = q(n) - e_L(n)$, where $q(n)$ is the equalized signal,

8F4) wherein the second corrected signal, $u(n)$, is
10 substantially of a form:

$u(n) = z(n)e^{j\phi(n)}$,

8F5) further including at least 8F5a-8F5b:

8F5a) a noise prediction filter (NPF), operably coupled between the equalizing means and the first
15 correcting means to receive and filter the equalized signal, so that a noise spectrum of the equalized signal is whitened; and

8F5b) an inverse noise prediction filter (NPF^{-1}), operably coupled between the second correcting means and the equalizing means, for filtering the error signal
20 from the second correcting means to provide a filtered error signal for updating equalizer coefficients,

8G) and, where selected, further including one of 8G1-8G3:

8G1) further including, for 8F1, at least one of
25 8G1a-8G1c:

8G1a) the listener echo estimating means includes at least 8G1a1-8G1a2:

8G1a1) a bulk delay line unit, operably coupled to the second correcting means and further being
30 operably coupled to one of:

8G1a1a) in the linear feedback configuration, the primary adding means, and

8G1a1b) in a linear feedforward configuration, the equalizing means,

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for providing a delay substantially in accordance with a listener echo bulk delay B_L; and

8G1a2) an adaptive transversal filter unit, operably coupled to bulk delay line unit, whose coefficients are $a_k(n)$, where $k = 0, 1, 2, ..., M-1$, where M is a number of taps in the transversal filter unit, and whose output is substantially

$$p(n) = \sum_{k=0}^{M-1} g(k + n + B_L)a_k(n),$$ where n is a discrete time

index and $g()$ is input to the bulk delay line unit, wherein, where selected, B_L is substantially determined by a talker far echo ranging method,

8G1b) the phase-correction listener echo estimate is substantially of a form: $e_L(n) = p(n)e^{j\psi(n)}$, where n is a discrete time index, $p(n)$ is the first listener echo estimate, and $\psi(n)$ is a listener echo phase correction estimate, and, where selected, further including that $\psi(n)$ is determined utilizing one of 8G1b1-8G1b2:

8G1b1) substantially utilizing a listener echo phase error $\theta(n)$ where

$$\theta(n) \approx \frac{e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)}{|q(n)||e_L(n)|},$$

where e_{Lr} and e_{Li} are the real and imaginary parts, respectively, of $e_L(n)$, and q_r and q_i are the real and imaginary parts, respectively, of the equalized signal $q(n)$; and

further including that a listener echo phase-locked loop of the first correcting unit determines an estimate of the listener echo frequency offset component $f_L(n)$ and a phase correction estimate $\psi(n)$ for substantially correcting a phase of the signal $p(n)$, wherein:

$$f_L(n+1) = f_L(n) + b_1\theta(n),$$ and

$$\psi(n+1) = \psi(n) + b_2\theta(n) + b_3 f_L(n+1),$$

where b_1, b_2, and b_3 are constants that determine a phase lock loop characteristic and $f_L(n)$ is initialized, where desired,

utilizing a talker far echo frequency offset estimate to facilitate an initial convergence; and

8G1b2) substantially by determining a sign of $\theta(n)$, denoted as $s(n)$:

5

$s(n) = \text{sign}[e_{Li}(n)q_r(n)-e_{Lr}(n)q_i(n)]$,

defining $s(n)=1$ for $e_{Li}(n)q_r(n)-e_{Lr}(n)q_i(n)>TH$,

$s(n)=-1$ for $e_{Li}(n)q_r(n)-e_{Lr}n)q_i(n)<TH$, and

$s(n) = 0$ otherwise, where TH is a small predetermined positive threshold value;

10 and determining $f_L(n+1) = f_L(n) + d_1s(n)$, and

$\psi(n+1) = \psi(n) + d_2s(n) + b_3f_L(n+1)$, where d_1 and d_2 are selected constants,

8G1c) the rotated error signal, $\eta(n)$, is substantially of a form:

15 $\eta(n) = \varepsilon(n)e^{-j\psi(n)}$, where $\varepsilon(n)$ is the error signal from the second correcting means,

8G2) further including that the received data phase correction estimate $\phi(n)$ is substantially determined utilizing a received communication signal data phase error α where:

20 $\alpha(n) \approx \dfrac{v_r(n)u_i(n)-u_r(n)v_i(n)}{|v(n)|^2}$; which is substantially used

to estimate a frequency offset of a received communication signal $f_D(n)$ and the received data phase correction estimate $\phi(n)$, such that substantially:

25 $f_D(n+1) = f_D(n) + c_1\alpha(n)$; and

$\phi(n + 1) = \phi(n) + c_2\alpha(n) + c_3f_D(n+1)$,

where $u(n)$ is substantially the first corrected signal further phase-corrected by $\phi(n)$, u_r and u_i are the real and imaginary

30 parts, respectively, of $u(n)$, v_r and v_i are the real and imaginary parts, respectively, of $v(n)$, and c_1, c_2, and c_3 are constants that determine a desired phase-locked loop characteristic for a phase-locked loop having an input $\alpha(n)$,

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8G3) further including that a rotated decision signal $d(n)$ is substantially of a form:

$d(n) = v(n)e^{-j\phi(n)}$, n being the discrete time index, and $v(n)$ being the reference signal $r(n)$ for selection of a reference
5 directed training mode and being a preliminary decision output for selection of a communication signal receiving mode.

9. A method for minimizing a listener echo signal interference in a substantially demodulated, where desired, equalized communication signal received over a channel having simultaneous transmission and reception, the method

5   comprising at least the steps of 9A-9F:

9A) receiving the demodulated, where desired, communication signal, for substantially providing an equalized signal;

9B) determining at least a listener echo estimate;

10   and

9C) combining the equalized signal with the listener echo estimate to provide at least a first corrected signal;

9D) providing at least a phase correction to the

15   first corrected signal to generate and output substantially a second corrected signal that is an equalized, listener echo-corrected and phase-corrected communication signal;

9E) providing at least an error signal for adjusting an equalization process and a listener echo estimation;

20   9F) providing at least a rotated reference signal in a reference-directed training mode for facilitating an initial training of a listener echo estimation.

10.   The method of claim 9, further including at least one of 10A-10D:

      10A) at least the steps of 10A1-10A7:

         10A1)   substantially obtaining a difference between the equalized signal and that listener echo estimate, being the first corrected signal;

         10A2)   selecting, as desired, one of:

            10A2a)   the first corrected signal,

            10A2b)   the equalized signal, and

            10A2c)   the rotated reference signal, as a first selected signal;

         10A3)   utilizing the first selected signal to determine a first listener echo estimate;

         10A4)   providing a listener echo phase correction estimate and substantially combining the first listener echo estimate and the listener echo correction estimate to provide at least the phase-corrected listener echo estimate;

         10A5)   utilizing the equalized signal and the phase-corrected listener echo estimate to provide a listener echo phase error;

         10A6)   utilizing the listener echo phase error to provide a listener echo phase correction estimate; and

         10A7)   providing an error signal and substantially utilizing the listener echo phase correction estimate and the error signal for providing a rotated error signal for updating the first listener echo estimate,

      and wherein, where selected, steps 10A1-10A7 further include one of the sets of steps of 10A8-10A9:

         10A8)   the steps of:

            10A8a)   substantially determining a data phase correction and utilizing that data phase correction to provide a data phase corrected communication signal;

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10A8b)   providing a preliminary decision
output signal of the communication signal transmitted by the
remote modem;

10A8c)   selecting, as desired, one of:

5   10A8c1)   the preliminary decision
output signal, and

10A8c2)   a reference signal,
as a second selected signal;

10A8d)   substantially determining a
10   received data phase error α;

10A8e)   substantially providing a received
data phase correction estimate $\phi(n)$;

10A8f)   providing a rotated decision
signal; and

15   10A8g)   substantially subtracting the
first corrected signal from the rotated decision signal to
provide an error signal $\varepsilon(n)$,

10A9)   further including that the rotated error
signal, $\eta(n)$, is substantially of a form:

20    $\eta(n) = \varepsilon(n)e^{-j\psi(n)}$, where $\varepsilon(n)$ is the error signal,

and wherein, where selected, steps 10A8a-10A8g further
include one of 10A8h-10A8k:

10A8h)   at least the steps 10A8h1-10A8h2:

25   10A8h1)   utilizing a bulk delay unit to
provide a delay substantially in accordance with a listener
echo bulk delay B_L; and

10A8h2)   utilizing an adaptive transversal
filter unit whose coefficients are $a_k(n)$, where $k = 0, 1, 2, ...,$
30   M-1, where M is a number of taps in the transversal filter unit,
and whose output is substantially

$p(n) = \sum_{k=0}^{M-1} g(k + n + B_L)a_k(n)$, where n is a discrete time

index and g() is input from the first switching unit, wherein,

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where selected, B_L is substantially determined by a talker far echo ranging method,

10A8i) further including that the received data phase correction estimate $\phi(n)$ is substantially determined utilizing a received communication signal data phase error α where:

$$\alpha(n) \approx \frac{v_r(n)u_i(n) - u_r(n)v_i(n)}{|v(n)|^2}$$; which is substantially used to estimate a frequency offset of a received communication signal $f_D(n)$ and the received data phase correction estimate $\phi(n)$, such that substantially:

$$f_D(n+1) = f_D(n) + c_1\alpha(n); \text{ and}$$

$$\phi(n+1) = \phi(n) + c_2\alpha(n) + c_3f_D(n+1) \ ,$$

where $u(n)$ is substantially the first corrected signal further phase-corrected by $\phi(n)$, u_r and u_i are the real and imaginary parts, respectively, of $u(n)$, v_r and v_i are the real and imaginary parts, respectively, of $v(n)$, wherein $v(n)$ is substantially the reference signal $r(n)$ for selection of a reference directed training mode and being the preliminary decision output for selection of a communication signal receiving mode,

and c_1, c_2, and c_3 are constants that determine a desired phase-locked loop characteristic for a phase-locked loop having an input $\alpha(n)$,

10A8j)   further including that the rotated decision signal $d(n)$ is substantially of a form $d(n) = v(n)e^{-j\phi(n)}$, n being the discrete time index, and

10A8k)   further including at least the steps of: utilizing a noise prediction filter (NPF) to receive and filter the equalized signal, so that a noise spectrum of the equalized signal is whitened; and

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utilizing an inverse noise prediction filter (NPF^{-1}) for filtering the error signal to provide a filtered error signal for updating equalizer coefficients,

10B) further including that the listener echo estimate is
5   substantially of a form:

$e_L(n) = p(n)e^{j\psi(n)}$, where n is a discrete time index, $p(n)$ is the first listener echo estimate, and $\psi(n)$ is a listener echo phase correction estimate, wherein, where selected, $\psi(n)$ is determined utilizing one of 10B1-10B2:

10   10B1) substantially utilizing a listener echo phase error $\theta(n)$ where

$$\theta(n) \approx \frac{e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)}{|q(n)||e_L(n)|},$$

where e_{Lr} and e_{Li} are the real and imaginary parts, respectively, of $e_L(n)$, and q_r and q_i are the real and imaginary
15   parts, respectively, of the equalized signal $q(n)$; and

further including that a listener echo phase-locked loop of the first correcting unit determines an estimate of the listener echo frequency offset component $f_L(n)$ and a phase correction estimate $\psi(n)$ for substantially correcting a phase
20   of the signal $p(n)$, wherein:

$f_L(n+1) = f_L(n) + b_1\theta(n)$, and

$\psi(n+1) = \psi(n) + b_2\theta(n) + b_3 f_L(n+1)$,

where b_1, b_2, and b_3 are constants that determine a phase lock loop characteristic and $f_L(n)$ is initialized, where desired,
25   utilizing a talker far echo frequency offset estimate to facilitate an initial convergence; and

10B2) substantially by determining, a sign of $\theta(n)$, denoted as $s(n)$:

$s(n) = sign[e_{Li}(n)q_r(n)-e_{Lr}(n)q_i(n)]$,
30   defining $s(n)=1$ for $e_{Li}(n)q_r(n)-e_{Lr}(n)q_i(n)>TH$,

$s(n)=-1$ for $e_{Li}(n)q_r(n)-e_{Lr}(n)q_i(n)<TH$, and

$s(n) = 0$ otherwise, where TH is a small predetermined positive threshold value;

and determining $f_L(n+1) = f_L(n) + d_1 s(n)$, and

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$\psi(n+1) = \psi(n) + d_2 s(n) + b_3 f_L(n+1)$, where d_1 and d_2 are selected constants and $f_L(n)$, where desired, is initialized using a talker far echo frequency offset estimate to facilitate an initial convergence,

5   10C)   further including that the first corrected signal, $z(n)$, is substantially of a form:

$z(n) = q(n) - e_L(n)$, where $q(n)$ is the equalized signal, and

10D)   further including that the second corrected signal, $u(n)$, is substantially of a form:

10    $u(n) = z(n)e^{j\phi(n)}$.

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1. (Amended) A listener echo canceller (LECR) for reducing a listener echo interference in a digital communication system having a selected sampling interval, and having an input and an output, said input comprising a sum of a desired signal and a

5   listener echo interference, and said output being free of listener echo interference, said listener echo canceller comprising:

a bulk delay line means, operably coupled to receive and store one sample of one of: the input and the output of said

1 0   listener echo canceller, to provide a bulk delay line output;

an adaptive listener echo interference estimator means, operably coupled to receive the bulk delay line output to generate an estimate of the listener echo interference; and

an interference cancelling means, operably coupled to

1 5   receive the input of the listener echo canceller and the estimate of the listener echo interference, for subtracting said estimate of the listener echo interference from said input of the listener echo canceller.

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2. (Amended) The LECR of claim 1, wherein said adaptive listener echo interference estimator means further includes:

a set of filter coefficients and a tapped delay line, operably coupled to receive and store samples of said bulk
5   delay line output; and

wherein the said estimate of the listener echo interference is related to a weighted combination of the stored samples of said bulk delay line output such that the weighting is determined by the filter coefficients, and the
10   said filter coefficients are adaptively adjusted to produce the estimate of said listener echo interference.

3. (Amended) The LECR of claim 1, wherein the said bulk delay
15   line output is one of 3A-3B:

3A)   the input of the LECR, delayed by a selected number of sampling intervals; and

3B)   the output of the LECR, delayed by a selected number of sampling intervals;
20   wherein said selected number of sampling intervals is non-zero.

25   4. (Amended) The LECR of claim 1, wherein said adaptive listener echo interference estimator means further includes compensating means, operably coupled to receive the input of the LECR and to receive a phase-corrected listener echo estimate, for compensating a frequency offset in the said
30   estimate of the listener echo interference, and, where selected, wherein the means for compensating the frequency offset includes 4A-4C:

4A)   a phase-error estimating means, operably coupled to receive the input of the LECR and to receive a phase-
35   corrected listener echo estimate, for generating a phase error

that is a phase difference between the estimate of the listener echo estimate and the said input of the LECR;

    4B)   a phase-locked loop, operably coupled to receive the said phase error, for generating a phase correction

5   estimate; and

    4C)   a phase-correction means, operably coupled to receive the phase correction estimate, for generating a phase-corrected listener echo estimate.

10

5. (Amended) A device for minimizing a listener echo signal
interference in a demodulated, where selected, communication
signal received over a channel having simultaneous
transmission and reception, the device comprising 5A-5B:

5   5A) equalizing means, operably coupled to receive the
demodulated, where desired, communication signal, for
providing an equalized signal;

           5B) a first correcting means, operably coupled to the
equalizing means and to a second correcting means, and being
10   configured for 5B1-5B3:

              5B1) receiving the equalized signal;

              5B2) determining a listener echo estimate; and

              5B3) combining the equalized signal with the
listener echo estimate to provide a first corrected signal;

15   wherein the second correcting means is operably coupled
to the first correcting means and to the equalizing means, and
is configured for 5B4-5B6:

              5B4) providing a phase correction to the first
corrected signal to generate and output a second corrected

20   signal that is an equalized listener echo corrected and phase-
corrected communication signal;

              5B5) providing an error signal to the equalizing
means for adjusting an equalization process of the equalizing
means and to the first correcting means for adjusting the

25   listener echo estimation; and

              5B6) providing a rotated reference signal in
reference-directed training mode for facilitating an initial
training of a listener echo estimation.

30

6. (Amended) The device of claim 5, wherein the first correcting means comprises 6A-6C:

6A) primary adding means, operably coupled to the

5 equalizing means and to a listener echo estimating means together with a listener echo phase correcting means that provide a phase-corrected listener echo estimate, for obtaining a difference between the equalized signal and that listener echo estimate, being the first corrected signal;

10 6B) listener echo estimating means, operably coupled to one of 6B1-6B2:

6B1) the primary adding means in a linear feedback configuration, and

6B2) the equalizing means in a linear

15 feedforward configuration;

and further being operably coupled to the second correcting means, for utilizing:

6B3) in a data-receiving mode, one of 6B3a-

20 6B3b:

6B3a) the first corrected signal, and

6B3b) the equalized signal;

and

6B4) in a reference-directed training

25 mode, the rotated reference signal;

to determine a first listener echo estimate;

6C) listener echo phase error determining means, operably coupled to the listener echo phase correcting means and one of:

30 6C1) in the data-receiving mode, the preliminary decision means, and

6C2) in the reference-directed training mode, a reference signal means,

35 for determining a listener echo phase error;

wherein the listener echo phase-locked loop means is operably coupled to the listener echo phase error determining means for utilizing the listener echo phase error to provide a listener echo phase correction estimate; and

5 wherein the listener echo phase correction inverse means is operably coupled to the listener echo phase-locked loop means and to the second correcting means that provides an error signal, for utilizing the listener echo phase correction estimate and the second correcting means error signal for

10 providing a rotated error signal for updating the listener echo estimating means,

6D) and, where selected, one of 6D1-6D2:

6D1) further including that the listener echo

15 estimating means includes 6D1a-6D1b:

6D1a) a bulk delay line unit, operably coupled to the second correcting means, and further being operably coupled to one of 6D1a-6D1b:

6D1a1) in the linear feedback

20 configuration, the primary adding means, and

6D1a2) in a linear feedforward configuration, the equalizing means,

for providing a delay in accordance with a listener echo bulk delay B_L; and

25 6D1b) an adaptive transversal filter unit, operably coupled to bulk delay line unit, whose coefficients are $a_k(n)$, where $k = 0, 1, 2, ..., M-1$, where M is a number of taps in the transversal filter unit, and whose output is of a form

30 $$p(n) = \sum_{k=0}^{M-1} g(k + n + B_L)a_k(n),$$ where n is a discrete time index and g() is input to the bulk delay line unit, wherein, where selected, B_L is determined by a talker far echo ranging method,

6D2) further including that the second correcting means of 5B comprises 6D2a-6D2e:

6D2a) received data phase correcting
5   means, operably coupled to the first correcting means and to a received data phase-locked loop means, for determining a data phase correction and utilizing that data phase correction to provide a data phase corrected communication signal;

6D2b) preliminary decision means,
10   operably coupled to the received data phase correcting means, for providing a preliminary estimate of the communication signal transmitted by a remote modem;

6D2c) received data phase error determining means, operably coupled to the received data
15   phase correcting means and to one of 6D2c1-6D2c2:

6D2c1) in the data-receiving mode, the preliminary decision means, and

6D2c2) in the reference-directed training mode, the reference signal means,
20   for determining a received data phase error α;

6D2d) received data phase-locked loop means, operably coupled to the received data phase correcting means and to a received data phase correction inverse means, for providing the received data phase correction estimate $\phi(n)$;
25   the received data phase correction inverse means being operably coupled to the received data phase-locked loop means and to one of 6D2d1-6D2d2:

6D2d1) the preliminary decision means, and
30   6D2d2) the reference signal means, to provide a rotated decision signal;

6D2e) a combiner, operably coupled to the received data phase correction inverse means and to the first

correcting means, for subtracting the first corrected signal
from the rotated decision signal to provide an error signal $\varepsilon(n)$,

6E)   and, where selected, in addition to 6D, further
including one of 6E1-6E2:
        6E1)   the following filters 6E1a-6E1b:
                6E1a)   a noise prediction filter (NPF),
operably coupled between the equalizing means and the first
correcting means to receive and filter the equalized signal, so
that a noise spectrum of the equalized signal is whitened; and
                6E1b)   an inverse noise prediction filter
(NPF^{-1}), operably coupled between the second correcting
means and the equalizing means, for filtering the error signal
from the second correcting means to provide a filtered error
signal for updating equalizer coefficients, and
                6E2)   the phase-corrected listener echo estimate is
of a form: $e_L(n) = p(n)e^{j\psi(n)}$, where n is a discrete time index,
p(n) is the first listener echo estimate, and $\psi(n)$ is a listener
echo phase correction estimate,
6F)   and, where selected, in addition to 6E, one of 6F1
and 6F2:
                6F1)   further including that $\psi(n)$ is
determined utilizing one of 6F1a-6F1b:
                        6F1a)   utilizing a listener echo phase
error $\theta(n)$ where

$$\theta(n) \approx \frac{e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)}{|q(n)||e_L(n)|} ,$$

where e_{Lr} and e_{Li} are the real and imaginary parts,
respectively, of $e_L(n)$, and q_r and q_i are the real and imaginary
parts, respectively, of the equalized signal q(n); and
                further including that a listener echo phase-locked loop
of the first correcting unit determines an estimate of the
listener echo frequency offset component $f_L(n)$ and a phase
correction estimate $\psi(n)$ for correcting the phase of the signal
p(n), wherein:

$$f_L (n+1) = f_L(n) + b_1 \theta(n), \text{ and}$$

$$\psi(n+1) = \psi(n) + b_2 \theta(n) + b_3 f_L(n+1),$$

where b_1, b_2, and b_3 are constants that determine a phase-locked loop characteristic, and $f_L(n)$ may be initialized using a talker far echo frequency offset estimate to facilitate an initial convergence; and

6F1b) by determining, a sign of $\theta(n)$, denoted as $s(n)$:

$$s(n) = \text{sign}[e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)],$$

defining $s(n)=1$ for $e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)>TH$,

$$s(n)=-1 \text{ for } e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)<TH, \text{ and}$$

$s(n) = 0$ otherwise, where TH is a small predetermined positive threshold value;

and determining $f_L (n+1) = f_L(n) + d_1 s(n)$, and

$$\psi(n+1) = \psi(n) + d_2 s(n) + b_3 f_L(n+1),$$ where d_1 and d_2 are selected constants and $f_L(n)$, an estimate of the listener echo frequency offset component, may be initialized using a talker far echo frequency offset estimate to facilitate an initial convergence,

6F2) wherein the first corrected signal, $z(n)$, is of a form:

$$z(n) = q(n) - e_L(n),$$ where $q(n)$ is the equalized signal,

6G) and, where selected, in addition to 6F2, further including that the rotated error input, $\eta(n)$ is of a form:

$$\eta(n) = \varepsilon (n)e^{-j\psi(n)},$$ where $\varepsilon(n)$ is the error signal from the second correcting means,

6H) and, where selected, in addition to 6G, further including that $\phi(n)$ is determined utilizing a received communication signal data phase error α where:

$$\alpha(n) \approx \frac{v_r(n)u_i(n) - u_r(n)v_i(n)}{|v(n)|^2} \text{ ; which is used to estimate a}$$

frequency offset of a received communication signal $f_D(n)$ and the received data phase correction estimate $\phi(n)$, such that:

$$f_D(n+1) = f_D(n) + c_1\alpha(n); \text{ and}$$

$$\phi(n+1) = \phi(n) + c_2\alpha(n) + c_3 f_D(n+1) ,$$

where $u(n)$ is the first corrected signal further phase-corrected by $\phi(n)$, u_r and u_i are the real and imaginary parts, respectively, of $u(n)$, v_r and v_i are the real and imaginary parts, respectively, of $v(n)$, and c_1, c_2, and c_3 are constants that determine a desired phase-locked loop characteristic for a phase-locked loop having an input $\alpha(n)$,

6I) and, where selected, in addition to 6H, further including that the second corrected signal, $u(n)$, is of a form:

$u(n) = z(n)e^{j\phi(n)}$, n being the discrete time index and $z(n)$ being the first corrected signal,

6J) and, where selected, in addition to 6I, further including that a rotated decision signal $d(n)$ is of a form:

$d(n) = v(n)e^{-j\phi(n)}$, n being the discrete time index, and $v(n)$ being the reference signal $r(n)$ for selection of a reference directed training mode and being a preliminary decision output for selection of a communication signal receiving mode.

7. (Amended) A modem having a linear listener echo
cancelling device, the modem being utilized for communicating
information with a remote device in both directions over a
channel, the modem comprising:

5   transmission means, operably coupled to receive the
information to be communicated, for preparing an analog signal
carrying that information for transmission;

           hybrid coupling means, operably coupled to the
transmission means and to a receiving means, for transmitting

10   the analog signal and for receiving another analog signal from
a remote device;

           talker echo estimating means, operably coupled to the
transmission means, for providing at least a talker echo
estimate to the receiving means; and

15   the receiving means, operably coupled to the talker echo
estimating means and to the hybrid coupling means, for
recovering information from the analog signal transmitted by
the remote device, said receiving means including one of:

           a linear feedback listener echo canceller, and

20   a linear feedforward listener echo canceller,
for reducing a listener echo interference.

8. (Amended) The modem of claim 7, wherein the
transmission means includes one of 8A-8D:

     5   8A) the following means:

8A1) encoding means, operably coupled to receive
the information to be communicated, for providing an encoded
data signal;

8A2) modulation means operably coupled to the
10   encoding means, for providing a modulated signal; and

8A3) transmission filtering means, operably
coupled to the modulation means, for providing a modulated
filtered transmission data signal at a desired sampling rate;
and

15   8A4) digital-to-analog converting means, operably
coupled to the transmission filtering means, for converting the
modulated filtered transmission data signal to an analog
signal,

8B) wherein the talker echo estimating means includes:
20   talker far echo delay estimating means for
estimating a talker far echo delay; and

wherein the listener echo correcting means
comprises a bulk delay line whose length is determined by the
estimated talker far echo delay, for reducing the listener echo
25   interference,

8C) wherein the talker echo estimating means includes:
a far-end echo frequency offset determining means,
for estimating a far-end echo frequency offset; and

wherein the listener echo correcting means comprises a
30   frequency offset phase-correcting means for correcting
frequency offset in the listener echo estimate, said phase-
correcting means further including a phase-locked loop having
an initial value determined by the far-end talker echo
frequency offset estimate,

35   8D) wherein the receiving means includes 8D1-8D8:

8D1)   analog-to-digital converting means, operably coupled to the hybrid coupling means, for converting received analog signals to digital signals at a preselected sampling rate;

5   8D2)   first combining means, operably coupled to the talker echo estimating means and to the analog-to-digital converting means, for combining the received digital signal and the talker echo estimate to provide a first talker echo corrected signal;

10   8D3)   rate converting means, where desired, operably coupled to the first combining means, for converting the first talker echo corrected signal, being sampled at a transmitter sampling clock, to a second talker echo corrected signal, being sampled at a desired receiver sampling clock;

15   8D4)   demodulation means, operably coupled to the rate converting means, for providing a demodulated talker echo corrected signal;

8D5)   receiving filtering means, operably coupled to the demodulation means, for filtering the demodulated

20   talker echo corrected signal;

8D6)   equalizing means, operably coupled to the receiving filtering means, for providing an equalized, demodulated filtered talker echo corrected signal;

8D7)   listener echo cancelling means, operably

25   coupled to the equalizing means, for providing a listener echo corrected, equalized, demodulated, filtered talker echo corrected signal; and

8D8)   decoding means, operably coupled to the listener echo cancelling means, for decoding the listener echo

30   corrected, equalized, demodulated, filtered, talker echo corrected signal to provide received information,

8E)   and wherein, where selected, the listener echo cancelling means of 8D7 comprises a first correcting means,

operably coupled to the equalizing means and to a second correcting means, and being configured for:

8E1)   receiving the equalized signal;

8E2)   determining a listener echo estimate; and

8E3)   combining the equalized signal with the listener echo estimate to provide a first corrected signal;

wherein the second correcting means is operably coupled to the first correcting means and to the equalizing means, and is configured for:

8E4)   providing a phase correction to the first corrected signal to generate and output a second corrected signal that is an equalized, listener echo-corrected, and phase-corrected communication signal;

8E5)   providing an error signal to the equalizing means for adjusting an equalization process of the equalizing means, and to the first correcting means for adjusting the listener echo estimate; and

8E6)   providing a rotated reference signal in reference-directed training mode for facilitating an initial training in a listener echo estimation,

8F)   and wherein, where selected, in addition to 8E, one of 8F1-8F5:

8F1)   wherein the first correcting means comprises 8F1a-8F1c:

8F1a)   an adding means, operably coupled to the equalizing means and to a listener echo estimating means together with a listener echo phase-correcting means that provide a phase-corrected listener echo estimate, for obtaining a difference between the equalized signal and that listener echo estimate, being the first corrected signal;

8F1b)   listener echo estimating means, operably coupled to operably coupled to the second correcting means, and further being operably coupled to one of 8Fb1-8Fb2:

          8F1b1) the primary adding means in a linear feedback configuration, and

          8F1b2) the equalizing means in a linear feedforward configuration;

5   for utilizing:

          in a data-receiving mode, one of:

            the first corrected signal, and

            the equalized signal;

    and

10   in a reference-directed training mode,

           the rotated reference signal;

to determine a first listener echo estimate;

          8F1c) listener echo phase error determining means, operably coupled to the listener echo phase correcting

15 means and one of:

          8F1c1) in the data-receiving mode, the preliminary decision means, and

          8F1c2) in the reference-directed training mode, a reference signal means,

20 for determining a listener echo phase error;

         wherein the listener echo phase-locked loop means is operably coupled to the listener echo phase error determining means for utilizing the listener echo phase error to provide a listener echo phase correction estimate; and

25   wherein the listener echo phase correction inverse means is operably coupled to the listener echo phase-locked loop means and to the second correcting means that provides an error signal, for utilizing the listener echo phase correction estimate and the second correcting means error signal for

30 providing a rotated error signal for updating the listener echo estimating means,

         8F2) further including that the second correcting means comprises 8F2a-8F2e:

8F2a)   a received data phase correcting
means, operably coupled to the first correcting means and to a
received data phase-locked loop means, for determining a data
phase correction and utilizing that data phase correction to
5   provide a data phase corrected communication signal;
8F2b)   a preliminary decision means,
operably coupled to the received data phase correcting means,
for providing a preliminary estimate of the communication
signal transmitted by a remote modem;
10   8F2c)   received data phase error
determining means, operably coupled to the received data
phase correcting means and to one of:
8F2c1)   in the data-receiving mode, the
preliminary decision means, and
15   8F2c2)   in the reference-directed
training mode, the reference signal means,
for determining a received data phase error α;
8F2d)   received data phase-locked loop
means, operably coupled to the received data phase correcting
20   means and to a received data phase correction inverse means,
for providing a received data phase correction estimate $\phi(n)$;
the received data phase correction inverse means being
operably coupled to the received data phase-locked loop means
and to one of:
25   8F2d1)   the preliminary decision means,
and
8F2d2)   the reference signal means,
to provide a rotated decision signal;
8F2e)   a combiner, operably coupled to
30   the received data phase correction inverse means and to the
first correcting means, for subtracting the first corrected
signal from the rotated decision signal to provide an error
signal $\varepsilon(n)$,

8F3) wherein the first corrected signal, $z(n)$, is of a form:

$z(n) = q(n) - e_L(n)$, where $q(n)$ is the equalized signal,

8F4) wherein the second corrected signal, $u(n)$, is of a form:

$u(n) = z(n)e^{j\phi(n)}$,

8F5) further including 8F5a-8F5b:

8F5a) a noise prediction filter (NPF), operably coupled between the equalizing means and the first correcting means to receive and filter the equalized signal, so that a noise spectrum of the equalized signal is whitened; and

8F5b) an inverse noise prediction filter (NPF^{-1}), operably coupled between the second correcting means and the equalizing means, for filtering the error signal from the second correcting means to provide a filtered error signal for updating equalizer coefficients,

8G) and, where selected, further including one of 8G1-8G3:

8G1) further including, for 8F1, one of 8G1a-8G1c:

8G1a) the listener echo estimating means includes 8G1a1-8G1a2:

8G1a1) a bulk delay line unit, operably coupled to the second correcting means and further being operably coupled to one of:

8G1a1a) in the linear feedback configuration, the primary adding means, and

8G1a1b) in a linear feedforward configuration, the equalizing means,

for providing a delay in accordance with a listener echo bulk delay B_L; and

8G1a2) an adaptive transversal filter unit, operably coupled to bulk delay line unit, whose coefficients are $a_k(n)$, where $k = 0, 1, 2, ..., M-1$, where M is a

number of taps in the transversal filter unit, and whose output
is of a form

$$p(n) = \sum_{k=0}^{M-1} g(k + n + B_L)a_k(n), \text{ where } n \text{ is a discrete time}$$

index and g() is input to the bulk delay line unit, wherein,
5   where selected, B_L is determined by a talker far echo ranging
method,

        8G1b)   the phase-correction listener echo
estimate is of a form: $e_L(n) = p(n)e^{j\psi(n)}$, where n is a discrete
time index, p(n) is the first listener echo estimate, and $\psi(n)$ is
10   a listener echo phase correction estimate,   and, where
selected, further including that $\psi(n)$ is determined utilizing
one of 8G1b1-8G1b2:

        8G1b1)   utilizing a listener echo phase
error $\theta(n)$ where

15      $$\theta(n) \approx \frac{e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)}{|q(n)||e_L(n)|},$$

where e_{Lr} and e_{Li} are the real and imaginary parts,
respectively, of $e_L(n)$, and q_r and q_i are the real and imaginary
parts, respectively, of the equalized signal q(n); and

        further including that a listener echo phase-locked loop
20   of the first correcting unit determines an estimate of the
listener echo frequency offset component $f_L(n)$ and a phase
correction estimate $\psi(n)$ for correcting a phase of the signal
p(n), wherein:

        $f_L(n+1) = f_L(n) + b_1\theta(n)$, and
25      $\psi(n+1) = \psi(n) + b_2\theta(n) + b_3f_L(n+1)$,

where b_1, b_2, and b_3 are constants that determine a phase lock
loop characteristic and $f_L(n)$ is initialized, where desired,
utilizing a talker far echo frequency offset estimate to
facilitate an initial convergence; and
30   8G1b2)   by determining a sign of
$\theta(n)$, denoted as s(n):

        $s(n) = \text{sign}[e_{Li}(n)q_r(n)-e_{Lr}(n)q_i(n)]$,

defining s(n)=1 for $e_{Li}(n)q_r(n)-e_{Lr}(n)q_i(n)>TH$,

s(n)=-1 for $e_{Li}(n)q_r(n)-e_{Lr}n)q_i(n)<TH$, and

s(n) = 0 otherwise, where TH is a small predetermined positive threshold value;

5   and determining $f_L(n+1) = f_L(n) + d_1 s(n)$, and

$\psi(n+1) = \psi(n) + d_2 s(n) + b_3 f_L(n+1)$, where d_1 and d_2 are selected constants,

8G1c)   the rotated error signal, $\eta(n)$, is of a form:

10    $\eta(n) = \varepsilon(n)e^{-j\psi(n)}$, where $\varepsilon(n)$ is the error signal from the second correcting means,

8G2)   further including that the received data phase correction estimate $\phi(n)$ is determined utilizing a received communication signal data phase error α where:

15    $\alpha(n) \approx \dfrac{v_r(n)u_i(n)-u_r(n)v_i(n)}{|v(n)|^2}$; which is used to estimate a frequency offset of a received communication signal $f_D(n)$ and the received data phase correction estimate $\phi(n)$, such that:

$f_D(n+1) = f_D(n) + c_1\alpha(n)$; and

20

$\phi(n+1) = \phi(n) + c_2\alpha(n) + c_3 f_D(n+1)$,

where u(n) is the first corrected signal further phase-corrected by $\phi(n)$, u_r and u_i are the real and imaginary parts, respectively, of u(n), v_r and v_i are the real and imaginary

25   parts, respectively, of v(n), and c_1, c_2, and c_3 are constants that determine a desired phase-locked loop characteristic for a phase-locked loop having an input $\alpha(n)$,

8G3)   further including that a rotated decision signal d(n) is of a form:

30    $d(n) = v(n)e^{-j\phi(n)}$, n being the discrete time index, and v(n) being the reference signal r(n) for selection of a reference directed training mode and being a preliminary decision output for selection of a communication signal receiving mode.

9.   (Amended)   A method for minimizing a listener echo signal
interference in a demodulated, where selected, equalized
communication signal received over a channel having
simultaneous transmission and reception, the method
5   comprising the steps of 9A-9F:
              9A)   receiving the demodulated, where desired,
communication signal, for providing an equalized signal;
              9B)   determining at least a listener echo estimate;
and
10   9C)   combining the equalized signal with the
listener echo estimate to provide at least a first corrected
signal;
              9D)   providing at least a phase correction to the
first corrected signal to generate and output a second
15   corrected signal that is an equalized, listener echo-corrected
and phase-corrected communication signal;
              9E)   providing at least an error signal for adjusting
an equalization process and a listener echo estimation;
              9F)   providing at least a rotated reference signal in
20   a reference-directed training mode for facilitating an initial
training of a listener echo estimation.

10. (Amended) The method of claim 9, further including one of 10A-10D:

    10A) the steps of 10A1-10A7:

        10A1)   obtaining a difference between the equalized signal and that listener echo estimate, being the first corrected signal;

        10A2)   selecting, as desired, one of:

            10A2a) the first corrected signal,

            10A2b) the equalized signal, and

            10A2c) the rotated reference signal, as a first selected signal;

        10A3)   utilizing the first selected signal to determine a first listener echo estimate;

        10A4)   providing a listener echo phase correction estimate and combining the first listener echo estimate and the listener echo correction estimate to provide the phase-corrected listener echo estimate;

        10A5)   utilizing the equalized signal and the phase-corrected listener echo estimate to provide a listener echo phase error;

        10A6)   utilizing the listener echo phase error to provide a listener echo phase correction estimate; and

        10A7)   providing an error signal and utilizing the listener echo phase correction estimate and the error signal for providing a rotated error signal for updating the first listener echo estimate,

    and wherein, where selected, steps 10A1-10A7 further include one of the sets of steps of 10A8-10A9:

        10A8)   the steps of:

            10A8a) determining a data phase correction and utilizing that data phase correction to provide a data phase corrected communication signal;

10A8b)   providing a preliminary decision output signal of the communication signal transmitted by the remote modem;

10A8c)   selecting, as desired, one of:

10A8c1)   the preliminary decision output signal, and

10A8c2)   a reference signal,

as a second selected signal;

10A8d)   determining a received data phase error α;

10A8e)   providing a received data phase correction estimate φ(n);

10A8f)   providing a rotated decision signal; and

10A8g)   subtracting the first corrected signal from the rotated decision signal to provide an error signal ε(n),

10A9)   further including that the rotated error signal, η(n), is of a form:

$$\eta(n) = \varepsilon(n)e^{-j\psi(n)}, \text{where } \varepsilon(n) \text{ is the error signal,}$$

and wherein, where selected, steps 10A8a-10A8g further include one of 10A8h-10A8k:

10A8h)   the steps 10A8h1-10A8h2:

10A8h1)   utilizing a bulk delay unit to provide a delay in accordance with a listener echo bulk delay B_L; and

10A8h2)   utilizing an adaptive transversal filter unit whose coefficients are $a_k(n)$, where k = 0, 1, 2, ..., M-1, where M is a number of taps in the transversal filter unit, and whose output is of a form

$$p(n) = \sum_{k=0}^{M-1} g(k + n + B_L)a_k(n), \text{ where n is a discrete time}$$

index and g() is input from the first switching unit, wherein,

where selected, B_L is determined by a talker far echo ranging method,

     10A8i) further including that the received data phase correction estimate $\phi(n)$ is determined utilizing a
5 received communication signal data phase error α where:

$$\alpha(n) \approx \frac{v_r(n)u_i(n) - u_r(n)v_i(n)}{|v(n)|^2}$$; which is used to estimate a

frequency offset of a received communication signal $f_D(n)$ and the received data phase correction estimate $\phi(n)$, such that:

10       $f_D(n+1) = f_D(n) + c_1\alpha(n)$; and

       $\phi(n + 1) = \phi(n) + c_2\alpha(n) + c_3 f_D(n+1)$,

where u(n) is the first corrected signal further phase-corrected by $\phi(n)$, u_r and u_i are the real and imaginary parts,
15 respectively, of u(n), v_r and v_i are the real and imaginary parts, respectively, of v(n), wherein v(n) is the reference signal r(n) for selection of a reference directed training mode and being the preliminary decision output for selection of a communication signal receiving mode,
20 and c_1, c_2, and c_3 are constants that determine a desired phase-locked loop characteristic for a phase-locked loop having an input $\alpha(n)$,

     10A8j) further including that the rotated decision signal d(n) is of a form
25 $d(n) = v(n)e^{-j\phi(n)}$, n being the discrete time index, and

     10A8k) further including the steps of:

     utilizing a noise prediction filter (NPF) to receive and filter the equalized signal, so that a noise spectrum of the equalized signal is whitened; and
30   utilizing an inverse noise prediction filter (NPF^{-1}) for filtering the error signal to provide a filtered error signal for updating equalizer coefficients,

     10B) further including that the listener echo estimate is of a form:

$e_L(n) = p(n)e^{j\psi(n)}$, where n is a discrete time index, p(n) is the first listener echo estimate, and $\psi(n)$ is a listener echo phase correction estimate, wherein, where selected, $\psi(n)$ is determined utilizing one of 10B1-10B2:

5   10B1) utilizing a listener echo phase error $\theta(n)$ where

$$\theta(n) \approx \frac{e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)}{|q(n)||e_L(n)|} ,$$

where e_{Lr} and e_{Li} are the real and imaginary parts, respectively, of $e_L(n)$, and q_r and q_i are the real and imaginary

10   parts, respectively, of the equalized signal q(n); and

further including that a listener echo phase-locked loop of the first correcting unit determines an estimate of the listener echo frequency offset component $f_L(n)$ and a phase correction estimate $\psi(n)$ for correcting a phase of the signal

15   p(n), wherein:

$f_L(n+1) = f_L(n) + b_1\theta(n)$, and

$\psi(n+1) = \psi(n) + b_2\theta(n) + b_3f_L(n+1)$,

where b_1, b_2, and b_3 are constants that determine a phase lock loop characteristic and $f_L(n)$ is initialized, where desired,

20   utilizing a talker far echo frequency offset estimate to facilitate an initial convergence; and

10B2)   by determining, a sign of $\theta(n)$, denoted as s(n):

$s(n) = \text{sign}[e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n)]$,

25   defining s(n)=1 for $e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n) > TH$,

s(n)=-1 for $e_{Li}(n)q_r(n) - e_{Lr}(n)q_i(n) < TH$, and

s(n) = 0 otherwise, where TH is a small predetermined positive threshold value;

and determining $f_L(n+1) = f_L(n) + d_1s(n)$, and

30   $\psi(n+1) = \psi(n) + d_2s(n) + b_3f_L(n+1)$, where d_1 and d_2 are selected constants and $f_L(n)$, where desired, is initialized using a talker far echo frequency offset estimate to facilitate an initial convergence,

10C)   further including that the first corrected signal, z(n), is of a form:

$z(n) = q(n) - e_L(n)$, where q(n) is the equalized signal, and

10D) further including that the second corrected signal,
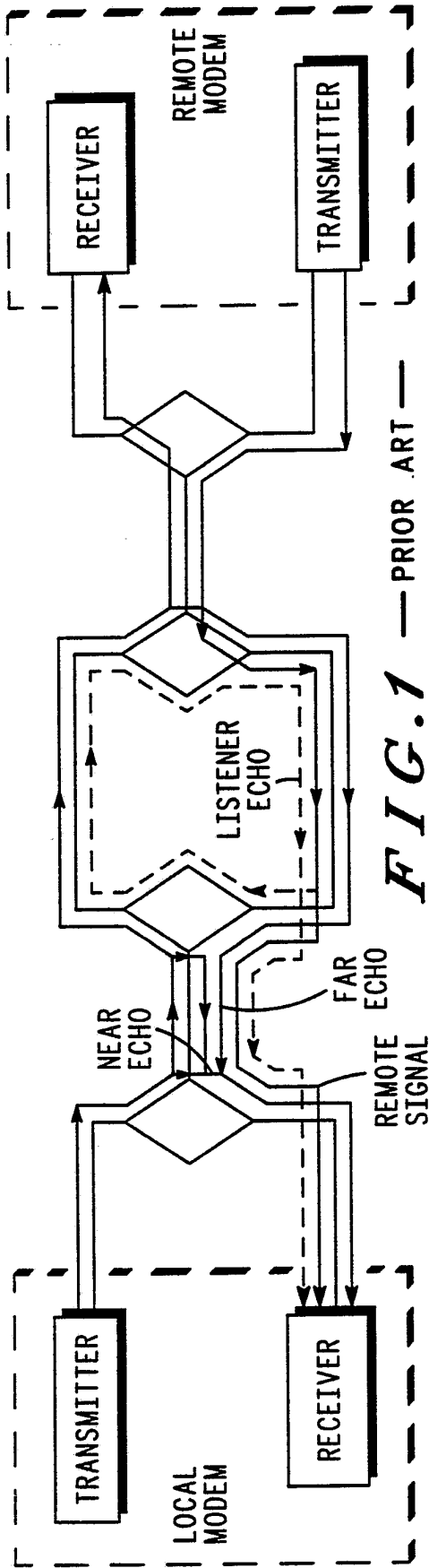
5   u(n), is of a form:

$u(n) = z(n)e^{j\phi(n)}$.

FIG.1 —PRIOR ART—

FIG.2A
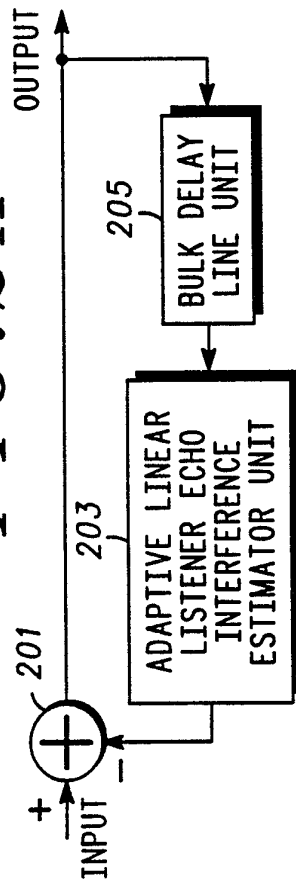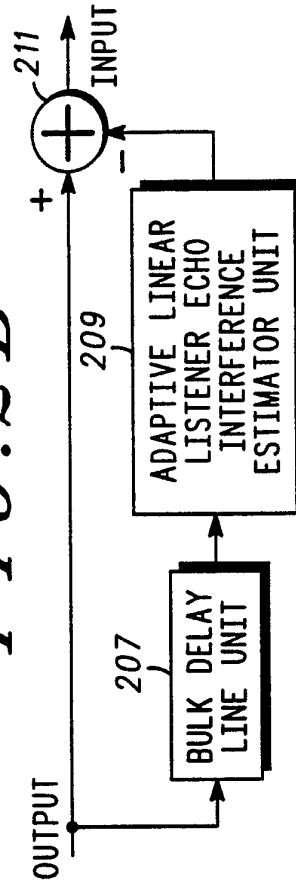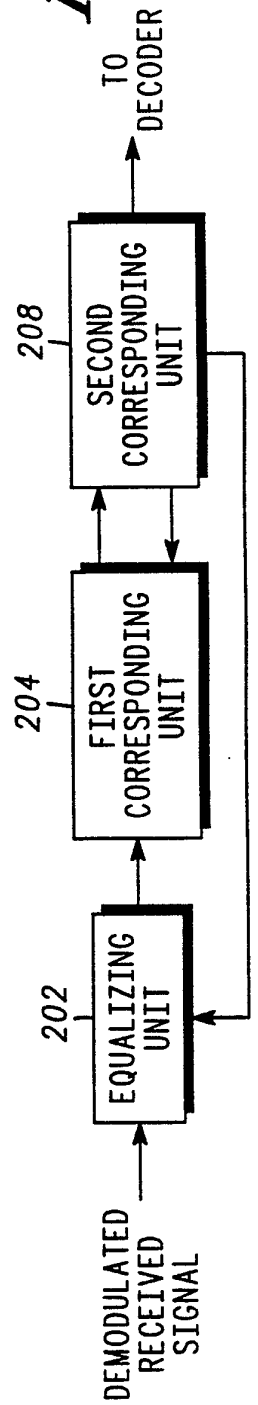
FIG.2B

FIG.2C
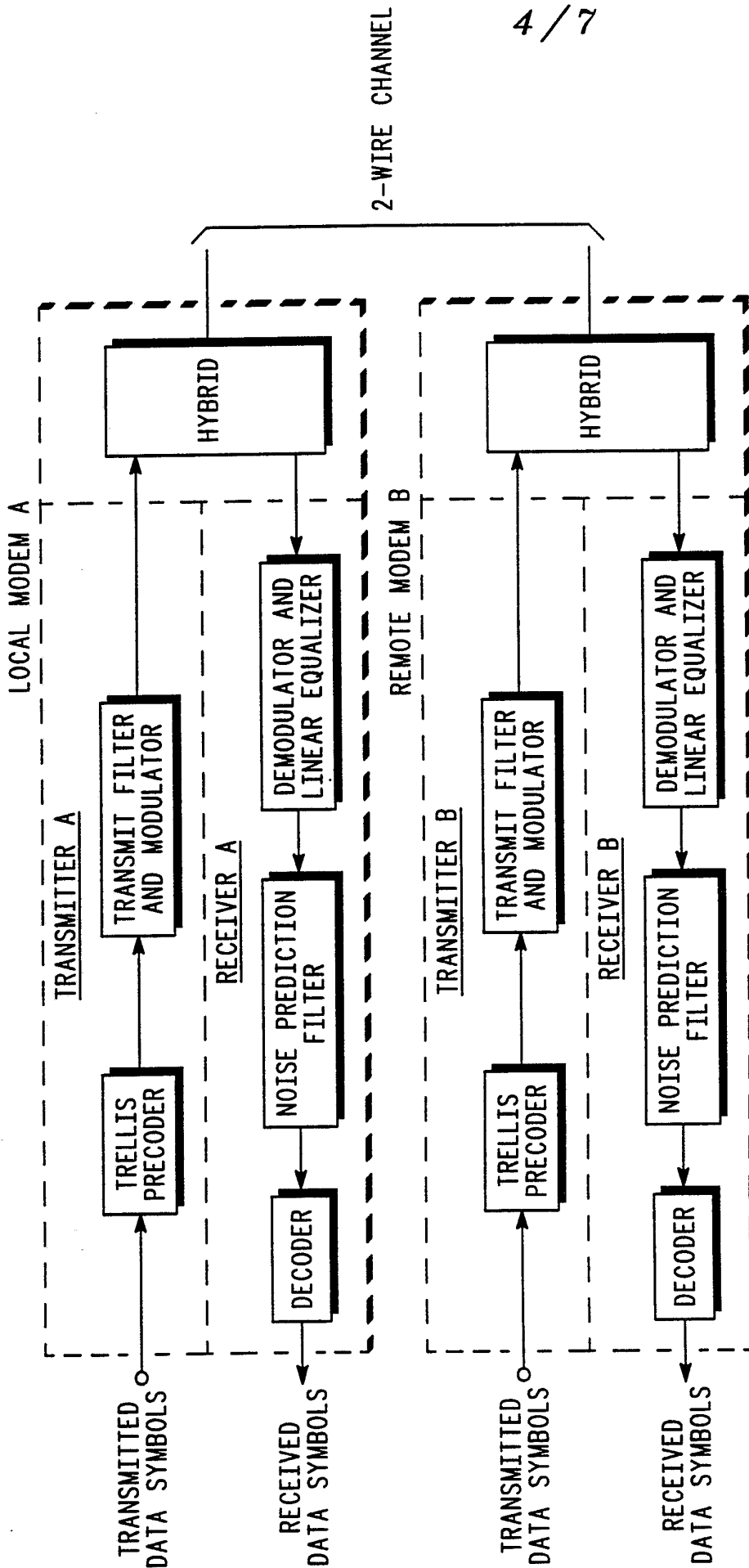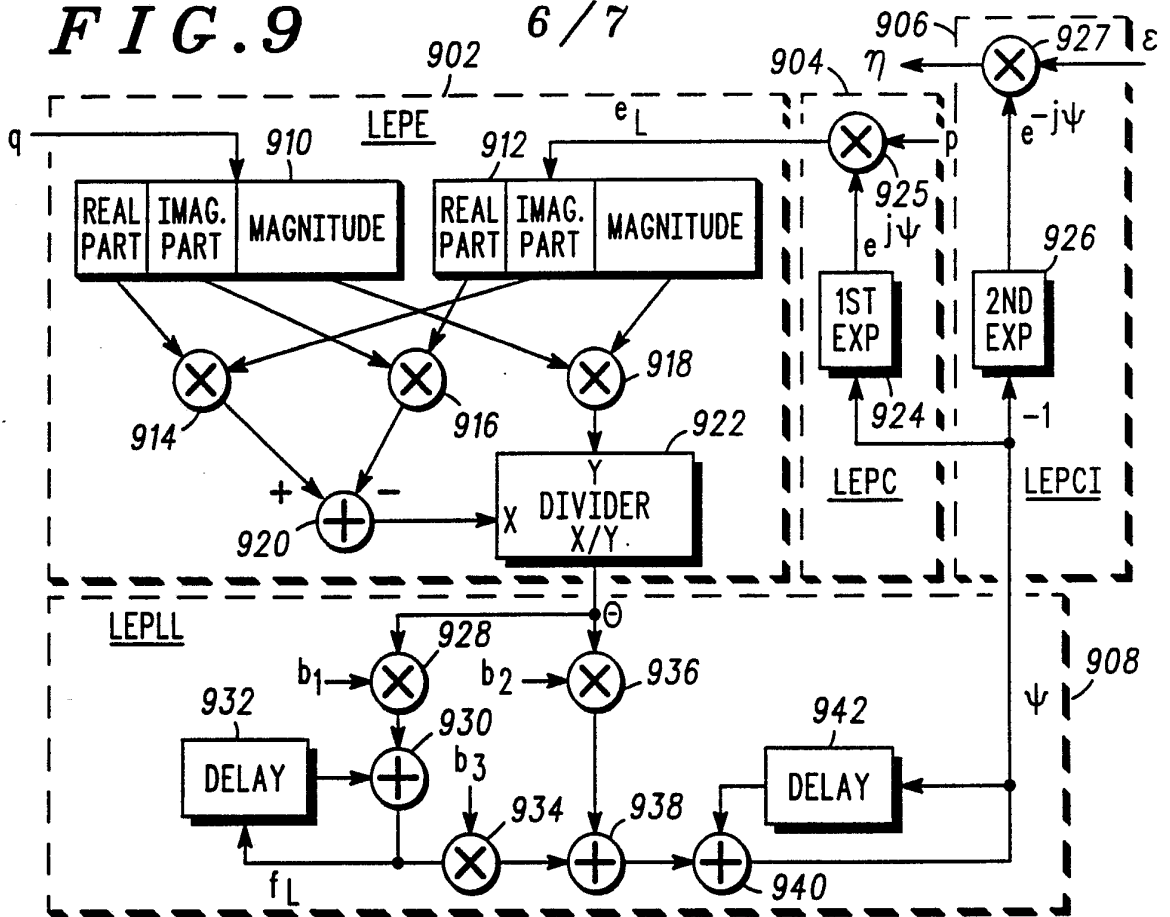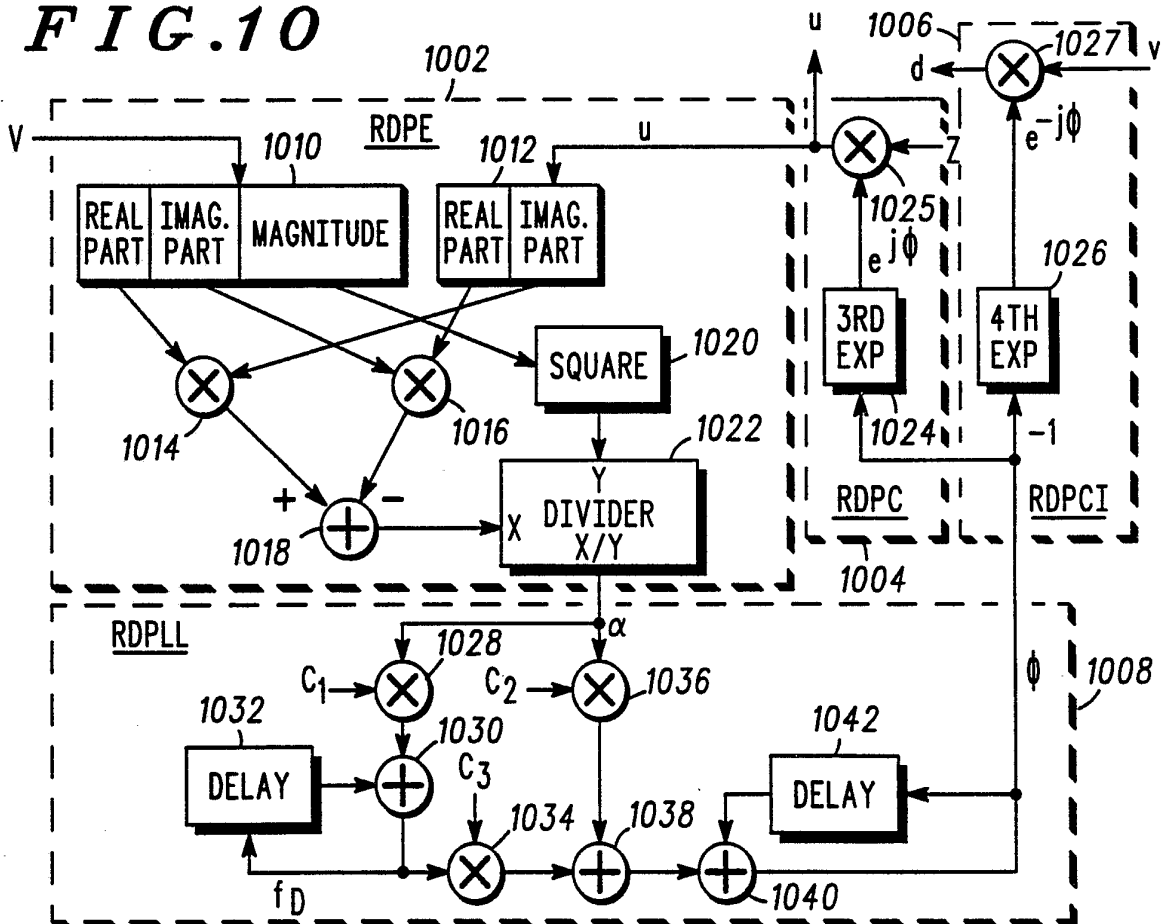
FIG.2D

FIG.2E

FIG.5

FIG.3

FIG.4

FIG.6

FIG.7

FIG.8

FIG.9

FIG.10

7 / 7

FIG.11

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H04J 1/00
US CL :370/32.1; 379/406; 379/410
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 375/34, 103; 379/407, 411

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

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

Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P Y	US,A, 5,117,418 (Chaffee et al.) 26 May 1992 (26.06.92) col. 3, lines 39-48, lines 49-64, and col. 4, lines 1-10.	1-4,7 8
X,P Y	US,A, 5,132,963 (Ungerboeck) 21 July 1992 (21.07.92) col. 3, line 10, and figure 1.	5,9 6, 10
Y	US,A, 4995,031 (Aly et al.) 19 February 1991 (19.02.91) col. 2, lines 42-48, col. 7, line 17 to col. 8, line 7.	6, 8, 10

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
25 NOVEMBER 1992	04 JAN 1993
Name and mailing address of the ISA/ Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. NOT APPLICABLE	Authorized officer SCHICK HOM Telephone No. (703) 305-4795

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

B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

USPTO APS

(echo canceller and delay line)
(echo canceller and equaling?)
(echo canceller and feedbank and feed   forward)