# United States Patent [19]

**Atkinson et al.**

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[54] **METHOD AND APPARATUS FOR DIVERSITY RECEPTION OF TIME-DISPERSED SIGNALS**


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[51] **Int. Cl.**[5] ........................ **H04B 7/005;** H04B 7/08

[52] **U.S. Cl.** ........................................ **375/13;** 375/14; 375/96; 375/100; 455/138

[58] **Field of Search** ..................... 375/13, 14, 96, 100, 375/102, 103, 106; 455/137, 138, 139


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G. Ungerboeck, "Adaptive Maximum Likelihood Receiver for Carrier–Modulated Data–Transmission Systems," IEEE Transactions on Communications, vol. COM–22, No. 5, May 1974, pp. 624–636.

G. D. Forney, "Maximum Likelihood Sequence Estimation of Digital Sequences in the Presence of Intersymbol Interference", IEEE Transactions on Information Theory, vol. IT–18, No. 3, May, 1972, pp. 363–377.

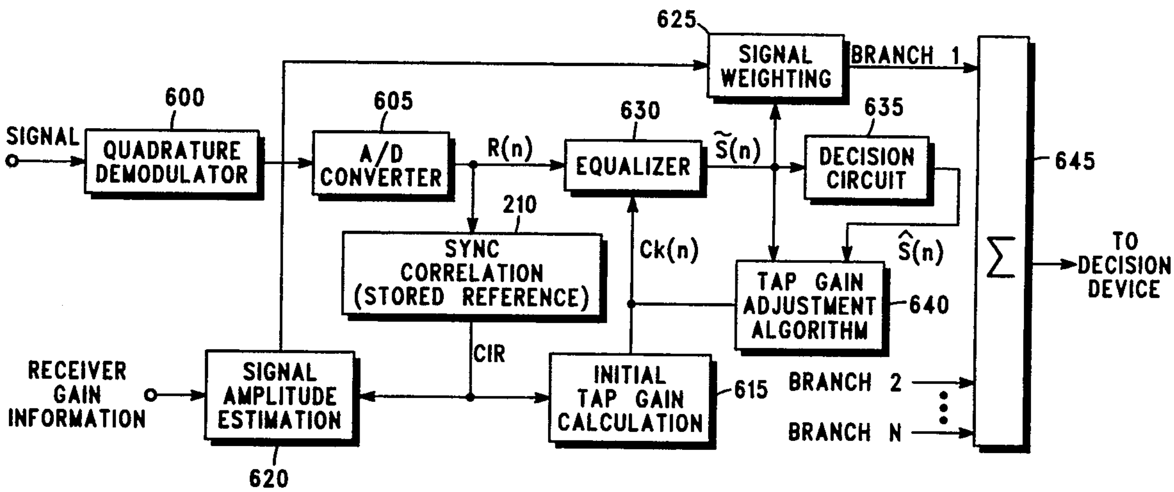
John G. Proakis, "Digital Communications", McGraw–Hill Book Company, 1983, pp. 357–386.


*Primary Examiner*—Benedict V. Safourek
*Attorney, Agent, or Firm*—Shawn B. Dempster; F. John Motsinger

[57] **ABSTRACT**


A method and appartus for diversity reception in a communication system wherein at least a dual branch receiver is provided with a stored replica of expected reference information that is correlated with the received time-dispersed signals to obtain an estimate of the transmission channel's impulse response as seen by each branch, and determine, among other things, phase error between the branch local oscillators and the time-dispersed signals. Matched filters are constructed which then coherently align the time-dispersed signals from each branch with that branch's local oscillator, also constituting the first part of the equalization. The diversity processing stage may perform bit by bit selection on the re-aligned signals, maximal ratio combining of the re-aligned signals, or equal gain combining of the re-aligned signals, following each by a sequence estimation which uses similarly selected or combined channel distortion compensation parameters to complete the equalization process on the new signal. In digital modulated carrier systems, providing expected reference information eliminates the neeed for carrier recovery feedback for each branch while performing part of the equalization process.


**27 Claims, 3 Drawing Sheets**



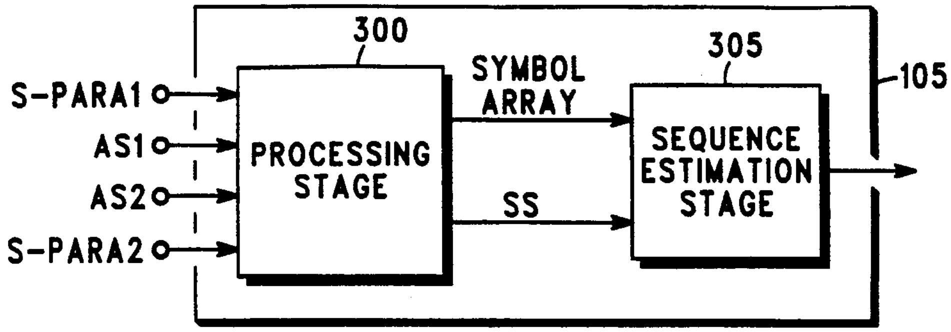



FIG. 3

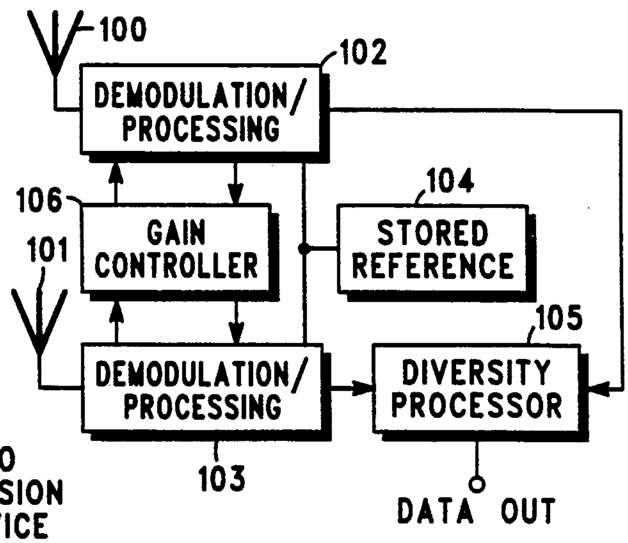



FIG. 1

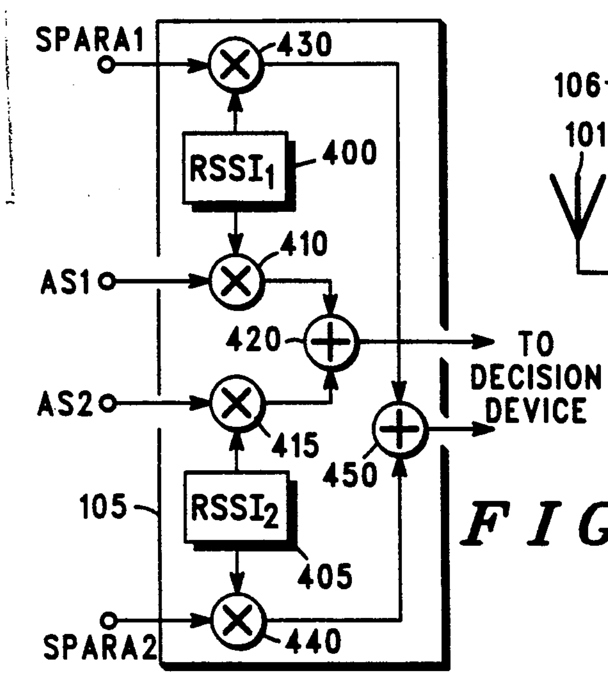



FIG. 4

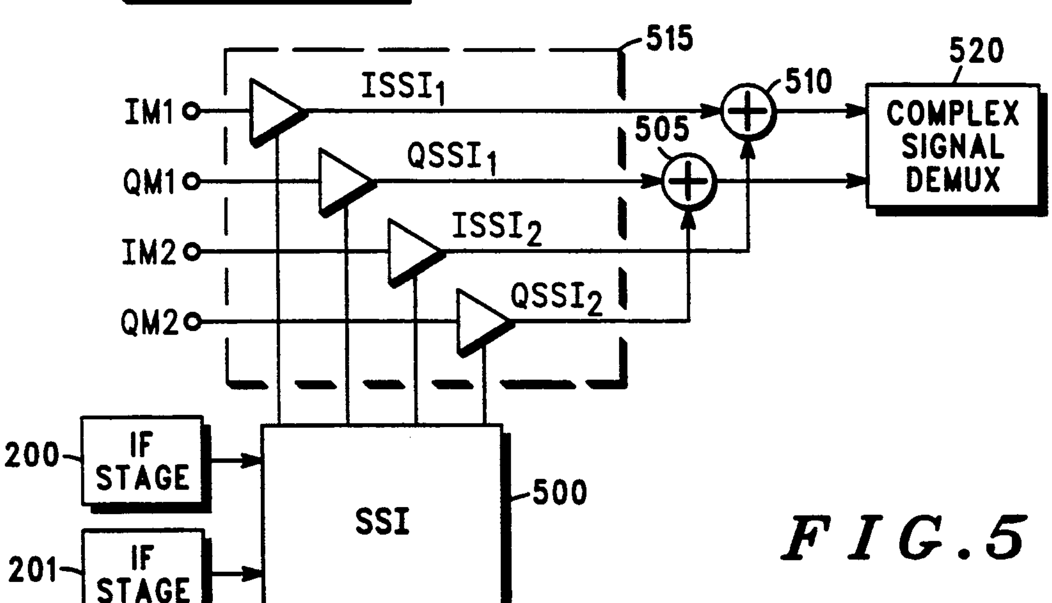



FIG. 5

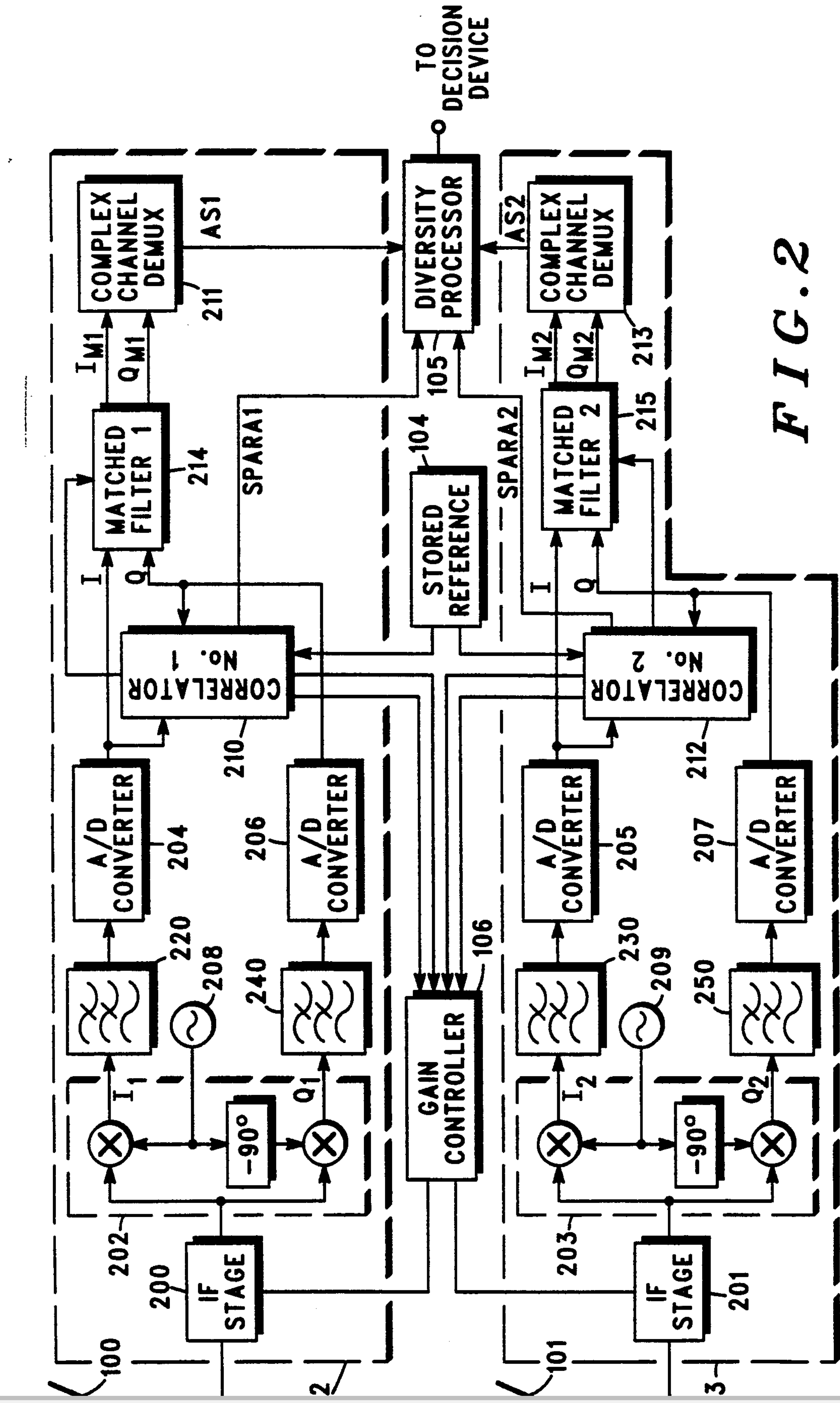

TO DECISION DEVICE
COMPLEX CHANNEL DEMUX
AS1
211
DIVERSITY PROCESSOR
AS2
COMPLEX CHANNEL DEMUX
213
$I_{M1}$
$Q_{M1}$
105
$I_{M2}$
$Q_{M2}$
MATCHED FILTER 1
214
SPARA1
104
STORED REFERENCE
SPARA2
MATCHED FILTER 2
215
I
Q
I
Q
CORRELATOR No. 1
CORRELATOR No. 2
210
212
A/D CONVERTER
204
206
A/D CONVERTER
A/D CONVERTER
205
207
A/D CONVERTER
220
208
240
106
230
209
250
GAIN CONTROLLER
$I_1$
$Q_1$
$I_2$
$Q_2$
-90°
-90°
202
203
200
IF STAGE
IF STAGE
201
100
2
101
3

FIG. 2

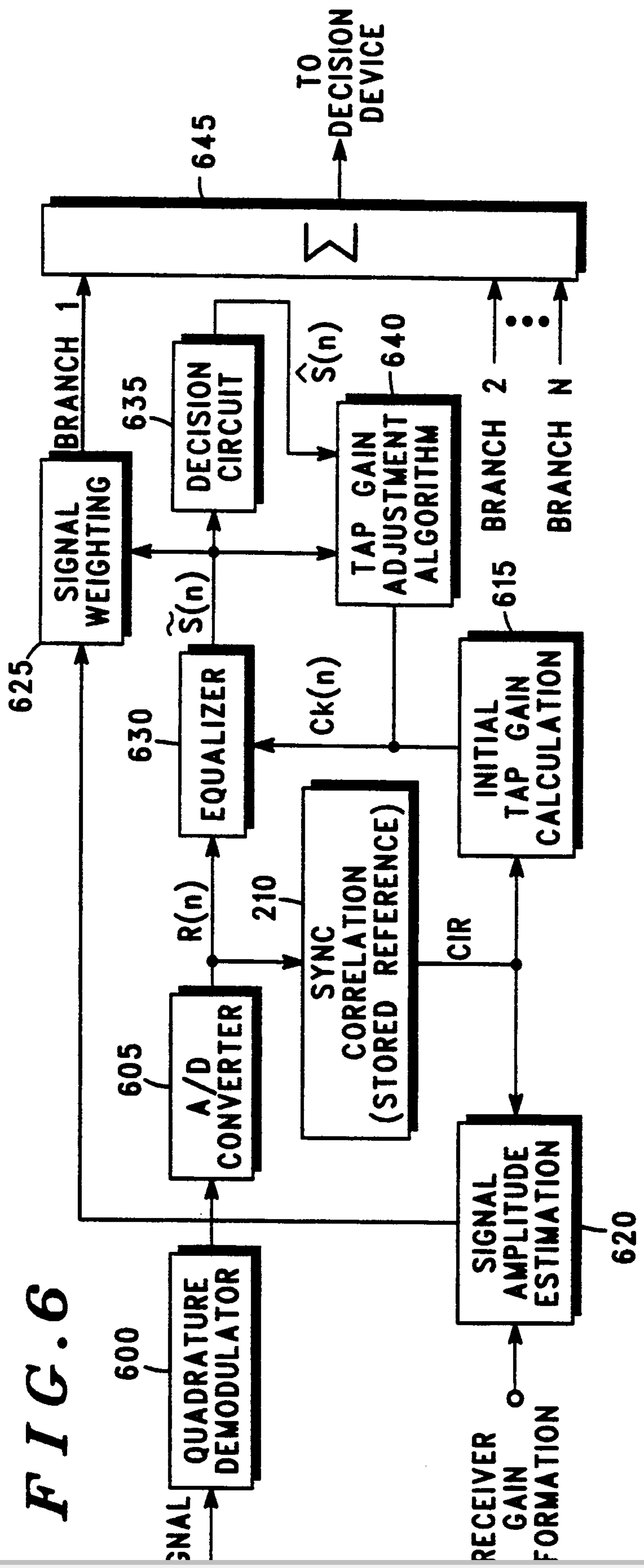

TO DECISION DEVICE
645
Σ
BRANCH 1
SIGNAL WEIGHTING
625
635
DECISION CIRCUIT
Ŝ(n)
640
TAP GAIN ADJUSTMENT ALGORITHM
S̃(n)
BRANCH 2
BRANCH N
615
630
EQUALIZER
Ck(n)
INITIAL TAP GAIN CALCULATION
210
SYNC CORRELATION (STORED REFERENCE)
R(n)
CIR
605
A/D CONVERTER
SIGNAL AMPLITUDE ESTIMATION
620
600
QUADRATURE DEMODULATOR
RECEIVER
GAIN

FIG. 6

# METHOD AND APPARATUS FOR DIVERSITY RECEPTION OF TIME-DISPERSED SIGNALS

## TECHNICAL FIELD OF INVENTION

This invention relates generally to diversity receivers in communication systems and more specifically to receivers providing diversity reception for time-dispersed signals in communication systems.

## BACKGROUND OF THE INVENTION

Enhanced signal detection in a time-dispersive medium generally requires a receiver to perform some type of echo signal equalization on the received time-dispersed signals to produce an output which has a better output than would result from allowing the echoes to interfere with one another. One such equalization technique used in a digital radio Time Division Multiple Access (TDMA) system is described in instant assignee's U.S. Pat. No. 4,829,543 entitled "Phase-Coherent TDMA Quadrature Receiver for Multipath Fading Channels" filed on behalf of Borth et al.

The Borth et al. invention describes a phase coherent method for demodulating a Quadrature Phase Shift Keyed (QPSK) radio signal that is subjected to multipath fading. Equalization is facilitated by correlating a stored training sequence, known to the receiver, against the incoming signal, and using the resulting correlation to remove the phase difference between the incoming signal and the receiver's local oscillator, effecting coherent detection. Equalization can then proceed.

Other techniques have been proposed for dealing with the intersymbol interference which can be generated in a transmitted signal by a time-dispersive transmission channel. Such receivers are described in "Adaptive Maximum Likelihood Receiver for Carrier-Modulated Data-Transmission Systems", authored by G. Ungerboeck, IEEE Transactions on Communications, Vol. COM-22, No. 5, May 1974, pp. 624–636, and "Maximum Likelihood Sequence Estimation of Digital Sequences in the Presence of Intersymbol Interference", authored by G. D. Forney, IEEE Transactions on Information Theory, Vol IT-18, No. 3, May, 1972, pp. 363–377.

However, in high data rate systems where transmission is through a severely delay-spread radio channel, single branch-single receiver equalization may fail to provide adequate time-dispersed distortion (multi-ray fading) correction. For example, practical implementations of equalizing receivers may have imperfect estimates of the critical error signal in the case of decision feedback equalization, or imperfect estimates of the transmission channel's impulse response in some other equalization schemes.

Therefore, diversity reception (the same signal received on multiple branches—which may be on different antennas, or on a single antenna at different times, or made in other ways, as is well known in the art) is typically necessary to sufficiently reduce the effect of multi-ray fading. One such receiver is described in U.S. Pat. No. 4,271,525 entitled, "Adaptive Diversity Receiver For Digital Communications". This patent describes an adaptive diversity receiver using an adaptive transversal filter for each receiver branch, followed by a decision feedback equalizer. The tap gains of the transversal filters are updated via feedback from the output of the equalizer, and other points in the receiver.



U.S. Pat. No. 4,731,801 entitled "Method For The Reception And Detection Of Digital Signals" discloses an improvement over U.S. Pat. No. 4,271,525 and other prior art by improving reception in highly dispersive transmission paths using coherent demodulation. This invention uses a technique wherein the output of the bit decision circuitry becomes a basis for calculating a correction signal. A reference carrier, resulting from summing the quadrature baseband signals and the in-phase baseband signals, is fed back to the local oscillator of quadrature demodulators which in turn compensates the phase difference between the received signals and the receiver's local oscillator to facilitate coherent demodulation.

However, inventions such as described in U.S. Pat. No. 4,271,525 require a set of adaptive transversal filters, one for each receiver branch, in addition to the equalization circuitry. Inventions such as U.S. Pat. No. 4,731,801 require complex circuitry to phase shift the signal in each diversity branch, and, more importantly, cannot arrive at the correct phase adjustments quickly enough to be useful in, for example, TDMA systems characterized by information which is received, and must be corrected, in short bursts separated by relatively long periods of time. During these long periods, signal phases in multi-ray fading channels can change radically relative to the receiver's local oscillator.

Accordingly, there exists a need for a reduced complexity receiver that performs diversity reception on continuous, or non-continuous, high speed digital signals and is capable of substantially reducing effects of both flat fading and multi-ray, dispersive fading due to time-dispersive transmission mediums.

## SUMMARY OF THE INVENTION

These needs and others are substantially met by the method and apparatus for diversity reception of time-dispersed signals in communication systems disclosed below. The described method comprises correlating a first time-dispersed signal received on a first receiver branch against a known reference, resulting in a first correlation signal, and correlating a second time-dispersed signal received on at least a second receiver branch, against the known reference, resulting in a second correlation signal, then, using the correlation signals, re-aligning the first time dispersed signal and the second time dispersed signal to the known receiver reference signal and the branch's local oscillator, resulting in a first aligned signal and a second aligned signal, and generating a resulting signal in view of the first aligned signal and the second aligned signal.

The known reference signal is located in a stored look-up table (containing multiple synchronizing sequences as is appropriate in the case of either a Time Division Multiple Access (TDMA) system or a Frequency Domain Multiple Access (FDMA) system with embedded reference signals). The correlation determines, among other things, an estimate of the radio transmission channel's impulse response. After correlation is complete, a matched filter, usually a transversal filter having taps derived from the estimated channel impulse response, is used to perform a convolution on the time-dispersed received signals, thereby performing a phase equalization. The phase equalization substantially compensates for the phase difference between the received time-dispersed signal and the local oscillator in each receiver branch.

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