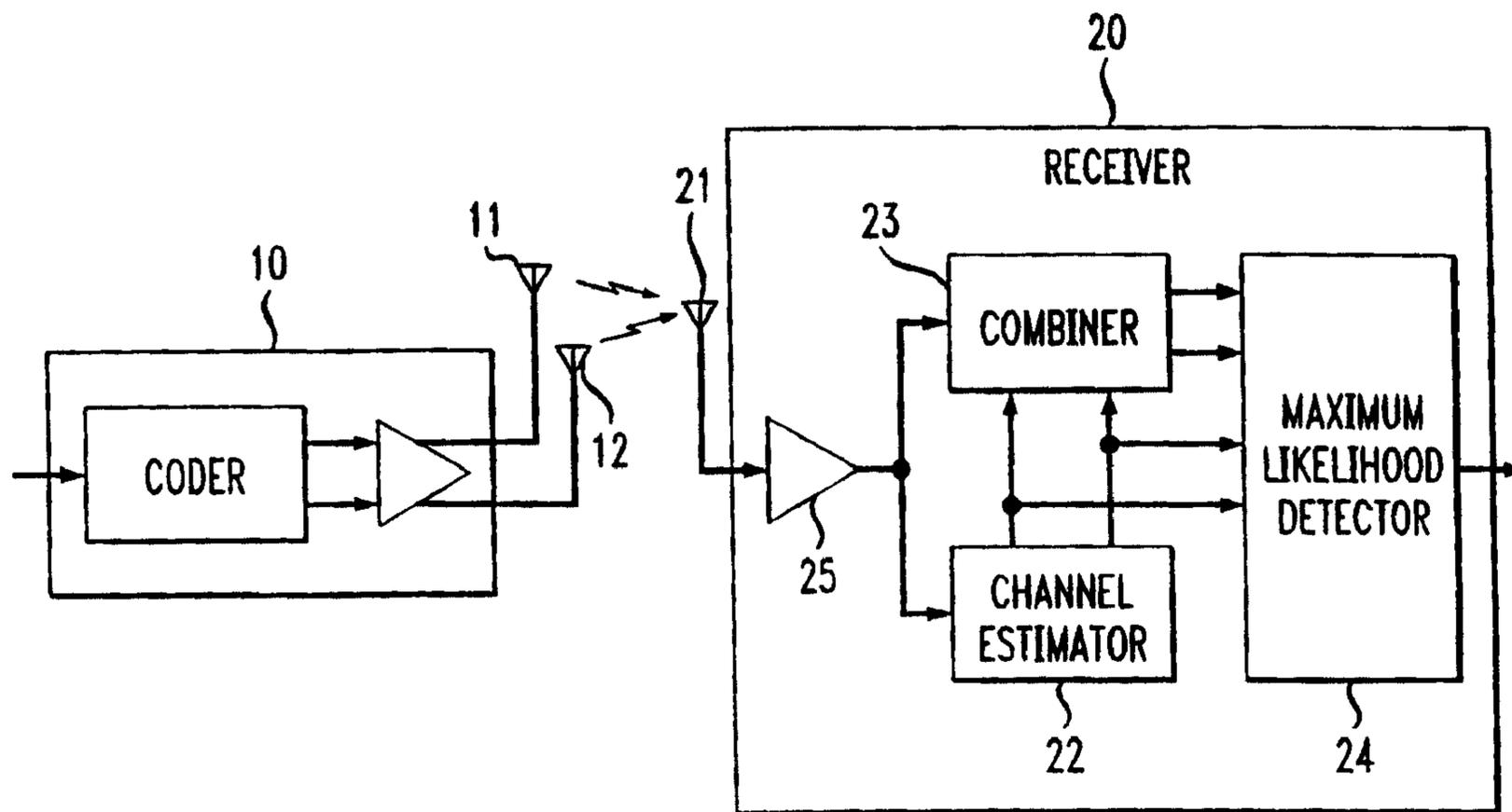




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(57) Abrégé/Abstract:

A simple block coding arrangement is created with symbols transmitted over a plurality of transmit channels, in connection with coding that comprises only simple arithmetic operations, such as negation and conjugation. The diversity created by the transmitter utilizes space diversity and either time or frequency diversity. Space diversity is effected by redundantly transmitting over a plurality of antennas, time diversity is effected by redundantly transmitting at different times, and frequency diversity is effected by redundantly transmitting at different frequencies. Illustratively, using two transmit antennas and a single receive antenna, one of the disclosed embodiments provides the same diversity gain as the maximal-ratio receiver combining (MRRC) scheme with one transmit antenna and two receive antennas. The principles of this invention are applicable to arrangements with more than two antennas, and an illustrative embodiment is disclosed using the same space block code with two transmit and two receive antennas.

(57) Abstract

A simple block coding arrangement is created with symbols transmitted over a plurality of transmit channels, in connection with coding that comprises only simple arithmetic operations, such as negation and conjugation. The diversity created by the transmitter utilizes space diversity and either time or frequency diversity. Space diversity is effected by redundantly transmitting over a plurality of antennas, time diversity is effected by redundantly transmitting at different times, and frequency diversity is effected by redundantly transmitting at different frequencies. Illustratively, using two transmit antennas and a single receive antenna, one of the disclosed embodiments provides the same diversity gain as the maximal-ratio receiver combining (MRRC) scheme with one transmit antenna and two receive antennas. The principles of this invention are applicable to arrangements with more than two antennas, and an illustrative embodiment is disclosed using the same space block code with two transmit and two receive antennas.

Transmitter Diversity Technique for Wireless Communications

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Background of the Invention

This invention relates to wireless communication and, more particularly, to techniques for effective wireless communication in the presence of fading and other degradations.

The most effective technique for mitigating multipath fading in a wireless radio channel is to cancel the effect of fading at the transmitter by controlling the transmitter's power. That is, if the channel conditions are known at the transmitter (on one side of the link), then the transmitter can pre-distort the signal to overcome the effect of the channel at the receiver (on the other side). However, there are two fundamental problems with this approach. The first problem is the transmitter's dynamic range. For the transmitter to overcome an x dB fade, it must increase its power by x dB which, in most cases, is not practical because of radiation power limitations, and the size and cost of amplifiers. The second problem is that the transmitter does not have any knowledge of the channel as seen by the receiver (except for time division duplex systems, where the transmitter receives power from a known other transmitter over the same channel). Therefore, if one wants to control a transmitter based on channel characteristics, channel information has to be sent from the receiver to the transmitter, which results in throughput degradation and added complexity to both the transmitter and the receiver.

Other effective techniques are time and frequency diversity. Using time interleaving together with coding can provide diversity improvement. The same holds for frequency hopping and spread spectrum. However, time interleaving results in unnecessarily large delays when the channel is slowly varying.

Equivalently, frequency diversity techniques are ineffective when the coherence bandwidth of the channel is large (small delay spread).

It is well known that in most scattering environments antenna diversity is the most practical and effective technique for reducing the effect of multipath fading.

5 The classical approach to antenna diversity is to use multiple antennas at the receiver and perform combining (or selection) to improve the quality of the received signal.

The major problem with using the receiver diversity approach in current wireless communication systems, such as IS-136 and GSM, is the cost, size and power consumption constraints of the receivers. For obvious reasons, small size, weight and cost are paramount. The addition of multiple antennas and RF chains (or selection and switching circuits) in receivers is presently not be feasible. As a result, diversity techniques have often been applied only to improve the up-link (receiver to base) transmission quality with multiple antennas (and receivers) at the base station. Since a base station often serves thousands of receivers, it is more economical to add equipment to base stations rather than the receivers

Recently, some interesting approaches for transmitter diversity have been suggested. A delay diversity scheme was proposed by A. Wittneben in "Base Station Modulation Diversity for Digital SIMULCAST," Proceeding of the 1991 IEEE Vehicular Technology Conference (VTC 41 st), PP. 848-853, May 1991, and in "A New Bandwidth Efficient Transmit Antenna Modulation Diversity Scheme For Linear Digital Modulation," in Proceeding of the 1993 IEEE International Conference on Communications (IICC '93), PP. 1630-1634, May 1993. The proposal is for a base station to transmit a sequence of symbols through one antenna, and the same sequence of symbols –but delayed – through another antenna.

25 U.S. patent 5,479,448, issued to Nambirajan Seshadri on December 26, 1995, discloses a similar arrangement where a sequence of codes is transmitted through two antennas. The sequence of codes is routed through a cycling switch that directs each code to the various antennas, in succession. Since copies of the

same symbol are transmitted through multiple antennas at different times, both space and time diversity are achieved. A maximum likelihood sequence estimator (MLSE) or a minimum mean squared error (MMSE) equalizer is then used to resolve multipath distortion and provide diversity gain. See also N. Seshadri, J.H. Winters, "Two Signaling Schemes for Improving the Error Performance of FDD Transmission Systems Using Transmitter Antenna Diversity," *Proceeding of the 1993 IEEE Vehicular Technology Conference (VTC 43rd)*, pp. 508-511, May 1993; and J. H. Winters, "The Diversity Gain of Transmit Diversity in Wireless Systems with Rayleigh Fading," *Proceeding of the 1994 ICC/SUPERCOMM*, New Orleans, Vol. 2, PP. 1121-1125, May 1994.

In still another interesting approach symbols are encoded according to the antennas through which they are simultaneously transmitted, and are decoded using a maximum likelihood decoder. More specifically, the process at the transmitter handles the information in blocks of M_1 bits, where M_1 is a multiple of M_2 , i.e., $M_1 = k * M_2$. It converts each successive group of M_2 bits into information symbols (generating thereby k information symbols), encodes each sequence of k information symbols into n channel codes (developing thereby a group of n channel codes for each sequence of k information symbols), and applies each code of a group of codes to a different antenna.

Summary

The problems of prior art systems are overcome, and an advance in the art is realized with a simple block coding arrangement where symbols are transmitted over a plurality of transmit channels and the coding comprises only simple arithmetic operations, such as negation and conjugation. The diversity created by the transmitter utilizes space diversity and either time diversity or frequency diversity. Space diversity is effected by redundantly transmitting over a plurality of

antennas; time diversity is effected by redundantly transmitting at different times; and frequency diversity is effected by redundantly transmitting at different frequencies. Illustratively, using two transmit antennas and a single receive antenna, one of the disclosed embodiments provides the same diversity gain as the maximal-ratio receiver combining (MRRC) scheme with one transmit antenna and two receive antennas. The novel approach does not require any bandwidth expansion or feedback from the receiver to the transmitter, and has the same decoding complexity as the MRRC. The diversity improvement is equal to applying maximal-ratio receiver combining (MRRC) at the receiver with the same number of antennas. The principles of this invention are applicable to arrangements with more than two antennas, and an illustrative embodiment is disclosed using the same space block code with two transmit and two receive antennas. This scheme provides the same diversity gain as four-branch MRRC.

15 **Brief Description of the Drawings**

FIG. 1 is a block diagram of a first embodiment in accordance with the principles of this invention;

FIG. 2 presents a block diagram of a second embodiment, where channel estimates are not employed;

20 FIG. 3 shows a block diagram of a third embodiment, where channel estimates are derived from recovered signals; and

FIG. 4 illustrates an embodiment where two transmitter antennas and two receiver antennas are employed.

25 **Detail Description**

In accordance with the principles of this invention, effective communication is achieved with encoding of symbols that comprises merely negations and conjugations of symbols (which really is merely negation of the imaginary part) in

combination with a transmitter created diversity. Space diversity and either frequency diversity or time diversity are employed.

FIG. 1 presents a block diagram of an arrangement where the two controllable aspects of the transmitter that are used are space and time. That is, the FIG. 1 arrangement includes multiple transmitter antennas (providing space diversity) and employs multiple time intervals. Specifically, transmitter 10 illustratively comprises antennas 11 and 12, and it handles incoming data in blocks n symbols, where n is the number of transmitter antennas, and in the illustrative embodiment of FIG. 1, it equals 2, and each block takes n symbol intervals to transmit. Also illustratively, the FIG. 1 arrangement includes a receiver 20 that comprises a single antenna 21.

At any given time, a signal sent by a transmitter antenna experiences interference effects of the traversed channel, which consists of the transmit chain, the air-link, and the receive chain. The channel may be modeled by a complex multiplicative distortion factor composed of a magnitude response and a phase response. In the exposition that follows therefore, the channel transfer function from transmit antenna 11 to receive antenna 21 is denoted by h_0 and from transmit antenna 12 to receive antenna 21 is denoted by h_1 , where:

$$\begin{aligned} h_0 &= \alpha_0 e^{j\theta_0} \\ h_1 &= \alpha_1 e^{j\theta_1} . \end{aligned} \quad (1)$$

Noise from interference and other sources is added at the two received signals and, therefore, the resulting baseband signal received at any time and outputted by reception and amplification section 25 is

$$r(t) = \alpha_0 e^{j\theta_0} s_i + \alpha_1 e^{j\theta_1} s_j + n(t) , \quad (2)$$

where s_i and s_j are the signals being sent by transmit antenna 11 and 12, respectively.

As indicated above, in the two-antenna embodiment of FIG. 1 each block comprises two symbols and it takes two symbol intervals to transmit those two symbols. More specifically, when symbols s_i and s_j need to be transmitted, at a first time interval the transmitter applies signal s_i to antenna 11 and signal s_j to antenna 12, and at the next time interval the transmitter applies signal $-s_i^*$ to antenna 11 and signal s_j^* to antenna 12. This is clearly a very simple encoding process where only negations and conjugations are employed. As demonstrated below, it is as effective as it is simple. Corresponding to the above-described transmissions, in the first time interval the received signal is

$$r(t) = h_0 s_i + h_1 s_j + n(t),$$

(3)

and in the next time interval the received signal is

$$r(t+T) = -h_0 s_j^* + h_1 s_i^* + n(t+T).$$

(4)

Table 1 illustrates the transmission pattern over the two antennas of the FIG. 1 arrangement for a sequence of signals $\{s_0, s_1, s_2, s_3, s_4, s_5, \dots\}$.

Table 1

Time:	t	t+T	t+2T	t+3T	t+4T	t+5T	
Antenna 11	s_0	$-s_1^*$	s_2	$-s_3^*$	s_4	$-s_5^*$
Antenna 12	s_1	s_0^*	s_3	s_2^*	s_5	s_4^*

The received signal is applied to channel estimator 22, which provides signals representing the channel characteristics or, rather, the best estimates thereof. Those signals are applied to combiner 23 and to maximum likelihood detector 24. The estimates developed by channel estimator 22 can be obtained by sending a known training signal that channel estimator 22 recovers, and based on the recovered signal the channel estimates are computed. This is a well known approach.

Combiner 23 receives the signal in the first time interval, buffers it, receives the signal in the next time interval, and combines the two received signals to develop signals

$$\begin{aligned}\tilde{s}_i &= \tilde{h}_0 * r(t) + \tilde{h}_1 r^*(t+T) \\ \tilde{s}_j &= \tilde{h}_1 * r(t) - \tilde{h}_0 r^*(t+T).\end{aligned}\tag{5}$$

Substituting equation (1) into (5) yields

$$\begin{aligned}\tilde{s}_i &= (\tilde{\alpha}_0^2 + \tilde{\alpha}_1^2)s_i + \tilde{h}_0 * n(t) + \tilde{h}_1 n^*(t+T) \\ \tilde{s}_j &= (\tilde{\alpha}_0^2 + \tilde{\alpha}_1^2)s_j - \tilde{h}_0 n^*(t+T) + \tilde{h}_1 * n(t),\end{aligned}\tag{6}$$

)

where $\tilde{\alpha}_0^2 = \tilde{h}_0 \tilde{h}_0^*$ and $\tilde{\alpha}_1^2 = \tilde{h}_1 \tilde{h}_1^*$, demonstrating that the signals of equation (6) are, indeed, estimates of the transmitted signals (within a multiplicative factor).

Accordingly, the signals of equation (6) are sent to maximum likelihood detector 24.

In attempting to recover s_i , two kind of signals are considered: the signals actually received at time t and $t+T$, and the signals that should have been received if s_j were the signal that was sent. As demonstrated below, no assumption is made regarding the value of s_j . That is, a decision is made that $s_i = s_x$ for that value of x for which

$$d^2[r(t), (h_0 s_x + h_1 s_j)] + d^2[r(t+T), (-h_1 s_j^* + h_0 s_x^*)]$$

is less than

$$d^2[r(t), (h_0 s_x + h_1 s_j)] + d^2[r(t+T), (-h_1 s_j^* + h_0 s_x^*)],$$

(7)

where $d^2(x, y)$ is the squared Euclidean distance between signals x and y , i.e.,

$$d^2(x, y) = |x - y|^2.$$

Recognizing that $\tilde{h}_0 = h_0 + \text{noise}$ that is independent of the transmitted symbol, and that $\tilde{h}_1 = h_1 + \text{noise}$ that is independent of the transmitted symbol, equation (7) can be rewritten to yield

$$(\alpha_0^2 + \alpha_1^2)|s_x|^2 - \tilde{s}_i s_x^* - \tilde{s}_i^* s_x \leq (\alpha_0^2 + \alpha_1^2)|s_k|^2 - \tilde{s}_i s_k^* - \tilde{s}_i^* s_k$$

5 (8)

where $\alpha_0^2 = h_0 h_0^*$ and $\alpha_1^2 = h_1 h_1^*$; or equivalently,

$$(\alpha_0^2 + \alpha_1^2 - 1)|s_x|^2 + d^2(\tilde{s}_i, s_x) \leq (\alpha_0^2 + \alpha_1^2 - 1)|s_k|^2 + d^2(\tilde{s}_i, s_k).$$

(9)

In Phase Shift Keying modulation, all symbols carry the same energy, which means that $|s_x|^2 = |s_k|^2$ and, therefore, the decision rule of equation (9) may be simplified to

10

$$\text{choose signal } \hat{s}_i = s_x \text{ iff } d^2(\tilde{s}_i, s_x) \leq d^2(\tilde{s}_i, s_k).$$

(10)

Thus, maximum likelihood detector 24 develops the signals s_k for all values of k , with the aid of \tilde{h}_0 and \tilde{h}_1 from estimator 22, develops the distances $d^2(\tilde{s}_i, s_k)$, identifies x for which equation (10) holds and concludes that $\hat{s}_i = s_x$. A similar process is applied for recovering \hat{s}_j .

15

In the above-described embodiment each block of symbols is recovered as a block with the aid of channel estimates \tilde{h}_0 and \tilde{h}_1 . However, other approaches to recovering the transmitted signals can also be employed. Indeed, an embodiment for recovering the transmitted symbols exists where the channel transfer functions need not be estimated at all, provided an initial pair of transmitted signals is known to the receiver (for example, when the initial pair of transmitted signals is prearranged). Such an embodiment is shown in FIG. 2, where maximum likelihood detector 27 is responsive solely to combiner 26. (Elements in FIG. 3 that are

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referenced by numbers that are the same as reference numbers in FIG. 1 are like elements.) Combiner 26 of receiver 30 develops the signals

$$\begin{aligned}
 r_0 &= r(t) = h_0 s_0 + h_1 s_1 + n_0 \\
 r_1 &= r(t+T) = h_1 s_0^* - h_0 s_1^* + n_1 \\
 5 \quad r_2 &= r(t+2T) = h_0 s_2 + h_1 s_3 + n_2 \\
 r_3 &= r(t+3T) = h_1 s_2^* - h_0 s_3^* + n_3,
 \end{aligned}
 \tag{1}$$

1)

then develops intermediate signals A and B

$$\begin{aligned}
 10 \quad A &= r_0 r_3^* - r_2 r_1^* \\
 B &= r_2 r_0^* + r_1 r_3^*, \\
 (12)
 \end{aligned}$$

and finally develops signals

$$\begin{aligned}
 \tilde{s}_2 &= A s_1^* + B s_0 \\
 15 \quad \tilde{s}_3 &= -A s_0^* + B s_1, \\
 (13)
 \end{aligned}$$

where N_3 and N_4 are noise terms. It may be noted that signal r_2 is actually

$r_2 = h_0 \hat{s}_2 + h_1 \hat{s}_3 = h_0 s_2 + h_1 s_3 + n_2$, and similarly for signal r_3 . Since the makeup of signals A and B makes them also equal to

$$\begin{aligned}
 20 \quad A &= (\alpha_0^2 + \alpha_1^2)(s_2 s_1 - s_3 s_0) + N_1 \\
 B &= (\alpha_0^2 + \alpha_1^2)(s_2 s_0^* + s_3 s_1^*) + N_2, \\
 (14)
 \end{aligned}$$

where N_1 and N_2 are noise terms, it follows that signals \tilde{s}_2 and \tilde{s}_3 are equal to

$$\begin{aligned}
 \tilde{s}_2 &= (\alpha_0^2 + \alpha_1^2)(|s_0|^2 + |s_1|^2)s_2 + N_3 \\
 25 \quad \tilde{s}_3 &= (\alpha_0^2 + \alpha_1^2)(|s_0|^2 + |s_1|^2)s_3 + N_4. \\
 (15)
 \end{aligned}$$

When the power of all signals is constant (and normalized to 1) equation (15) reduces to

$$\tilde{s}_2 = (\alpha_0^2 + \alpha_1^2)s_2 + N_3$$

$$\tilde{s}_3 = (\alpha_0^2 + \alpha_1^2)s_3 + N_4.$$

5 (16)

Hence, signals \tilde{s}_2 and \tilde{s}_3 are, indeed, estimates of the signals s_2 and s_3 (within a multiplicative factor). Equation (15) demonstrates the recursive aspect of equation (13), where signal estimates \tilde{s}_2 and \tilde{s}_3 are evaluated with the aid of recovered signals s_0 and s_1 that are fed back from the output of the maximum likelihood
10 detector.

Signals \tilde{s}_2 and \tilde{s}_3 are applied to maximum likelihood detector 24 where recovery is effected with the metric expressed by equation (10) above. As shown in FIG. 2, once signals s_2 and s_3 are recovered, they are used together with received signals r_2, r_3, r_4 , and r_5 to recover signals s_4 and s_5 , and the process repeats.

15 FIG. 3 depicts an embodiment that does not require the constellation of the transmitted signals to comprise symbols of equal power. (Elements in FIG. 3 that are referenced by numbers that are the same as reference numbers in FIG. 1 are like elements.) In FIG. 3, channel estimator 43 of receiver 40 is responsive to the output signals of maximum likelihood detector 42. Having access to the recovered signals
20 s_0 and s_1 , channel estimator 43 forms the estimates

$$\tilde{h}_0 = \frac{r_0 s_0^* - r_1 s_1}{|s_0|^2 + |s_1|^2} = h_0 + \frac{s_0^* n_0 + s_1 n_1}{|s_0|^2 + |s_1|^2}$$

$$\tilde{h}_1 = \frac{r_0 s_1^* - r_1 s_0}{|s_0|^2 + |s_1|^2} = h_1 + \frac{s_1^* n_0 + s_0 n_1}{|s_0|^2 + |s_1|^2}$$

(17)

and applies those estimates to combiner 23 and to detector 42. Detector 24 recovers
25 signals s_2 and s_3 by employing the approach used by detector 24 of FIG. 1, except

that it does not employ the simplification of equation (9). The recovered signals of detector 42 are fed back to channel estimator 43, which updates the channel estimates in preparation for the next cycle.

The FIGS. 1-3 embodiments illustrate the principles of this invention for arrangements having two transmit antennas and one receive antenna. However, those principles are broad enough to encompass a plurality of transmit antennas and a plurality of receive antennas. To illustrate, FIG. 4 presents an embodiment where two transmit antennas and two receive antennas are used; to wit, transmit antennas 31 and 32, and receive antennas 51 and 52. The signal received by antenna 51 is applied to channel estimator 53 and to combiner 55, and the signal received by antenna 52 is applied to channel estimator 54 and to combiner 55. Estimates of the channel transfer functions h_0 and h_1 are applied by channel estimator 53 to combiner 55 and to maximum likelihood detector 56. Similarly, estimates of the channel transfer functions h_2 and h_3 are applied by channel estimator 54 to combiner 55 and to maximum likelihood detector 56. Table 2 defines the channels between the transmit antennas and the receive antennas, and table 3 defines the notion for the received signals at the two receive antennas.

Table 2

	Antenna 51	Antenna 52
Antenna 31	h_0	h_2
Antenna 32	h_1	h_3

Table 3

	Antenna 51	Antenna 52
Time t	r_0	r_2
Time t+T	r_1	r_3

Based on the above, it can be shown that the received signals are

$$r_0 = h_0 s_0 + h_1 s_1 + n_0$$

$$r_1 = -h_0 s_1^* + h_1 s_0^* + n_1$$

$$\begin{aligned}
 r_2 &= h_2 s_0 + h_3 s_1 + n_2 \\
 r_3 &= -h_2 s_1^* + h_3 s_0^* + n_3
 \end{aligned}
 \tag{18}$$

where n_0, n_1, n_2 , and n_3 are complex random variables representing receiver
 5 thermal noise, interferences, etc.

In the FIG. 4 arrangement, combiner 55 develops the following two signals
 that are sent to the maximum likelihood detector:

$$\begin{aligned}
 \tilde{s}_0 &= h_0^* r_0 + h_1 r_1^* + h_2^* r_2 + h_3 r_3^* \\
 \tilde{s}_1 &= h_1^* r_0 - h_0 r_1^* + h_3^* r_2 - h_2 r_3^* .
 \end{aligned}
 \tag{19}$$

Substituting the appropriate equations results in

$$\begin{aligned}
 \tilde{s}_0 &= (\alpha_0^2 + \alpha_1^2 + \alpha_2^2 + \alpha_3^2) s_0 + h_0^* n_0 + h_1 n_1^* + h_2^* n_2 + h_3 n_3^* \\
 \tilde{s}_1 &= (\alpha_0^2 + \alpha_1^2 + \alpha_2^2 + \alpha_3^2) s_1 + h_1^* n_0 - h_0 n_1^* + h_3^* n_2 - h_2 n_3^* ,
 \end{aligned}
 \tag{20}$$

15 which demonstrates that the signals \tilde{s}_0 and \tilde{s}_1 are indeed estimates of the signals s_0
 and s_1 . Accordingly, signals \tilde{s}_0 and \tilde{s}_1 are sent to maximum likelihood decoder 56,
 which uses the decision rule of equation (10) to recover the signals \hat{s}_0 and \hat{s}_1 .

As disclosed above, the principles of this invention rely on the transmitter to
 force a diversity in the signals received by a receiver, and that diversity can be
 20 effected in a number of ways. The illustrated embodiments rely on space diversity –
 effected through a multiplicity of transmitter antennas, and time diversity – effected
 through use of two time intervals for transmitting the encoded symbols. It should be
 realized that two different transmission frequencies could be used instead of two
 time intervals. Such an embodiment would double the transmission speed, but it
 25 would also increase the hardware in the receiver, because two different frequencies
 need to be received and processed simultaneously.

The above illustrated embodiments are, obviously, merely illustrative implementations of the principles of the invention, and various modifications and enhancements can be introduced by artisans without departing from the spirit and scope of this invention, which is embodied in the following claims. For example,
5 all of the disclosed embodiments are illustrated for a space-time diversity choice, but as explained above, one could choose the space-frequency pair. Such a choice would have a direct effect on the construction of the receivers.

WHAT IS CLAIMED IS:

1. A system for wireless communication, comprising:
a transmitter for transmitting signals and comprising a coder that causes
5 diversity, wherein the signals comprise blocks of symbols, the
transmitter comprising at least two transmit antennas, and wherein
diversity includes space diversity and one type of diversity chosen
from a group comprising time diversity and frequency diversity, and
wherein at least some blocks of symbols provided to a transmit
10 antenna include negated and complex conjugated replications of
transmitted symbols; and
a receiver that receives diverse signals from the transmitter, wherein the
receiver comprises a combiner that combines signals received.
- 15 2. The system of claim 1, wherein the receiver comprises a channel estimator
developing estimates of transmit channel characteristics based on the
received signals.
- 20 3. The system of claim 1, wherein the receiver further comprises a maximum
likelihood detector that receives the combined signals and recovers the
transmitted signals based on a developed maximum likelihood decision.
- 25 4. The system of claim 3, wherein:
the combiner and the maximum likelihood detector receive the estimates of
transmit channel characteristics from the channel estimator, and
wherein
the symbols are symbols carrying equal energy.
- 30 5. The system of claim 3, wherein the maximum likelihood detector uses a
channel transfer function estimated by the channel estimator to determine a

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distance for which a relationship between the transmitted signal and the estimated channel characteristics holds.

6. The system of claim 1, wherein the receiver further comprises:
 5 more than one antenna that each receives the diverse signals from the transmitter; and
 more than one channel estimator that each receives the diverse signals from one of the more than one antennas.
- 10 7. The system of claim 4, wherein incoming data are in blocks of n symbols, and the multiple transmitting antennas comprise n transmitting antenna means, and wherein encoding further includes encoding an incoming block of symbols s_0 and s_1 into a sequence of symbols s_0 and $-s_1^*$, and into a sequence of symbols s_1 and s_0^* , where s_i^* is the complex conjugate of s_i .
- 15 8. The system of claim 7, wherein the multiple transmitting antennas comprise n transmitting antennas, and wherein in response to a sequence $\{s_0, s_1, s_2, s_3, s_4, \dots\}$ of incoming symbols the coder develops a sequence $\{s_0, -s_1^*, s_2, -s_3^*, s_4, -s_5^*, \dots\}$ that is applied to a first transmitting antenna, and a sequence
 20 $\{s_1, s_0^*, s_3, s_2^*, s_5, s_4^*, \dots\}$ that is applied to a second transmitting antenna, where s_i^* is the complex conjugate of s_i .
9. An electronic circuit for coding communication signals, comprising:
 25 coder circuitry that in response to receiving an incoming block of symbols s_0, s_1 encodes the signals into transmission sequences, including a first transmission sequence and a second transmission sequence;
 wherein the first transmission sequence comprises symbols s_0 and $-s_1^*$, and second transmission sequence comprises symbols s_1 and s_0^* , where s_i^* is the complex conjugate of s_i ; and

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- wherein the transmission sequences are routed to be forwarded to at least two transmitting antenna inputs to create space diversity, including a first transmitting antenna routing path and a second transmitting antenna routing path, wherein the first transmission sequence is applied to the first transmitting antenna routing path, and the second transmission sequence is applied to the second transmitting antenna routing path.
- 5
- 10
10. The electronic circuit of claim 9, wherein the incoming data are in blocks of n symbols, and the at least two transmitting antenna inputs comprise n transmitting antenna inputs.
- 15
11. The electronic circuit of claim 9, wherein the at least two transmitting antenna inputs include K transmitting antenna inputs to effect K distinct channels, wherein $n \cdot m$ symbols are to be distributed to K antennas over L time intervals, where $K=m$ and $L=n$, or $K=n$ and $L=m$.
- 20
12. The electronic circuit of claim 9, wherein the at least two transmitting antenna inputs include K transmitting antenna inputs to effect K distinct channels, wherein $n \cdot m$ symbols are to be distributed to K antennas over L frequencies, where $K=m$ and $L=n$, or $K=n$ and $L=m$.
- 25
13. The electronic circuit of claim 9, wherein the blocks of symbols comprise symbols of equal energy.
- 30
14. An electronic circuit for decoding wireless communication signals, comprising:
a combiner that receives an incoming signal stream representing blocks of encoded symbols, wherein the blocks of symbols have been transmitted by a plurality of spatially diverse antennas, wherein the

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- combiner is configured to combine the received encoded symbols,
and wherein the received encoded signals include negating selected
symbols and conjugating selected symbols, and
a maximum likelihood detector that receives the combined encoded symbols
5 and recovers a transmitted signal using a channel transfer function to
determine a distance for which a relationship between the transmitted
signal and an estimated channel characteristics holds.
15. The electronic circuit of claim 14, further comprising:
10 at least one channel estimator that generates estimates of transmit channel
characteristics and forwards the estimates to the combiner and to the
maximum likelihood detector.
16. The electronic circuit of claim 15,
15 wherein the encoded signals comprise block of symbols s_0 and s_1 that have
been encoded into a sequence of symbols s_0 and $-s_1^*$, and into a
sequence of symbols s_1 and s_0^* , where s_i^* is the complex conjugate
of s_i .
- 20 17. The electronic circuit of claim 16, wherein the combiner combines 2×2
blocks of symbols.
18. The electronic circuit of claim 16, further comprising a channel estimator
25 that produces a plurality of channel estimates h_n , where each channel
estimate corresponds to a channel associated with one of the plurality of
spatially diverse antennas, and wherein the maximum likelihood detector
determines values based in part on the plurality of channel estimates h_n .
19. The electronic circuit of claim 14, wherein the maximum likelihood detector
30 receives from the combiner signals that represent complex values

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corresponding to symbols transmitted by the plurality of spatially diverse antennas, generates likely values for the transmitted signals, and determines a maximum likely value of the transmitted signals based on a minimum distance between the likely values and the received signals.

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20. A method of receiving signals, comprising:
combining at least two non-noise signals received by an antenna to develop sets of information symbol estimates, wherein the combining is responsive to channel estimates developed for at least two concurrent space diverse paths over which the at least two non-noise signals arrive at the antenna, and wherein the combining develops the sets of information symbol estimates by combining the non-noise signals received by the antenna with the channel estimates via operations that involve multiplications, negations, and conjugations; and
developing maximum likelihood decisions regarding information symbols encoded into channel symbols and embedded in the non-noise signals received by the antenna, wherein the developing is responsive to the sets of information symbol estimates.

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- 20 21. The method of claim 20 further comprising developing the channel estimates responsive to the signals received by the antenna.

22. The method of claim 21 wherein developing the channel estimates includes developing the channel estimates when the signals received by the antenna contain a known sequence.

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23. The method of claim 20 further comprising estimating the channel estimates responsive to the sets of information symbols.

24. The method of claim 20 further comprising estimating and developing the channel estimates responsive to output signals from the step of developing.

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FIG. 1

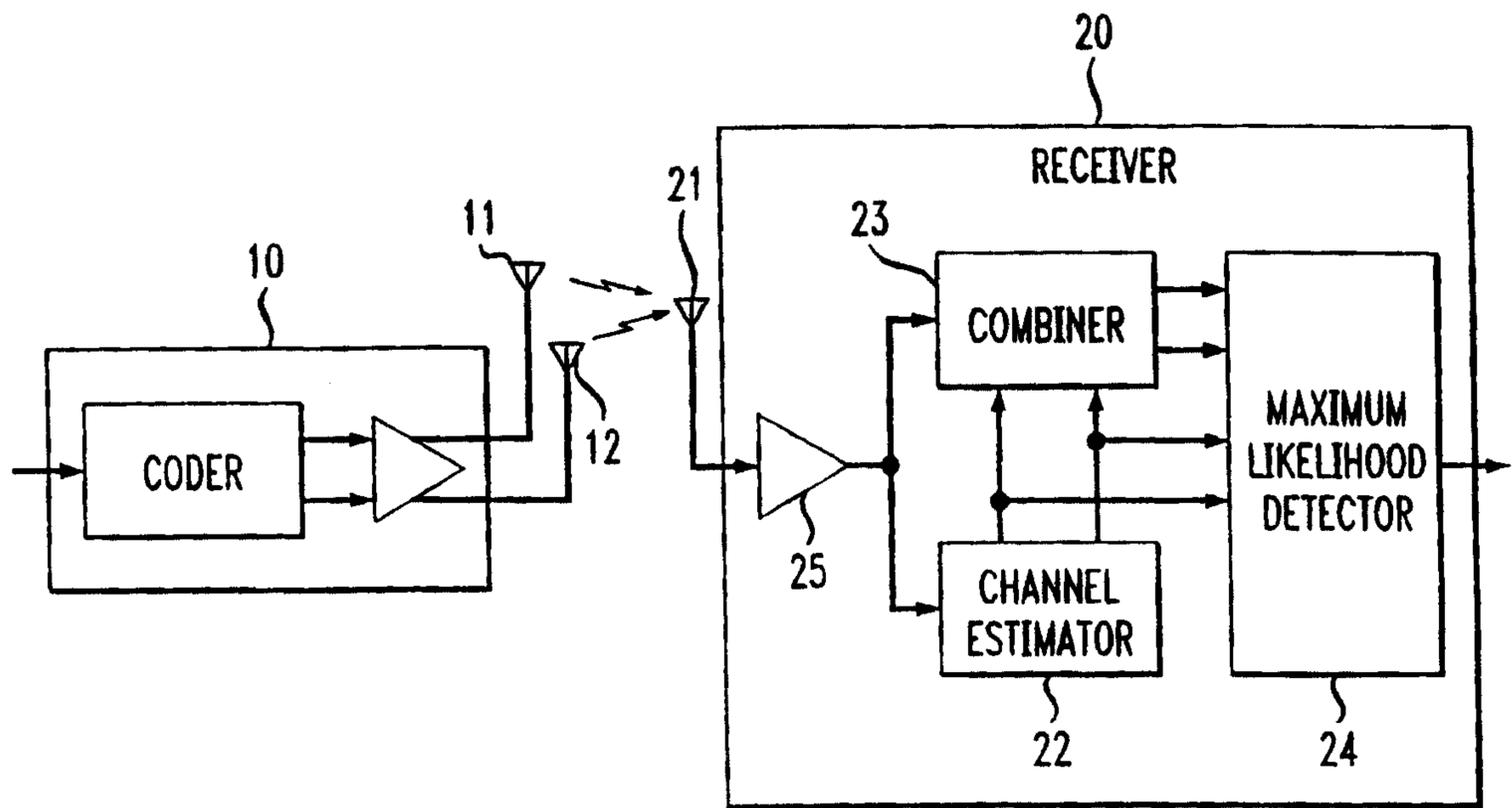
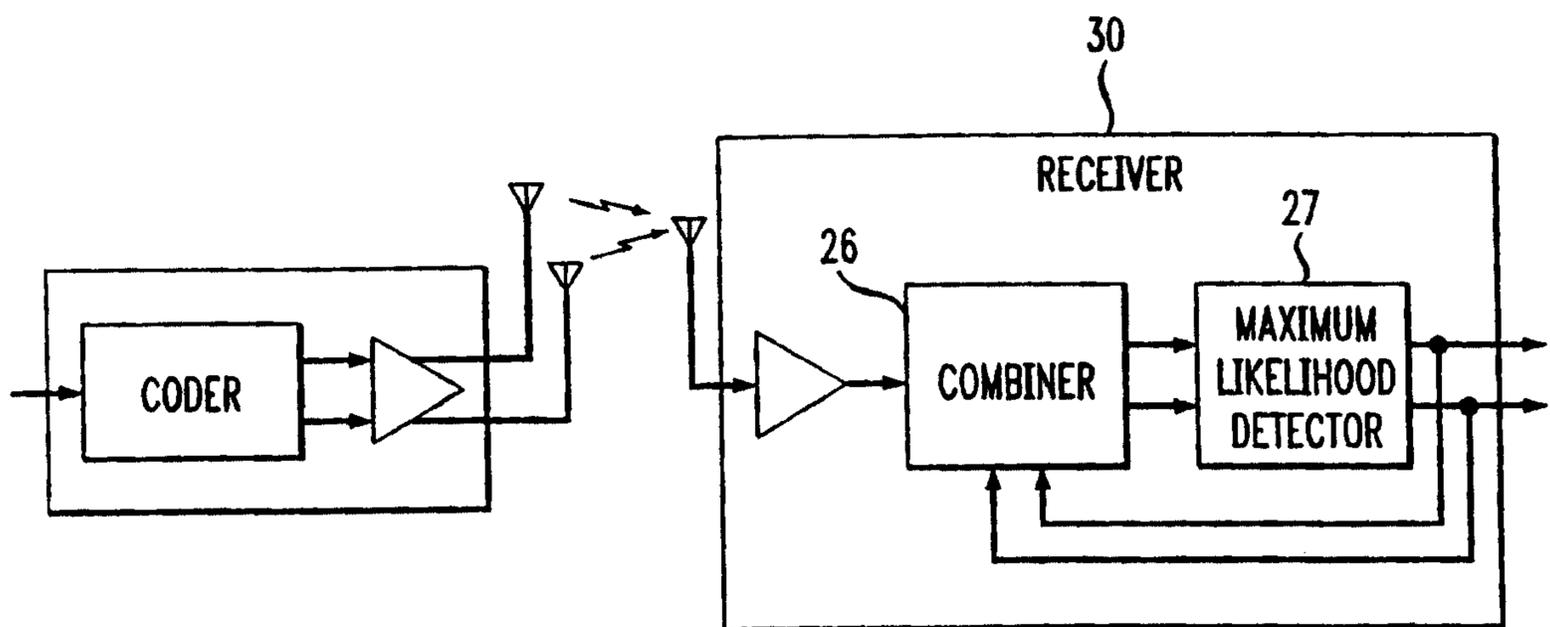


FIG. 2



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FIG. 3

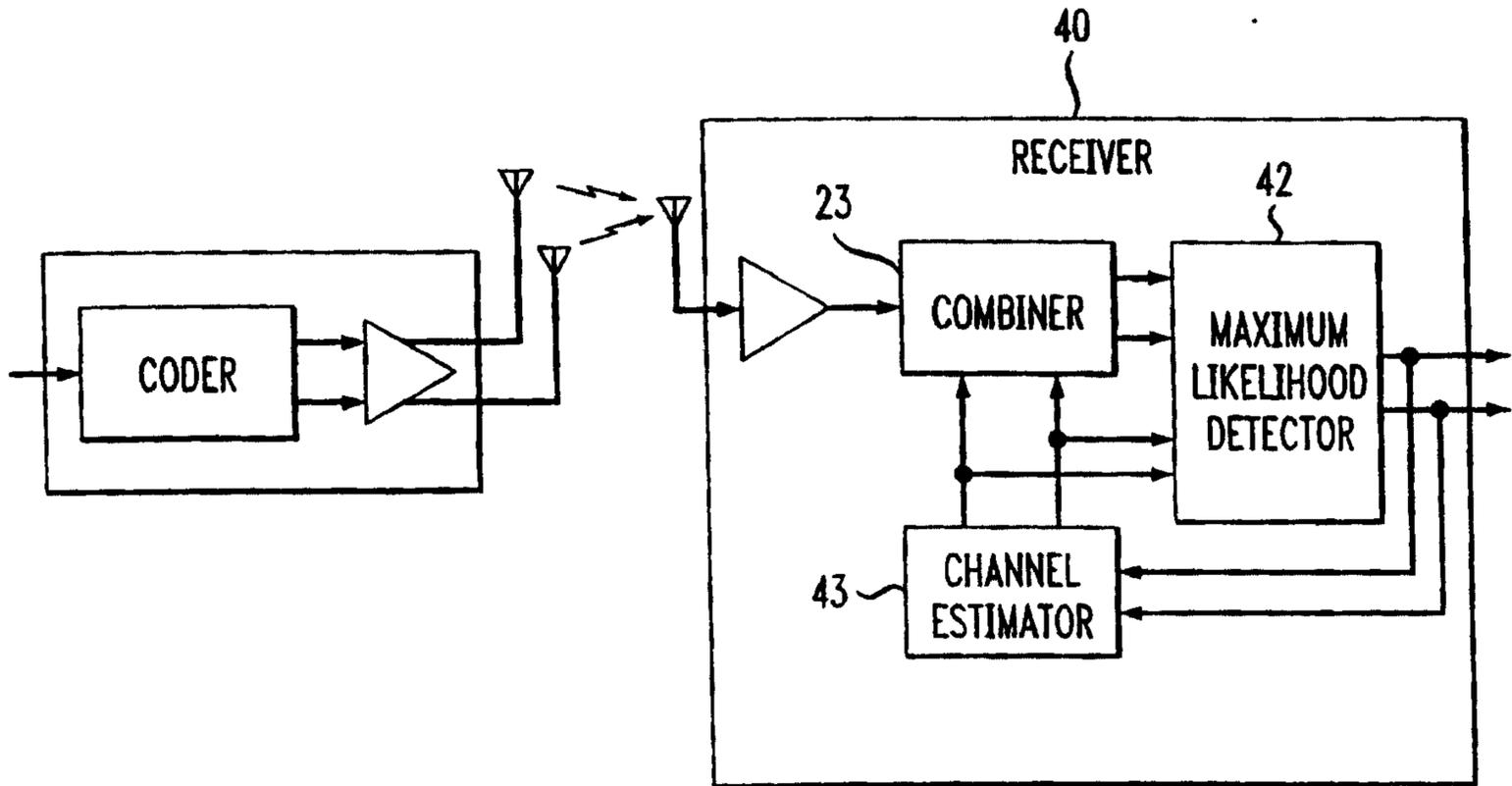


FIG. 4

