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TITLE OF THE INVENTION

OFDM DIVERSITY RECEIVER

BACKGROUND OF THE INVENTION

The preset invention relates to an OFDM

5 (Orthogonal Frequency Division Multiplexing) diversity receiver which performs diversity reception on a carrier by carrier basis using two or more OFDM demodulators.

10 Studies on digitization of ground television broadcasting have been intensively conducted in recent years. Europe and Japan have decided the adoption of an orthogonal frequency division multiplexing (hereinafter referred to as OFDM) system as the transmission system of digital ground television

15 broadcasting. In Europe in particular, a digital ground television broadcasting system has been standardized and has been up to the level of practical use. The OFDM system is adapted to transmit a broadband signal through the use of a number of

20 orthogonal carriers, thus offering a feature of ability to improve delay and interference characteristics of multipath transmission which are essential transmission conditions of ground television broadcasting. In addition, the OFDM system is known to show excellent

25 transmission characteristics against frequency-selective transmission path distortion, such as multipath distortion, by combining error corrections

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because transmit data are transmitted on two or more carriers.

5 In digital ground broadcasting, diversity reception by carrier has been proposed in order to improve further the transmission characteristics under bad receiving conditions as in the case of mobile reception. With combination diversity reception, typical for diversity reception, demodulated signals obtained generally from two OFDM demodulators are
10 combined on a carrier-by-carrier basis according to received power. In this case, since two transmission paths differ in response, the frequency-selective transmission path distortion can be improved significantly. In addition, time-varying fading that
15 may occur at the time of mobile reception will likewise be improved. The same holds for selective diversity reception that chooses a signal of larger received power though its characteristics are inferior to those of the combination diversity reception.

20 However, conventional OFDM receivers based on generally known techniques employs the magnitude of received power as an evaluation index used in combining or making a selection from two or more demodulated signals. In the event that a specific frequency
25 suffers from interference, a signal of large received power is not always of good receive quality.

For example, in the event that an analog TV

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broadcasting signal is mixed in the band of an OFDM-based digital TV broadcasting signal, its video carrier or sound carrier signal may interfere with a specific OFDM carrier signal with resulting distortion. In this case, however, the received power of the carrier signal will increase. With conventional diversity reception of such an OFDM signal as has a distorted carrier signal, the overall error correction would be made on the basis of the distorted carrier signal, resulting in a degradation in the error correction characteristic.

BRIEF SUMMARY OF THE INVENTION

Example embodiments of the invention may provide an OFDM diversity receiver which, even in the event that a specific carrier signal suffers from interference, allows effective diversity reception to be performed so that the error correction characteristic is improved.

In accordance with an aspect of the invention, there is provided an OFDM diversity receiver including OFDM receiving/demodulating means provided in each of two or more receiving systems for individually receiving an OFDM signal, transforming the received signal from time domain to frequency domain to extract each carrier signal, and demodulating information allocated to each carrier signal, and diversity processing means for receiving demodulated information of each carrier signal and performing diversity processing on a

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carrier-by-carrier basis, further comprising: reliability information acquire means for making a decision as to the level of interference suffered by demodulated information obtained for each carrier signal by the OFDM receiving/demodulating means in each of the receiving systems and determining information indicating a measure of reliability of the demodulated information on the basis of the result of the decision; and diversity processing control means responsive to reliability information determined by the reliability information acquire means for each of the receiving systems for controlling diversity processing by the diversity processing means on demodulated information to restrict a carrier signal suffering from interference.

In the above arrangement, since a decision of the level of interference suffered by demodulated information extracted from each carrier signal in each receiving system may be made and then the reliability of the demodulated information may be determined from the result of the decision. The resulting reliability information may be used to control diversity processing on demodulated information to restrict a carrier signal suffering interference. Therefore, diversity reception can be performed with demodulated information from a carrier signal deteriorated due to frequency-selective interference removed, resulting in an improvement in

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error correction characteristic.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIG. 1 is a block diagram of an OFDM receiver according to a first embodiment of the present invention;

FIG. 2 is a block diagram of the variance detector of FIG. 1;

FIGS. 3A and 3B are diagrams for use in explanation of the operation of interference detection using variance in the first embodiment;

FIG. 4 is a block diagram of an OFDM receiver according to a second embodiment of the present invention;

FIG. 5 is a block diagram of an OFDM receiver according to a third embodiment of the present invention;

FIG. 6 is a block diagram of an OFDM receiver according to a fourth embodiment of the present invention; and

FIGS. 7A and 7B show received power versus frequency for signals received over two transmission paths in OFDM-based carrier-by-carrier diversity.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. 1, there is illustrated, in block diagram form, an OFDM diversity receiver which combines demodulated output signals from first and second receiving systems for each carrier.

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In the first receiving system shown in FIG. 1, an OFDM modulated signal is received by an antenna 11 and then applied to a tuner 12 where a given channel signal is selected. The channel signal is then converted into a digital signal by an analog-to-digital (A/D) converter 13. An output signal of the A/D converter 13 is applied to an AGC (Automatic Gain Control) circuit 14, which detects the output level of the tuner from the output of the A/D converter and then applies a gain control voltage to the tuner so that its output level is maintained at a given level.

The output signal of the A/D converter 13 is converted by an IQ demodulator 15 into complex baseband signals which, in turn, are applied to an FFT (Fast Fourier Transform) circuit 16. The FFT circuit transforms the OFDM modulated signal from the temporal domain to the frequency domain. That is, the output of the FFT circuit indicates amplitude and phase of each carrier signal.

The output of the FFT circuit 16 is applied to a demodulator circuit 17, which performs demodulation by estimating the transmission path response for each carrier. This estimation is performed using data corresponding processed one symbol ahead of unprocessed symbols in each carrier in the case where the form of modulation of carrier is differential modulation. On the other hand, in the case where the form of

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modulation is QAM (Quadrature amplitude modulation), a pilot signal multiplexed into a transmit signal is used. Thus, OFDM carrier data is demodulated.

5 The FFT circuit 16 and the demodulator circuit 17 feed a reliability information calculation circuit 18. In this reliability information calculation circuit, a power detector circuit 181 detects the received power of each carrier using the output of the FFT circuit 16. A variance detector circuit 182 examines I and Q data
10 extracted from each carrier in the demodulator circuit 17 to determine a measure of variance from the original point of transmission for each carrier.

A specific arrangement of the variance detector circuit 182 is illustrated in FIG. 2. The I and Q data
15 are applied to hard decision circuits A1 and A3, respectively. In each of the decision circuits, the reference point nearest to the point of reception is determined. The input and the output of each of the hard decision circuits A1 and A3 are applied to a
20 corresponding one of difference circuits A2 and A4, so that the difference from the reference point is detected for each of the I and Q data. The outputs of the difference circuits A2 and A4 are applied to a sum-of-squares circuit A5 where the sum of squares of input
25 difference signals is obtained. The output of the sum-of-squares circuit is applied to an integration circuit A6 where the sum-of-squares signal is integrated (i.e.,

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averaged) for each carrier. Thus, a variance is obtained for each carrier.

The output of the variance detector 182 is branched into a threshold calculation circuit 183 and a threshold decision circuit 184. The threshold calculation circuit 183 calculates a threshold value used to make a decision as to the variance of each carrier signal on the basis of the average value of variances of all carrier signals. The output of the threshold calculation circuit is applied to the threshold decision circuit 184, which makes a decision as to whether the variance of each carrier signal is greater or smaller than the threshold value. When the variance of a carrier signal is greater than the threshold value, the decision circuit decides that the carrier signal is suffering from interference.

FIG. 3A shows the condition in which a frequency-selective unwanted interfering signal is mixed in the band of an OFDM signal, and FIG. 3B shows a decision threshold value determined from the average value of variances of carrier signals. As shown in FIG. 3A, noise is uniformly distributed over the OFDM signal. When the receive level of the OFDM signal is high enough, variances will not exceed the decision threshold value as shown in FIG. 3B even if noise is contained. If, on the other hand, a frequency-selective unwanted signal is mixed in the band of an

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OFDM signal as shown in FIG. 3B, then the variance at a specific frequency will become so great that the decision threshold value is exceeded. The threshold decision circuit 184 determines the frequency at which the threshold value is exceeded and decides that a carrier signal corresponding to that frequency is suffering from interference.

The result of decision by the threshold decision circuit 184 is fed into a correction circuit 185, which corrects the received power of the carrier signal suffering from interference to 0. Thus, the output of the correction circuit 185 indicates reliability information for each carrier signal containing the results of decisions as to whether or not carrier signals are suffering from interference.

In the second receiving system shown in FIG. 1, on the other hand, an OFDM signal received by an antenna 19 is applied to a tuner 20 tuned to the same channel as the first receiving system and then applied to an A/D converter 21, an AGC circuit 22, an IQ demodulation circuit 23, an FFT circuit 24, and a demodulation circuit 25, whereby information is demodulated from each carrier signal and then applied to a reliability information calculation circuit 26 as in the first receiving system. As in the reliability information calculation circuit 18 in the first receiving system, the reliability information calculation circuit 26 is

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composed of a power detector 261, a variance detector 262, a threshold calculation circuit 263, a threshold decision circuit 264, and a correction circuit 265 and produces carrier reliability information from demodulated information from each carrier signal.

The outputs of the reliability information detection circuits 18 and 26 are fed into a weighting coefficient calculation circuit 27, which makes a comparison in reliability information between the first and second receiving systems to calculate a weighting coefficient for each receiving system. When a carrier signal is suffering from interference in one receiving system, the reliability information therefore has been made 0. As a result, the weighting coefficient for the receiving system suffering from interference is set to 0. When the reliability information for both of the first and second receiving systems indicates 0, the weighting coefficients have no significance. In this case, a weighting coefficient of 0 is output for both the first and second receiving systems.

The weighting coefficients of the respective receiving systems determined by the weighting coefficient calculation circuit 27 are applied to a combination diversity circuit 28. In this circuit, the combination of demodulated information from carrier signals is accomplished by first weighting demodulated information from the first and second receiving systems

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by corresponding weighting coefficients in multipliers 281 and 282 and then combining the weighted demodulated information in an adder 283. In this case, when one receiving system is suffering from interference, the
5 corresponding weighting coefficient has been set to 0, thus allowing combination diversity with no effect of the interference. The reliability information for carrier signals are also combined using multipliers 284 and 285 and an adder 286. That is, the reliability
10 information can be combined with no effect of interference from which one receiving system is suffering as in the case of combination of the demodulated information. When both the first and second receiving systems are suffering from
15 interference, the reliability information after combination becomes 0, allowing a succeeding error correction circuit 29 to erase the both demodulated information.

The demodulated information from carrier signals
20 and the reliability information obtained by the combination diversity circuit 28 are applied to the error correction circuit 29, so that error corrections are made and received information is obtained.

As described above, the present embodiment allows
25 combination diversity by carrier with no adverse effect of interference and combination of reliability information for carriers for subsequent error

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correction in the error correction circuit 29. In the diversity reception as well, therefore, the error correction characteristic can be improved using the reliability information.

5 In the first embodiment shown in FIG. 1, not only the demodulated information but also the reliability information are combined with weighting. With the reliability information for the first and second receiving systems, the one having a greater value may
10 be used with the same result.

 In FIG. 4 there is illustrated in block diagram form an OFDM diversity receiver according to a second embodiment of the present invention which performs selective diversity reception by carrier using
15 demodulated outputs of first and second receiving systems. In FIG. 4, like reference numerals are used to denote corresponding components to those in FIG. 4 and descriptions thereof are omitted.

 The outputs of the reliability information detect
20 circuits 18 and 26 are applied to a comparator 30, which makes a comparison in reliability information between the first and second receiving systems for each carrier signal to provide a control signal for choosing a receiving system that is greater in reliability
25 information. When one of the first and second receiving systems is suffering from interference, its reliability information is set to 0; thus, the other

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receiving system that is not suffering from interference is selected. When the reliability information for each of the first and second receiving systems is 0, either of them is selected.

5 The output of the comparator 30 is applied to selectors 311 and 312 in a selective diversity circuit 31. The selector 311 is supplied with demodulated information from the first and second receiving systems and responds to the control signal from the comparator
10 30 to selectively output the demodulated information from one of the first and second receiving systems. The selector 312 is supplied with reliability information from the first and second receiving systems and responds to the control signal from the comparator
15 30 to selectively output the reliability information from one of the first and second receiving systems.

 The above arrangement allows selective diversity reception with no effect of interference because the comparator 30 produces a control signal to select one
20 of the first and second receiving systems when the other is suffering from interference. When both the first and second receiving systems are suffering from interference, provision is made to make corrections for loss in the error correction circuit 29 because the
25 reliability information after selective diversity becomes 0.

 Thus, the second embodiment allows selective

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diversity reception by carrier without being adversely affected by carrier interference and the error correction characteristic to be improved because the carrier reliability information is also selectively applied to the error correction circuit 29. Compared with the combination diversity shown in FIG. 1, the selective diversity has an advantage of being simple in circuit arrangement though there is some degradation in performance.

FIG. 5 is a block diagram of an OFDM diversity receiver according to a third embodiment of the present invention which uses a reliability information calculation circuit different from that in the first embodiment. In this figure, like reference numerals are used to denote corresponding components to those of FIG. 1 and descriptions thereof are omitted.

The threshold values for variance decision calculated in the threshold calculation circuits 183 and 263 in the reliability information calculation circuits 18 and 26 shown in FIG. 5 are applied to a threshold select circuit 32, which compares the threshold values from the first and second receiving systems and selectively outputs a smaller one. The threshold decision circuits 183 and 263 in the reliability detect circuit 18 and 26 makes a decision as to variance for each carrier using the threshold value selected by the threshold select circuit 32.

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When receiving conditions are degraded due to some cause, say, an antenna failure, the variances of all carrier signals increase and the threshold value for variance decision also increases accordingly. The
5 threshold value for variance decision indicates the average receiving quality of all carriers. Thus, by selecting a smaller one from the threshold values for the first and second receiving systems for use as the threshold value as in this embodiment, even if the
10 receiving conditions of one of the receiving systems are degraded, it becomes possible to consider the one of the receiving systems to be suffering from interference and ignore it.

FIG. 6 is a block diagram of an OFDM diversity
15 receiver according to a fourth embodiment of the present invention which uses a reliability information calculation circuit different in arrangement from those in the first and third embodiments. In this figure, like reference numerals are used to denote corre-
20 sponding components to those of FIG. 1 and descriptions thereof are omitted.

In the first and second reliability information calculation circuits 18 and 26 shown in FIG. 6, neither carrier variance detection nor threshold calculation is
25 performed. Instead, each of threshold decision circuits 186 and 266 compares the received power level of each carrier detected by a corresponding one of the

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power detect circuits 181 and 261 with a preset threshold value and decides that the corresponding receiving system is suffering from interference when the received power level is greater than the preset threshold value.

Compared with the first embodiment of FIG. 1 in which interference decision is made based on carrier variance detection, the fourth embodiment has an advantage of allowing for the decision of a high level of interference using simple circuit arrangement though there is some degradation in interference detection accuracy.

Although the third and fourth embodiments shown in FIGS. 5 and 6 are directed to the combination diversity reception, it is apparent that the principles of the present invention can also be applied to the selective diversity reception.

In addition, although the above embodiments have been described in terms of diversity reception by carrier using demodulated information from two paths or channels, it is apparent that the present invention is also applicable to diversity reception for three or more paths or channels.

In the case of combination diversity reception, the combination of demodulated information from receiving systems can be optimized by setting decision threshold values in steps according to the levels of

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interference and setting weighting coefficients for the receiving systems in steps.

The present invention is not limited to the embodiments described so far and may be practiced or
5 embodied in still other ways.

So far, receivers have been described which perform combination or selective diversity reception by OFDM carrier according to received power. As can be seen from FIGS. 7A and 7B, the frequency responses of two
10 paths or channels are generally different from each other. Thus, the frequency-selective transmission path distortion can be improved significantly by combining or selecting demodulated signals of two or more paths as in the aforementioned embodiments. In addition,
15 time-varying fading that may occur at the time of mobile reception can likewise be improved.

According to the present invention, as described above, there is provided an OFDM diversity receiver which, even in the event that a specific carrier signal
20 suffers from interference, allows effective diversity reception to be performed so that the error correction characteristic is improved.

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WHAT IS CLAIMED IS:

1. An OFDM diversity receiver including OFDM receiving/demodulating means provided in each of two or more receiving systems for individually receiving an OFDM signal, transforming the received signal from time domain to frequency domain to extract each carrier signal, and demodulating information allocated to each carrier signal, and diversity processing means for receiving demodulated information of each carrier signal and performing diversity processing on a carrier-by-carrier basis, further comprising:

reliability information acquire means for making a decision as to the level of interference suffered by demodulated information obtained for each carrier signal by the OFDM receiving/demodulating means in each of the receiving systems and determining reliability information indicating a measure of reliability of the demodulated information on the basis of the result of the decision; and

diversity processing control means responsive to reliability information determined by the reliability information acquire means for each of the receiving systems for controlling diversity processing by the diversity processing means on demodulated information to restrict a carrier signal suffering from interference.

2. An OFDM diversity receiver according to

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claim 1, wherein the reliability information acquire means comprises a received power detect section for detecting the received power of each carrier signal obtained by the OFDM receiving/demodulating means for each of the receiving systems, an interference decision section for making a decision as to the level of interference suffered by each carrier signal obtained by the OFDM receiving/demodulating means for each of the receiving systems, and a reliability information calculation section for calculating reliability information indicating a measure of reliability of demodulated information obtained for each carrier signal by the OFDM receiving/demodulating means for each of the receiving systems on the basis of the result of detection by the received power detect section and the result of decision by the interference decision section.

3. An OFDM diversity receiver according to claim 2, wherein the interference decision section comprises variance detecting means for detecting a variance of each carrier signal from demodulated information of the carrier signal obtained by the OFDM receiving/demodulating means for each of the receiving systems, threshold calculation means for determining a threshold value greater than unity from the variance of each carrier signal obtained by the variance detecting means for each of the receiving systems, and decision

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means for making a decision as to the level of interference suffered by each carrier signal by comparing the variance obtained for the carrier signal with the threshold value obtained by the threshold calculation means.

4. An OFDM diversity receiver according to claim 2, wherein the interference decision section comprises variance detecting means for detecting a variance of each carrier signal from demodulated information of the carrier signal obtained by the OFDM receiving/demodulating means for each of the receiving systems, threshold calculation means for averaging variances of carrier signals obtained by the variance detected means for each of the receiving systems and setting the smallest average variance for one of the receiving systems as a threshold value serving as the criterion for interference decision, and decision means for making a decision as to the level of interference suffered by each carrier signal by comparing the variance obtained for the carrier signal with the threshold value set by the threshold calculation means.

5. An OFDM diversity receiver according to claim 3 or 4, wherein the variance detecting means determines a two-valued variance by subjecting demodulated information of each carrier signal to hard decision.

6. An OFDM diversity receiver according to

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claim 3 or 4, wherein the variance detecting means determines a variance in steps by subjecting demodulated information of each carrier signal to hard decision.

5 7. An OFDM receiver according to claim 2, wherein the interference decision section makes a decision at to the level of interference suffered by each carrier signal by comparing the received power of the carrier signal detected by the received power detection section
10 with a preset threshold value.

 8. An OFDM receiver according to claim 1, wherein the diversity processing means combines demodulated information obtained from the OFDM receiving/
demodulating means of the receiving systems for each
15 carrier signal, and the diversity processing control means weights each of the demodulated information of each carrier signal to be combined by the diversity processing means on the basis of the reliability information for the carrier signal obtained by the
20 reliability information acquire means.

 9. An OFDM receiver according to claim 1, wherein the diversity processing means selects demodulated information obtained from the OFDM receiving/
demodulating means of the receiving systems for each
25 carrier signal, and the diversity processing control means specifies demodulated information to be selected by the diversity processing means for each carrier

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signal on the basis of the reliability information for the carrier signal obtained by the reliability information acquire means.

5 10. An OFDM receiver according to claim 1, further comprising error correction means for correcting errors in demodulated information processed by the diversity processing means, and wherein the diversity processing means subjects reliability information for each carrier signal obtained by the reliability information acquire means for the receiving systems to diversity
10 processing, and the error correcting means corrects the demodulated information on the basis of the reliability information subjected to diversity processing.