# A Receiver Module And Method For Receiving A Signal Using Diversity Switched Combining

## FIELD OF INVENTION

The invention relates broadly to a receiver module and a method for receiving a signal in a diversity switched combining module.

## BACKGROUND

Multicarrier modulation is a technique for transmitting a stream of data by dividing the data into several parallel streams and using each stream to modulate a carrier. Orthogonal Frequency Division Multiplexing (OFDM), which is an example of a multicarrier modulation transmission technique, is being widely used in wireless communication systems, such as Wireless Local Area Networks (WLANs) and Digital Video Broadcasting (DVB) systems. OFDM is widely used because of its capability to mitigate effects of multipath fading and/or strong signal interference.

In a wideband fading channel, different carriers are faded to different extents. As a result, some carriers in a deep fade may be received with extremely low power. This may degrade the performance of OFDM systems having such carriers. Antenna diversity techniques have been adopted to deal with the above issue. A typical diversity receiver consists of several separate receivers (or diversity branches) and each separate receiver has its own antenna. By arranging the antennas such that their outputs are faded independently, each set of received carriers from each diversity branch can be combined in an efficient way to improve the overall receiver performance. Typical combining schemes include Maximum Ratio Combining (MRC), Selection Combining (SC) and Equal Gain Combining (EGC). US Pat. No. 6940932 describes the diversity receiver discussed above.

The diversity receiver discussed above makes use of multiple receivers having the same structures which results in an increase in cost and circuitry size. To reduce circuitry complexity and cost, one alternative is to use diversity switched combiners, in

which only a single receiver is required in the diversity receiver. The receiver is switched between multiple antennas according to a certain switch criteria. An example of a switch criteria is the signal strengths provided by different antennas.

There are currently a number of methods for diversity switched combining for OFDM systems. One method is to split and send the received signal into two separate channels with each channel carrying a respective frequency band. The input of each channel is switched between different antennas. The switch settings are determined in accordance with the signal qualities for different settings (see US Pat. App. Pub. No. 2006/0009176). One problem that may arise with this method is that two basic front ends, each comprising a splitter, a switch and a filter, are typically required in order to have simultaneous access to signals received at different antennas.

Instead of the above, another method has been proposed. This method is directed at processing the received signal over a whole frequency band. For example, during each guard interval, an antenna may be selected based on the signal strengths provided by different antennas (see US Pat. App. Pub. No. 2005/0254608). However, as the fading characteristics vary among different carriers, one problem that may arise with this method is that only a minor diversity gain is typically obtained when the delay spread is large. Furthermore, since antenna switching occurs during each guard interval, there is typically higher power consumption.

Yet another method for diversity switched combining is directed at evaluating each carrier individually. JP Pat. No. 2005236666 describes an antenna switching that occurs when the number of low signal level carriers for an activated antenna exceeds a fixed number. The low signal level carriers are determined based on signal amplitudes. However, one problem that may arise with this method is that unnecessary antenna switching may occur when the signal qualities of carriers for a substituting antenna are inferior to those for the activated antenna.

In another method for diversity switched combining described in US Pat. App. Pub. No. 2005/0107048, a receiver is switched between two antennas during each guard interval and signal amplitudes of carriers are estimated for the two antennas. The

decision for using one of the two antennas is made by determining which antenna provides a greater number of stronger carriers.

One problem that may arise is that signal amplitude estimation of carriers may be inaccurate since Fast Fourier Transform (FFT) is only applied to a limited number of samples within the guard interval of an OFDM symbol. Another problem that may arise is that in addition to the FFT operations used for switching control, other FFT operations are also required for OFDM symbol demodulation. Yet another problem that may arise is that since antenna switching is carried out during each guard interval, such switching typically results in higher power consumption.

Further to the above, it has been recognised that the power consumption problems discussed above are particularly critical for battery powered devices.

Hence, there exists a need for a receiver module and method for receiving a signal using diversity switched combining that seeks to address at least one of the above problems.

## SUMMARY

In accordance with a first aspect of the present invention, there is provided a receiver module comprising a receiver circuit for converting and demodulating an incoming signal received via an antenna, the receiver circuit being arranged for estimating channel amplitudes, phases, or both at a plurality of carrier frequencies; a quality estimation unit for estimating signal qualities at the plurality of carrier frequencies based on the estimated channel amplitudes, phases, or both, and for determining a reference quality level based on the estimated signal qualities over a time period; and a quality evaluation unit for determining a number of low quality carrier frequencies of the plurality of carrier frequencies, the low quality carrier frequencies having respective estimated qualities below the reference quality level.

The receiver module may further comprise first and second antennas; a switching unit for selectively coupling one of the first and second antennas to the

receiver circuit; and a control unit for the switching unit; wherein the quality estimation unit may estimate and store signal qualities at the plurality of carrier frequencies for the first antenna; the quality evaluation unit may determine a number of low quality carrier frequencies for the first antenna based on the reference quality level; and the control unit may control a setting of the switching unit based on the determined number of low quality carrier frequencies for the first antenna.

The control unit may change the setting of the switching unit when the determined number of low quality carrier frequencies for the first antenna exceeds a predetermined number.

When the control unit controls the switching unit to couple the second antenna to the receiver circuit based on the determined number of low quality carrier frequencies for the first antenna, the quality estimation unit may estimate signal qualities at the plurality of carrier frequencies for the second antenna; and the quality evaluation unit may make a determination whether the first antenna has a better signal quality based on comparing the stored estimated signal qualities of the first antenna with the estimated signal qualities of the second antenna; and the control unit may control the setting of the switching unit based on said determination by the quality evaluation unit.

The control unit may control the switching unit to couple the first antenna to the receiver circuit when the first antenna has the better signal quality.

The receiver module may further comprise first and second antennas; a switching unit for selectively coupling one of the first and second antennas to the receiver circuit; and a control unit for the switching unit; wherein the quality estimation unit may estimate signal qualities at the plurality of carrier frequencies for the first antenna; the quality evaluation unit may determine and store a number of low quality carrier frequencies for the first antenna based on the reference quality level; and the control unit may control a setting of the switching unit based on the determined number of low quality carrier frequencies for the first antenna.

The control unit may change the setting of the switching unit when the determined number of low quality carrier frequencies for the first antenna exceeds a predetermined number.

When the control unit controls the switching unit to couple the second antenna to the receiver circuit based on the determined number of low quality carrier frequencies for the first antenna, the quality estimation unit may estimate signal qualities at the plurality of carrier frequencies for the second antenna; and the quality evaluation unit may make a determination whether the stored number of low quality carrier frequencies for the first antenna is smaller than a number of low quality carrier frequencies for the second antenna based on said reference quality level; and the control unit may control the setting of the switching unit based on said determination by the quality evaluation unit.

The control unit may control the switching unit to couple the first antenna to the receiver circuit when the number of low quality carrier frequencies for the first antenna is smaller than the number of low quality carrier frequencies for the second antenna.

The controlling a setting of the switching unit may be carried out during a guard interval of the incoming signal.

The plurality of carrier frequencies may comprise signals of pilot carrier frequencies having known values.

The estimating channel amplitudes, phases, or both may be carried out at each pilot carrier frequency.

The estimating channel amplitudes, phases, or both may be carried out at each carrier frequency.

The estimating signal qualities may be based on said estimated channel amplitudes, phases, or both at each pilot carrier frequency.

The estimating signal qualities may be based on said estimated channel amplitudes, phases, or both at each carrier frequency.

The estimating signal qualities may be based on a distance between a pilot carrier frequency measurement and a known correct position in a signal constellation.

The reference quality level may be set to an average of the estimated signal qualities at a plurality of pilot carrier frequencies during the time period.

The reference quality level may be set to an average of the estimated signal qualities at the plurality of carrier frequencies during the time period.

The time period may be smaller than a channel coherent time.

The estimating channel amplitudes, phases, or both may be carried out during a useful duration of the incoming signal.

The estimating signal qualities may be carried out during a useful duration of the incoming signal.

The estimating signal qualities may be carried out during a guard interval of the incoming signal.

The determining a number of low quality carrier frequencies may be carried out during a guard interval of the incoming signal.

The time period may comprise a predetermined number of symbol durations of the incoming signal.

The reference quality level may be updated for each symbol of the incoming signal.

The incoming signal may be an Orthogonal Frequency Division Multiplexing (OFDM) modulated signal.

In accordance with a second aspect of the present invention, there is provided a method for receiving a signal in a diversity switched combining module, the method comprising converting and demodulating an incoming signal received via an antenna; estimating channel amplitudes, phases, or both at a plurality of carrier frequencies; estimating signal qualities at the plurality of carrier frequencies based on the estimated channel amplitudes, phases, or both; determining a reference quality level based on the estimated signal qualities over a time period; and determining a number of low quality carrier frequencies of the plurality of carrier frequencies wherein the low quality carrier frequencies have respective estimated qualities below the reference quality level.

The method may further comprise selectively coupling one of a first and second antennas to a receiver circuit; estimating and storing signal qualities at the plurality of carrier frequencies for the first antenna; determining a number of low quality carrier frequencies for the first antenna based on the reference quality level; and controlling the coupling based on the determined number of low quality carrier frequencies for the first antenna.

The controlling may change the coupling when the determined number of low quality carrier frequencies for the first antenna exceeds a predetermined number.

When the controlling occurs to couple the second antenna to the receiver circuit based on the determined number of low quality carrier frequencies for the first antenna, the method may further comprise estimating signal qualities at the plurality of carrier frequencies for the second antenna; making a determination whether the first antenna has a better signal quality based on comparing the stored estimated signal qualities of the first antenna with the estimated signal qualities of the second antenna; and controlling the coupling based on said determination.

The controlling may occur to couple the first antenna to the receiver circuit when the first antenna has the better signal quality.

The method may further comprise selectively coupling one of a first and second antennas to a receiver circuit; estimating signal qualities at the plurality of carrier frequencies for the first antenna; determining and storing a number of low quality carrier frequencies for the first antenna based on the reference quality level; and controlling the coupling based on the determined number of low quality carrier frequencies for the first antenna.

The controlling may change the coupling when the determined number of low quality carrier frequencies for the first antenna exceeds a predetermined number.

When the controlling occurs to couple the second antenna to the receiver circuit based on the determined number of low quality carrier frequencies for the first antenna, the method may further comprise estimating signal qualities at the plurality of carrier frequencies for the second antenna; making a determination whether the stored number of low quality carrier frequencies for the first antenna is smaller than a number of low quality carrier frequencies for the second antenna based on said reference quality level; and controlling the coupling based on said determination.

The controlling may change the coupling to couple the first antenna to the receiver circuit when the number of low quality carrier frequencies for the first antenna is smaller than the number of low quality carrier frequencies for the second antenna.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Figure 1 is a schematic diagram showing an Orthogonal Frequency Division Multiplexing (OFDM) signal.

Figure 2 is a schematic block diagram illustrating an OFDM diversity receiver.

Figure 3 is a schematic block diagram illustrating a switch combining unit in a first example embodiment

Figure 4 is a flowchart illustrating antenna diversity signal reception in the first example embodiment.

Figure 5 is a schematic block diagram illustrating a switch combining unit in a second example embodiment.

Figure 6 is a flowchart illustrating antenna diversity signal reception in the second example embodiment.

Figure 7 is a flowchart illustrating a method for receiving a signal in a diversity switched combining module.

## DETAILED DESCRIPTION

The example embodiments described below can provide a receiver module and method for receiving a signal using diversity switched combining. The signal may be a multicarrier signal and may additionally be a wideband signal. For description purposes, an OFDM system is described in the example embodiments.

Some portions of the description which follows are explicitly or implicitly presented in terms of algorithms and functional or symbolic representations of operations on data within a computer memory. These algorithmic descriptions and functional or symbolic representations are the means used by those skilled in the data processing arts to convey most effectively the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities, such as electrical, magnetic or optical signals capable of being stored, transferred, combined, compared, and otherwise manipulated.

Unless specifically stated otherwise, and as apparent from the following, it will be appreciated that throughout the present specification, discussions utilizing terms such as "scanning", "calculating", "determining", "replacing", "generating", "initializing", "outputting", or the like, refer to the action and processes of a computing system, or similar electronic device, that manipulates and transforms data represented as physical quantities within the computing system into other data similarly represented as physical quantities within the computing system or other information storage, transmission or display devices.

The present specification also discloses an apparatus for performing the operations of the methods. Such apparatus may be specially constructed for the required purposes, or may comprise a general purpose computer or other devices selectively activated or reconfigured by a computer program stored in the computer. The algorithms presented herein are not inherently related to any particular computer or other apparatus. Various general purpose machines may be used with programs in accordance with the teachings herein. Alternatively, the construction of more specialized apparatus to perform the required method steps may be appropriate.

In addition, the present specification also implicitly discloses a computer program, in that it would be apparent to the person skilled in the art that the individual steps of the method described herein may be put into effect by computer code. The computer program is not intended to be limited to any particular programming language and implementation thereof. It will be appreciated that a variety of programming languages and coding thereof may be used to implement the teachings of the disclosure contained herein. Moreover, the computer program is not intended to be limited to any particular control flow. There are many other variants of the computer program, which can use different control flows without departing from the spirit or scope of the invention.

Furthermore, one or more of the steps of the computer program may be performed in parallel rather than sequentially. Such a computer program may be stored on any computer readable medium. The computer program when loaded and executed on a general-purpose computer effectively results in an apparatus that implements the steps of the preferred method.

Figure 1 is a schematic diagram showing an incoming OFDM signal 102 in the example embodiments. In the signal 102, a first symbol 104 comprises a first guard interval 106 and a first useful duration 108, a second symbol 110 comprises a second guard interval 112 and a second useful duration 114 and a third symbol 116 comprises a third guard interval 118 and a third useful duration 120.

Figure 2 is a schematic block diagram illustrating an OFDM diversity receiver 202 in the example embodiments. The receiver 202 comprises an antenna section 204, a switch 206, a receiver circuit 208 and a switch combining unit 210.

In the antenna section 204, a first antenna 212 and a second antenna 214 are arranged so that their antenna outputs fade substantially independently. The output of either the first antenna 212 or the second antenna 214 is coupled to the receiver circuit 208 by operating the switch 206. It will be appreciated by a person skilled in the art that the example embodiments are not limited to using two antennas.

In the description below, an activated antenna is an antenna currently being selected for receiving signals while a substituting antenna is an antenna being switched to after the activated antenna is determined to be poor in performance. For description purposes, the currently activated antenna is taken to be the first antenna 212 and the substituting antenna is taken to be the second antenna 214.

The receiver circuit 208 comprises a tuner 216, an FFT and channel estimation block 218 and a demodulator 220. The tuner 216 is for down-converting a received incoming signal at numeral 222 to a baseband format, the FFT and channel estimation block 218 is for generating OFDM carrier signals and the demodulator 220 is for demodulating the signal output from the FFT and channel estimation block 218. In addition, the FFT and channel estimation block 218 provides information regarding channel amplitudes, phases, or both, of signals at a plurality of pilot carrier frequencies. This information is also termed as channel state information or channel estimates. The signals at the pilot carrier frequencies are known values. As a result, the channel amplitude, phase, or both, may be estimated at each pilot carrier frequency. Alternatively, the FFT and channel estimation block 218 may interpolate the above

amplitude and phase results to provide similar information at every carrier frequency. By evaluating the carrier frequencies individually, the effect of fading of different carrier frequencies is taken into account in example embodiments.

Figure 3 is a schematic block diagram illustrating the switch combining unit 210 in a first example embodiment. The switch combining unit 210 comprises a quality estimation module 302, a quality evaluation module 304, a threshold memory module 306, a first carrier quality memory module 308, a second carrier quality memory module 310 and a switch control module 312. The switch control module 312 output is used to control a setting of the switch 206 (Figure 2) (see numeral 224 in Figure 2).

The quality estimation module 302 estimates signal qualities at a plurality of carrier frequencies based on the OFDM carrier signals and the channel estimates of carriers provided by the FFT and channel estimation block 218. The signal quality estimates are stored in either the first carrier quality memory module 308 or the second carrier quality memory module 310, depending on whether the respective first antenna 212 (Figure 2) or the second antenna 214 (Figure 2) is being activated. In the example embodiment, the minimum capacities of the first carrier quality memory module 308 and the second carrier quality memory 310 are equated to the number of pilot carriers per OFDM symbol if only pilot carriers are considered in the switch combining process.

The quality estimation module 302 can estimate the signal qualities at the plurality of carrier frequencies using a number of ways. For example, the channel amplitude at each carrier frequency may be used as a quality indicator. One alternative is to use the channel amplitude at each pilot carrier frequency to estimate signal quality. Another alternative is to use the distance of a carrier output from its expected correct position in a signal constellation as a quality merit.

In the example embodiment, the channel estimates and the quality estimates at a plurality of carrier frequencies are obtained during a useful duration e.g. 108 (Figure 1) of an OFDM signal e.g. 102 (Figure 1). The quality estimates may alternatively be obtained during a guard interval e.g. 112 (Figure 1) of an OFDM signal e.g. 102 (Figure 1).

The quality evaluation module 304 is used to compare the quality estimates at the plurality of carrier frequencies for the activated antenna 212 (Figure 2) against a predetermined threshold or reference quality level obtained by the quality estimation module 302. The threshold obtained by the quality estimation module 302 is transmitted to the quality evaluation module 304. The carriers having quality estimates smaller than the threshold are considered to be of low quality. The number of low quality carriers is subsequently transferred to the switch control module 312. In addition to the number of low quality carriers for the activated antenna 212 (Figure 2), the quality estimates at the plurality of carrier frequencies for the two antennas 212, 214 (Figure 2) are also sent to the switch control module 312 from the first carrier quality memory module 308 and the second carrier quality memory module 310.

With regard to the threshold or reference quality level, there are a number of ways for determining the threshold for use in the quality evaluation process. For example, if only pilot carriers are considered in the switch combining process, the threshold may be set to be an average of the quality estimates at the plurality of pilot carrier frequencies during a time period. Alternatively, the threshold may be set to be an average of the quality estimates at the plurality of carrier frequencies (instead of pilot carrier frequencies) during a time period. In the example embodiment, the threshold is common to both the first antenna 212 (Figure 2) and the second antenna 214 (Figure 2).

The above time period is kept shorter than the channel coherent time in the example embodiment. However, the time period may cover several OFDM symbol durations. Thus, some OFDM symbols considered for determining the threshold may be received by the first antenna 212 (Figure 2) and the others may be received by the second antenna 214 (Figure 2). In the example embodiment, the threshold is preferably updated for each OFDM symbol. For example, if the time period described above is selected to cover N OFDM symbol durations, for the purpose of calculating the threshold for a current OFDM symbol, N-1 average values of quality estimates for the previous N-1 OFDM symbols are stored in the threshold memory module 306. The threshold for the current OFDM symbol is calculated based on the stored N-1 average values and the quality estimates for the current OFDM symbol.

The switch control module 312 operates in two different modes. In a first mode, the switch control module 312 compares the number of low quality carriers for the activated antenna 212 (Figure 2) against a fixed number. For example, the fixed number may be set to be about 40% of the number of pilot carriers per OFDM symbol if only pilot carriers are considered in the switch combining process. If the number of low quality carriers for the activated antenna 212 (Figure 2) is larger than the fixed number, the switch control module 312 controls the switch 206 (Figure 2) to switch to the substituting antenna 214 (Figure 2).

In a second mode, the switch control module 312 compares quality estimates at each carrier frequency for the two antennas 212, 214 (Figure 2). If the substituting antenna 214 (Figure 2) provides a larger number of carriers with better quality than the activated antenna 212 (Figure 2), the switch control module 312 controls the switch 206 (Figure 2) to switch to the substituting antenna 214 (Figure 2).

Figure 4 is a flowchart 400 illustrating antenna diversity signal reception in the first example embodiment. References are also made across Figures 1 to 3.

At step 402, the reception operation of the first example embodiment starts. At step 404, the receiver 202 (Figure 2) utilises the activated antenna 212 (Figure 2) to receive the first useful duration 108 (Figure 1) of the first symbol 104 (Figure 1) of the incoming signal 102 (Figure 1). In the same step, channel state information for the first antenna 212 (Figure 2) is obtained by the FFT and channel estimation block 218 (Figure 2).

At step 406, during the second guard interval 112 (Figure 1) of the second symbol 110 (Figure 1), the receiver 202 (Figure 2) estimates signal qualities at the plurality of carrier frequencies based on the channel state information of carriers for the first antenna 212 (Figure 2). In this same step, the receiver 202 (Figure 2) also stores the carrier quality estimates in the corresponding first carrier quality memory module 308 (Figure 3).

At step 408, the receiver 202 (Figure 2) determines the number of low quality carriers from the carrier quality estimates for the first antenna 212 (Figure 2). The

determination is based on a threshold obtained from e.g. an average of the quality estimates at the plurality of carrier frequencies during a time period, as described above.

After the quality evaluation for the first antenna 212 is completed at step 408, at step 410, the receiver 202 (Figure 2) compares the number of low quality carriers for the first antenna 212 (Figure 2) with a fixed number. If the number of low quality carriers is smaller than the fixed number, the signal quality for the first antenna 212 (Figure 2) is considered to be satisfactory.

If the signal quality is satisfactory, at step 412, the receiver 202 (Figure 2) proceeds to receive the second useful duration 114 (Figure 1) of the second symbol 110 (Figure 1) using the first antenna 212 (Figure 2). Following step 412, the reception operation loops back to step 402. If the signal quality is not satisfactory at step 410, then at step 416, the receiver 202 (Figure 2) activates the substituting second antenna 214 (Figure 2) to receive the second useful duration 114 (Figure 1) of the second symbol 110 (Figure 1).

At step 418, during the third guard interval 118 (Figure 1) of the third symbol 116 (Figure 1), the receiver 202 (Figure 2) determines the quality estimates at the plurality of carrier frequencies according to the channel state information for the second antenna 214 (Figure 2). In this same step, the receiver 202 (Figure 2) stores the carrier quality estimates to the corresponding second carrier quality memory module 310 (Figure 3).

At step 420, based on the carrier quality estimates for the first antenna 212 (Figure 2) and the second antenna 214 (Figure 2) ie. stored at steps 406 and 418 respectively, the receiver 202 (Figure 2) determines which one of the first antenna 212 (Figure 2) and the second antenna 214 (Figure 2) produces a better signal quality for a greater number of carriers.

If the first antenna 212 (Figure 2) provides the greater number of stronger carriers than the second antenna 214 (Figure 2), then at step 422, the receiver 202 (Figure 2) activates the first antenna 212 (Figure 2) to receive the third useful duration 120 of the third symbol 116. Following step 422, the reception operation loops back to step 402.

If the second antenna 214 (Figure 2) provides the greater number of stronger carriers than the first antenna 212 (Figure 2), then at step 426, the receiver 202 (Figure 2) continues using the second antenna 214 (Figure 2) to receive the third useful duration 120 of the third symbol 116. Following step 426, the reception operation loops back to step 402.

The example embodiment described above uses a "variable" threshold for determining the number of low signal quality carriers (see e.g. step 408) and antenna switching is based on the threshold (see e.g. step 410) and the quality estimates for the two antennas (see e.g. step 420).

Therefore, the example embodiment may reduce power consumption since switching in each guard interval may not be required. Furthermore, the example embodiment may reduce unnecessary antenna switching based on comparing the quality estimates results for the two antennas.

In addition, the example embodiment described above uses only a single front end and also takes into account the effect of fading on different carriers by evaluating the carriers individually. Furthermore, FFT is applied to the useful duration of an OFDM symbol to obtain channel and quality estimates of carriers and only a single FFT operation is carried out for both switch control and data demodulation. This may provide more accurate estimation results and can avoid additional FFT processing in e.g. a guard interval. In addition, the example embodiment may further reduce power consumption since the antenna switching is not carried out if the signal qualities of carriers for the activated antenna are satisfactory.

Following the description of the first example embodiment above, a second example embodiment is described below.

Figure 5 is a schematic block diagram illustrating the switch combining unit 210 in a second example embodiment. The switch combining unit 210 comprises a quality estimation module 502, a quality evaluation module 504, a threshold memory module 505, a first carrier quality memory module 506, a second carrier quality memory module

508 and a switch control module 510. The switch control module 510 output is used to control the switch 206 (Figure 2) (see numeral 224 in Figure 2). The threshold memory module 505 is used for storing average values of quality estimates for OFDM symbols.

It will be appreciated by a person skilled in the art that although the modules of Figure 5 are identically named to the modules of Figure 3, there are functional differences which are described below.

The quality estimation module 502 does not store the quality estimates at the plurality of carrier frequencies in the first carrier quality memory module 506 or the second carrier quality memory module 508, unlike the quality estimation module 302 (Figure 3). Instead, the quality evaluation module 504 stores the number of low quality carriers to the first carrier quality memory module 506 or the second carrier quality memory module 508, depending on whether the first antenna 212 (Figure 2) or the second antenna 214 (Figure 2) is currently being activated. Therefore, the switch combining unit 210 in this second example embodiment has an advantage over the switch combining unit 210 of the first example embodiment in terms of memory requirement.

In addition, the switch control module 510 is not directly coupled to the quality evaluation module 504, unlike the switch control module 312 (compare Figure 3). Instead, the switch control module 510 operates based on the numbers of low quality carriers for the two antennas 212, 214 (Figure 2) as retrieved from the first carrier quality memory module 506 and the second carrier quality memory module 508 respectively.

The switch control module 510 operates in two different modes. In a first mode, the switch control module 510 compares the number of low quality carriers for the activated antenna 212 (Figure 2) with a fixed number. If the number of low quality carriers is larger than the fixed number, the switch control module 510 controls the switch 206 (Figure 2) to switch to the substituting antenna 214 (Figure 2).

In a second mode, the switch control module 510 compares the two numbers of low quality carriers for the two antennas 212, 214 (Figure 2). If the substituting antenna 214 (Figure 2) provides a smaller number of low quality carriers than the activated

antenna 212 (Figure 2), the switch control module 510 controls the switch 206 (Figure 2) to switch to the substituting antenna 214 (Figure 2).

Figure 6 is a flowchart 600 illustrating antenna diversity signal reception in the second example embodiment. References are also made across Figures 1, 2 and 5.

At step 602, the reception operation of the second example embodiment starts. At step 604, the receiver 202 (Figure 2) utilises the activated first antenna 212 (Figure 2) to receive the first useful duration 108 (Figure 1) of the first symbol 104 (Figure 1) of the incoming signal 102 (Figure 1).

At step 606, during the second guard interval 112 (Figure 1) of the second symbol 110 (Figure 1), the receiver 202 (Figure 2) estimates signal qualities at the plurality of carrier frequencies based on the channel state information of carriers for the first antenna 212 (Figure 2).

At step 608, the receiver determines the number of low quality carriers based on the carrier quality estimates for the first antenna 212 (Figure 2). The determination is based on a threshold obtained from e.g. an average of the quality estimates at the plurality of carrier frequencies during a time period, as described above. In addition, in this same step, the receiver 202 (Figure 2) stores the number of low quality carriers to the first carrier quality memory module 506 (Figure 5).

At step 610, the receiver 202 (Figure 2) compares the number of low quality carriers for the first antenna 212 (Figure 2) with a fixed number. If the number of low quality carriers is smaller than the fixed number, then at step 612, the receiver 202 (Figure 2) receives the second useful duration 114 (Figure 1) of the second symbol 110 (Figure 1) using the first antenna 212 (Figure 2). Following step 612, the reception operation loops back to step 602.

If the number of low quality carriers is more than the fixed number at step 610, then at step 616, the receiver 202 (Figure 2) activates the substituting second antenna 214 (Figure 2) to receive the second useful duration 114 (Figure 1) of the second symbol 110 (Figure 1).

At step 618, during the third guard interval 118 of the third symbol 116, the receiver 202 (Figure 2) determines the quality estimates at the plurality of carrier frequencies according to the channel state information for the second antenna 214 (Figure 2). At step 620, the receiver 202 (Figure 2) determines the number of low quality carriers for the second antenna 214 (Figure 2). The determination is based on the threshold used in step 608. In this same step 620, the receiver 202 (Figure 2) stores the number to the second carrier quality memory module 508.

At step 622, the receiver 202 (Figure 2) determines which one of the first antenna 212 (Figure 2) and the second antenna 214 (Figure 4) produces a smaller number of low quality carriers.

If the first antenna 212 (Figure 2) provides the smaller number of low quality carriers compared to the second antenna 214 (Figure 2), then at step 624, the receiver 202 (Figure 2) activates the first antenna 212 (Figure 2) to receive the third useful duration 120 of the third symbol 116. Following step 624, the reception operation loops back to step 602.

If the second antenna 214 (Figure 2) provides the smaller number of low quality carriers compared to the first antenna 212 (Figure 2), then in step 628, the receiver 202 (Figure 2) continues utilising the second antenna 214 (Figure 2) to receive the third useful duration 120 of the third symbol 116. Following step 628, the reception operation loops back to step 602.

Figure 7 is a flowchart 700 illustrating a method for receiving a signal in a diversity switched combining module. At step 702, an incoming signal received via an antenna is converted and demodulated. At step 704, channel amplitudes, phases, or both are estimated at a plurality of carrier frequencies. At step 706, signal qualities at the plurality of carrier frequencies are estimated based on the estimated channel amplitudes, phases, or both. At step 708, a reference quality level is determined based on the estimated signal qualities over a time period. At step 710, a number of low quality carrier frequencies of the plurality of carrier frequencies is

determined wherein the low quality carrier frequencies have respective estimated qualities below the reference quality level.

The example embodiments described above may reduce power consumption since switching in each guard interval is not required. Further, the example embodiments use only a single radio frequency (RF) front end and take into account the effect of fading on different carriers by evaluating the carriers individually. Furthermore, the example embodiments may utilise a useful duration of an OFDM symbol to perform channel and quality estimation at a plurality of carrier frequencies. This may provide more accurate estimation results and may reduce additional FFT processing. The example embodiments may also assess the quality estimates at a plurality of carrier frequencies for an activated antenna to determine whether to commence an antenna selection procedure. In addition, a decision may be made in the example embodiments to use a particular antenna for reception by determining which one of two antennas provides a larger number of stronger carriers (or by determining which one of the two antennas produces a smaller number of low quality carriers), if antenna selection is required. The above may reduce unnecessary antenna switching and lead to further reduction in power consumption.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

**CLAIMS**

1. A receiver module comprising:

a receiver circuit for converting and demodulating an incoming signal received via an antenna, the receiver circuit being arranged for estimating channel amplitudes, phases, or both at a plurality of carrier frequencies;

a quality estimation unit for estimating signal qualities at the plurality of carrier frequencies based on the estimated channel amplitudes, phases, or both, and for determining a reference quality level based on the estimated signal qualities over a time period; and

a quality evaluation unit for determining a number of low quality carrier frequencies of the plurality of carrier frequencies, the low quality carrier frequencies having respective estimated qualities below the reference quality level.

2. The receiver module as claimed in claim 1, further comprising:

first and second antennas;

a switching unit for selectively coupling one of the first and second antennas to the receiver circuit; and

a control unit for the switching unit;

wherein the quality estimation unit estimates and stores signal qualities at the plurality of carrier frequencies for the first antenna;

the quality evaluation unit determines a number of low quality carrier frequencies for the first antenna based on the reference quality level; and

the control unit controls a setting of the switching unit based on the determined number of low quality carrier frequencies for the first antenna.

3. The receiver module as claimed in claim 2, wherein the control unit changes the setting of the switching unit when the determined number of low quality carrier frequencies for the first antenna exceeds a predetermined number.

4. The receiver module as claimed in claims 2 or 3, wherein, when the control unit controls the switching unit to couple the second antenna to the receiver circuit based on the determined number of low quality carrier frequencies for the first

antenna, the quality estimation unit estimates signal qualities at the plurality of carrier frequencies for the second antenna; and

the quality evaluation unit makes a determination whether the first antenna has a better signal quality based on comparing the stored estimated signal qualities of the first antenna with the estimated signal qualities of the second antenna; and

the control unit controls the setting of the switching unit based on said determination by the quality evaluation unit.

5. The receiver module as claimed in claim 4, wherein the control unit controls the switching unit to couple the first antenna to the receiver circuit when the first antenna has the better signal quality.

6. The receiver module as claimed in claim 1, further comprising:

first and second antennas;

a switching unit for selectively coupling one of the first and second antennas to the receiver circuit; and

a control unit for the switching unit;

wherein the quality estimation unit estimates signal qualities at the plurality of carrier frequencies for the first antenna;

the quality evaluation unit determines and stores a number of low quality carrier frequencies for the first antenna based on the reference quality level; and

the control unit controls a setting of the switching unit based on the determined number of low quality carrier frequencies for the first antenna.

7. The receiver module as claimed in claim 6, wherein the control unit changes the setting of the switching unit when the determined number of low quality carrier frequencies for the first antenna exceeds a predetermined number.

8. The receiver module as claimed in claims 6 or 7, wherein, when the control unit controls the switching unit to couple the second antenna to the receiver circuit based on the determined number of low quality carrier frequencies for the first antenna, the quality estimation unit estimates signal qualities at the plurality of carrier frequencies for the second antenna; and

the quality evaluation unit makes a determination whether the stored number of low quality carrier frequencies for the first antenna is smaller than a number of low quality carrier frequencies for the second antenna based on said reference quality level; and

the control unit controls the setting of the switching unit based on said determination by the quality evaluation unit.

9. The receiver module as claimed in claim 8, wherein the control unit controls the switching unit to couple the first antenna to the receiver circuit when the number of low quality carrier frequencies for the first antenna is smaller than the number of low quality carrier frequencies for the second antenna.

10. The receiver module as claimed in any one of claims 2 to 9, wherein said controlling a setting of the switching unit is carried out during a guard interval of the incoming signal.

11. The receiver module as claimed in any one of claims 1 to 10, wherein the plurality of carrier frequencies comprise signals of pilot carrier frequencies having known values.

12. The receiver module as claimed in claim 11, wherein said estimating channel amplitudes, phases, or both is carried out at each pilot carrier frequency.

13. The receiver module as claimed in any one of claims 1 to 12, wherein said estimating channel amplitudes, phases, or both is carried out at each carrier frequency.

14. The receiver module as claimed in any one of claims 11 to 13, wherein said estimating signal qualities is based on said estimated channel amplitudes, phases, or both at each pilot carrier frequency.

15. The receiver module as claimed in any one of claims 1 to 14, wherein said estimating signal qualities is based on said estimated channel amplitudes, phases, or both at each carrier frequency.

16. The receiver module as claimed in any one of claims 1 to 15, wherein said estimating signal qualities is based on a distance between a pilot carrier frequency measurement and a known correct position in a signal constellation.

17. The receiver module as claimed in any one of claims 1 to 16, wherein the reference quality level is set to an average of the estimated signal qualities at a plurality of pilot carrier frequencies during the time period.

18. The receiver module as claimed in any one of claims 1 to 16, wherein the reference quality level is set to an average of the estimated signal qualities at the plurality of carrier frequencies during the time period.

19. The receiver module as claimed in any one of claims 1 to 18, wherein the time period is smaller than a channel coherent time.

20. The receiver module as claimed in any one of claims 1 to 19, wherein said estimating channel amplitudes, phases, or both is carried out during a useful duration of the incoming signal.

21. The receiver module as claimed in any one of claims 1 to 20, wherein said estimating signal qualities is carried out during a useful duration of the incoming signal.

22. The receiver module as claimed in any one of claims 1 to 20, wherein said estimating signal qualities is carried out during a guard interval of the incoming signal.

23. The receiver module as claimed in any one of claims 1 to 22, wherein said determining a number of low quality carrier frequencies is carried out during a guard interval of the incoming signal.

24. The receiver module as claimed in any one of claims 1 to 23, wherein the time period comprises a predetermined number of symbol durations of the incoming signal.

25. The receiver module as claimed in any one of claims 1 to 24, wherein the reference quality level is updated for each symbol of the incoming signal.

26. The receiver module as claimed in any one of claims 1 to 25, wherein the incoming signal is an Orthogonal Frequency Division Multiplexing (OFDM) modulated signal.

27. A method for receiving a signal in a diversity switched combining module, the method comprising:

converting and demodulating an incoming signal received via an antenna;

estimating channel amplitudes, phases, or both at a plurality of carrier frequencies;

estimating signal qualities at the plurality of carrier frequencies based on the estimated channel amplitudes, phases, or both;

determining a reference quality level based on the estimated signal qualities over a time period; and

determining a number of low quality carrier frequencies of the plurality of carrier frequencies wherein the low quality carrier frequencies have respective estimated qualities below the reference quality level.

28. The method as claimed in claim 27, further comprising:

selectively coupling one of a first and second antennas to a receiver circuit;

estimating and storing signal qualities at the plurality of carrier frequencies for the first antenna;

determining a number of low quality carrier frequencies for the first antenna based on the reference quality level; and

controlling the coupling based on the determined number of low quality carrier frequencies for the first antenna.

29. The method as claimed in claim 28, wherein the controlling changes the coupling when the determined number of low quality carrier frequencies for the first antenna exceeds a predetermined number.

30. The method as claimed in claims 28 or 29, wherein, when the controlling occurs to couple the second antenna to the receiver circuit based on the determined number of low quality carrier frequencies for the first antenna, the method further comprises

estimating signal qualities at the plurality of carrier frequencies for the second antenna;

making a determination whether the first antenna has a better signal quality based on comparing the stored estimated signal qualities of the first antenna with the estimated signal qualities of the second antenna; and

controlling the coupling based on said determination.

31. The method as claimed in claim 30, wherein the controlling occurs to couple the first antenna to the receiver circuit when the first antenna has the better signal quality.

32. The method as claimed in claim 27, further comprising:

selectively coupling one of a first and second antennas to a receiver circuit;

estimating signal qualities at the plurality of carrier frequencies for the first antenna;

determining and storing a number of low quality carrier frequencies for the first antenna based on the reference quality level; and

controlling the coupling based on the determined number of low quality carrier frequencies for the first antenna.

33. The method as claimed in claim 32, wherein the controlling changes the coupling when the determined number of low quality carrier frequencies for the first antenna exceeds a predetermined number.

34. The method as claimed in claims 32 or 33, wherein, when the controlling occurs to couple the second antenna to the receiver circuit based on the determined

number of low quality carrier frequencies for the first antenna, the method further comprises

estimating signal qualities at the plurality of carrier frequencies for the second antenna;

making a determination whether the stored number of low quality carrier frequencies for the first antenna is smaller than a number of low quality carrier frequencies for the second antenna based on said reference quality level; and

controlling the coupling based on said determination.

35. The method as claimed in claim 34, wherein the controlling changes the coupling to couple the first antenna to the receiver circuit when the number of low quality carrier frequencies for the first antenna is smaller than the number of low quality carrier frequencies for the second antenna.