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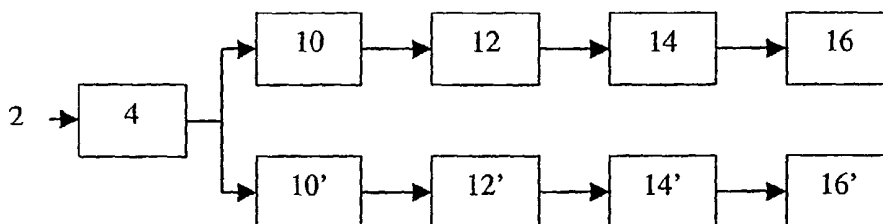
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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: COFDM TRANSMITTER WITH DIVERSITY AND TIME DELAY



(57) Abstract: The transmission system utilizes transmit diversity over a first and at least one further coded OFDM channel in the same frequency band, where each channel after the first channel has a time delay relative to the first channel. Digital filters (10, 10') in each channel (A, B) have different phase and magnitude responses in order to achieve the required time delay and provide different gain values as a function of frequency.

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## COFDM TRANSMITTER WITH DIVERSITY AND TIME DELAY

**Background of the Invention**

The present invention relates to broadband wireless communications and in particular, but not exclusively, systems suitable for transmitting the large quantities of data  
5 needed for Internet access for users who are not connected to the existing telephone and cable systems.

More specifically the present invention relates to a transmitter station for providing broadband communications suitable for use in the 3.5GHz band, where a narrow  
14MHz band is available for wireless internet access in Europe including Scandinavia  
10 and parts of the Middle and Near East, Mexico and South America. The band could also become available in the US and Canada, where it is currently assigned to military use. The invention is also applicable to situations where a wider bandwidth is available such as the 56MHz band at 2.5GHz.

**Technical Problem**

15 The technical problem is to transmit reliably by wireless a large amount of data such as required for digital television or internet data. In the frequency band of interest multipath effects and significant fading are serious problems. Spread spectrum solutions combined with forward error correction (FEC) can improve the reliability of such channels but still do not provide sufficient reliability for data purposes where  
20 99.99% accuracy is required to maintain acceptable standards.

**Coded Orthogonal Frequency Division Multiplexing (OFDM)**

Coded OFDM is an established technique for broadband communications in which digital data coded with redundancy for FEC is encoded as a plurality of voltage  
vectors that are transmitted simultaneously on a set of carriers in the frequency  
25 domain.

This technique alone will not achieve the required accuracy.

### Solution of the Invention

The transmission system of the present invention utilizes transmit diversity over a first and at least one further coded OFDM channel in the same frequency band, where each channel after the first channel has a time delay relative to the first channel.

- 5 Preferably the channels are adapted to have different gain and phase values as a function of frequency where such values may be fixed or vary in time.

### Advantages of the Invention

- When used in fixed radio communication links this system can deliver improved fade margin statistics which can be used to reduce transmitter power, increase range,  
10 modulation depth and frequency reuse. These improvements are also applicable to mobile applications.

- This system can reduce the time taken to statistically characterize the radio paths to a given location. Where installation of a receiver at a given location requires characterization of the radio paths to the location, this system results in a reduced  
15 installation time.

### Brief Description of the Drawings

In order that the invention may be well understood an embodiment thereof will now be described, by way of example only, with reference to the accompanying diagrammatic drawings, in which:

- 20 Figure 1 shows a block diagram of a transmitter; and  
Figure 2 shows an example channel response for a multi-channel embodiment of the invention.

### Overview

The system is a coded OFDM transmitter incorporating transmit diversity.

### Detailed Description of a Preferred Embodiment

An implementation of the invention using two transmit channels A and B is described with reference to Fig 1.

A data signal to be transmitted is input at 2 to a baseband coder 4 that generates a  
 5 baseband coded OFDM signal. The signal at this point is represented by digital samples of the real and imaginary components of the signal. The output of the coder 4 is then fed to the input of each of two channels A and B. The elements of the channels are indicated by the same reference numerals with those in channel B being indicated by the addition of a prime sign (').

10 In channel A the signal is supplied to a digital filters 10. The output of the digital filter 10 is supplied to an RF modulator, 12. The RF modulator 12 converts the digital signal into an analogue signal and also performs the frequency conversion to translate the signal to the required carrier frequency.

The RF signal output from the RF modulator 12 is supplied to a power amplifier 14.  
 15 The output of the power amplifier 14 is supplied to an antennas 16 which radiates the signal for channel A.

The digital filters, 10, 10', have complex coefficients. They are implemented using standard digital signal processing techniques using either programmable digital signal processors, field programmable gate arrays or dedicated logic circuits. Both the phase  
 20 responses and magnitude responses of the filters are different from each other. The difference in phase response of the two filters results in a difference in group delay between the two signal paths. Typically for an OFDM signal bandwidth of 3 to 15 MHz, the filters will be selected to impart a group delay difference of 5 to  $\frac{1}{2}$   $\mu$ s.

The two filters also have different magnitude responses. Assume the filter magnitude  
 25 responses are given as follows:

$$M_{10}(f) \quad \text{for filter 10}$$

$$M_{10'}(f) \quad \text{for filter } 10'$$

The filter responses are selected so that the composite power response is constant:

5

$$(M_{10}(f))^2 + (M_{10'}(f))^2 = k$$

Example magnitude responses for the two channel case are as follows:

Scheme	Magnitude response
1	$M_{10}(f) = 1, M_{10'}(f) = a, f < 0$ $M_{10'}(f) = 1, M_{10}(f) = a, f \geq 0$ where $a$ is between 0 and 1, typically 0.33 and $f$ is the frequency
2	$M_{10}(f) = \sqrt{\frac{1}{1 + 10^{f \cdot a}}}$ $M_{10'}(f) = \sqrt{1 - \frac{1}{1 + 10^{f \cdot a}}}$ where $f$ is the normalized frequency and $a$ is a scaling factor

10

Preferably, the filter phase and magnitude responses may be varied slowly in time.

Typically the bandwidth of the variations will be less than 1 kHz to allow the OFDM demodulator time to track the changes in the channel state using existing demodulators.

15

Alternatively, using an enhanced OFDM demodulator, the bandwidth of the magnitude and phase response may be increased up to a rate equal to that of the OFDM burst rate. The phase and magnitude responses may be varied in a periodic or a pseudo-random manner known to both the transmitter and the receiver.

20

The filtering functions implemented by blocks 10 and 10' may be performed at other points in the signal processing chain. They may be performed prior to the inverse Fourier transformation in the OFDM coder 4 or performed on the IF signal. Similarly the filter may be performed on an analogue or digital version of the signal.

The implementation detailed in Fig 1 applies to a transmitter with two diverse channels. In a multi-channel implementation the blocks 10, 12, 14 and 16 are repeated for each channel. In general, for each channel, the respective blocks are identical apart from the filter implemented by the equivalent of block 10. The phase responses of  
5 each filter are selected to impart a different group delay to each channel. Again group delay differences in the ranges 5 to  $\frac{1}{2}$   $\mu$ s are typical.

An example channel response for the multi-channel case is shown in Figure 2

The factor  $a$  is some value between 0 and 1.

The magnitude spectrum satisfies the following requirement:

$$10 \quad \sum_{channels} (M_{channel}(f))^2 = k$$

In a radio system employing transmit diversity, receive diversity can also be used to advantage. If there are two transmitters and two receive antennas, then there are four communication paths. If the paths are statistically independent, then substantial gain  
15 can result depending upon the Ricean K factor of the paths, and upon the use of an optimal receive combiner and upon the desired link reliability.

These transmit diversity techniques are particularly useful in point to multi-point systems where the benefit of a small increase in base site complexity is distributed across many outstations.

20 This transmission system can be used with any known error correction coding such as FEC.

## Claims

1. A transmission system comprising means for generating an OFDM signal coded with redundancy for forward error correction from a data signal to be transmitted and means for transmitting said signal over a first and at least one further channel in the same frequency band, where each channel after the first channel has a positive or negative time delay relative to the first channel.  
5
2. A transmission system as claimed in claim 1, wherein the transmitting means provides the channels with different gain and phase values as a function of frequency which values do not vary in time.
- 10 3. A transmission system as claimed in claim 1, wherein the transmitting means provides the channels with different gain and phase values as a function of frequency which values vary in time with a rate less than the OFDM symbol rate.
4. A transmission system as claimed in claim 1, for use with a receiver having at least two antennas in order to define at least four transmission paths.  
15
5. A transmission system as claimed in claim 2, for use with a receiver having at least two antennas in order to define at least four transmission paths.
6. A transmission system as claimed in claim 3, for use with a receiver having at least two antennas in order to define at least four transmission paths.

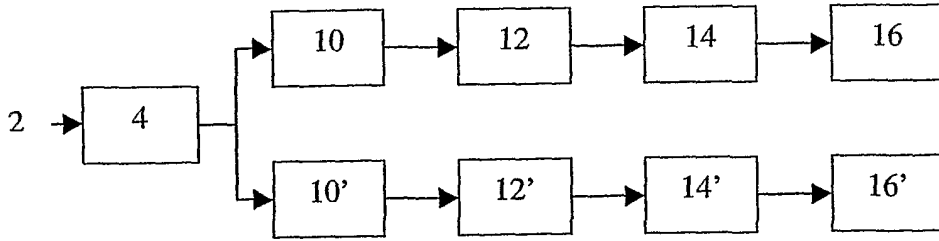


Fig.1

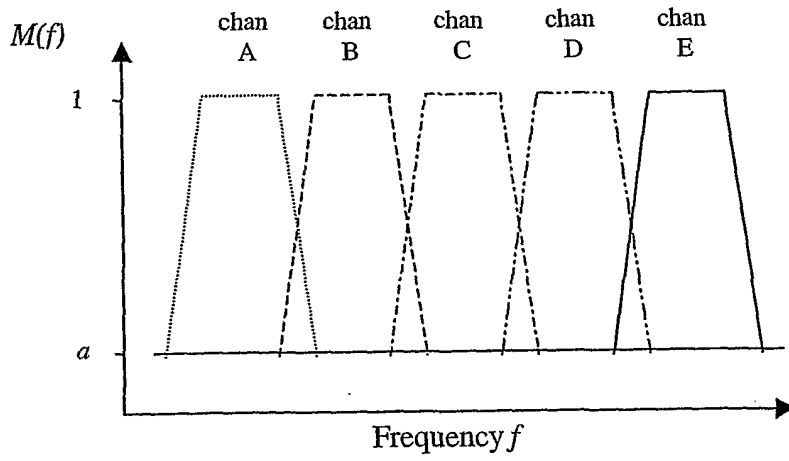


Fig.2

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 H04L27/26 H04L1/06 H04B7/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 H04L H04B

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

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

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	LI Y ET AL: "TRANSMITTER DIVERSITY FOR OFDM SYSTEMS AND ITS IMPACT ON HIGH-RATE DATA WIRELESS NETWORKS" IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, IEEE INC. NEW YORK, US, vol. 17, no. 7, July 1999 (1999-07), pages 1233-1243, XP000834945 ISSN: 0733-8716 page 1233, column 2, paragraph 3 - paragraph 4 page 1234, column 1, paragraph 3 - column 2, paragraph 1 figure 1A	1, 4
Y	---	2, 3, 5, 6
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Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

° Special categories of cited documents :

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
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- \*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- \*&\* document member of the same patent family

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## INTERNATIONAL SEARCH REPORT

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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 196 44 430 C (BAYERISCHER RUNDFUNK ANSTALT D) 18 December 1997 (1997-12-18) abstract column 1, line 10 - line 22 column 1, line 66 -column 2, line 30 claims 1,2 figure 1	1,4
Y	---	2,3,5,6
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P,A	EP 1 073 214 A (MITSUBISHI ELECTRIC CORP) 31 January 2001 (2001-01-31) abstract paragraph '0010! - paragraph '0012! paragraph '0016! paragraph '0030! paragraph '0036! - paragraph '0038! paragraph '0041! - paragraph '0042! claims 1,2 figure 1	2,3,5,6
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