(12) **UK Patent Application** (19) **GB** (11) **2 442 264** (13) **A**

(43) Date of A Publication **02.04.2008**

(21) Application No: **0618990.6**

(22) Date of Filing: **26.09.2006**

(71) Applicant(s):
**ITI Scotland Ltd**
**(Incorporated in the United Kingdom)**
**5th Floor, 191 West George Street,**
**GLASGOW, G2 2LB, United Kingdom**

(72) Inventor(s):
**Fraser Edwards**
**Robert Tan**

(74) Agent and/or Address for Service:
**Haseltine Lake**
**Redcliff Quay, 120 Redcliff Street, Bristol,**
**BS1 6HU, United Kingdom**

(51) INT CL:
***H04L 27/26*** (2006.01) ***H04B 1/69*** (2006.01)

(56) Documents Cited:
**EP 0929172 A1** **EP 0849919 A2**
**WO 2006/099324 A1** **WO 2005/101694 A2**
**US 20050232134 A1**

(58) Field of Search:
UK CL (Edition X ) **H4P**
INT CL **H04B, H04L**
Other:

(54) Abstract Title**: Anti-aliasing zero-padding before IFFT in an UWB MB-OFDM system**

(57) In Ultra Wide Band (UWB) communication via a Multiple frequency band Orthogonal Frequency Division Multiplex system (MB-OFDM), aliasing in an Inverse Fast Fourier Transform (IFFT, fig. 2) is avoided by zero padding the data points beforehand instead of filtering out the alias afterwards (fig. 3). The number of appended, pre-pended or interleaved zeroes is typically similar to the size of the data set, thus doubling the data set in size (128 points at 528 MHz in fig. 2, 256 points at 1024 MHz in fig. 5). After zero padding and IFF transformation, Digital Analogue Conversion (DAC) and filtering can be carried out to reduce the alias still further. The apparatus can be implemented as a Digital Signal Processor (DSP), an Integrated Circuit (ASIC) or a Field Programmable Array (FPGA).

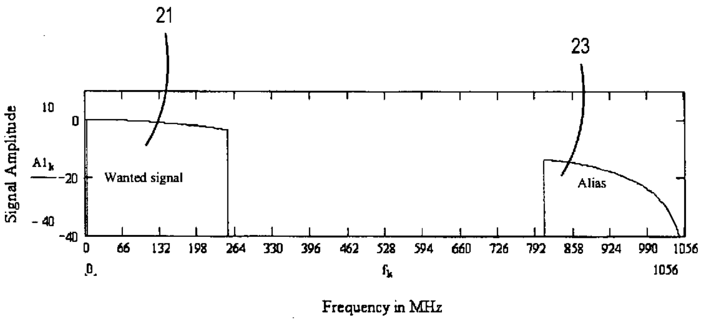


Figure 6

GB 2 442 264 A

Original Printed on Recycled Paper

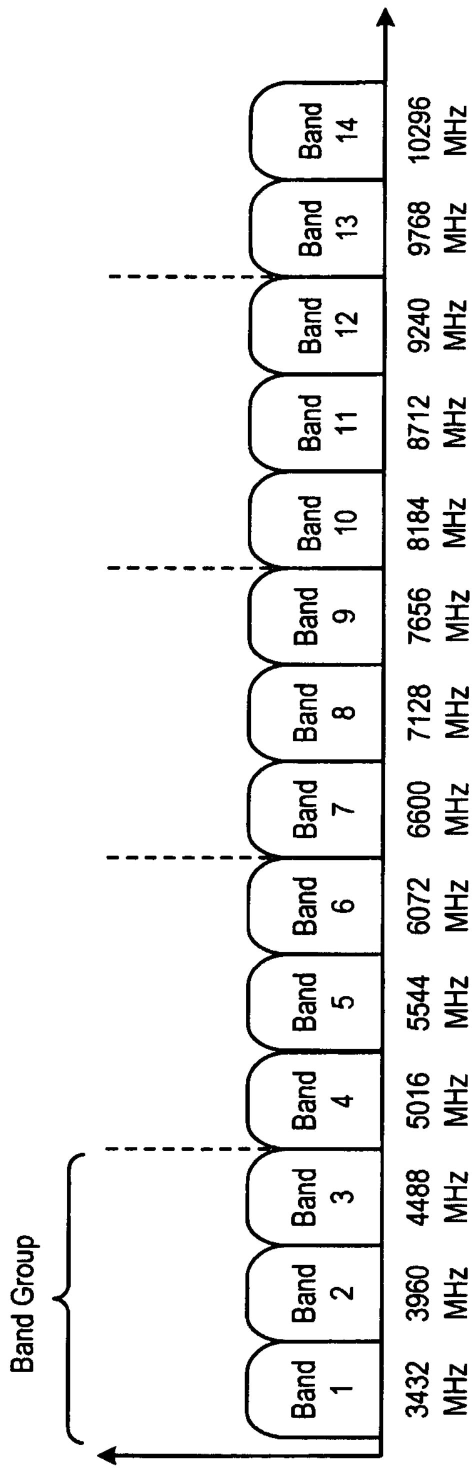
Band Group
Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Band 7
Band 8
Band 9
Band 10
Band 11
Band 12
Band 13
Band 14
3432 MHz
3960 MHz
4488 MHz
5016 MHz
5544 MHz
6072 MHz
6600 MHz
7128 MHz
7656 MHz
8184 MHz
8712 MHz
9240 MHz
9768 MHz
10296 MHz

Figure 1

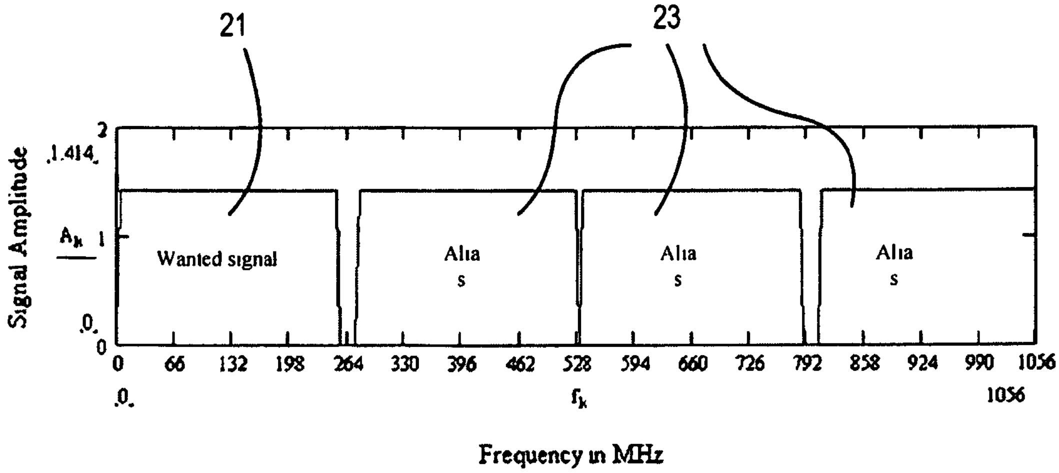


Figure 2

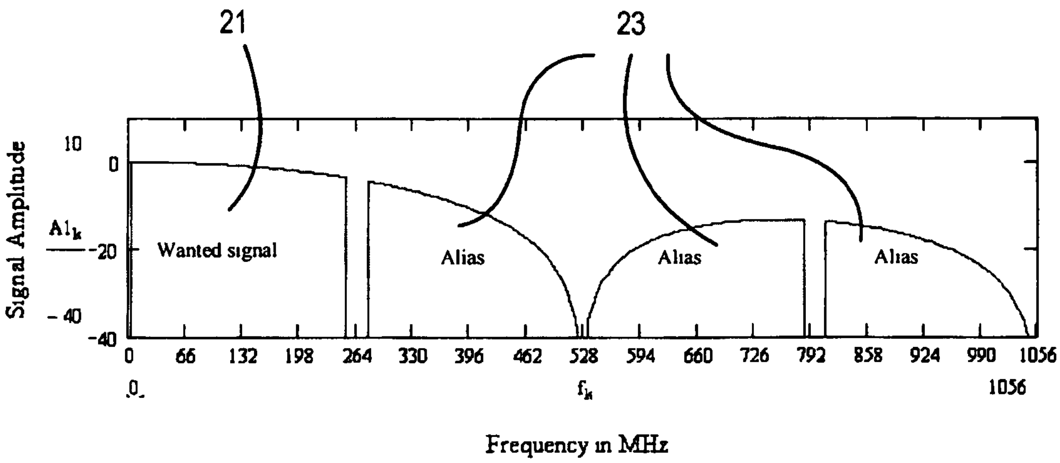


Figure 3

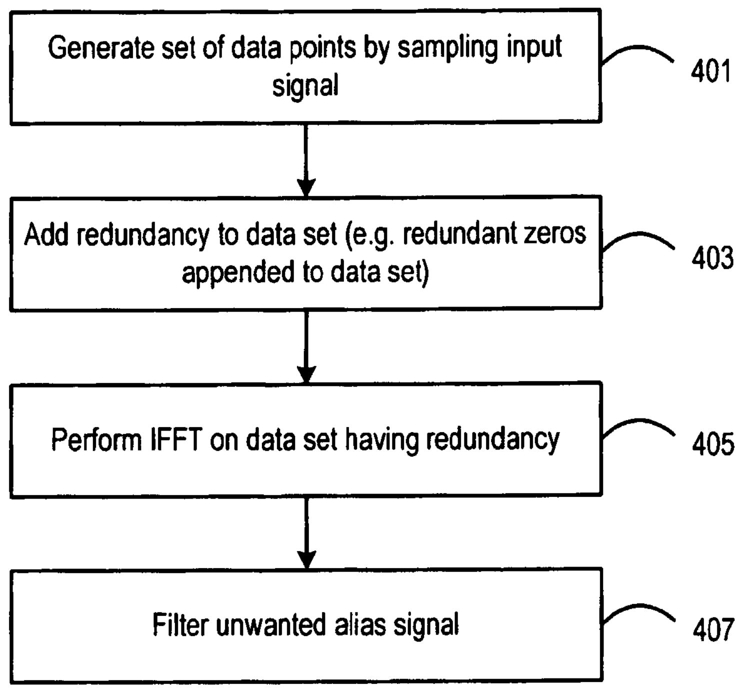
Generate set of data points by sampling input signal
401
Add redundancy to data set (e.g. redundant zeros appended to data set)
403
Perform IFFT on data set having redundancy
405
Filter unwanted alias signal
407

Figure 4

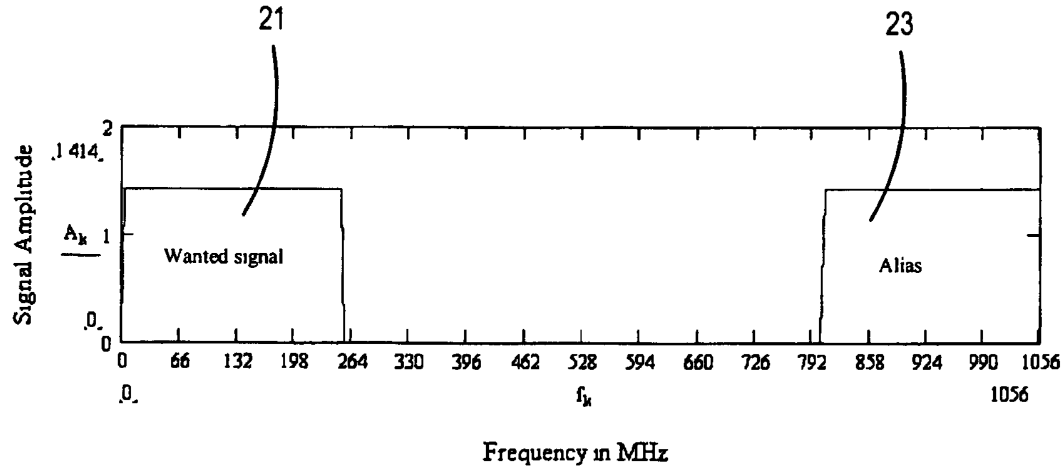


Figure 5

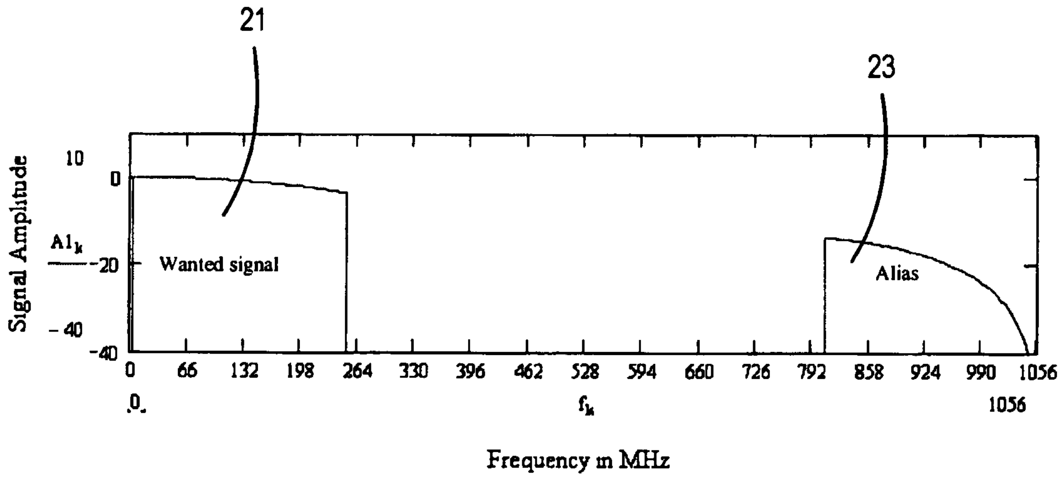


Figure 6

2442264



# APPARATUS AND METHOD FOR CREATING OFDM SYMBOLS

## Technical field of the invention

The invention relates to an apparatus and a method of creating OFDM symbols, and in particular to an apparatus and method for creating OFDM symbols such that the complexity of filtering signal aliases from the generated symbol is reduced.

## Background of the invention

Ultra-wideband is a radio technology that transmits digital data across a very wide frequency range, 3.1 to 10.6 GHz. It makes use of ultra low transmission power, typically less than –41 dBm/MHz, so that the technology can literally hide under other transmission frequencies such as existing Wi-Fi, GSM and Bluetooth. This means that ultra-wideband can co-exist with other radio frequency technologies. However, this has the limitation of limiting communication to distances of typically 5 to 20 metres.

There are two approaches to UWB: the time-domain approach, which constructs a signal from pulse waveforms with UWB properties, and a frequency-domain modulation approach using conventional FFT-based Orthogonal Frequency Division Multiplexing (OFDM) over Multiple (frequency) Bands, giving MB-OFDM. Both UWB approaches give rise to spectral components covering a very wide bandwidth in the frequency spectrum, hence the term ultra-wideband, whereby the bandwidth occupies more than 20 per cent of the centre frequency, typically at least 500MHz.

These properties of ultra-wideband, coupled with the very wide bandwidth, mean that UWB is an ideal technology for providing high-speed wireless communication in the home or office environment, whereby the communicating devices are within a range of 20m of one another.

Figure 1 shows the arrangement of frequency bands in a multi-band orthogonal frequency division multiplexing (MB-OFDM) system for ultra-wideband communication. The MB-OFDM system comprises fourteen sub-bands of 528 MHz each, and uses frequency hopping every 312 ns between sub-bands as an access method. Within each sub-band OFDM and QPSK or DCM coding is employed to transmit data. It is noted that the sub-band around 5 GHz, currently 5.1–5.8 GHz, is left blank to avoid interference with existing narrowband systems, for example 802.11a WLAN systems, security agency communication systems, or the aviation industry.

The fourteen sub-bands are organized into five band groups, four band groups having three 528 MHz sub-bands, and one band group having two 528 MHz sub-bands. As shown in Figure 1, the first band group comprises sub-band 1, sub-band 2 and sub-band 3. An example UWB system will employ frequency hopping between sub-bands of a band group, such that a first data symbol is transmitted in a first 312.5 ns duration time interval in a first frequency sub-band of a band group, a second data symbol is transmitted in a second 312.5 ns duration time interval in a second frequency sub-band of a band group, and a third data symbol is transmitted in a third 312.5 ns duration time interval in a third frequency sub-band of the band group. Therefore, during each time interval a data symbol is transmitted in a respective sub-band having a bandwidth of 528 MHz, for example sub-band 2 having a 528 MHz baseband signal centred at 3960 MHz.

The technical properties of ultra-wideband mean that it is being deployed for applications in the field of data communications. For example, a wide variety of applications exist that focus on cable replacement in the following environments:

- communication between PCs and peripherals, i.e. external devices such as hard disc drives, CD writers, printers, scanner, etc.
- home entertainment, such as televisions and devices that connect by wireless means, wireless speakers, etc.
- communication between handheld devices and PCs, for example mobile phones and PDAs, digital cameras and MP3 players, etc.

An OFDM symbol is generated by taking the inverse fast Fourier transform (IFFT) of a set of data points. Depending on the number of points in the IFFT, this leads to a phenomenon known as aliasing.

Aliasing is a familiar problem in the art, and will not be described in greater detail herein. It is sufficient to say that the process of digitising the signal causes additional unwanted frequency components to be present in the output signal. These extra components are known as aliases, and must be removed to preserve the original signal quality.

Figure 2 is a graph of signal amplitude versus frequency, illustrating the alias problem.

This particular example is of a 128-point IFFT with a sampling frequency of 528 MHz. The desired signal 21 exists from 0 Hz to 256 Hz. However, digitising of the signal during the IFFT process results in signal aliases 23 being introduced, only the first three of which are shown for brevity. Typically, the signal will be passed to a digital to analogue converter (DAC) after the IFFT has been performed, and the effect of the DAC on the spectrum of Figure 2 is shown in Figure 3.

One known technique for removing the signal aliases 23 shown in Figure 2 or Figure 3 is to up-sample the transformed signal using an interpolation filter, followed by the step of removing the aliases 23 using an alias filter.

As will be appreciated from Figures 2 and 3, the desired signal 21 and the aliases 23 are very close to one another in the frequency domain, which means that the aliases 23 are difficult to remove without compromising the wanted signal.

In addition, these filters tend to be extremely complex and require fast processing of large amounts of complex data. The amount of data that needs to be shuffled during the filtering process is difficult to achieve, particularly for applications such as ultra-wideband. Furthermore, this process is power consumptive and can require considerable processing power.

It is therefore an object of the present invention to provide an apparatus and method for creating OFDM symbols that do not suffer from the disadvantages mentioned above.

Summary of the invention

According to a first aspect of the present invention, there is provided an apparatus for generating an orthogonal frequency divisional multiplexed symbol. The apparatus comprises means for sampling a signal by taking a series of data points, and means for performing an inverse fast Fourier transform on the series of data points to obtain the OFDM symbol. Furthermore, the apparatus comprises means for adding redundant data to the series of data points prior to performing an inverse fast Fourier transform, thereby enabling subsequent filtering of any unwanted alias frequencies to be performed more easily.

According to another aspect of the present invention, there is provided a method of generating an orthogonal frequency divisional multiplexed symbol, the method comprising the steps of: sampling a signal by taking a series of data points; and performing an inverse fast Fourier transform on the series of data points to obtain the OFDM symbol; wherein, prior to the step of performing an inverse fast Fourier transform, redundant data is added to the series of data points, thereby enabling subsequent filtering of any unwanted alias frequencies to be performed more easily.

Thus, spectral shaping of an OFDM baseband signal by adding redundant information prior to the IFFT has the advantage that the complexity of any subsequent filtering process is greatly reduced.

Brief description of the drawings

For a better understanding of the present invention, and to show more clearly how it may be carried into effect, reference will now be made, by way of example only, to the following drawings in which:

Figure 1 shows the multi-band OFDM alliance (MBOA) approved frequency spectrum of a MB-OFDM system;

Figure 2 is a graph of signal amplitude versus frequency, illustrating the alias problem;

Figure 3 is a graph showing the spectrum of Figure 2 but including the additional effects of a digital to analogue converter:

Figure 4 is a flow chart describing the method of the present invention;

Figure 5 is a graph of signal amplitude versus frequency for the same data set as used in Figure 2, but wherein the data has been processed according to the present invention: and

Figure 6 is a graph showing the spectrum of Figure 5 but including the additional effects of a digital to analogue converter.

Detailed description of a preferred embodiment of the present invention

As described above, it is inherent that the spectrum and the position of the signal aliases, in the frequency domain, are defined by the number of points in the IFFT. In order to be able to filter the aliases the transformed signal can be up-sampled with an interpolation filter and the aliases removed with an alias filter.

The present invention provides a method of generating OFDM symbols, whereby the complexity of filtering the aliases is greatly reduced, by introducing a degree of redundancy in the set of data points prior to the IFFT.

Referring to the flow chart of Figure 4, according to the invention, a set of data points is first generated by sampling an input signal, step 401. However, before performing an IFFT of the set of data points to obtain an OFDM symbol, redundant data is added to the set of data points. In a preferred embodiment, the redundant data comprises a plurality of zeros appended to the set of data points, preferably to the extent that the data set is exactly doubled. Therefore, the new data set, prior to the IFFT process, consists of the original set of data points with redundant data bits in the form of a plurality of zeros appended thereto, step 403. The data set having redundant data bits is then subjected to a IFFT process, step 405. The transformed signal is then filtered, step 407, to remove the signal aliases.

As mentioned above, the spectrum and position of the signal aliases are defined by the number of points in the IFFT. Therefore, by adding redundant data such as zeros to the set of data points, the invention has the effect of increasing the number of points in the IFFT. This added redundancy in turn has the effect of moving the signal aliases further apart in the frequency domain, and therefore makes the aliases easier to remove with filtering.

Figure 5 is a graph of signal amplitude versus frequency, wherein the aliasing problem has been reduced by appending zeros to the data points prior to the IFFT process.

This particular example is the same as that in Figure 2, except that a plurality of zeros have been appended to the data set, thereby increasing the IFFT size to 256 points, with the sampling frequency increased to 1056 MHz. It is noted that the sampling frequency is increased in view of the fact that there is more data to process, i.e. due to the inclusion of the redundant data bits. The insertion of the zeros allows the aliases to be pushed out (in frequency) and thus filtered more easily.

As can be seen, the aliasing problem is greatly reduced since only one signal alias exists now in the frequency range of the graph, where before there were three. In addition, there is a much greater gap in frequency between the wanted signal and the alias, thereby enabling subsequent filtering of any unwanted alias frequencies to be performed more easily.

Figure 6 is a graph showing the effect of the DAC on the spectrum of figure 5.

It can be seen from the above that the addition of redundant data prior to carrying out the IFFT process has the advantage of enabling the desired signal to be filtered more easily, thereby reducing the complexity and cost of the filter.

It is noted that the apparatus can be implemented in many ways, including a digital signal processor (DSP), an application specific integrated circuit (ASIC), or a field programmable gate array (FPGA).

While the preferred embodiment has been described with reference to the plurality of zeros being appended to the set of data points, it will be appreciated that the plurality of zeros may also be pre-pended to the set of data points, or interleaved with the data points. In addition, while the preferred embodiment is described as having the same number of redundant data bits as data points, it will be appreciated that the number of redundant data bits could be more than the number of data points, or less than the number of data points.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. The word "comprising" does not exclude the presence of elements or steps other than those listed in a claim, "a" or "an" does not exclude a plurality, and a single processor or other unit may fulfil the functions of several units recited in the claims. Any reference signs in the claims shall not be construed so as to limit their scope.

**CLAIMS:**

1. A method of generating an orthogonal frequency divisional multiplexed symbol, the method comprising the steps of:

sampling a signal by taking a series of data points; and

performing an inverse fast Fourier transform on the series of data points to obtain the OFDM symbol;

wherein, prior to the step of performing an inverse fast Fourier transform, redundant data is added to the series of data points, thereby enabling subsequent filtering of any unwanted alias frequencies to be performed more easily.

2. A method as claimed in claim 1, wherein redundant data is appended to the series of data points.

3. A method as claimed in claim 1 or 2, wherein the redundant data comprises a plurality of zeros.

4. A method as claimed in claim 2 or 3, wherein the redundant data comprises a number of bits, the number of bits in the redundant data being equal to the number of data points.

5. An apparatus for generating an orthogonal frequency divisional multiplexed symbol, the apparatus comprising:

means for sampling a signal by taking a series of data points;

means for performing an inverse fast Fourier transform on the series of data points to obtain the OFDM symbol; and

means for adding redundant data to the series of data points prior to performing an inverse fast Fourier transform, thereby enabling subsequent filtering of any unwanted alias frequencies to be performed more easily.

6. An apparatus as claimed in claim 5, wherein the means for adding redundant data is adapted to append redundant data to the series of data points.

7. An apparatus as claimed in claim 5 or 6, wherein the means for adding redundant data is adapted to add a plurality of zeros.

8. An apparatus as claimed in claim 6 or 7, wherein the means for adding redundant data is adapted to append a number of redundant data bits that equal the number of data points.

9. An apparatus as claimed in any one of claims 5 to 8, wherein the apparatus is implemented in a digital signal processor, DSP, an application specific integrated circuit, ASIC, or a field programmable gate array, FPGA.

10. An ultra-wideband device comprising apparatus as claimed in any one of claims 5 to 9.

**Application No:** GB0618990.6 **Examiner:** Dr Mark Lewney

**Claims searched:** 1-10 **Date of search:** 5 December 2006

## Patents Act 1977: Search Report under Section 17

**Documents considered to be relevant:**

| Category | Relevant to claims | Identity of document and passage or figure of particular relevance |
|---|---|---|
| X,Y | X: 1-8, Y: 9-10 | US2005/232134 A1 (AGERE) - See especially paragraph [0021]. |
| X,Y | X: 1-8, Y: 9-10 | EP0929172 A1 (LUCENT) - See especially paragraph [0015]. |
| X,Y | X:1-8, Y: 9-10 | EP0849919 A2 (LUCENT) - See fig. 7 and accompanying description. |
| X,Y | X:1-8, Y:9-10 | WO2006/099324 A1 (QUALCOMM) - See especially fig. 3 and paragraph [0026]. |
| Y | Y: 9-10 | WO2005/101694 A2 (TEXAS) - See abstract and paragraph [0033]. |

Categories:

| | | | |
|---|---|---|---|
| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art. |
| Y | Document indicating lack of inventive step if combined with one or more other documents of same category | P | Document published on or after the declared priority date but before the filing date of this invention |
| & | Member of the same patent family | E | Patent document published on or after, but with priority date earlier than, the filing date of this application. |

### Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC$^{X}$ :

H4P

Worldwide search of patent documents classified in the following areas of the IPC

H04B; H04L

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC