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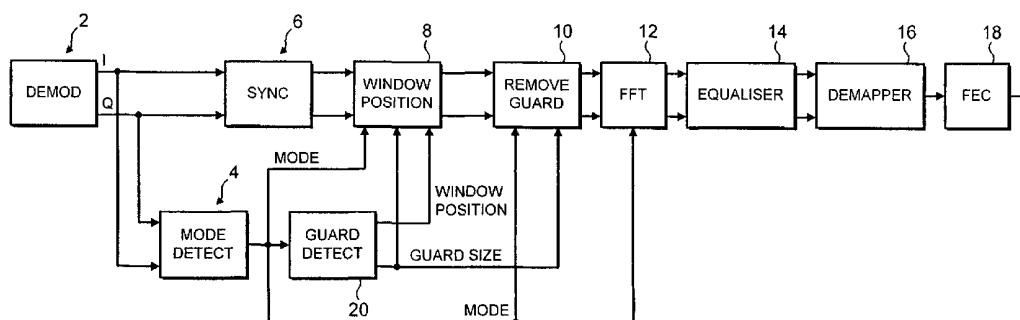
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(54) Title: RECEIVER CIRCUIT



(57) **Abstract:** A receiver circuit, for use in receiving signals transmitted according to the European DVD-T (Digital Video Broad-
casting-Terrestrial) standard, which uses Coded Orthogonal Frequency Division Multiplexing (COFDM) of transmitted signals,
processes a received signal to determine a size of a guard interval therein. The receiver circuit forms digital samples of the received
signal; generates from the digital samples a correlation function with peaks at positions which are determined by the size of the guard
interval and a position of the guard interval within the received signal; and includes a plurality of comb filters, each corresponding to
a possible guard interval size, each receiving a series of sample locations at which the correlation function exceeds a predetermined
threshold to the series of sample locations, and each producing an output for determining the guard interval size therefrom. The
advantageously allows the receiver circuit to determine the guard interval size quickly, even in the case of received signals with
relatively low signal-noise ratio.

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RECEIVER CIRCUIT**TECHNICAL FIELD OF THE INVENTION**

This invention relates to a receiver circuit, in particular for receiving signals in which a portion of a transmitted signal forms a guard interval.

BACKGROUND OF THE INVENTION

The European DVB-T (Digital Video Broadcasting - Terrestrial) standard ETS 300 744 for digital terrestrial television (DTT) uses Coded Orthogonal Frequency Division Multiplexing (COFDM) of transmitted signals, which are therefore grouped into blocks and frames.

It is necessary to transmit the DTT signals over transmission paths which are of uncertain quality. In particular, the area close to the transmission path may include objects such as tall buildings, which cause reflections. That is, a signal may be received at a receiver twice, once on a direct path from the transmitter, and then, after a short delay, as an indirect reflected path. As is well known, this can cause inter-symbol interference (ISI) in the receiver. To minimize this problem, DVB-T COFDM signals include a cyclic prefix guard interval to each active symbol. Specifically, the end portion of the active symbol is repeated before the current active symbol.

These cyclic signals must be correctly removed before demodulation, or the demodulation performance can be seriously degraded.

Before the cyclic signals can be removed, it is necessary to know the duration of the guard interval. This is not a constant value, because the presence of the guard interval reduces the efficiency with which the transmission channel can be used, and so it is advantageous to vary the size of the guard interval to be the minimum allowed by the conditions.

The receiver must therefore include a mechanism

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for determining the size of the guard interval.

The chosen mechanism must be robust enough to deal with noisy signals, and with signals which suffer from multipath and co-channel interference.

5 SUMMARY OF THE INVENTION

It is an object of the invention to provide a receiver circuit which overcomes some of the disadvantages of the prior art.

10 In particular, it may be advantageous for the receiver circuit to be able to determine the guard interval size quickly, even in the case of received signals with relatively low signal-noise ratio.

More specifically, the invention relates in a first aspect to a receiver circuit, for processing a received
15 signal to determine a size of a guard interval therein, comprising:

a sampler for forming digital samples of the received signal;

20 a correlator for generating from the digital samples a correlation function with peaks at positions which are determined by the size of the guard interval and a position of the guard interval within the received signal; and

25 a plurality of comb filters, each corresponding to a possible guard interval size, each receiving a series of sample locations at which the correlation function exceeds a predetermined threshold to the series of sample locations, and each producing an output for determining the guard interval size therefrom.

30 Further, the invention relates in a second aspect to a method of determining a guard interval size of a received signal, the method comprising:

forming digital samples of the received signal;

35 generating from the digital samples a correlation function with peaks at positions which are determined by the size of the guard interval and a position of the

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guard interval within the received signal;

determining a series of sample locations at which the correlation function exceeds a predetermined threshold;

5 applying a plurality of comb filters, each corresponding to a possible guard interval size, to the series of sample locations; and

determining the guard interval size from outputs of said comb filters.

10 This provides a quick and robust way of determining the guard interval size.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 is a block schematic diagram of a receiver circuit according to the invention.

15 Figure 2 is a block schematic diagram of one component of the receiver circuit of Figure 1.

Figure 3 is a flow chart representing a method according to the second aspect of the invention.

20 Figure 4 is an explanatory diagram of a step in the method of Figure 3.

Figure 5 is a further explanatory diagram of a step in the method of Figure 3.

25 Figure 6, comprising Figures 6(a)-6(d), is a further explanatory diagram of a step in the method of Figure 3.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 is a block diagram of a receiver circuit according to the invention. Typically, in the exemplary case of a digital terrestrial television signal receiver, for example receiving signals using the DVB-T standard with Coded Orthogonal Frequency Division Multiplexing, the receiver includes an antenna (not shown) and a tuner for receiving the signals. Received signals are supplied to a demodulator 2, which mixes the received RF input signal down to baseband in-phase (I) and quadrature (Q) components and produces digital

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samples. The baseband I and Q components are supplied to a mode detection block 4, which determines whether the received signal was transmitted in 2k or 8k mode, and provides a mode detection output. The baseband I and Q components are also supplied to a synchroniser 6, which removes frequency and sampling rate offsets, and then to a window position block 8. Following determination of the window position, the received signals are applied to a guard removal block 10, FFT block 12, equaliser 14, demapper 16, and FEC block 18. The resulting MPEG data is output to a demultiplexing device for ultimate display.

As described so far, the receiver is generally conventional. The receiver also includes a guard detection block 20, which determines the size and position of the guard interval, for supply to the window position block 8 and guard removal block 10, allowing them to operate accurately.

The guard detection block 20 is illustrated schematically in Figure 2, and the method of the present invention, for determining the guard interval size, will be described with reference to Figure 2, and to Figure 3, which is a flow chart illustrating the method according to the invention.

The method of Figure 3 includes a first step, step 201, of receiving the digital samples at respective I and Q inputs 22. For each sample, the complex conjugate of the sample is formed, and the sample is applied to a delay block 24, in step 203. The delay block 24 is a FIFO buffer of A taps, and thus applies a delay equivalent to the duration of A samples, where A is the FFT size (that is, 2048 in 2k mode or 8192 in 8k mode), and is the duration of the active part of the symbol, expressed in samples.

Then, in step 205, a correlation function is calculated in a multiplication block 26, by multiplying

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each input symbol with the appropriate symbol obtained in step 203 with the delay applied thereto, thereby obtaining a measure of the correlation between them. The results are then supplied to a summing block 28, in which, in step 207, a running average is calculated over a number of samples g , which equals the smallest allowed guard interval size, that is, $1/32$ of the active symbol or $1/32$ of the FFT size. Thus, $g=64$ samples in 2k mode or 256 samples in 8k mode. The output average value is then obtained by applying the result from block 28 to a block 30, which takes the modulus of the output complex numbers.

The calculated correlation function is a measure of the degree to which each sample is correlated with the sample appearing in the input signal after a particular delay. The function is averaged over time to provide a measure of the correlation between a particular sequence of samples and the sequence of samples appearing after that delay. Since it is known that the guard interval contains samples which are repeats of samples from the active symbol appearing later in the signal, a high value of the correlation function may be an indication that it is the samples of the guard interval that are being examined.

Figure 4 is an explanatory graph of the value of this averaged correlation function, obtained from block 30, showing how it varies over a large number of samples, for one particular set of trial data.

It can be seen that the correlation function has a value which varies in an unpredictable way, because of chance correlations between the samples at different times, but which includes a number of peaks. These peaks can again arise because of chance correlations, or may arise because it is the samples of the guard interval which are under examination.

In step 209, the value of the correlation function

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is then compared with a threshold value in a thresholding block 32, and it is only positions at which the value of the correlation function exceeds the threshold value which are investigated further, in order to determine whether the large value of the correlation function is due to chance or indicates the position of the guard interval. A counter 34 is connected to the thresholding block 32, and used to create a dead period immediately after the threshold is crossed, during which the output is zero. The length of the dead period may for example be half of one symbol period.

The use of the threshold value and dead period provide robustness. The presence of multipath and/or co-channel interference can distort the shape of the peak in the correlation function. However, it will not remove the rising edge of the peak. Thus, the use of the threshold value means that the method relies not on the shape of the peak (which is subject to this distortion), but on the periodicity of the peaks (which is not significantly affected by the interference). Further, the use of the dead period (provided this is not too short) ensures that multiple successive spurious peaks are not recorded.

The selection of the threshold value is clearly important. If the value is too high, some of the points of potential interest will be missed, while, if it is too low, too many points will be examined, possibly leading to an inaccurate estimate of the guard interval size. It may be possible to set the threshold in initial settings of the receiver circuit. Alternatively, a further algorithm can adjust the threshold value, by starting with a high value, and reducing it until a stable value of the guard interval size is obtained. A further alternative is to measure the range of the correlation signals and to set the threshold at a fraction of the maximum. For example,

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values in the range of 0.6 to 0.8 of the maximum have been found to work. It is assumed hereafter that a suitable threshold has been adopted.

5 With a suitable threshold selected, Figure 5 shows the points at which the value of the correlation function exceeds the threshold value. Based on the particular correlation function illustrated in Figure 4, the points shown in Figure 5 are in fact obtained by using a threshold value of 0.8.

10 This procedure is then repeated until either a predetermined number of samples have been examined, or a predetermined number of points have been obtained.

The procedure described above is one way of obtaining a function which has peaks corresponding to the guard interval location. Similar functions could be obtained in other ways, for example by performing a subtraction rather than a complex correlation in step 205.

20 The spacing of the spikes in the graph of Figure 5 will indicate which guard interval is present. However, it is difficult to measure this directly for two reasons. Firstly, some spikes are missing, where the peaks did not reach the threshold set in the thresholding block 32. Secondly, the exact location of the spikes is noisy, due to channel noise and self-noise, which mean that the positions of peaks in the correlation are subject to noise. Thirdly, some peaks will be due to noise only, particularly where the threshold has been set too low, or where the noise power is high.

30 In order to resolve these problems, the function illustrated in Figure 5 is further filtered.

Specifically, as shown at step 211 in Figure 3, each of a number of comb filters 34 is applied to the detected series of points at which the threshold is exceeded. This is shown schematically in Figure 2.

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Each comb filter 34 has a pattern of zeroes and ones, the ones forming the teeth of the comb. The teeth of the comb have a finite width, which deals with the lateral positional noise in the spacing of the spikes. Moreover, the fact that some spikes will be missing from the series, as discussed above, is dealt with by providing a large number of teeth. For ease of illustration, Figure 2 shows a comb filter in which the teeth have a width of four samples and a spacing of nine samples. In one practical example, the teeth of the comb filter have a width of 32 samples and a spacing which is equal to the total symbol size, that is, the sum of the active symbol size and the guard interval size. In other words, the spacing of the teeth in the comb filter is equal to the repetition spacing of the guard interval. In 2k mode, testing for a guard interval size of 1/32 of the active symbol size, the spacing is $2048 + 64 = 2112$ samples.

There is one comb filter 34 for each possible guard interval size. Thus, if there are four possible sizes of the guard interval, there are four comb filters.

The outputs from each comb filter 34 are summed in a block 36, and added into an accumulator forming part of a circular buffer 38. The pointer then moves on to the next accumulator. At the end of the buffer, it jumps back to the start. Just as there is one comb filter 34 for each possible guard interval size, similarly, there is one buffer connected to each comb filter, and hence one buffer for each possible guard interval size. It should be noted that, because the different possible guard sizes are tested for in parallel, the time taken to complete the process is largely independent of the number of possible sizes.

Thus, the described technique uses large amounts of memory within the receiver. However, it is only

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necessary to perform the required guard interval size detection once, during an acquisition phase, at a time when there is a large amount of RAM in the receiver which is not being used for other purposes.

5 The length of each buffer is equal to the symbol length expressed in samples, and thus corresponds to the spacing of the teeth in the corresponding comb filter. Therefore, in 2k mode, testing for a guard interval size of $1/32$ of the active symbol size, the
10 buffer consists of $2048 + 64 = 2112$ accumulators.

 In other words, a correlation value is calculated between a first function which comprises a series of regularly spaced delta functions (the comb filter), and a second function which comprises a delta function at
15 each of the positions at which the correlation exceeds the threshold.

 At one position of the comb filter relative to the function shown in Figure 5, the spikes will line up with the teeth, and give a high output. When the
20 spikes and the filter teeth do not line up, the output will be low, because the spikes will align mainly with zeroes in the comb filter. The results must be averaged over many symbols because, if the transmitted signal had a guard size equal to $1/4$ of the active
25 symbol size, part of the symbol would align with the comb filter teeth even for the comb which is detecting the $1/32$ guard size. This partial overlap is removed by the averaging process, because the alignment would occur at different points in the buffer. The averaging
30 process also deals with the problem of missing spikes, or spikes occurring due to noise only.

 Outputs from the buffers 38 are supplied to MAX blocks 40, which find the positions, and heights, of the biggest accumulator outputs.

35 Figure 5 shows the result of this process for the data used in Figures 3 and 4. Specifically, Figure

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5(a) shows the output of the comb filter corresponding to a guard interval size of $1/4$ FFT size (512 samples); Figure 5(b) shows the output of the comb filter corresponding to a guard interval size of $1/8$ FFT size (256 samples); Figure 5(c) shows the output of the comb filter corresponding to a guard interval size of $1/16$ FFT size (128 samples); and Figure 5(d) shows the output of the comb filter corresponding to a guard interval size of $1/32$ FFT size (64 samples).

10 Outputs from the MAX blocks 40 are supplied to a further MAX block 42, which outputs the index of whichever input was the largest.

15 From Figure 5, it can be seen that there is a clear peak in the output of the comb filter which corresponds to a guard interval size of 64 samples. As a result, this is determined to be the actual guard interval size.

20 The fact that the signals are analysed by the four (in this example) comb filters and buffers in parallel means that the start up time, required to find the guard interval size, can be reduced.

25 Moreover, the position of the peak can be used to determine the position of the start of each symbol. Specifically, the position of the peak within the circular buffer indicates the position along the input stream of samples at which the averaging window aligns directly with the cyclic prefix. This allows the position of the start of the active part of the symbol to be calculated, at least approximately, very quickly. 30 This means that the acquisition phase of operation of the receiver can be completed quickly.

35 There is therefore described a method of determination of the guard interval size which allows the size to be detected quickly, even in the presence of relatively large noise signals. The method is robust in noise, and also robust enough to handle

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signals with severe multipath and/or co-channel interference. Moreover, the method is of low complexity, and can be implemented in a VLSI.

CLAIMS

1. A method of processing a received signal, to determine a size of a guard interval therein, the method comprising:

5 forming digital samples of the received signal;
 generating from the digital samples a correlation function with peaks at positions which are determined by the size of the guard interval and a position of the guard interval within the received signal;

10 determining a series of sample locations at which the correlation function exceeds a predetermined threshold;

 applying a plurality of comb filters, each corresponding to a possible guard interval size, to the series of sample locations; and

15 determining the guard interval size from outputs of said comb filters.

2. A method as claimed in claim 1, comprising generating the correlation function by:

20 applying a predetermined delay to the digital samples; and

 calculating the correlation function from a correlation between a sequence of digital samples and a sequence of digital samples having a delay applied thereto.

3. A method as claimed in claim 1, comprising: summing outputs from each of the comb filters.

4. A method as claimed in claim 1, wherein each comb filter has a plurality of teeth, with a spacing corresponding to the size of a symbol formed by an active symbol and the corresponding possible guard interval size.

5. A method as claimed in claim 1, comprising determining the guard interval size by determining which of said comb filters produces an output which indicates that peaks in said correlation function occur

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at positions which are spaced by a separation corresponding to a size of a symbol formed by an active symbol and the corresponding possible guard interval size.

5 6. A method as claimed in claim 1, wherein the step of determining the series of sample locations comprises applying a dead period, such that multiple successive sample locations cannot be recorded.

10 7. A receiver circuit, for processing a received signal to determine a size of a guard interval therein, comprising:

 a sampler for forming digital samples of the received signal;

15 a correlator for generating from the digital samples a correlation function with peaks at positions which are determined by the size of the guard interval and a position of the guard interval within the received signal; and

20 a plurality of comb filters, each corresponding to a possible guard interval size, each receiving a series of sample locations at which the correlation function exceeds a predetermined threshold to the series of sample locations, and each producing an output for determining the guard interval size therefrom.

25 8. A receiver circuit as claimed in claim 7, further comprising:

 a plurality of buffers of accumulators, each corresponding to a respective one of the plurality of comb filters, for summing the outputs therefrom; and

30 means for determining which of said buffers of accumulators produces the maximum output level.

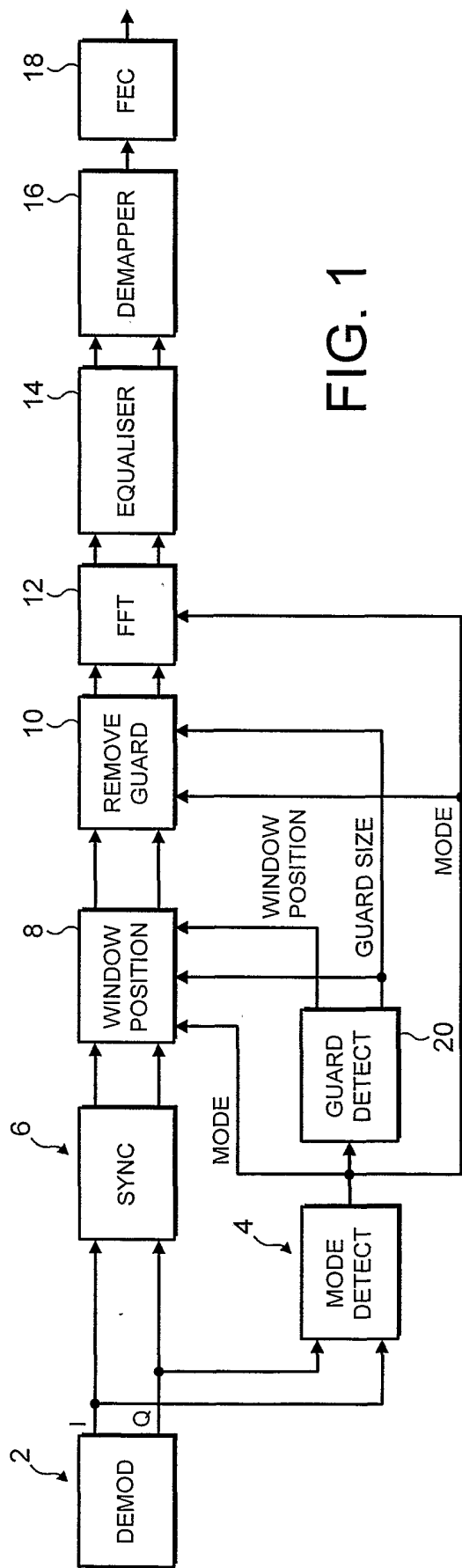


FIG. 1

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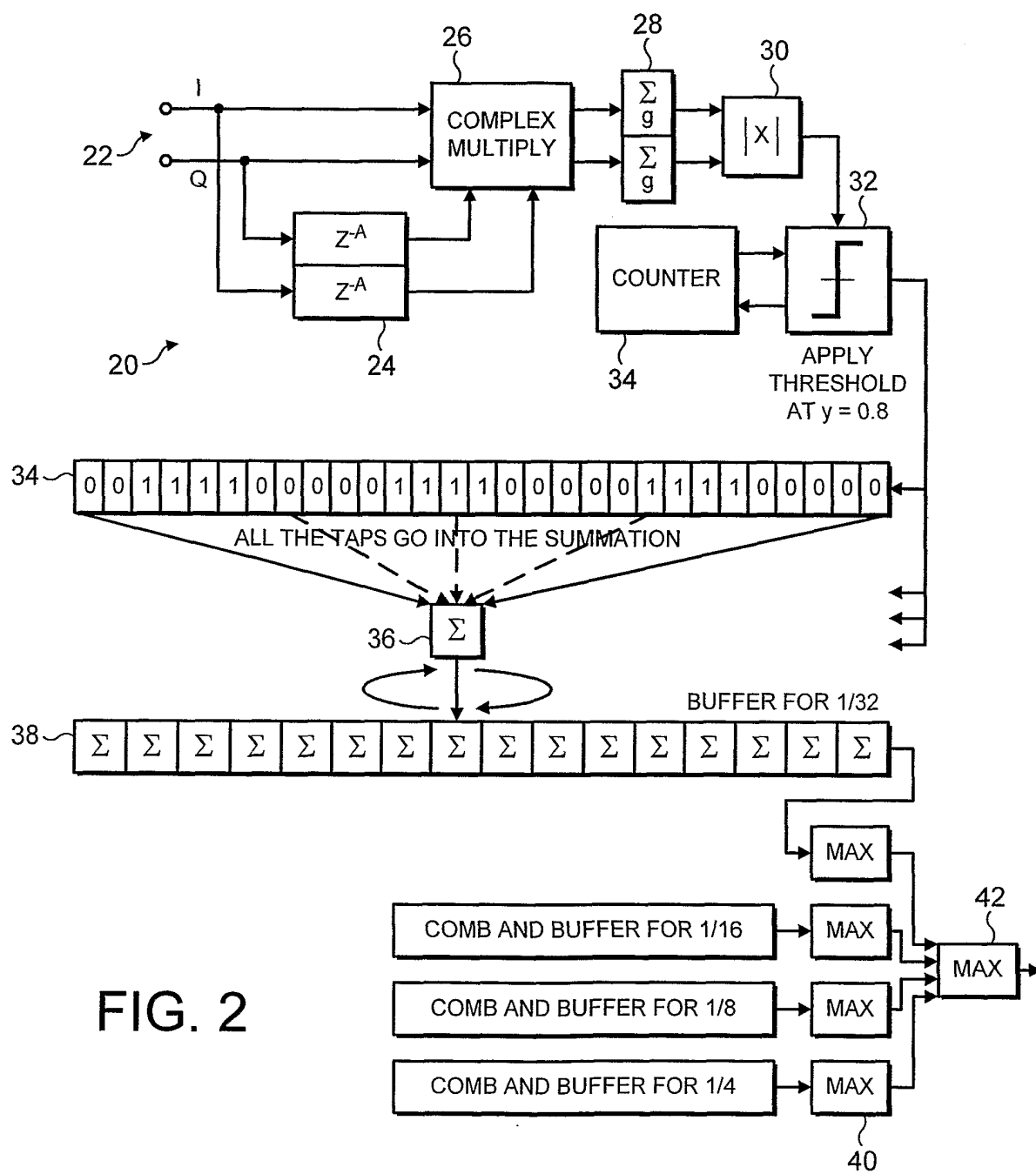


FIG. 2

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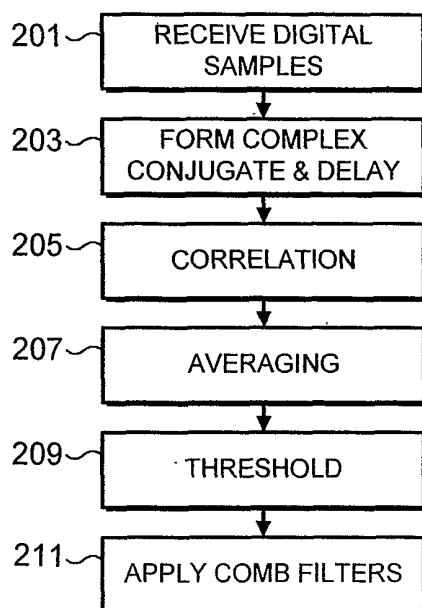


FIG. 3

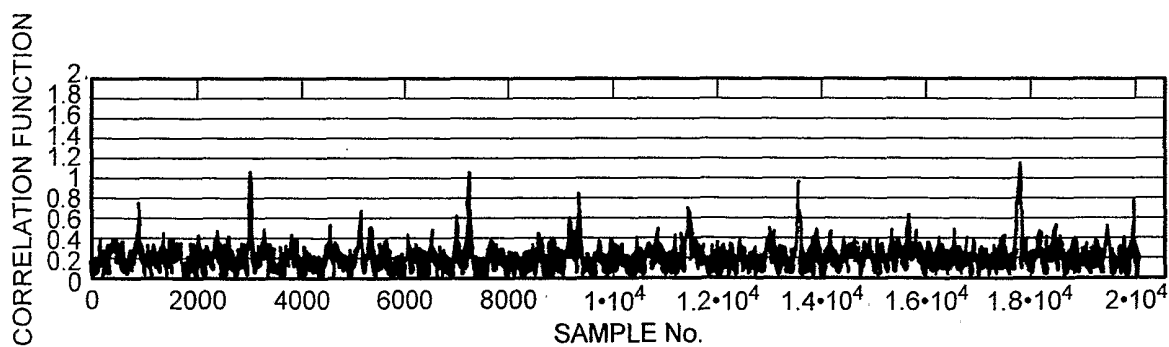


FIG. 4

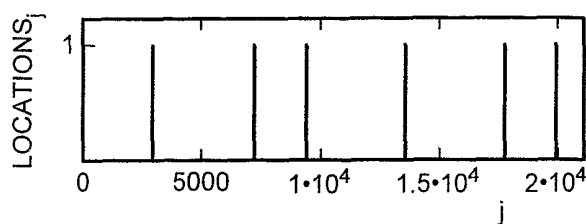


FIG. 5

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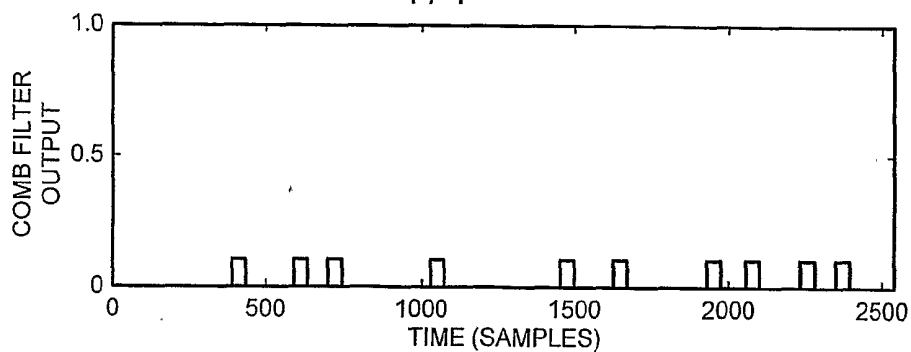


FIG. 6(a)

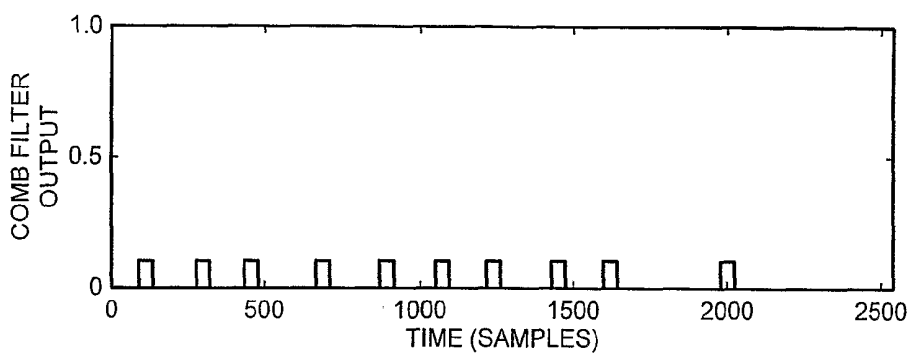


FIG. 6(b)

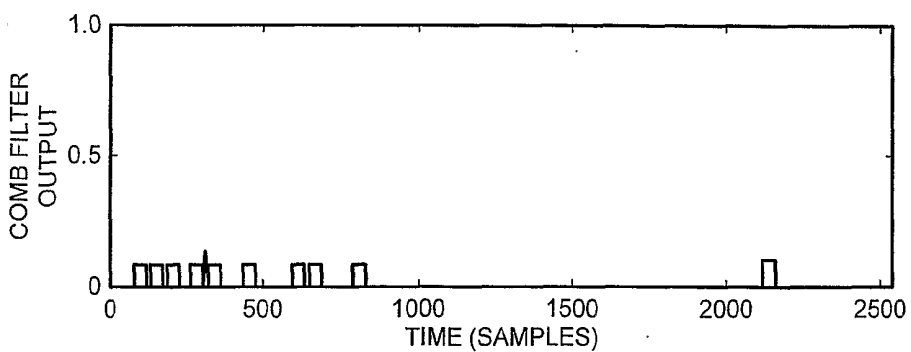


FIG. 6(c)

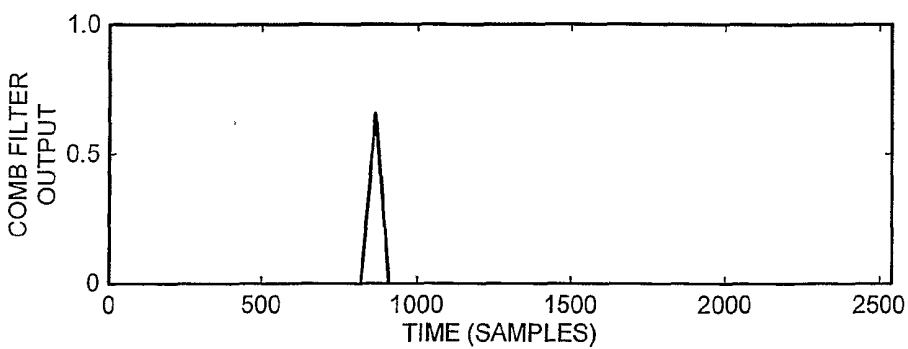


FIG. 6(d)

INTERNATIONAL SEARCH REPORT

International Application No
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A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H04L27/26

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 H04N

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, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	EP 0 656 706 A (TOKYO SHIBAURA ELECTRIC CO) 7 June 1995 (1995-06-07) column 5, line 17 -column 6, line 19 column 9, line 29 - line 45 figure 3 ---	1-8
A	EP 0 881 804 A (KONINKL PHILIPS ELECTRONICS NV) 2 December 1998 (1998-12-02) abstract ---	1-8
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Patent family members are listed in annex.

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 01/07655

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