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(54) TRANSFORMATION BETWEEN TIME DOMAIN AND FREQUENCY DOMAIN BASED ON NEARLY ORTHOGONAL FILTER BANKS

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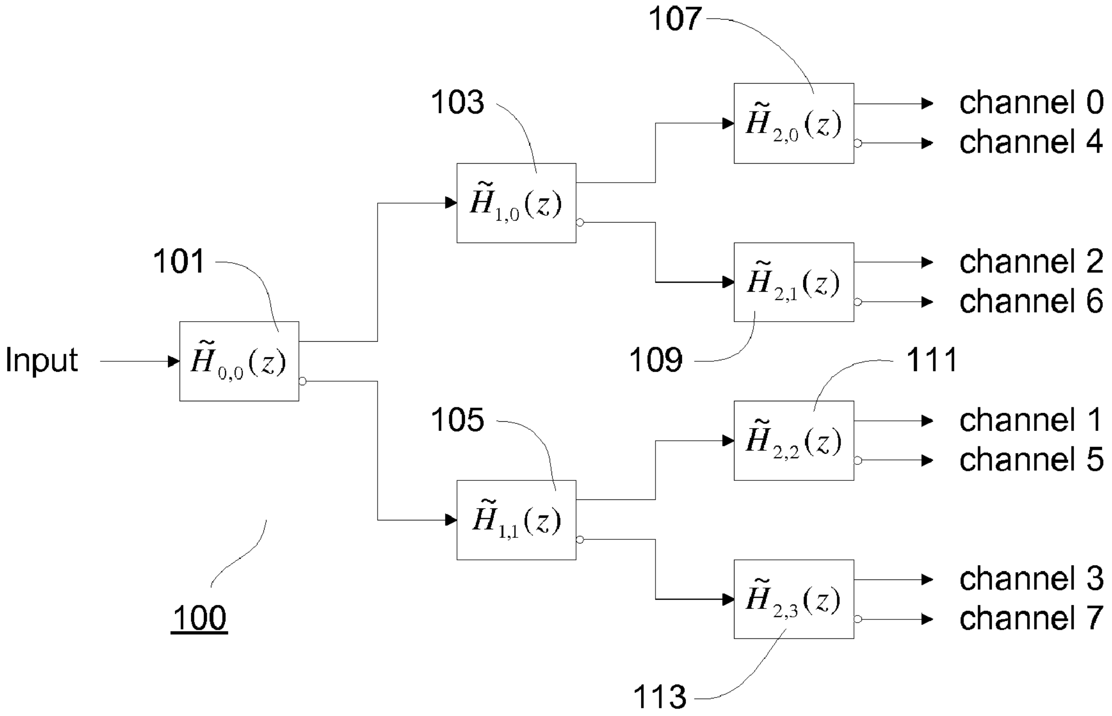
(57) **ABSTRACT**

A filter bank for signal decomposition is provided. The filter bank comprises a plurality of filter units each of which has one input and two outputs forming two paths whose transfer functions are complementary to each other, where the plurality of filter units are connected to form a tree structure.



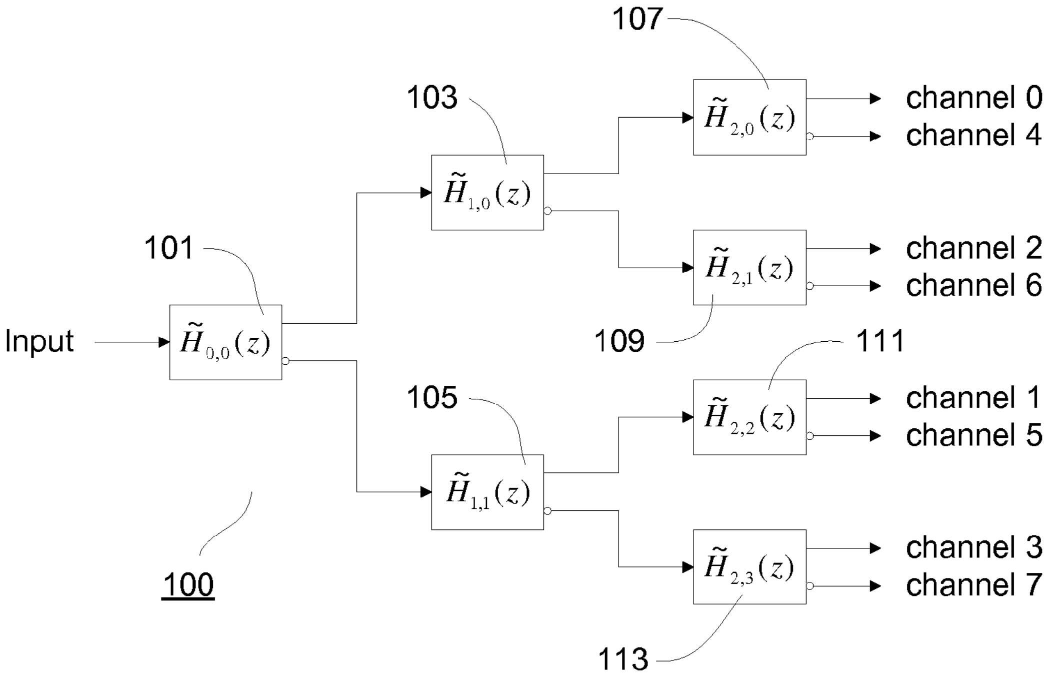

107
103
channel 0
channel 4
$\tilde{H}_{2,0}(z)$
$\tilde{H}_{1,0}(z)$
101
channel 2
channel 6
$\tilde{H}_{2,1}(z)$
Input
$\tilde{H}_{0,0}(z)$
109
111
105
channel 1
channel 5
$\tilde{H}_{2,2}(z)$
$\tilde{H}_{1,1}(z)$
channel 3
channel 7
$\tilde{H}_{2,3}(z)$
100
113

FIG.1

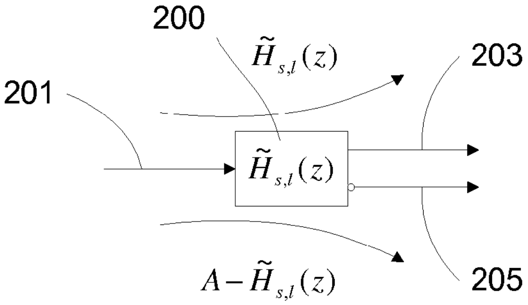

200
$\tilde{H}_{s,l}(z)$
201
203
$\tilde{H}_{s,l}(z)$
$A-\tilde{H}_{s,l}(z)$
205

FIG.2

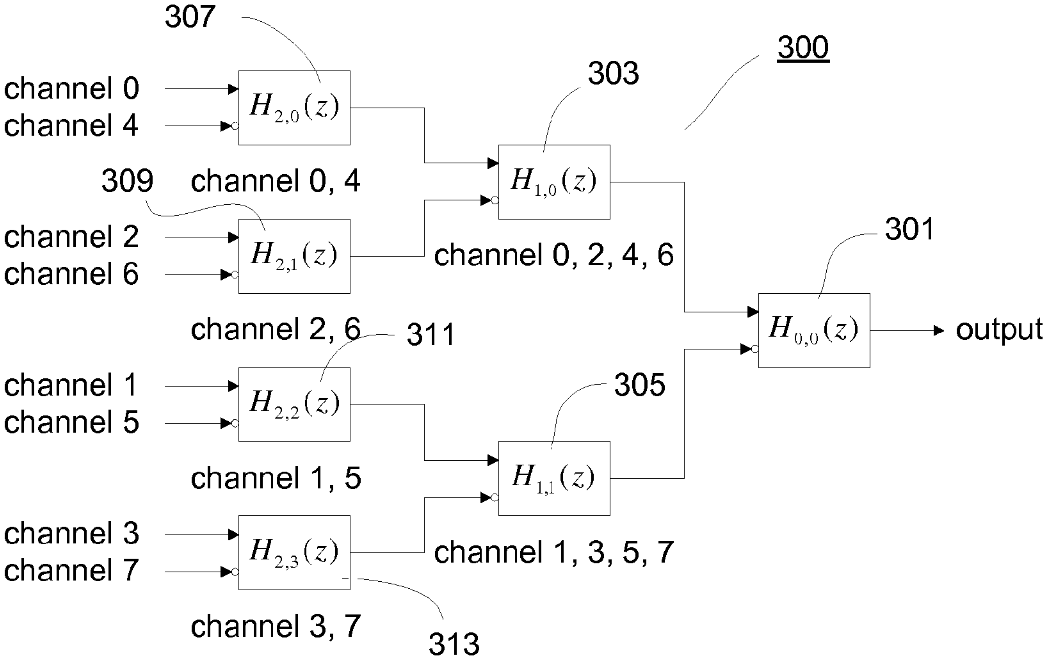

307
300
303
channel 0
channel 4
$H_{2,0}(z)$
channel 0, 4
$H_{1,0}(z)$
309
channel 2
channel 6
$H_{2,1}(z)$
channel 0, 2, 4, 6
301
channel 2, 6
311
$H_{0,0}(z)$
output
channel 1
channel 5
$H_{2,2}(z)$
305
channel 1, 5
$H_{1,1}(z)$
channel 3
channel 7
$H_{2,3}(z)$
channel 1, 3, 5, 7
channel 3, 7
313

FIG.3

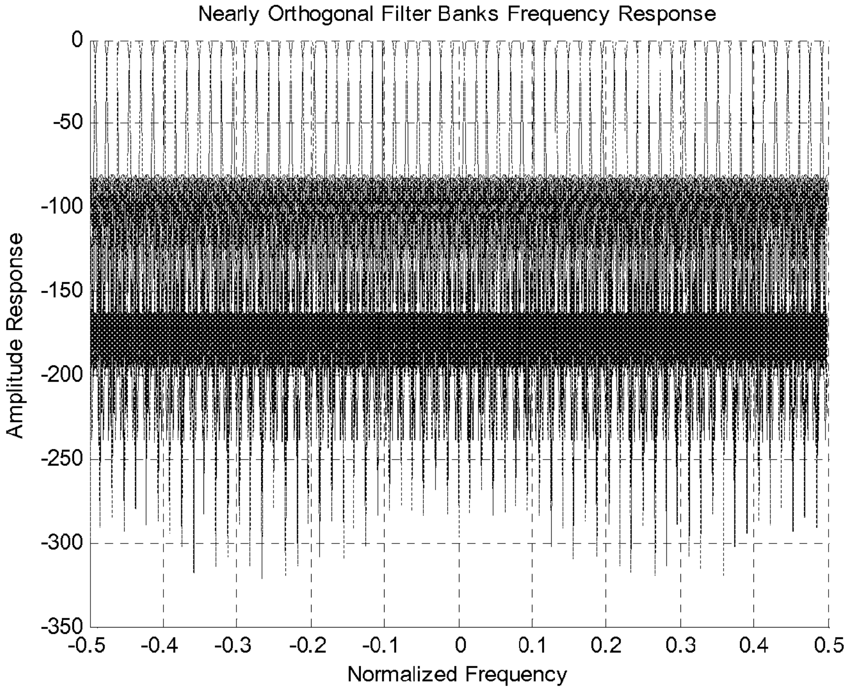

Nearly Orthogonal Filter Banks Frequency Response
Amplitude Response
0
-50
-100
-150
-200
-250
-300
-350
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
Normalized Frequency

FIG.4

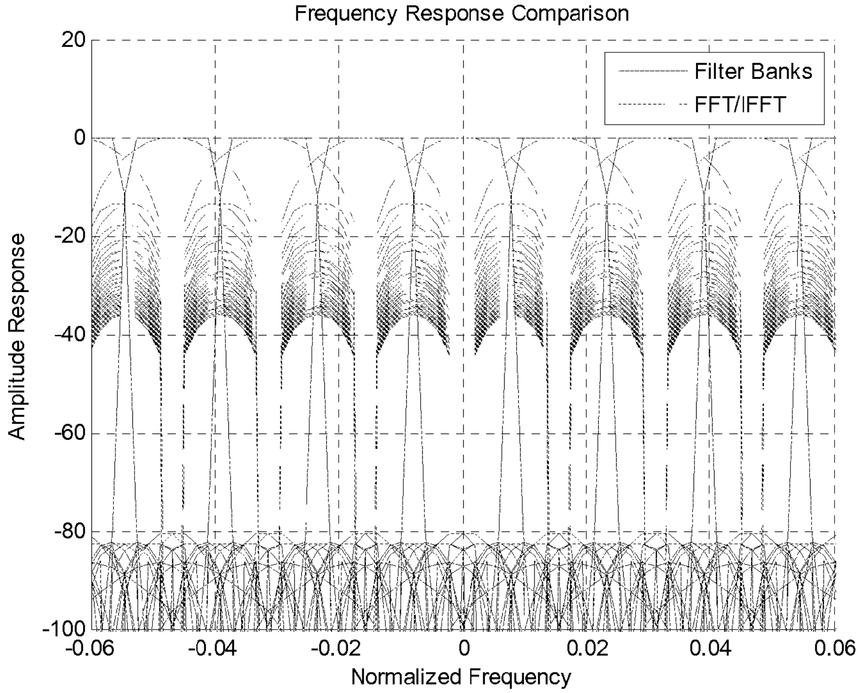

Frequency Response Comparison
Filter Banks
FFT/IFFT
Amplitude Response
20
0
-20
-40
-60
-80
-100
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
Normalized Frequency

FIG.5

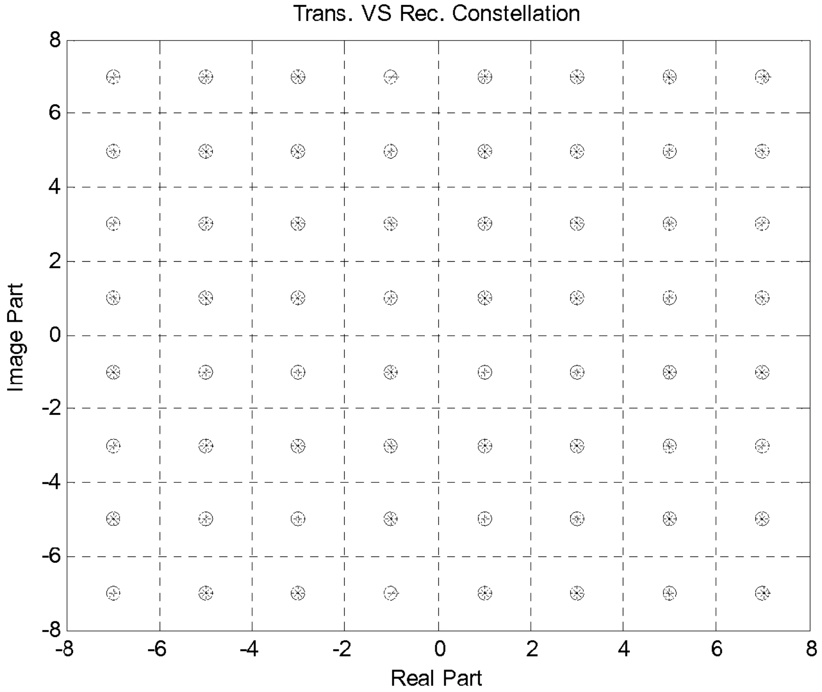

Trans. VS Rec. Constellation
Image Part
8
6
4
2
0
-2
-4
-6
-8
-8
-6
-4
-2
0
2
4
6
8
Real Part

FIG.6

TRANSFORMATION BETWEEN TIME DOMAIN AND FREQUENCY DOMAIN BASED ON NEARLY ORTHOGONAL FILTER BANKS

TECHNICAL FIELD

[0001] The present application generally relates to a communication system based on nearly orthogonal filter banks.

BACKGROUND

[0002] Signal decomposition and composition are usually carried out based on Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT), respectively. However, these methods based on FFT and IFFT is sensitive to channel noise, carrier frequency offset, and Doppler effect. Therefore, new signal decomposition and composition methods are needed.

SUMMARY

[0003] In one embodiment, a filter bank for signal decomposition is provided. The filter bank includes a plurality of filter units having one input and two outputs which forms two paths whose transfer functions are complementary to each other, where the plurality of filter units are connected to form a tree structure.

[0004] In some embodiments, the filter bank is for decomposing signals containing N_c sub-carrier signals. The filter bank includes N_s stages and stage s includes 2^s levels, where $N_s=\log_2 N_c$, s stands for stage number, and $s\in[0,1\ldots N_s-1]$.

[0005] In some embodiments, two outputs of s^{th} stage 1^{th} level filter unit are respectively connected to inputs of $(s+1)^{th}$ stage $(2l)^{th}$ level filter unit and $(s+1)^{th}$ stage $(2l+1)^{th}$ level filter unit, where $l\in[0,1\ldots 2^s-1]$.

[0006] In some embodiments, n^{th} order impulse response coefficient of s^{th} stage q^{th} level filter unit $h_{s,q}(n)$ can be calculated by multiplying n^{th} order impulse response coefficient of s^{th} stage p^{th} level filter unit $h_{s,p}(n)$ and a rotation factor, where $p\in[0,1\ldots 2^s-1]$, and $q\in[0,1\ldots 2^s-1]$, where the rotation factor is a complex exponential factor.

[0007] In some embodiments, impulse response coefficients of s^{th} stage q^{th} level filter unit can be calculated according to below equation:

$$h_{s,q}(n)=h_{s,p}(n)\cdot W_{N_c}^{-n(\tilde{p}-\tilde{q})}$$

where $h_{s,q}(n)$ represents n^{th} order impulse response coefficient of s^{th} stage q^{th} level filter unit, $h_{s,p}(n)$ represents n^{th} order impulse response coefficient of s^{th} stage p^{th} level filter unit,

$$W_{N_c}^{-n(\tilde{p}-\tilde{q})} = e^{j\frac{2\pi}{N_c}(\tilde{p}-\tilde{q})}$$

where $\tilde{p}$ is the value of bit reversed version of N_s-1 bits binary encode of p, $\tilde{q}$ is the value of bit reversed version of N_s-1 bits binary encode of q.

[0008] In one embodiment, a filter bank for signal composition is provided. The filter bank includes a plurality of filter units having two inputs and one output which forms two paths whose transfer functions are complementary to each other, where the plurality of filter units are connected to form a tree structure.

[0009] In some embodiments, the filter bank is for composing signals containing N_c sub-carrier signals. The filter bank includes N_s stages and stage s includes 2^s levels, where $N_s=\log_2 N_c$, s stands for stage number, and $s\in[0,1\ldots N_s-1]$.

[0010] In some embodiments, two inputs of s^{th} stage 1^{th} level filter unit are respectively connected to output of $(s+1)^{th}$ stage $(2l)^{th}$ level filter unit and output of $(s+1)^{th}$ stage $(2l+1)^{th}$ level filter unit, where $l\in[0,1\ldots 2^s-1]$.

[0011] In some embodiments, n^{th} order impulse response coefficient of s^{th} stage q^{th} level filter unit $h_{s,q}(n)$ can be calculated by multiplying n^{th} order impulse response coefficient of s^{th} stage p^{th} level filter unit $h_{s,p}(n)$ and a rotation factor, where $p\in[0,1\ldots 2^s-1]$, and $q\in[0,1\ldots 2^s-1]$, where the rotation factor is a complex exponential factor.

[0012] In some embodiments, impulse response coefficients of s^{th} stage q^{th} level filter unit can be calculated according to below equation:

$$h_{s,q}(n) = h_{s,p}(n)\cdot W_{N_c}^{-n(\tilde{p}-\tilde{q})} = h_{s,p}(n)\cdot e^{j\frac{2\pi}{N_c}n(\tilde{p}-\tilde{q})}$$

where $h_{s,q}(n)$ represents n^{th} order impulse response coefficient of s^{th} stage q^{th} level filter unit, $h_{s,p}(n)$ represents n^{th} order impulse response coefficient of s^{th} stage p^{th} level filter unit, $\tilde{p}$ stands for the value of bit reversed version of N_s-1 bits binary encode of p, $\tilde{q}$ stands for the value of bit reversed version of N_s-1 bits binary encode of q.

[0013] In one embodiment, a receiver is provided. The receiver includes a first filter bank for decomposing signals composed by a second filter bank of a transmitter which signals contain N_c sub-carrier signals. The first filter bank includes N_c channels corresponding to the N_c sub-carriers. The second filter bank also includes N_c channels corresponding to the N_c sub-carriers. Vector form transfer function of channel p of the first filter bank is nearly orthogonal to vector form transfer function of channel q of the second filter bank.

[0014] In some embodiments, when p=q, the result of $[\vec{H}_{t,q}]^H\cdot\vec{H}_{r,p}$ substantially equals to 1; when $|p-q|=1$, the result of $[\vec{H}_{t,q}]^H\cdot\vec{H}_{r,p}$ is less than a predetermined threshold; otherwise $[\vec{H}_{t,q}]^H\cdot\vec{H}_{r,p}=0$, where $[\ ]^H$ stands for conjugate transpose operation, where the predetermined threshold is small enough such that a signal composed by the transmitter can be decomposed by the receiver correctly, where the result of $[\vec{H}_{t,q}]^H\cdot\vec{H}_{r,p}$ is normalized. When p=q, the result of $[\vec{H}_{t,q}]^H\cdot\vec{H}_{r,p}$ is not required to be exactly equal to 1, instead it is required to be close enough to 1 such that the N_c sub-carrier signals can be decomposed correctly.

[0015] In some embodiments, the threshold may be determined based on modulation method used by the transmitter.

[0016] In one embodiment, a signal composing method is provided. The method may include: feeding N_c sub-carrier signals into N_c inputs of a tree structured filter bank, respectively, where the filter bank has a plurality of filter units having two inputs and one output which forms two paths whose transfer functions are complementary to each other; and obtain a composed signal containing the N_c sub-carrier signals from an output of the filter bank.

[0017] In one embodiment, a signal decomposing method is provided. The method may include: feeding a signal containing N_c sub-carrier signals into a tree structured filter bank having one input and N_c outputs, where the filter bank has a plurality of filter units having one input and two outputs which forms two paths whose transfer functions are complementary to each other; and obtain the N_c sub-carrier signals from the N_c outputs of the filter bank, respectively.

[0018] In one embodiment, a communication method is provided. The method may include: composing N_c sub-carrier signals using a first tree structured filter bank having N_c channels to obtain a composed signal containing the N_c sub-carrier signals; and decomposing the composed signal using a second tree structured filter bank having N_c channels to obtain the N_c sub-carrier signals, where vector form transfer function of channel q of the first filter bank is nearly orthogonal to vector form transfer function of channel p of the second filter bank.

[0019] In some embodiments, when p=q, the result of $[\vec{H}_{t,q}]^H \cdot \vec{H}_{r,p}$ substantially equals to 1; when $|p-q|=1$, the result of $[\vec{H}_{t,q}]^H \cdot \vec{H}_{r,p}$ is less than a predetermined threshold; otherwise $[\vec{H}_{t,q}]^H \cdot \vec{H}_{r,p}=0$, where $\vec{H}_{t,q}$ is vector form transfer function of channel q of the first filter bank and $\vec{H}_{r,p}$ is vector form transfer function of channel p of the second filter bank, where $[\ ]^H$ stands for conjugate transpose operation, where the predetermined threshold is small enough such that the N_c sub-carrier signals composed by the first filter bank can be decomposed by the second filter bank correctly, where the result of $[\vec{H}_{t,q}]^H \cdot \vec{H}_{r,p}$ is normalized.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The foregoing and other features of the present disclosure will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only several embodiments in accordance with the disclosure and are, therefore, not to be considered limiting of its scope, the disclosure will be described with additional specificity and detail through use of the accompanying drawings.

[0021] FIG. **1** illustrates a schematic block diagram of a filter bank for signal decomposition in one embodiment.

[0022] FIG. **2** illustrates a schematic block diagram of a filter unit of the filter bank in FIG. **1**.

[0023] FIG. **3** illustrates a schematic block diagram of a filter bank for signal composition in one embodiment.

[0024] FIG. **4** illustrates a spectrum obtained in one experiment using a communication system of one embodiment.

[0025] FIG. **5** illustrates an enlarged view of the spectrum in FIG. **4** and a spectrum of a conventional communication system based on FFT/IFFT.

DETAILED DESCRIPTION

[0026] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the Figures, can be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly contemplated and make part of this disclosure.

[0027] Referring to FIG. **1**, a three stage filter bank **100** for decomposing signals containing eight sub-carrier signals is illustrated. The filter bank **100** includes three stages. The 0^{th} stage includes one filter unit **101**, the 1^{st} stage includes two filter units **103** and **105**, and the 2^{nd} stage includes four filter units **107**, **109**, **111**, and **113**. Each of the filter units includes one input and two outputs which form two paths. The filter bank **100** as a whole includes one input and eight outputs, in other words, the filter bank **100** includes eight channels.

[0028] A filter bank for decomposing signals having N_c sub-carrier signals includes $N_s=\log_2 N_c$ stages, stage s includes 2^s filter units/levels, where s stands for stage number.

[0029] Referring to FIG. **2**, the s^{th} stage l^{th} level filter unit **200** has an input **201** and two outputs **203** and **205**, which form an upper path and a lower path. Given the frequency domain transfer function of the upper path is $\tilde{H}_{s,l}(z)$, then the frequency domain transfer function of the lower path shall be $A-\tilde{H}_{s,l}(z)$, these two transfer functions are complementary to each other, where A represents a magnitude, z stands for z-transform i.e. $z=e^{j\Phi}$, where $j=\sqrt{-1}$.

[0030] Channel number c may be binary encoded, $[c]_{10}=[B_{N_s-1}B_{N_s-2} \ldots B_0]_2$, where B_{N_s-1} is the most significant bit (MSB), and B_0 is the least significant bit (LSB). For example, referring to FIG. **1**, the channel number of "channel **4**" is four.

[0031] Given the frequency domain transfer function of the s^{th} stage 0^{th} level filter unit is written as Equation (1),

$$\tilde{H}_{s,0}(z) = h_s(0) + \sum_{n=1}^{M_s-1} h_s(n) z^{-n} \qquad \text{Equation (1)}$$

where M_s-1 represents order of transfer functions in s^{th} stage, and $h_s(0)$, $h_s(1) \ldots h_s(n)$ are impulse response coefficients of the transfer function of s^{th} stage 0^{th} level filter unit, then the frequency domain transfer function of channel c in s^{th} stage may be written as Equation (2),

$$\tilde{H}_c^s = h_s(0) + \sum_{n=1}^{M_s-1} (-1)^{B_s} h_s(n) W_{N_c}^{nk} z^{-n \cdot 2^{N_s-s-1}} \qquad \text{Equation (2)}$$

where B_s stands for the s^{th} element/bit of the binary encode of the channel number c, N_c stands for the sum of channels in the communication system, N_s stands for the sum of stages in the signal decomposition system, for example, assuming $N_c=8$, s=2, and c=6, the binary encode of c is 110, then B_s is the 2^{nd} element of 110 which is 1, where 0^{th} element of a binary encode $e_2e_1e_0$ is e0, 1^{st} element of $e_2e_1e_0$ is e_1, and 2^{nd} element of $e_2e_1e_0$ is e_2,

$$W_{N_c}^{nk} = e^{-j\frac{2\pi}{N_c}nk},$$

where

$$k = k_0 \cdot 2^{N_s-s-1},$$

where k_0 stands for the value of the least s bits of the binary encode of c. For example, assuming $N_s=3$, s=2 and c=6, the binary encode of c is 110, the least s=2 bits of the binary encode of c is 10, and $k_0=2$ in this example. When s=0, $k_0=0$.

[0032] For channel c, when its frequency domain transfer function in each stage is obtained, the channel transfer function $\tilde{H}z_c$ in the frequency domain may be written as:

$$\tilde{H}z_c=H_1\cdot\tilde{H}_c^{0}\cdot\tilde{H}_c^{1}\ldots\cdot H_c^{N_s-1} \qquad \text{Equation (3),}$$

where H_1 may be defined as:

$$H_1=H_0=\frac{1}{\sqrt{|h_c(0)|^2+|h_c(1)|^2\ \ldots\ |h_c(M_c-1)|^2}} \qquad \text{Equation (4)}$$

where $h_c(n)$ is a coefficient of transfer function, $n\in[0,1\ldots M_c-1]$, where M_c-1 is order of the transfer function of channel c.

[0033] Referring to FIG. **3**, a three stage filter bank **300** for composing signals having eight sub-carrier signals is illustrated. A signal composed using the filter bank **300** can be decomposed using the filter bank **100**. The filter bank **300** also includes three stages. The 0th stage includes one filter unit **301**, the 1st stage includes two filter units **303** and **305**, and the 2nd stage includes four filter units **307**, **309**, **311**, and **313**. Each of the filter units includes one output and two inputs which form two paths. The filter bank **300** as a whole includes one output and eight inputs, in other words, the filter bank **300** also includes eight channels.

[0034] A filter bank for composing N_c sub-carrier signals into one signal containing the N_c sub-carrier signals includes $N_s=\log_2 N_c$ stages, stage s includes 2^s filter units/levels, and each filter unit includes two inputs which form two paths whose transfer functions are complementary to each other. Its structure is substantially inverse to that of a filter bank for decomposing signals composed by it.

[0035] Assuming the frequency domain transfer function of channel c in the filter bank **100** may be written as:

$$\tilde{H}z_c=\alpha\cdot[h_c(0)+\Sigma_{n=1}^{M_c-1}h_c(n)z^{-n}] \qquad \text{Equation (5),}$$

where α may be defined as:

$$\alpha=\frac{1}{\sqrt{|h_c(0)|^2+|h_c(1)|^2\ \ldots\ |h_c(M_c-1)|^2}}. \qquad \text{Equation (6)}$$

[0036] For simplicity, the transfer function of channel c in the filter bank **100** may be re-written in vector form as:

$$\vec{H}_{r,c}=\alpha\cdot[h_c(0),h_c(1)\ldots h_c(M_c-1)]^T \qquad \text{Equation (7)}$$

where $[\ ]^T$ stands for transpose operation.

[0037] The transfer function of channel c in the filter bank **300** may be re-written in vector form as:

$$\vec{H}_{t,c}=\vec{H}^*_{r,c}=\alpha\cdot[h_c(0),h_c(1)\ldots h_c(M_c-1)]^H \qquad \text{Equation (8),}$$

where $[\ ]^*$ stands for conjugate operation, and $[\ ]^H$ stands for conjugate transpose operation. As a result, the following Equation (9) may be obtained:

$$\vec{H}^H_{t,c}\cdot\vec{H}_{r,c}=1 \qquad \text{Equation (9).}$$

[0038] In a signal composition system of a transmitter, if a symbol X_c is fed to a channel c having a transfer function of $\vec{H}_{t,c}$, then a symbol $X_c\cdot\vec{H}_{t,c}$ may be generated by the channel c. Since the transmitted symbol X is constituted by symbols generated by all channels, the transmitted symbol X may be written as:

$$X=X_1\cdot\vec{H}_{t,1}+X_2\cdot\vec{H}_{t,2}\ldots X_{N_c-1}\cdot\vec{H}_{t,N_c-1} \qquad \text{Equation (10).}$$

[0039] In a signal decomposition system of a receiver, for a received symbol X, a channel c having a transfer function of $\vec{H}_{r,c}$ may generate a symbol $\tilde{X}_c$ according to Equation (11):

$$\tilde{X}_c=X^T\cdot\vec{H}_{r,c} \qquad \text{Equation (11).}$$

[0040] According to Equations (9) and (10), Equation (12) may be obtained:

$$\begin{aligned}\tilde{X}_c&=X^T\cdot\vec{H}_{r,c}\\&=\begin{bmatrix}X_1\cdot\vec{H}_{t,1}+\ldots+X_c\cdot\vec{H}_{t,c}+\ldots\\X_{N_c-1}\cdot\vec{H}_{t,N_c-1}\end{bmatrix}^T\cdot\vec{H}_{r,c}\\&=X_1\cdot\vec{H}_{t,1}^T\cdot\vec{H}_{r,c}+\ldots+X_c\cdot\vec{H}_{t,c}^T\cdot\vec{H}_{r,c}+\ldots\\&\quad X_{N_c-1}\cdot\vec{H}_{t,N_c-1}^T\cdot\vec{H}_{r,c}\\&=X_1\cdot\vec{H}_{t,1}^T\cdot\vec{H}_{r,c}+\ldots+X_c+\ldots\ X_{N_c-1}\cdot\\&\quad\vec{H}_{t,N_c-1}^T\cdot\vec{H}_{r,c}.\end{aligned} \qquad \text{Equation (12)}$$

[0041] Then Equation (13) may be obtained:

$$\tilde{X}_c-X_c=X_1\cdot\vec{H}_{t,1}{}^T\cdot\vec{H}_{r,c}+\ldots+X_{c-1}\cdot\vec{H}_{t,c-1}{}^T\cdot\vec{H}_{r,c}+X_{c+1}\cdot\vec{H}_{t,c+1}{}^T\cdot\vec{H}_{r,c}+\ldots+X_{N_c-1}\cdot\vec{H}_{t,N_c-1}{}^T\cdot\vec{H}_{r,c} \qquad \text{Equation (13),}$$

where the items on the right of the equation may be called interference items.

[0042] To guarantee that $\tilde{X}_c-X_c$ is equal to zero, vector $\vec{H}_{r,p}$ of the receiver shall be orthogonal to vector $\vec{H}_{t,q}$ of the transmitter. However, in practice, perfect orthogonality is very difficult to achieve. If nearly orthogonality is achieved, symbols can also be decomposed correctly.

EXAMPLE

[0043] A communication system having 64 sub-carriers based on filter banks of the present application was designed, and FIG. **4** illustrates a spectrum of the communication system.

[0044] Referring to FIG. **5**, an enlarged view of the spectrum of the communication system based on filter banks and a spectrum of conventional FFT/IFFT method is shown. It can be seen that the communication system has the following characteristics: flat-pass band, narrow transition band, small interference between adjacent sub-carriers and large attenuation in the stop-band etc.

[0045] Given that $\vec{H}_{r,p}$ is the vector of the pth channel of the receiver and $\vec{H}_{t,q}$ is the vector of the qth channel of the transmitter. In this example, results of multiplication of the two arbitrary vectors are listed below:

$$[\vec{H}_{t,q}]^H\cdot\vec{H}_{r,p}=\left\{\begin{matrix}1,\ p=q\\0.0362,\ |p-q|=1\\0,\ \text{others}\end{matrix}\right\}.$$

[0046] Since when p=q, the result of $[\vec{H}_{t,q}]^H\cdot\vec{H}_{r,p}$ is substantially equal to 1; when $|p-q|=1$, the result of $[\vec{H}_{t,q}]^H\cdot\vec{H}_{r,p}$

is less than 0.0362 which is small enough to be negligible; otherwise the result of $[\vec{H}_{t,q}]^H \cdot \vec{H}_{r,p}$ equals to zero, then $\vec{H}_{t,q}$ and $\vec{H}_{r,p}$ may be regarded as nearly orthogonal. In this example, 1 and 0.0362 is the result of normalization.

[0047] In other words, as long as the above conditions are met, the receiver can decode symbols correctly. To decompose sub-carrier signals correctly, when $|p-q|=1$, the result of $[\vec{H}_{t,q}]^H \cdot \vec{H}_{r,p}$ shall be less than a certain threshold, and the threshold may be determined based on how the signal containing the sub-carrier signals is modulated in the transmitter.

[0048] Referring to FIG. **6**, differences between original symbols and decoded symbols are shown, where original symbols are represented using symbol "o", and decoded symbols are represented using symbol "*". It can be seen that the symbols were correctly decoded.

[0049] There is little distinction left between hardware and software implementations of aspects of systems; the use of hardware or software is generally a design choice representing cost vs. efficiency tradeoffs. For example, if an implementer determines that speed and accuracy are paramount, the implementer may opt for a mainly hardware and/or firmware vehicle; if flexibility is paramount, the implementer may opt for a mainly software implementation; or, yet again alternatively, the implementer may opt for some combination of hardware, software, and/or firmware.

[0050] While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

1. A filter bank for signal decomposition, comprising:

a plurality of filter units having one input and two outputs, where the two outputs comprise two paths that have complementary transfer functions, and where the plurality of filter units are connected to one another to form a tree structure.

2. The filter bank of claim **1**, where the filter bank is for decomposing signals having N_c sub-carrier signals, where the filter bank having N_s stages, stage s having 2^s levels, and where $N_s=\log_2 N_c$, s is a stage number, and $s \in [0,1 \ldots N_s-1]$.

3. The filter bank of claim **2**, wherein two outputs of an s^{th} stage, I^{th} level filter unit are respectively connected to inputs of an $(s+1)^{th}$ stage, $(21)^{th}$ level filter unit and an $(s+1)^{th}$ stage, $(21+1)^{th}$ level filter unit, where $l \in [0,1 \ldots 2^s-1]$.

4. The filter bank of claim **2**, wherein an n^{th} order impulse response coefficient of an s^{th} stage, q^{th} level filter unit, $h_{s,q}(n)$, is calculated by multiplying an n^{th} order impulse response coefficient of s^{th} stage, p^{th} level filter unit, $h_{s,p}(n)$, and a rotation factor, where the rotation factor is a complex exponential factor.

5. The filter bank of claim **4**, wherein the rotation factor is

$$e^{j\frac{2\pi}{N_C}(\tilde{p}-\tilde{q})},$$

where $\tilde{p}$ is the value of a bit reversed version of an N_s-1 bits binary encode of p, and $\tilde{q}$ is the value of bit reversed version of an N_s-1 bits binary encode of q.

6. A filter bank for signal composition, comprising:

a plurality of filter units having one output and two inputs, where the two inputs comprise two paths that have complementary transfer functions, and where the plurality of filter units are connected to one another to form a tree structure.

7. The filter bank of claim **6**, where the filter bank is for composing signals having N_c sub-carrier signals, the filter bank having N_s stages, stage s having 2^s levels, and where $N_s=\log_2 N_c$, s is a stage number, and $s \in [0,1 \ldots N_s-1]$.

8. The filter bank of claim **7**, wherein two outputs of an s^{th} stage, 1^{th} level filter unit are respectively connected to inputs of an $(s+1)^{th}$ stage, $(21)^{th}$ level filter unit and an $(s+1)^{th}$ stage, $(21+1)^{th}$ level filter unit, where $l \in [0,1 \ldots 2^s-1]$.

9. The filter bank of claim **7**, wherein an n^{th} order impulse response coefficient of an s^{th} stage, q^{th} level filter unit, $h_{s,q}(n)$, is calculated by multiplying an n^{th} order impulse response coefficient of s^{th} stage, p^{th} level filter unit, $h_{s,p}(n)$, and a rotation factor, where the rotation factor is a complex exponential factor.

10. The filter bank of claim **9**, wherein the rotation factor is

$$e^{j\frac{2\pi}{N_C}(\tilde{p}-\tilde{q})},$$

where $\tilde{p}$ is the value of a bit reversed version of an N_s-1 bits binary encode of p, and $\tilde{q}$ is the value of bit reversed version of an N_s-1 bits binary encode of q.

11. A receiver, comprising:

a first filter bank for decomposing signals, the signals containing N_c sub-carrier signals and composed by a second filter bank of a transmitter, where both the first filter bank and the second filter bank have N_s stages, and stage s of both the first filter bank and the second filter bank comprises 2^s levels to form N_c channels, where $N_s=\log_2 N_c$, s is a stage number, and $s \in [0,1 \ldots N_s-1]$, and where vector form transfer function $\vec{H}_{r,p}$ of channel p of the first filter bank is substantially orthogonal to vector form transfer function $\vec{H}_{t,q}$ of channel q of the second filter bank.

12. The receiver of claim **11**, wherein:

when p=q, the result of $[\vec{H}_{t,q}]^H \cdot \vec{H}_{r,p}$ is substantially equals to 1;

when $|p-q|=1$, the result of $[\vec{H}_{t,q}]^H \cdot \vec{H}_{r,p}$ is less than a predetermined threshold; and

otherwise, the result of $[\vec{H}_{t,q}]^H \cdot \vec{H}_{r,p}$ equals to 0, where $[\ ]^H$ is a conjugate transpose operation.

13. A signal composing method, comprising:

feeding N_c sub-carrier signals into N_c inputs of a tree-structured filter bank, respectively, where the filter bank has a plurality of filter units, each filter unit having one output and two inputs, where the two inputs comprise two paths that have complementary transfer functions; and

obtaining a composed signal containing the N_c sub-carrier signals from an output of the filter bank.

14. A signal decomposing method comprising:

feeding a signal containing N_c sub-carrier signals into a tree structured filter bank having one input and N_c outputs, where the filter bank has a plurality of filter units having one input and two outputs, where the two outputs comprise two paths that have complementary transfer functions; and obtaining the N_c sub-carrier signals from the N_c outputs of the filter bank, respectively.

15. A communication method, comprising:

composing N_c sub-carrier signals using a first tree structured filter bank having N_c channels to obtain a composed signal containing the N_c sub-carrier signals; and

decomposing the composed signal using a second tree structured filter bank having N_c channels to obtain the N_c sub-carrier signals,

where vector form transfer function $\vec{H}_{r,p}$ of channel p of the second filter bank is substantially orthogonal to vector form transfer function $\vec{H}_{t,q}$ of channel q of the first filter bank.

16. The communication method of claim **15**, wherein:

when p=q, the result of $[\vec{H}_{t,q}]^H \cdot \vec{H}_{r,p}$ is substantially equals to 1;

when $|p-q|=1$, the result of $[\vec{H}_{t,q}]^H \cdot \vec{H}_{r,p}$ is less than a predetermined threshold; and

otherwise, the result of $[\vec{H}_{t,q}]^H \cdot \vec{H}_{r,p}$ equals to 0, where $[\ ]^H$ is a conjugate transpose operation.

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