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(54) **Title**: METHOD FOR GENERATING DFT COEFFICIENTS

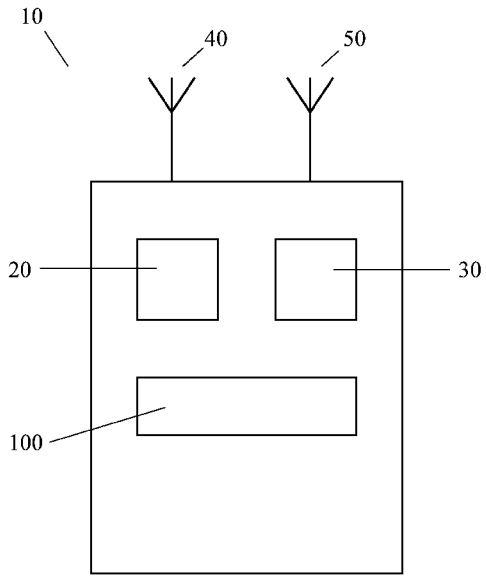


Fig. 1

(57) **Abstract**: The present invention relates to a method for generating DFT coefficients of a cyclically shifted ZC sequence, wherein said cyclically shifted ZC sequence is a basic ZC sequence with root u of length N cyclically shifted by p >1 sequence elements. Said method comprising the steps of: complex conjugating said basic ZC sequence; cyclically shifting said complex 5 conjugated basic ZC sequence; cyclically sampling said cyclically shifted complex conjugated basic ZC sequence; and multiplying said cyclically sampled cyclically shifted complex conjugated basic ZC sequence with a constant C so as to generate the DFT coefficients of said cyclically shifted ZC sequence. The invention also relates to a device and a computer program thereof.

METHOD FOR GENERATING DFT COEFFICIENTS

Technical Field

[0001] The present invention relates to a method for generating DFT coefficients, or more particularly to a method according to the preamble of claim 1. Furthermore, the invention also relates to a device and a computer program thereof.

Background of the Invention

[0002] In Long Term Evolution (LTE) cellular system standard Random Access (RA) preambles are used for uplink synchronisation, i.e. the RA preambles are used by User Equipments (UEs) for synchronisation with base stations. RA preambles are generated from cyclically shifted Zadoff-Chu (ZC) sequences of prime length N, by using so-called DFT-S-OFDM modulation, which is well known in the art.

[0003] The first step in generating such a RA preamble is to perform an N-point Discrete Fourier Transform (DFT) of a cyclically shifted ZC sequence characterized by root index u and cyclic shift p. The Fourier spectrum of the ZC sequence is then mapped into the central part of a band allocated for RA transmission by multiplying the DFT coefficients with the elements of a discrete complex exponential function. The RA preamble waveform is obtained by adding the cyclic prefix to the waveform resulting from the N-point Inverse DFT of the weighted DFT coefficients of the ZC sequence.

[0004] A closed-form formula for the DFT of a ZC sequence of prime length N has been derived as

$$X_u(n) = W^{-\frac{n(n+u)}{2u}} X_u(0) \qquad (1),$$

where

$$X_u(0) = \sum_{k=0}^{N-1} x_u(k) \qquad (2),$$

and $\{x_u(k)\}$ is a ZC sequence.

[0005] A ZC sequence is defined as

$$x_u(k) = W_N^{uk(k+N \bmod 2)/2}, \quad k=0,1,\ldots, N\text{-}1, \; W_N = e^{-j2\pi/N}, \; j=\sqrt{-1},$$

$$N \text{ is any positive integer, } (u,N)=1 \qquad (3),$$

where $u<N$ is an integer relatively prime to N. The DFT of the ZC sequence $\{x_u(k)\}$ is defined as

$$X_u(n) = \sum_{k=0}^{N-1} x_u(k) W_N^{nk} \qquad (4).$$

[0006] Equation (1) may be used to derive the efficient bank of matched filters for the pair of RA preambles $\{x_{u,p}(k)\}$ and $\{x_{N-u,p}(k)\}$, used in a base station receiver, where

$$x_{u,p}(k) = x_u((k+p) \bmod N) \qquad (5)$$

is a cyclically shifted (by p) version of $\{x_u(k)\}$.

[0007] Further, the formula (1) may be put into another form as

$$X_u(n) = x_u^*(u^{-1}n) X_u(0), \; n=0,1,\ldots, N\text{-}1, \; N \text{ is a prime} \qquad (6),$$

where "*" denotes complex conjugation, and $u^{-1}=1/u$ is the modular multiplicative inverse of u, i.e. an integer such that $u \cdot u^{-1}=1 \bmod N$. According to equation (6), the DFT coefficients of a ZC sequence can be obtained directly from the ZC sequence itself, which reduces the number of operations for obtaining the DFT coefficients if the ZC sequence is already generated.

[0008] However, equation (6) cannot always be used to reduce the number of operations in a transmitter of a LTE UE, as a transmitted RA preamble can be a cyclically shifted version of a ZC sequence.

Summary of the Invention

[0009] An object of the present invention is to provide a method, and a device and a computer program thereof, for generating DFT coefficients of a cyclically shifted ZC

sequence. Another object of the present invention is to provide a solution which reduces the number of operations for generating the DFT coefficients of the cyclically shifted ZC sequence. Yet another object of the present invention is to provide a solution for obtaining the DFT coefficients for a broader class of ZC sequences.

[0010] According to one aspect of the present invention the aforementioned objects are achieved by a method for generating DFT coefficients of a cyclically shifted ZC sequence, wherein said cyclically shifted ZC sequence is a basic ZC sequence with root u of length N cyclically shifted by $p>1$ sequence elements. Said method comprising the steps of:

- complex conjugating said basic ZC sequence;
- cyclically shifting said complex conjugated basic ZC sequence:
- cyclically sampling said cyclically shifted complex conjugated basic ZC sequence; and
- multiplying said cyclically sampled cyclically shifted complex conjugated basic ZC sequence with a constant C so as to generate the DFT coefficients of said cyclically shifted ZC sequence.

[0011] Various embodiments of the method above are disclosed in the dependent claims 2-12.

[0012] According to another aspect of the present invention the aforementioned objects are achieved with a computer program characterised in code means, which when run in a computer causes said computer to execute the method according to any of claims 1-12.

[0013] According to yet another aspect of the present invention the aforementioned objects are achieved with a device for generating DFT coefficients of a cyclically shifted ZC sequence, wherein said cyclically shifted ZC sequence is a basic ZC sequence with root u of length N cyclically shifted by $p>1$ sequence elements. Said device being arranged to:

- complex conjugating said basic ZC sequence;
- cyclically shifting said complex conjugated basic ZC sequence:
- cyclically sampling said cyclically shifted complex conjugated basic ZC sequence; and

- multiplying said cyclically sampled cyclically shifted complex conjugated basic ZC sequence with a constant C so as to generate the DFT coefficients of said cyclically shifted ZC sequence.

[0014] The device may further be configured in accordance with the different embodiments of the method according to the dependent claims 2-12.

[0015] An advantage with the present invention is that the number of computational operations for obtaining the DFT of a cyclically shifted ZC sequence can be reduced, which e.g. means that battery consumption in UEs can be reduced when generating RA preambles for uplink synchronisation. Another advantage with the present invention is that the solution is applicable to a broader class of problems, since the solution is generalised to any positive integer for length N of the ZC sequences.

[0016] Other advantages and applications of the present invention will be apparent from the following detailed description of the invention.

Brief Description of the Drawings

[0017] The appended drawing is intended to clarify and explain the present invention, in which:

[0018] Figure 1 schematically shows a UE comprising at least one device for generating DFT coefficients according to the present invention.

Detailed Description of Embodiments of the Invention

[0019] From the above description it is clear that equation (6) cannot always be used to reduce the number of operations in a transmitter of a LTE UE. The reason is that a transmitted RA preamble can be a cyclically shifted version of a ZC sequence, which not can be solved with equation (6).

[0020] According to the present invention, for a given root u and cyclic shift p of a basic ZC sequence of any integer length N, the corresponding DFT is delayed by p and then

cyclically sampled by integer increment complex-conjugated version of the already generated basic Zadoff-Chu sequence, multiplied by a constant C.

[0021] Therefore, the DFT coefficients can be calculated by N-1 number of complex additions and N+1 number of complex multiplications using only the elements of the already generated basic ZC sequence. A basic ZC sequence is henceforth defined as being a ZC sequence defined by equation (3) above.

[0022] According to an embodiment of the invention, the basic ZC sequence is cyclically sampled by integer increment u^{-1}, where $u \cdot u^{-1} = 1$ modulo N.

[0023] According to another embodiment of the invention, the constant C consists of two factors: the p+1:th element of the ZC sequence $f1$, and the sum of all the elements of the ZC sequence $f2$. The second factor $f2$ may also be expressed in closed form, which is described below.

[0024] According to yet another embodiment of the invention, the length of the ZC sequence N is a prime number, and the ZC sequence is used for generating a RA preamble in a mobile station terminal for uplink synchronisation in a wireless communication system. The mobile station terminal is in one embodiment a UE, and the wireless communication system is a LTE communication system or a LTE Advanced communication system.

[0025] Mathematically, the present invention solves the aforementioned problems by providing an expression for

$$X_{u,p}(n) = \sum_{k=0}^{N-1} x_u(k+p) W_N^{nk}, \quad n=0,1,\ldots,N\text{-}1,\ (u,N)=1,\ N \text{ is any positive integer} \qquad (7).$$

[0026] It should be noted that the length N of the ZC sequences in equation (7) is now generalized to be any positive integer, which makes the present solution applicable to the broader class of problems.

[0027] We start by expressing $x_u(k+p)W_N^{nk}$ as

$$x_u(k+p)W_N^{nk} = W_N^{-udp}\, W_N^{u[(k+p)(k+p+N \bmod 2)+2d(k+p)]/2}$$

$$= W_N^{-udp}\, W_N^{ul(l+N \bmod 2+2d)/2},\ l=k+p,\ d=u^{-1}n \bmod N \qquad (8).$$

[0028] Note that the modular multiplicative inverse u^{-1} mod N exists for any integers u and N such that $(u,N)=1$. The procedure from the Appendix of "Efficient matched filters for paired root Zadoff-Chu sequences", by B. M. Popovic and O. Mauritz (3GPP RAN1#48bis meeting, source: Huawei, tdoc number R1-071409, St. Julian's, Malta, March 26-30, 2007), can be directly applied to equation (8) as follows

$$x_u(k+p)W^{nk} = W_N^{-udp}\, W_N^{ul(l+N \bmod 2+2d)/2}\, \frac{W_N^{ud(d+N \bmod 2)/2}}{W_N^{ud(d+N \bmod 2)/2}}$$

$$= W_N^{-ud(d+N \bmod 2+2p)/2}\, x_u(l+d) \qquad (9).$$

[0029] If we then insert equation (9) into equation (7), we obtain

$$X_{u,p}(n) = W_N^{-ud(d+N \bmod 2+2p)/2} \sum_{k=0}^{N-1} x_u(k+p+d) \qquad (10).$$

[0030] As $p+d$ is a constant, the sum in equation (10) is equal to equation (2). The term outside the sum in equation (10) can be decomposed using the same procedure as to obtain equation (9), so we finally have

$$X_{u,p}(n) = x_u^*(u^{-1}n+p)\, x_u(p) X_u(0) \qquad (11).$$

[0031] From the equation (11) it follows that for given root u and the cyclic shift p of a basic ZC sequence of any length N, the corresponding DFT is cyclically delayed by p and then cyclically sampled by integer increment u^{-1} complex-conjugated version of already generated basic ZC sequence, multiplied by a constant C, consisting of two factors $f1$ and $f2$, where $f1$ is the p+1:th element of the basic ZC sequence, and $f2=X_u(0)$ is the sum of all the elements of the basic ZC sequence.

[0032] Therefore, the DFT of a basic ZC sequence can be calculated by N-1 complex additions and N+1 complex multiplications, by only using the elements of the already generated basic ZC sequence expressed in equation (3).

[0033] The constant $X_u(0)$ can be expressed in the closed-form. For N odd, $X_u(0)$ is by the definition in equation (2) equal to

$$X_u(0) = \sum_{k=0}^{N-1} W_N^{uk(k+1)/2} \quad (12).$$

[0034] As $k(k+1)/2$ is an integer for any integer k, it follows that

$$W_N^{u(N/2)k(k+1)} = e^{-j2\pi uk(k+1)/2} = 1 \quad (13).$$

[0035] Thus, by using equation (13), we can re-write equation (12) as

$$X_u(0) = \sum_{k=0}^{N-1} W_N^{u\alpha k(k+1)} \quad (14),$$

where $\alpha=(N+1)/2$ is an integer, as N is odd. By introducing an additional integer $\beta=(N-1)/2$, we can re-write equation (14) as

$$X_u(0) = \sum_{k=0}^{N-1} W_N^{u\alpha\left[(k-\beta)^2-\beta^2\right]}, \ \alpha = \frac{N+1}{2}, \ \beta = \frac{N-1}{2} \quad (15).$$

[0036] It further follows that

$$X_u(0) = W_N^{-u\alpha\beta^2} \sum_{k=0}^{N-1} W_N^{u\alpha k^2} = W_N^{u\alpha\beta/2} W_N^{-u(N/2)\alpha\beta} G(u\alpha, N)^* \quad (16),$$

where $G(m,L)^*$ is complex-conjugate of the quadratic Gauss sum $G(m,L)$, equal to

$$G(m,L) = \sum_{k=0}^{L-1} W_L^{mk^2} = \begin{cases} \left(\frac{m}{L}\right)\sqrt{L}, & L = 1 \bmod 4 \\ \left(\frac{m}{L}\right) j\sqrt{L}, & L = 3 \bmod 4 \\ \left(\frac{L}{m}\right)(1+j^m)\sqrt{L}, & L = 0 \bmod 4 \\ 0, & L = 2 \bmod 4 \end{cases} \quad (17).$$

[0037] In equation (17), $\left(\frac{m}{L}\right)$ denotes Jacobi symbol. A Jacobi symbol $\left(\frac{a}{b}\right)$ is defined for any integer a and any odd integer b as

$$\left(\frac{a}{b}\right) = \left(\frac{a}{p_1}\right)^{e_1} \left(\frac{a}{p_2}\right)^{e_2} \cdots \left(\frac{a}{p_k}\right)^{e_k} \quad (18),$$

where $p_1, p_2, \ldots p_k$ are primes, $e_1, e_2, \ldots e_k$ are positive integers, such that $b = p_1^{e_1} p_2^{e_2} \ldots p_k^{e_k}$, and $\left(\frac{a}{p_l}\right)$ is Legendre symbol defined for any integer a and any prime p_l, as

$$\left(\frac{a}{p_l}\right) = \begin{cases} 0, & \text{if } m = 0 \bmod p_l \\ +1, & \text{if } m \neq 0 \bmod p_l \text{ and there is an integer } x, \text{ such that } x^2 = m \bmod p_l \\ -1, & \text{if there is no such } x \end{cases} \quad (19).$$

[0038] The term $W_N^{u\alpha\beta/2}$ at the right-hand side of equation (16) is equal to $x_u(\beta)$, while the term $W_N^{-u(N/2)\alpha\beta} = 1$ according to equation (13). Hence, we finally obtain

$$X_u(0) = \left(\frac{u\alpha}{N}\right)\frac{1+j^N}{1+j}\sqrt{N}x_u(\beta), \text{ when } N \text{ is odd} \quad (20).$$

[0039] For N even, $X_u(0)$ is given by

$$X_u(0) = \left(\frac{2N}{u}\right)(1-j^u)\sqrt{N/2}, \; N \text{ is even} \quad (21).$$

[0040] The proof for equation (21) is straightforward: since a ZC sequence is periodic with period N, we can write

$$\begin{aligned} X_u(0) &= \sum_{k=0}^{N-1} W_N^{uk^2/2} \\ &= \frac{1}{2}\sum_{k=0}^{2N-1} W_{2N}^{uk^2} \\ &= \frac{1}{2}G(u,2N)^* \end{aligned} \quad (22).$$

[0041] The expression for $G(u,2N)^*$ is given by equation (17), for L=0 mod 4 ($2N$=0 mod 4 for any N even), so the final result directly follows from equation (22).

[0042] With closed form expressions for $X_u(0)$ according to equations (20) and (21), respectively, the number of operations for obtaining the DFT coefficients for ZC sequences reduces to N+1 number of complex multiplications compared to the general solution above, which requires N-1 number of complex additions and N+1 number of complex multiplications.

[0043] The present invention also relates to a device 100 for generating DFT coefficients of a cyclically shifted ZC sequence. Figure 2 schematically shows a mobile station terminal 10, such as a UE, comprising a device 100 according to the invention. The UE may also further comprise at least a transmitting 20 and at least a receiving circuitry 30 connected to one or more antennas 40, 50. The transmitting 20 and receiving 30 circuitries each comprises electronics for transmission and reception of communication signals, respectively. The DFT coefficients generated by the device 100 are preferable used when generating RA preambles for uplink synchronisation with base stations, such as eNodeB.

[0044] Furthermore, as understood by the person skilled in the art, the method for generating DFT coefficients of a cyclically shifted ZC sequence according to the invention may be implemented in a computer program, having code means, which when run in a computer causes the computer to execute the steps of the method. The computer program is included in a computer readable medium of a computer program product. The computer readable medium may consist of essentially any memory, such as a ROM (Read-Only Memory), a PROM (Programmable Read-Only Memory), an EPROM (Erasable PROM), a Flash memory, an EEPROM (Electrically Erasable PROM), or a hard disk drive.

[0045] Finally, it should also be understood that the present invention is not limited to the embodiments described above, but also relates to and incorporates all embodiments within the scope of the appended independent claims.

Claims

1. Method for generating Discrete Fourier Transform (DFT) coefficients of a cyclically shifted Zadoff-Chu (ZC) sequence, wherein said cyclically shifted Zadoff-Chu (ZC) sequence is a basic Zadoff-Chu (ZC) sequence with root u of length N cyclically shifted by $p>1$ sequence elements, said method being characterised by the steps of:

- complex conjugating said basic Zadoff-Chu (ZC) sequence;
- cyclically shifting said complex conjugated basic Zadoff-Chu (ZC) sequence;
- cyclically sampling said cyclically shifted complex conjugated basic Zadoff-Chu (ZC) sequence; and
- multiplying said cyclically sampled cyclically shifted complex conjugated basic Zadoff-Chu (ZC) sequence with a constant C so as to generate the Discrete Fourier Transform (DFT) coefficients of said cyclically shifted Zadoff-Chu (ZC) sequence.

2. Method according to claim 1, wherein the Discrete Fourier Transform (DFT) coefficients of said cyclically shifted Zadoff-Chu (ZC) sequence are defined as:

$$X_{u,p}(n) = \sum_{k=0}^{N-1} x_u(k+p) W_N^{nk}, \quad n=0,1,\ldots, N\text{-}1, (u,N)=1.$$

3. Method according to claim 1, wherein said basic Zadoff-Chu (ZC) sequence is defined as:

$$x_u(k) = W_N^{uk(k+N \bmod 2)/2},$$

where $k=0,1,\ldots, N\text{-}1$, $W_N = e^{-j2\pi/N}$, $j=\sqrt{-1}$, N is any positive integer, and $u<N$ is an integer relatively prime to N.

4. Method according to claim 1, wherein said basic Zadoff-Chu (ZC) sequence is cyclically shifted by a shift p modulo N.

5. Method according to claim 1, wherein said basic Zadoff-Chu (ZC) sequence is cyclically sampled by u^{-1}, where $u \cdot u^{-1} = 1$ modulo N.

6. Method according to claim 1, wherein said constant C is a product of a first $f1$ and a second $f2$ factor.

7. Method according to claim 6, wherein said first factor $f1$ is the p+1:th element of said basic Zadoff-Chu (ZC) sequence, and said second factor $f2$ is the sum of all elements of said basic Zadoff-Chu (ZC) sequence.

8. Method according to claim 6, wherein:

$f2 = \left(\frac{u\alpha}{N}\right)\frac{1+j^N}{1+j}\sqrt{N}x_u(\beta)$, when N is odd, and

$f2 = \left(\frac{2N}{u}\right)(1-j^u)\sqrt{N/2}$, when N is even.

9. Method according to claim 1, wherein N is a prime number.

10. Method according to claim 9, wherein said basic Zadoff-Chu (ZC) sequence is used for generating a Random Access (RA) preambles in a mobile station terminal for uplink synchronisation in a wireless communication system.

11. Method according to claim 10, wherein said mobile station terminal is a User Equipment (UE) and said wireless communication system is a Long Term Evolution (LTE) communication system or a Long Term Evolution (LTE) Advanced communication system.

12. Method according to claim 1, further comprising the steps of:

- receiving a signal carrying information representing said basic Zadoff-Chu (ZC); and
- using the generated Discrete Fourier Transform (DFT) coefficients in a electronic communication process.

13. Computer program, characterised in code means, which when run in a computer causes said computer to execute said method according to any of claims 1-12.

14. Computer program product comprising a computer readable medium and a computer program according to claim 13, wherein said computer program is included in the computer readable medium, and consist of one or more from the group: ROM (Read-Only Memory), PROM (Programmable ROM), EPROM (Erasable PROM), Flash memory, EEPROM (Electrically EPROM) and hard disk drive.

15. Device (100) for generating Discrete Fourier Transform (DFT) coefficients of a cyclically shifted Zadoff-Chu (ZC) sequence, wherein said cyclically shifted Zadoff-Chu (ZC) sequence is a basic Zadoff-Chu (ZC) sequence with root u of length N cyclically shifted by $p>1$ sequence elements, said device (100) characterised in being arranged to:

- complex conjugating said basic Zadoff-Chu (ZC) sequence;
- cyclically shifting said complex conjugated basic Zadoff-Chu (ZC) sequence;
- cyclically sampling said cyclically shifted complex conjugated basic Zadoff-Chu (ZC) sequence; and
- multiplying said cyclically sampled cyclically shifted complex conjugated basic Zadoff-Chu (ZC) sequence with a constant C so as to generate the Discrete Fourier Transform (DFT) coefficients of said cyclically shifted Zadoff-Chu (ZC) sequence.

16. Mobile station terminal (10), arranged for communication in a wireless communication system, comprising at least one device (100) according to claim 15.

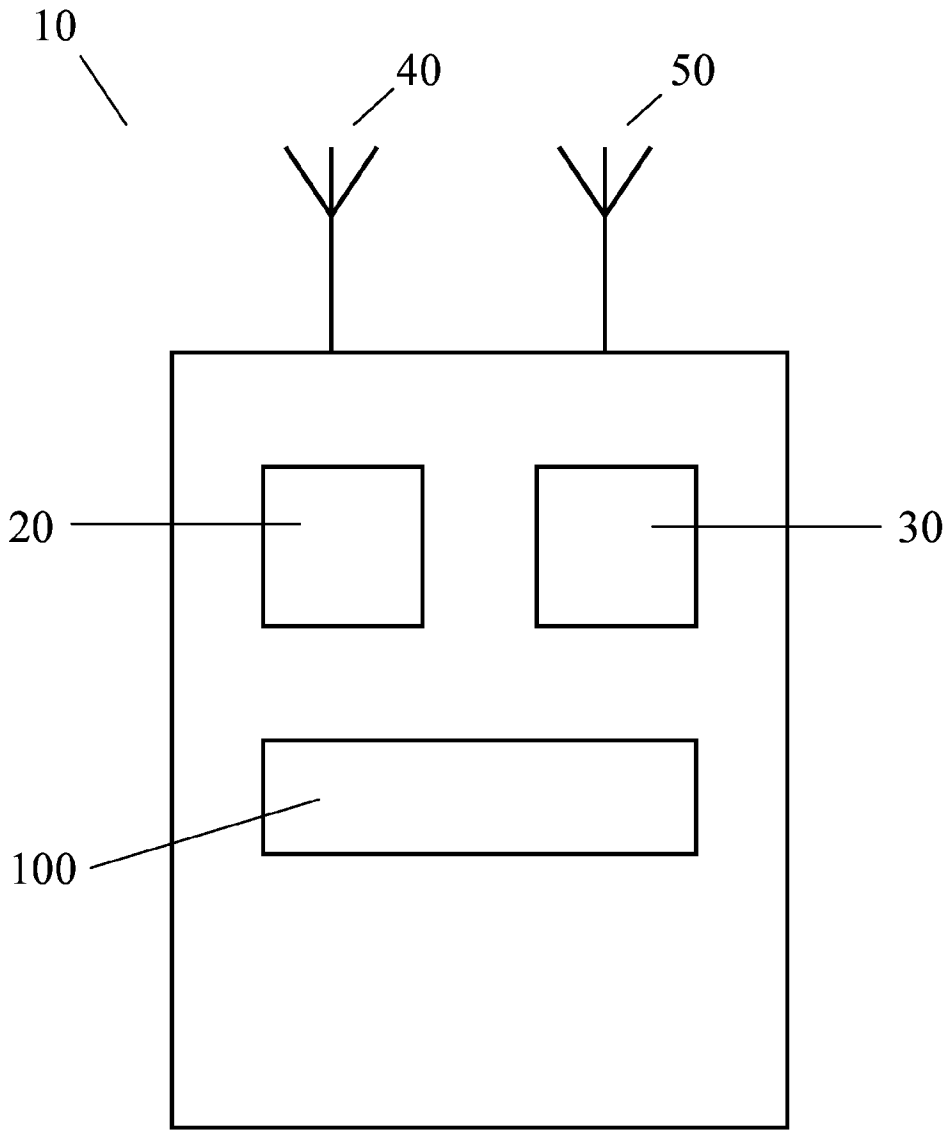


Fig. 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2009/073537

A. CLASSIFICATION OF SUBJECT MATTER

H04W16/00(2009.01)i

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: H04W, H04Q, 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 practicable, search terms used)

CPPABS, CPRSABS, CNTXT, CNKI, WPI, EPODOC, TXTWO1, TXTEP1: DFT, FFT, ZC, sequence, preamble, cycl+, shift+, sampl+, multipl+, constant

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN101455048A (TEXAS INSTRUMENTS INC) 10 June 2009 (10.06.2009) abstract, figure 4	1-16
A	CN101170346A (FUJITSU LTD) 30 Apr. 2008 (30.04.2008) the whole document	1-16
A	WO2008052032A2 (TEXAS INSTRUMENTS INC et al) 02 May 2008 (02.05.2008) the whole document	1-16

☐ Further documents are listed in the continuation of Box C. ☒ See patent family 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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"L" document which may throw doubts on priority claim (S) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&"document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 Apr. 2010 (21.04.2010)	**06 May 2010 (06.05.2010)**
Name and mailing address of the ISA/CN The State Intellectual Property Office, the P.R.China 6 Xitucheng Rd., Jimen Bridge, Haidian District, Beijing, China 100088 Facsimile No. 86-10-62019451	Authorized officer MENG Wenting Telephone No. (86-10)62411434

Form PCT/ISA /210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2009/073537

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
CN101455048A	10.06.2009	WO2007126793A2	08.11.2007
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