OPIC
Office de la propriété
intellectuelle du Canada

CIPO
Canadian Intellectual
Property Office

(12) (19) (CA) **Demande-Application**

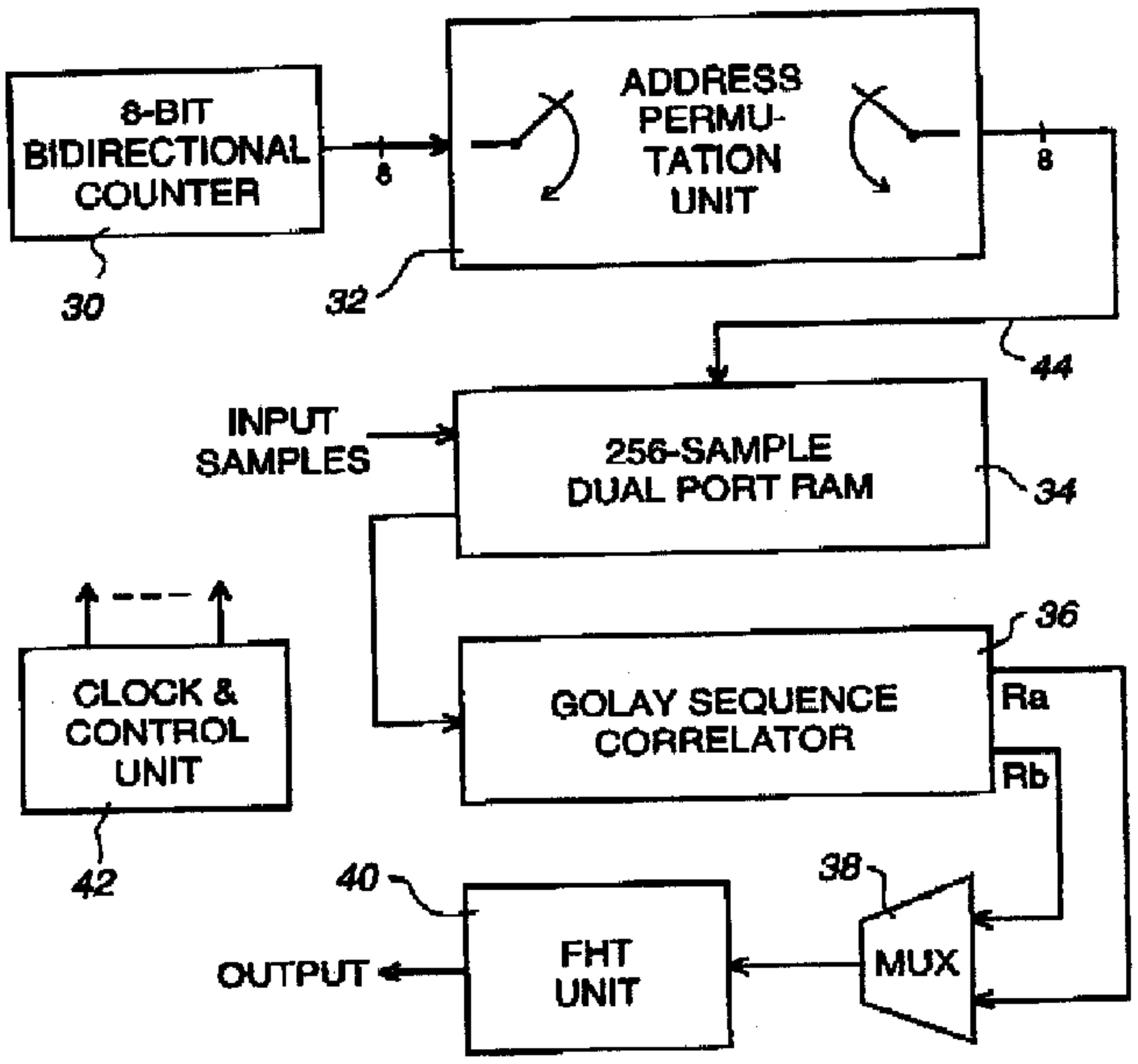
(21) (A1) **2,276,971**
(22) 1999/07/06
(43) 2001/01/06

(72) TONG, WEN, CA
(72) MASSIE, BASTIEN, FR
(72) BOUET, ETIENNE, FR
(72) LE STRAT, EVELYNE, FR
(71) TONG, WEN, CA
(71) MASSIE, BASTIEN, FR
(71) BOUET, ETIENNE, FR
(71) LE STRAT, EVELYNE, FR

(51) Int.Cl.^{6} H04B 7/216, H04Q 7/36

(54) SYNCHRONISEUR INITIAL FAISANT APPEL AU CODE DE GOLAY POUR UN CANAL D'ACCES DANS DES SYSTEMES DE COMMUNICATIONS CELLULAIRES

(54) PREAMBLE USING GOLAY SEQUENCE FOR ACCESS CHANNEL IN CELLULAR COMMUNICATIONS SYSTEMS



(57) A preamble for a reverse access channel (RACH) of a CDMA (code division multiple access) communications system comprises a pair of constituent Golay sequences A and B concatenated at least one pair, and preferably a plurality of different pairs, of transformed sequences which are also constituent Golay sequences, each pair of transformed sequences comprising a permutation of elements of the pair of sequences A and B. The permutations can include a reversed order of elements in the sequences, a reversed order of some or all of a set of address bits identifying locations of elements in the sequences, a concatenation of subsets of elements in odd and even locations of the sequences A and B, and combinations of these permutations. A method for providing the preamble, and related apparatus using a bidirectional counter (30) and an address permutation unit (32), are described.

Industrie Canada Industry Canada

Abstract of the Disclosure

A preamble for a reverse access channel (RACH) of a CDMA (code division multiple access) communications system comprises a pair of constituent Golay sequences A and B concatenated at least one pair, and preferably a plurality of different pairs, of transformed sequences which are also constituent Golay sequences, each pair of transformed sequences comprising a permutation of elements of the pair of sequences A and B. The permutations can include a reversed order of elements in the sequences, a reversed order of some or all of a set of address bits identifying locations of elements in the sequences, a concatenation of subsets of elements in odd and even locations of the sequences A and B, and combinations of these permutations. A method for providing the preamble, and related apparatus using a bidirectional counter (30) and an address permutation unit (32), are described.

PREAMBLE USING GOLAY SEQUENCE FOR ACCESS CHANNEL IN CELLULAR COMMUNICATIONS SYSTEMS

This invention relates to preambles using a Golay sequence for an access channel, in particular a so-called reverse access channel (RACH), in a cellular communications system.

Background of the Invention

In cellular communications systems, for example in a wireless cellular communications system using CDMA (code division multiple access) techniques for communications between a mobile terminal or station (MS) and a base station (BS), it is well known for the BS to transmit a pilot signal and a broadcast message including a preamble. On being powered up in a cell associated with the BS, a MS uses the pilot signal for synchronization to the BS, and downloads information including the preamble from the broadcast message. Having accordingly determined the timing of the BS, the MS transmits the preamble on the RACH. This is detected by the BS using correlation techniques, so that the BS is informed of the MS, and it can proceed with establishing communications on a traffic channel between the BS and the MS.

In submission TSGR1#3(99)205 to the TSG-RAN Working Group 1 meeting #3, March 22-26, 1999, entitled "New RACH preambles with low auto-correlation sidelobes and reduced detector complexity" (a copy of which is included herein as an Appendix at the end of the description), it is proposed that the preamble, which comprises 4096 code chips providing one of 16 orthogonal signatures of length 16 complex signals, be provided by binary Golay sequences, which have the advantageous property that the sum of their aperiodic auto-correlation functions is zero for all non-zero time shifts. Consequently, that submission proposes that the preamble be formed from a pair of complementary sequences A and B, which together constitute a Golay sequence and are referred to as constituent Golay sequences, each of 256 chips, repeated in a specific one of 16 signature patterns, so that the overall sequence has a length of 4096 chips, as shown by Table 1 below.

In Table 1, the signature patterns include the sequences A and B in normal and inverted forms, the inverted forms being denoted -A and -B respectively. The 4096 chips of an overall sequence can conveniently be included in one 10 ms time slot, the constituent Golay sequences A and B being individual to a specific cell and/or BS, and the above signature patterns being the same for all cells and base stations.

In contrast to using longer distinctive codes or sequences each of 4096 chips to identify the BS and any of 16 users, for which matched filtering would be required for sequences of 4096 chips, this preamble construction enables the matched filtering to be applied to the much shorter sequences of 256 chips, with a consequent substantial reduction in computational complexity.

1	A	A	B	B	A	-A	-B	B	A	-A	B	-B	A	A	-B	-B
2	A	A	B	B	A	-A	-B	B	-A	A	-B	B	-A	-A	B	B
3	A	-A	B	-B	A	A	-B	-B	A	A	B	B	A	-A	-B	B
4	A	-A	B	-B	A	A	-B	-B	-A	-A	-B	-B	-A	A	B	-B
5	A	A	B	B	-A	A	B	-B	A	-A	B	-B	-A	-A	B	B
6	A	A	B	B	-A	A	B	-B	-A	A	-B	B	A	A	-B	-B
7	A	-A	B	-B	-A	-A	B	B	A	A	B	B	-A	A	B	-B
8	A	-A	B	-B	-A	-A	B	B	-A	-A	-B	-B	A	-A	-B	B
9	A	A	-B	-B	A	-A	B	-B	A	-A	-B	B	A	A	B	B
10	A	A	-B	-B	A	-A	B	-B	-A	A	B	-B	-A	-A	-B	-B
11	A	-A	-B	B	A	A	B	B	A	A	-B	-B	A	-A	B	-B
12	A	-A	-B	B	A	A	B	B	-A	-A	B	B	-A	A	-B	B
13	A	A	-B	-B	-A	A	-B	B	A	-A	-B	B	-A	-A	-B	-B
14	A	A	-B	-B	-A	A	-B	B	-A	A	B	-B	A	A	B	B
15	A	-A	-B	B	-A	-A	-B	-B	A	A	-B	-B	-A	A	-B	B
16	A	-A	-B	B	-A	-A	-B	-B	-A	-A	B	B	A	-A	B	-B

Table 1

It has been found, however, that Golay sequences (and Gold code sequences which have previously been proposed) produce substantial cross correlation peaks for time shifts corresponding to 256 chip boundaries, corresponding for example to a communication distance of about 9 km. Such undesired cross correlation peaks are understood to be due to the repetitive nature of the constituent sequences in the signature patterns discussed above, and present a significant challenge if the delay due to communications distance can correspond to the preamble length or a multiple of the preamble length, and hence for situations where it is desired to use a relatively short preamble and relatively large cell sizes.

Accordingly, aspects of this invention seek to provide an improved preamble, and method for providing such a preamble, for use in an access channel of a communications system, a method of producing an extended sequence from a pair of constituent Golay sequences, and related apparatus.

Summary of the Invention

One aspect of this invention provides a method of producing an extended sequence from a pair of constituent Golay sequences A and B, comprising the steps of: transforming the pair of constituent Golay sequences A and B to form at least one pair of transformed sequences which are also constituent Golay sequences; and concatenating at least two of said pairs of constituent Golay sequences to produce the extended sequence.

The step of transforming the pair of constituent Golay sequences A and B to form each pair of transformed sequences preferably comprises a permutation of elements of the sequences. The permutation can comprise, for example, a reversal of the order of elements in the sequences, a reversal of a set of address bits identifying locations of elements in the sequences, a reversal of some but not all of a set of address bits identifying locations of elements in the sequences, or a concatenation of subsets of elements of the sequences selected by decimation, for example a concatenation of two subsets of elements, in even and odd locations in the sequences, or it can comprise combinations of these permutations.

The invention also provides a method of producing a preamble for use on an access channel of a cellular communications system, wherein the preamble includes an extended sequence produced by the above method. In particular, each of the constituent Golay sequences A and B and each of the transformed sequences can comprise 256 elements, and the preamble can comprise 4096 elements. Advantageously in this case the extended sequence can comprise the constituent Golay sequences A and B and seven different transformations of these sequences A and B.

Another aspect of this invention provides a method of providing a preamble for an access channel of a CDMA (code division multiple access) communications system, comprising the steps of: providing a pair of constituent Golay sequences A and B; permuting elements of the pair of sequences A and B to form at least one pair of transformed sequences which are also constituent Golay sequences; and concatenating said at least one pair of transformed sequences with the pair of constituent Golay sequences A and B for use as an extended sequence in the preamble.

The preamble can be provided by a concatenation of the pair of constituent Golay sequences A and B with a plurality of pairs of said transformed sequences according to different permutations of the elements of the pair of constituent Golay sequences A and B. The step of permuting elements of the pair of sequences A and B can comprise a reversal of the order of elements in the sequences, a reversal of at least some of a set of address bits identifying locations of elements in the sequences, or a concatenation of two subsets of elements of the sequences, the two subsets corresponding respectively to even and odd locations in the sequences.

The invention further provides apparatus for use in carrying out the above methods, comprising a memory for storing elements of each sequence, and address control means for addressing the memory for writing to or reading from the memory consecutively at locations according to the transformed sequences. The address control means can comprise a bidirectional counter for supplying memory addresses incremented in either of two opposite directions, and an address permutation unit for permuting said addresses in accordance with the transformed sequences and for supplying the permuted addresses to the memory.

Yet another aspect of the invention provides a preamble for an access channel of a CDMA (code division multiple access) communications system, comprising a pair of constituent Golay sequences A and B and, concatenated with the pair of constituent Golay sequences A and B, at least one pair of transformed sequences which are also constituent Golay sequences, each pair of transformed sequences comprising a permutation of elements of the pair of sequences A and B.

The preamble can comprise a plurality of pairs of said transformed sequences having different respective permutations of the elements of the pair of sequences A and B. In particular, respective pairs of transformed sequences can comprise the pair of sequences A and B with a reversed order of elements in the sequences, the pair of sequences A and B with elements in the sequences permuted in accordance with a reversed order of at least some of a set of address bits identifying locations of elements in the sequences, and elements in odd locations of the pair of sequences A and B concatenated with elements in even locations in the pair of sequences A and B.

Brief Description of the Drawings

The invention will be further understood from the following description with reference to the accompanying drawings, in which:

Figs. 1 to 4 are diagrams illustrating various transformations any of which may be carried out in implementations of the invention;

Fig. 5 schematically illustrates in a block diagram stages of a Golay sequence generator known in the art;

Fig. 6 schematically illustrates in a block diagram stages of a Golay sequence correlator known in the art; and

Fig. 7 schematically illustrates in a block diagram a preamble correlator and signature detector according to an embodiment of the invention.

Detailed Description

Embodiments of this invention serve to perform various transforms, alone or in combinations, on the constituent Golay sequences that are used to provide a concatenated preamble and signature, in a manner that can eliminate or substantially reduce the undesired cross correlation peaks discussed above. Some of these transforms are referred to as sequence reversal, address bit reversal, partial bit reversal, and resampling or even-odd partitioning, and are discussed in further detail below. The invention is also applicable to other transforms, and combinations of these and other transforms, that provide similar results and that may occur to those of ordinary skill in the art and/or are discussed later below. In each case the transform is applied to the two constituent Golay sequences A and B to result in another two sequences which, it can be shown, are also Golay sequences.

Sequence Reversal

This transform reverses the order of all of the elements of the constituent Golay sequences A and B to produce new constituent Golay sequences A* and B* respectively. Thus if the sequences A and B are given by:

$$A = [\, a_1, a_2, \ldots a_{N-1}, a_N \,]; \quad B = [\, b_1, b_2, \ldots b_{N-1}, b_N \,]$$

then the sequences A* and B* are given by:

$$A^* = [\, a_N, a_{N-1}, \ldots a_2, a_1 \,]; \quad B^* = [\, b_N, b_{N-1}, \ldots b_2, b_1 \,]$$

The preamble and signature can then be formed from both the two constituent Golay sequences A and B and the two reversed sequences A* and B*, in each case with N = 256 chips, as shown by the following Table 2, in which the 16 signature patterns, represented by the normal and inverted (-) forms of the sequences, are the same as in the following Table 2:

1	A	B	A*	B*	A	-B	-A*	B*	A	-B	A*	-B*	A	B	-A*	-B*
2	A	B	A*	B*	A	-B	-A*	B*	-A	B	-A*	B*	-A	-B	A*	B*
3	A	-B	A*	-B*	A	B	-A*	-B*	A	B	A*	B*	A	-B	-A*	B*
4	A	-B	A*	-B*	A	B	-A*	-B*	-A	-B	-A*	-B*	-A	B	A*	-B*
5	A	B	A*	B*	-A	B	A*	-B*	A	-B	A*	-B*	-A	-B	A*	B*
6	A	B	A*	B*	-A	B	A*	-B*	-A	B	-A*	B*	A	B	-A*	-B*
7	A	-B	A*	-B*	-A	-B	A*	B*	A	B	A*	B*	-A	B	A*	-B*
8	A	-B	A*	-B*	-A	-B	A*	B*	-A	-B	-A*	-B*	A	-B	-A*	B*
9	A	B	-A*	-B*	A	-B	A*	-B*	A	-B	-A*	B*	A	B	A*	B*
10	A	B	-A*	-B*	A	-B	A*	-B*	-A	B	A*	-B*	-A	-B	-A*	-B*
11	A	-B	-A*	B*	A	B	A*	B*	A	B	-A*	-B*	A	-B	A*	-B*
12	A	-B	-A*	B*	A	B	A*	B*	-A	-B	A*	B*	-A	B	-A*	B*
13	A	B	-A*	-B*	-A	B	-A*	B*	A	-B	-A*	B*	-A	-B	-A*	-B*
14	A	B	-A*	-B*	-A	B	-A*	B*	-A	B	A*	-B*	A	B	A*	B*
15	A	-B	-A*	B*	-A	-B	-A*	-B*	A	B	-A*	-B*	-A	B	-A*	B*
16	A	-B	-A*	B*	-A	-B	-A*	-B*	-A	-B	A*	B*	A	-B	A*	-B*

Table 2

Fig. 1 diagrammatically illustrates this transform for a simple case of 16 elements (N = 16) in a sequence A represented by dots at the top of the illustration, these being reordered as shown by lines into a sequence A* represented by dots at the bottom of the illustration.

Address Bit Reversal

This transform reverses address bits, represented as binary numbers from 0 to N-1, which can be used to identify the elements of each of the sequences A and B, to produce new constituent Golay sequences A^r and B^r respectively. Thus for example for N = 256, the elements $a_1, a_2, a_3, \ldots, a_{254}, a_{255}, a_{256}$ of the constituent sequence A can be identified by the binary numbers 00000000, 00000001, 00000010, ..., 11111101, 11111110, 11111111 respectively, which are reversed to give the binary numbers 00000000, 10000000, 01000000, ..., 10111111, 01111111, 11111111 respectively, corresponding to the elements $a_1, a_{129}, a_{65}, \ldots, a_{192}, a_{128}, a_{256}$ respectively forming the transformed sequence A^r. the sequence B is transformed to the sequence B^r in the same manner. This is in effect a random permutation of the positions of the constituent Golay sequences A and B, so that the transformed sequences A^r and B^r are also Golay sequences.

As described above in relation to sequence reversal and Table 2, the preamble and signature can be formed from the constituent Golay sequences A and B and the transformed sequences A^r and B^r, the latter transformed sequences substituting for the transformed sequences A^* and B^* in Table 2.

Fig. 2 diagrammatically illustrates this transform for a simple case of 16 elements (N = 16). As in the case of Fig. 1, the sequence A is represented by dots at the top of the illustration, and these are reordered as shown by lines into the sequence A^r represented by dots at the bottom of the illustration.

Partial Bit Reversal

This transform is similar to the address bit reversal described above, but reverses only a subset of the address bits, again represented as binary numbers, without making any change in the positions of the other address bits. For example, the most significant one of the address bits may be unchanged for each element of each sequence, with the other binary address bits being reversed in the manner described above, with the result that the transform reorders the elements of the sequence A in two distinct groups to form a transformed sequence A^{2r}. The elements of the sequence B are reordered in the same way to produce a transformed sequence B^{2r}. A^{2r} and B^{2r} are again constituent Golay sequences which can be used in place of the sequences A^* and B^* or A^r and B^r as described above. Other partitions between the unchanged and changed address bits can alternatively be made.

Fig. 3 diagrammatically illustrates this transform for a simple case of 16 elements (N = 16). As in Figs. 1 and 2, the sequence A is represented by dots at the top of the illustration, and these are reordered as shown by lines into the sequence A^{2r} represented by dots at the bottom of the illustration, the reordering in this case being in two groups in that the most significant bit for each element address is not changed, and the remaining 3 bits for each element address are reversed.

Resampling or Even-Odd Partitioning

This transform concatenates two (or more) sub-sequences of the elements of each of the sequences A and B obtained by decimation sampling to produce transformed sequences $A^\$$ and $B^\$$ respectively. The transformed sequences $A^\$$ and $B^\$$ are again constituent Golay sequences which can be used in place of the other transformed sequences as described above. For example, dividing the sequence A into two (even and odd) sub-sequences, its elements a1 to an are reordered as:

$$A^\$ = [\, a_1, a_3, \ldots, a_{N-1}, a_2, a_4, \ldots, a_N \,]$$

and the sequence B is similarly reordered to produce the sequence $B^\$$.

Fig. 4 diagrammatically illustrates this transform for a simple case of 16 elements (N = 16). As in Figs. 1 to 3, the sequence A is represented by dots at the top of the illustration, and these are reordered as shown by lines into the sequence $A^\$$ represented by dots at the bottom of the illustration.

The above are examples of transforms that can be used to permute the elements of the constituent Golay sequences A and B to form new constituent Golay sequences, and it can be appreciated that numerous other transforms can similarly be used. In addition, various combinations of these transforms can be used. For example, the elements of two of such transforms, or of one of such transforms and of the original constituent Golay sequences A and B, can be combined in an exclusive-or (XOR) logic operation to result in further constituent Golay sequences A^x and B^x. For example:

$$A^x = A \otimes A^r = [\, a_1 \otimes a_{r1}, a_2 \otimes a_{r2}, \ldots a_N \otimes a_{rN} \,]$$

and similarly for the sequence B^x.

It can be appreciated that although Table 2, and its equivalents using other transformed constituent sequences as described above, provides a reduced repetition of sequences within the overall sequence of 16 x 256 = 4096 chips, this repetition can be further reduced by use of different combinations of the transform sequences described above in a hybrid concatenated manner. By way of example, instead of the cycle A, B, A*, B* which is repeated four times as shown in Table 2 for each of the 16 signatures (determined by the absence and presence of - signs), a cycle of 16 original, transformed, and repeatedly transformed sequences can be used to provide an effective sequence of 4096 chips.

One example of this is given by the following Table 3:

A	B	C	D	E	F	G	H	A1	B1	C1	D1	E1	F1	G1	H1
A	B	A^{*}	B^{*}	A^{r}	B^{r}	A^{*r}	B^{*r}	$A^{\$}$	$B^{\$}$	$A^{*\$}$	$B^{*\$}$	A^{2r}	B^{2r}	A^{*2r}	B^{*2r}

Table 3

In Table 3, A to H and A1 to H1 represent respective ones of 16 constituent sequences produced as indicated by the second line of the table. For example, the sequence H is constituted by the sequence B after sequence reversal to produce the sequence B* as described above, this then being subject to transformation by address bit reversal as described above to produce a sequence B^{*r}. It can be appreciated that the concatenation alternates first the A and B constituent sequences and their respective transforms and then the sequence reversed transformations. Table 3 does not indicate the absence and presence of - signs representing the 16 signatures. Using for simplicity the nomenclature A to H and A1 to H1 of Table 3, the following Table 4 illustrates a possible allocation of 16 Hadamard-Walsh signatures which are arranged to facilitate operation in a high Doppler frequency environment:

1	A	B	C	D	E	F	G	H	A1	B1	C1	D1	E1	F1	G1	H1
2	A	-B	C	-D	E	-F	G	-H	A1	-B1	C1	-D1	E1	-F1	G1	-H1
3	A	B	-C	-D	E	F	-G	-H	A1	B1	-C1	-D1	E1	F1	-G1	-H1
4	A	-B	-C	D	E	-F	-G	H	A1	-B1	-C1	D1	E1	-F1	-G1	H1
5	A	B	C	D	-E	-F	-G	-H	A1	B1	C1	D1	-E1	-F1	-G1	-H1
6	A	-B	C	-D	-E	F	-G	H	A1	-B1	C1	-D1	-E1	F1	-G1	H1
7	A	B	-C	-D	-E	-F	G	H	A1	B1	-C1	-D1	-E1	-F1	G1	H1
8	A	-B	-C	D	-E	F	G	-H	A1	-B1	-C1	D1	-E1	F1	G1	-H1
9	A	B	C	D	E	F	G	H	-A1	-B1	-C1	-D1	-E1	-F1	-G1	-H1
10	A	-B	C	-D	E	-F	G	-H	-A1	B1	-C1	D1	-E1	F1	-G1	H1
11	A	B	-C	-D	E	F	-G	-H	-A1	-B1	C1	D1	-E1	-F1	G1	H1
12	A	-B	-C	D	E	-F	-G	H	-A1	B1	C1	-D1	-E1	F1	G1	-H1
13	A	B	C	D	-E	-F	-G	-H	-A1	-B1	-C1	-D1	E1	F1	G1	H1
14	A	-B	C	-D	-E	F	-G	H	-A1	B1	-C1	D1	E1	-F1	G1	-H1
15	A	B	-C	-D	-E	-F	G	H	-A1	-B1	C1	D1	E1	F1	-G1	-H1
16	A	-B	-C	D	-E	F	G	-H	-A1	B1	C1	-D1	E1	-F1	-G1	H1

Table 4

Instead of using transformations of a single pair of constituent Golay sequences A and B as described above to produce longer effective Golay sequences, this can also be done by using another pair of constituent Golay sequences C and D which are not derivable by transformation from the pair A and B. Thus for example a cycle of four constituent sequences A, B, C, and D can be repeated four times to produce the 16 x 256 = 4096 chips overall sequence length, with the 16 signatures being provided as described above by selective inversion of the individual ones of the constituent sequences. In addition, the transformation techniques described above can be applied to the sequences C and D as well as to the sequences A and B. However, this use of additional sequences C and D results in increased computational complexity and does not appear to produce improved correlation results.

Fig. 5 illustrates two stages 10 and 12 of a known Golay sequence generator which can be used to generate the constituent Golay sequences A and B. Each stage 10 or 12, shown within a dashed line box, has two inputs and two outputs, and the stages are concatenated with the two inputs of the first stage supplied with a binary 1 and the two outputs of the last stage providing the sequences A and B. Although only two stages are shown in Fig. 5, in fact the generator has $P = \log_2 N$ stages for providing sequences of length N. Thus for sequences of length N = 256 as described above, there are 8 stages of the Golay sequence generator.

The generator stages 10 and 12 all have the same arrangement of a delay unit 14 having an input coupled to one input of the generator stage, a multiplier 15 for multiplying the output of the delay unit 14 by a coefficient W, and cross-coupled adding and subtracting units 16 and 17 for providing respectively the sum and the difference of the other input of the stage and the output of the multiplier 15 to constitute the outputs of the generator stage. The generator stages differ from one another in the delays provided by the delay units 14, these delays being powers of 2 from 2^0 to 2^{P-1} and being arranged in any order among the stages, and the weights W which in Fig. 5 are indicated as W_1 and W_2 for the generator stages 10 and 12 respectively. For binary Golay sequences the weights W are binary weights of value ±1.

It is observed that the choices of the weights W and the order of the delay stages of the generator can be selected to provide optimum properties for the resulting constituent Golay sequences A and B.

Fig. 6 illustrates two stages 20 and 22 of a known Golay sequence correlator which is referred to as an efficient Golay correlator or EGC. As in the case of the generator of Fig. 5, the EGC of Fig. 6 has n stages where $n = \log_2 N$ and N is the sequence length, with each stage having two inputs and two outputs, the stages being concatenated with an input sequence supplied to both inputs of the first stage and correlation outputs Ra and Rb produced at the outputs of the last stage. Each correlator stage includes a delay unit providing a delay from 2^0 to 2^{n-1}, a multiplier with a respective weight W of ±1, and cross-coupled adding and subtracting units, in an arrangement which is similar to that of the Golay sequence generator except that the delay unit is provided in the other input path.

The use of the EGC of Fig. 6 for the RACH of a cellular communications system are known for example from submission TSGR1#3(99)205 referred to above. In addition, reference is directed to S. Z. Budisin, "Efficient pulse compressor for Golay complementary sequences", Electronics Letters, Vol. 27, No. 3, pp. 219-220, Jan. 1991. As these aspects are known in the art, they are not further described here.

Fig. 7 illustrates a block diagram of a preamble correlator and signature detector according to an embodiment of the invention. Such an arrangement is provided for example in a BS receiver of a cellular communications system, and it can be appreciated that a complementary arrangement, with similar address permutation to perform the transforms as described above, is provided for producing the concatenated preamble and signature.

For constituent sequences of length N = 256, the detector of Fig. 7 comprises an 8-bit bidirectional counter 30, an address permutation unit 32, a 256-sample dual port RAM 34, a Golay sequence correlator 36, a multiplexer 38, a Fast Hadamard Transform (FHT) unit 40, and a clock and control unit 42 which supplies clock and control signals to the other units via clock and control lines which are not shown. Input samples are supplied to an input of the RAM 34 and are stored therein, at addresses provided by the unit 32 via an 8-bit address bus 44 as further described below, in sets of 256 samples corresponding to the Golay sequence length. The samples are read out consecutively from the RAM 34 to the correlator 36, which has the known EGC form indicated above with reference to Fig. 6. The correlator outputs Ra and Rb are supplied via the multiplexer 38 to the FHT unit 38, which serves in known manner to provided a final detector output for example in accordance with the signatures of Table 4 above.

These signatures are of length 16, so that over the duration of the preamble of 4096 chips 16 sets of 256-chip samples are processed in the units 36, 38, and 40 in a substantially known manner. The units 30 and 32, operating under the control of the clock and control unit 42, provide a corresponding synchronized cycle of 16 address permutations for these sets, in accordance with the transforms described above and for example in the manner represented in Tables 3 and 4.

To this end, the address permutation unit 32 is arranged to provide a cyclic selection from among different sets of connections between its inputs and its outputs, as is represented diagrammatically in Fig. 7 by selector switches at the (8-bit wide) input and output of the unit 32. Within the unit 32, these connections can be in the form of direct connections between the inputs and outputs corresponding to the illustrations of Figs. 1 to 4 and their variants as described above, for example as given by Table 3. The sequence reversal transforms (indicated by the * in Table 3) are conveniently effected by reversing the count direction of the counter 30, so that samples are stored in the RAM 34 at a reversed sequence of addresses from that from which they are read out to the correlator. For the other transforms (e.g. A^r, A^s, and A^{2r} in relation to the sequence A) represented in Table 3, respective sets of direct connections are selected cyclically by the unit 32 in accordance with Figs. 2, 4, and 3 respectively, in comparison to straight-through (i.e. not permuted) connections for the sequence A.

Accordingly, the various transforms represented in Table 3, or other transforms that may be used, can be easily provided by an arrangement such as that of the bidirectional counter 30 and address permutation unit 32.

It can be appreciated that although Fig. 7 and the above description relate to permuted storage in, and consecutive read-out from, the RAM to provide decoding of the transformations described above, these operations could be interchanged with equivalent effect. In addition, it can be appreciated that substantially the same operations can be provided in substantially equivalent manner for effecting the transformations in generating the transformed sequences. Thus for example the correlator 36 of Fig. 7 could be replaced by a Golay sequence generator, having the form of Fig. 5, whose output is supplied to the RAM, an output of the RAM providing the generated and transformed sequences, with a similar counter and address permutation to that shown in Fig. 7.

Although particular embodiments of the invention and various alternatives have been described in detail, it should be appreciated that numerous modifications, variations, and adaptations may be made without departing from the scope of the invention as defined in the claims.

APPENDIX

TSG-RAN Working Group 1 meeting #3
Nynäshamn, Sweden
March 22-26, 1999

TSGR1#3(99)205

Agenda Item:

Source: Ericsson

Title: New RACH preambles with low auto-correlation sidelobes and reduced detector complexity

Document for:

---

1 Introduction

The preamble part of the random access burst signal format proposed for UTRA/FDD has the length of 4096 code chips [1]. The preamble consists of a *signature* of length 16 complex symbols, which are spread by a common, 256 chip long Orthogonal Gold sequence called *preamble spreading code*. In total there are 16 different signatures, obtained from the orthogonal *set* of binary Orthogonal Gold sequences of length 16, by multiplying each binary code with the constant complex number $C=(1+j)/\sqrt{2}$, where $j=\sqrt{-1}$.

The UE transmissions of the random access bursts can start at a number of well-defined time offsets (access slots), which are synchronised to the frame sync of the primary CCPCH. The primary CCPCH frame sync is extracted after the cell search procedure in the UE. Therefore the random access preambles are received at the base station at the beginning of each access slot interval with the time uncertainty equal to the round-trip propagation delay.

The current random access preamble construction allows simplified realisation of the bank of correlators required in the base station random access receiver if this time uncertainty is smaller than 255 chips. However, the aperiodic auto-correlation sidelobes of such codes are rather high, which means that the RACH preamble might be detected at wrong time positions. In other words, the preamble detection probability at correct time positions is deteriorated for moderate to high signal-to-noise ratios. Therefore it is desirable to find another random access preamble construction, which would also produce an *orthogonal set* of preamble codes with much lower *aperiodic auto-correlation* sidelobes, facilitating an efficient *matched filter implementation*.

2 Golay complementary sequences

The new RACH preambles are based on the application of binary sequences from the Golay complementary pairs. The major property of the binary sequences from the Golay complementary pair is that the sum of their aperiodic auto-correlation functions equals zero for all non-zero time shifts. The Golay sequences can be constructed for any length $L=2^N$, where N is any positive integer, and also for lengths 10 and 26, or for any combination of those three lengths. Besides the complementary property, such sequences exhibit some additional properties which make them attractive as synchronisation codes: they have low aperiodic auto-correlation sidelobes, and there is a large number of them for a given code length.

If the sequences are of length $L=2^N$, there is a general method for the construction of polyphase complementary pairs of sequences, where the Golay complementary sequences are just a special, binary case. That general construction is defined by the following recursive relation [2].

$$\begin{aligned}
a_0(k) &= \delta(k)\\
b_0(k) &= \delta(k)\\
a_n(k) &= a_{n-1}(k) + W_n \cdot b_{n-1}(k-D_n)\\
b_n(k) &= a_{n-1}(k) - W_n \cdot b_{n-1}(k-D_n),
\end{aligned}$$

$$k = 0, 1, 2, \ldots, 2^N-1,$$
$$n = 1, 2, \ldots, N,$$
$$D_n = 2^{P_n},$$

where

$a_n(k)$ and $b_n(k)$ are two complementary sequences of length 2^N,
$\delta(k)$ is the Kronecker delta function,
k is an integer representing the time scale,
n is the iteration number,
D_n is a delay,
P_n, $n = 1, 2, \ldots, N$, is any permutation of numbers $\{0, 1, 2, \ldots, N-1\}$,
W_n is an arbitrary complex number of unit magnitude.

If W_n has values +1 and −1, the binary (Golay) complementary sequences are obtained [3].

An efficient matched filter directly corresponding to the complementary sequences $a_N(k)$ and $b_N(k)$ defined by (1) is given in Figure 1. This filter performs the correlation of input signal $r(k)$ *simultaneously* with the two complementary sequences $a_N(k)$ and $b_N(k)$. The two matched filter outputs produce the two corresponding aperiodic cross-correlation functions $R_{ra}(\tau)$ and $R_{rb}(\tau)$. Such a digital filter will be called the Efficient Golay Correlator (EGC), although it is actually the filter matched also to any polyphase complementary pair defined by (1). The matched filter has complex conjugated coefficients W_n, denoted as W_n^*.

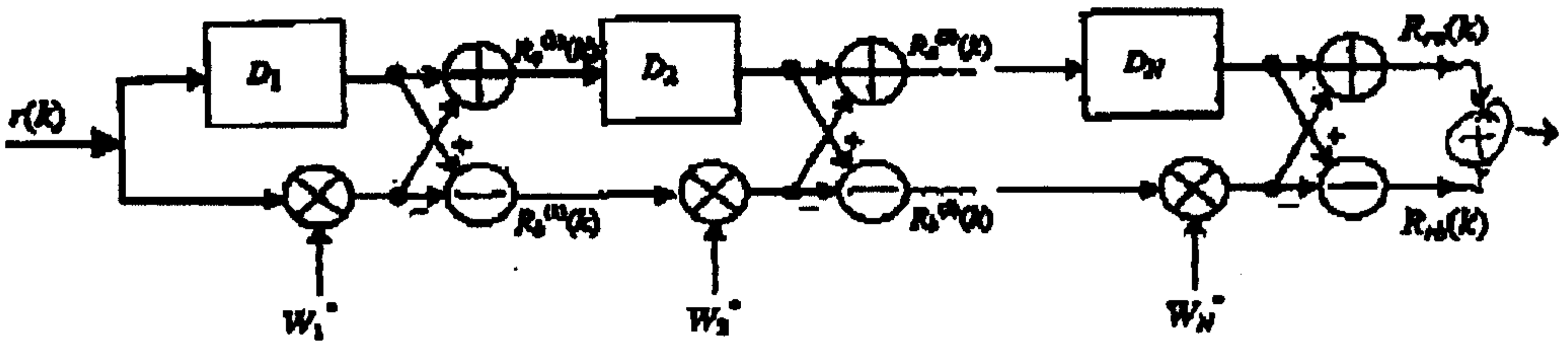


Figure 1: Efficient Golay Correlator (EGC).

The boxes in Figure 1 represent the corresponding delay lines with D_n memory elements. The number of *multiplications* in the EGC is equal to $\log_2(L)$, while in the straightforward matched filter implementation it would be L. The number of *additions* in the EGC is $2 \cdot \log_2(L)$, while in the straightforward matched filter implementation it would be L-1. The number of memory elements required for the EGC is L-1 ($=D_1+D_2+\ldots+D_N$), the same as for the straightforward implementation of a single matched filter corresponding to one of the complementary sequences.

3 Efficient Golay correlator with reduced memory

In the case when the expected delays τ of input signal are limited to be $|\tau|<T_{max}$ chips, it is possible to derive another Efficient Golay correlator with reduced memory. The EGC with reduced memory is based on the representation of a Golay sequence of length $L=2^N=J \cdot T_{max}$ in the so-called "factored" form, i.e. as a function of two shorter constituent complementary sequences $A(k)$ and $B(k)$ of length T_{max}. This relation is a simple consequence of the general recursive construction (1), which can actually start from any complementary pair of sequences. Namely, if the initial vectors $a_0(k)$ and $b_0(k)$ are taken to be

$$a_0(k) = A(k),$$
$$b_0(k) = B(k), \quad k=0, 1, 2, \ldots, T_{max}-1, \qquad (2)$$

where $A(k)$ and $B(k)$ are the two arbitrary complementary sequences of length T_{max}, the resulting pair of complementary sequences of length $L=2^N=J \cdot T_{max}$ is generated after J iterations. Note that all the delays D_n in (1) should be multiplied by the length of constituent sequences (T_{max}).

For example, if the constituent sequences are of length $T_{max}=256$, the permutation vector P_n and the weighting vectors W_n are of length 16 if the resulting complementary pair should be of length 4096. The resulting Golay sequences consists of 8 times repeated sequences $A(k)$ and $B(k)$, which are multiplexed according to some equivalent binary "interleaving" function $I_0(k)$ depending on the permutation vector P_n. The orthogonal set of 16 Golay sequences of length 4096, having the *common* constituent sequences $A(k)$ and $B(k)$ of length 256 (and a common interleaving function), can be obtained by choosing a single permutation vector of length 16, along with 8 appropriately chosen weighting vectors.

The additional 16 orthogonal Golay sequences of length 4096 having the same constituent sequences $A(k)$ and $B(k)$, but interleaved according to another interleaving function $I_1(k)$, can be obtained by taking

$$\begin{aligned} a_0(k) &= B(k), \\ b_0(k) &= A(k), \quad k=0, 1, 2, \ldots, T_{max}-1, \end{aligned} \qquad (5)$$

and using the same permutation and weighting vectors as for the first set of 16 sequences. Therefore in total there are 32 orthogonal Golay sequences of length 4096 having the common constituent sequences of length 256. In principle it is possible to generate $2J$ such orthogonal Golay sequences, where $J=L/T_{max}$.

The set of 16 orthogonal Golay sequences of length 4096 which is obtained according to the above algorithm and which can be used in UTRA/FDD is given in Table 1, as a function of two shorter, constituent complementary sequences $A(k)$ and $B(k)$ of length 256. The additional set of 16 orthogonal Golay sequences of length 4096 can be obtained by replacing $A(k)$ with $B(k)$ and $B(k)$ with $A(k)$ in Table 1. As $A(k)$ and $B(k)$ are orthogonal, the additional set is orthogonal to the first one.

Table 1: First 16 orthogonal Golay sequences of length 4096.

k	0...255...															...4095
S(0,k)	A	A	B	B	A	-A	-B	B	A	-A	B	-B	A	A	-B	-B
S(1,k)	A	A	B	B	A	-A	-B	B	-A	A	-B	B	-A	-A	B	B
S(2,k)	A	-A	B	-B	A	A	-B	-B	A	A	B	B	A	-A	-B	B
S(3,k)	A	-A	B	-B	A	A	-B	-B	-A	-A	-B	-B	-A	A	B	-B
S(4,k)	A	A	B	B	-A	A	B	-B	A	-A	B	-B	-A	-A	B	B
S(5,k)	A	A	B	B	-A	A	B	-B	-A	A	-B	B	A	A	-B	-B
S(6,k)	A	-A	B	-B	-A	-A	B	B	A	A	B	B	-A	A	B	-B
S(7,k)	A	-A	B	-B	-A	-A	B	B	-A	-A	-B	-B	A	-A	-B	B
S(8,k)	A	A	-B	-B	A	-A	B	-B	A	-A	-B	B	A	A	B	B
S(9,k)	A	A	-B	-B	A	-A	B	-B	-A	A	B	-B	-A	-A	-B	-B
S(10,k)	A	-A	-B	B	A	A	B	B	A	A	-B	-B	A	-A	B	-B
S(11,k)	A	-A	-B	B	A	A	B	B	-A	-A	B	B	-A	A	-B	B
S(12,k)	A	A	-B	-B	-A	A	-B	B	A	-A	-B	B	-A	-A	-B	-B
S(13,k)	A	A	-B	-B	-A	A	-B	B	-A	A	B	-B	A	A	B	B
S(14,k)	A	-A	-B	B	-A	-A	-B	-B	A	A	-B	-B	-A	A	-B	B
S(15,k)	A	-A	-B	B	-A	-A	-B	-B	-A	-A	B	B	A	-A	B	-B

The RACH preamble correlator with reduced memory, corresponding to the above set of 32 orthogonal preambles is shown in Figure 2. The number of memory elements per received signature in this scheme is the same as for the RACH preamble correlator described in UMTS XX.07. However, the total number of adders and multipliers is significantly reduced due to the use of EGC instead of preamble spreading code matched filter.

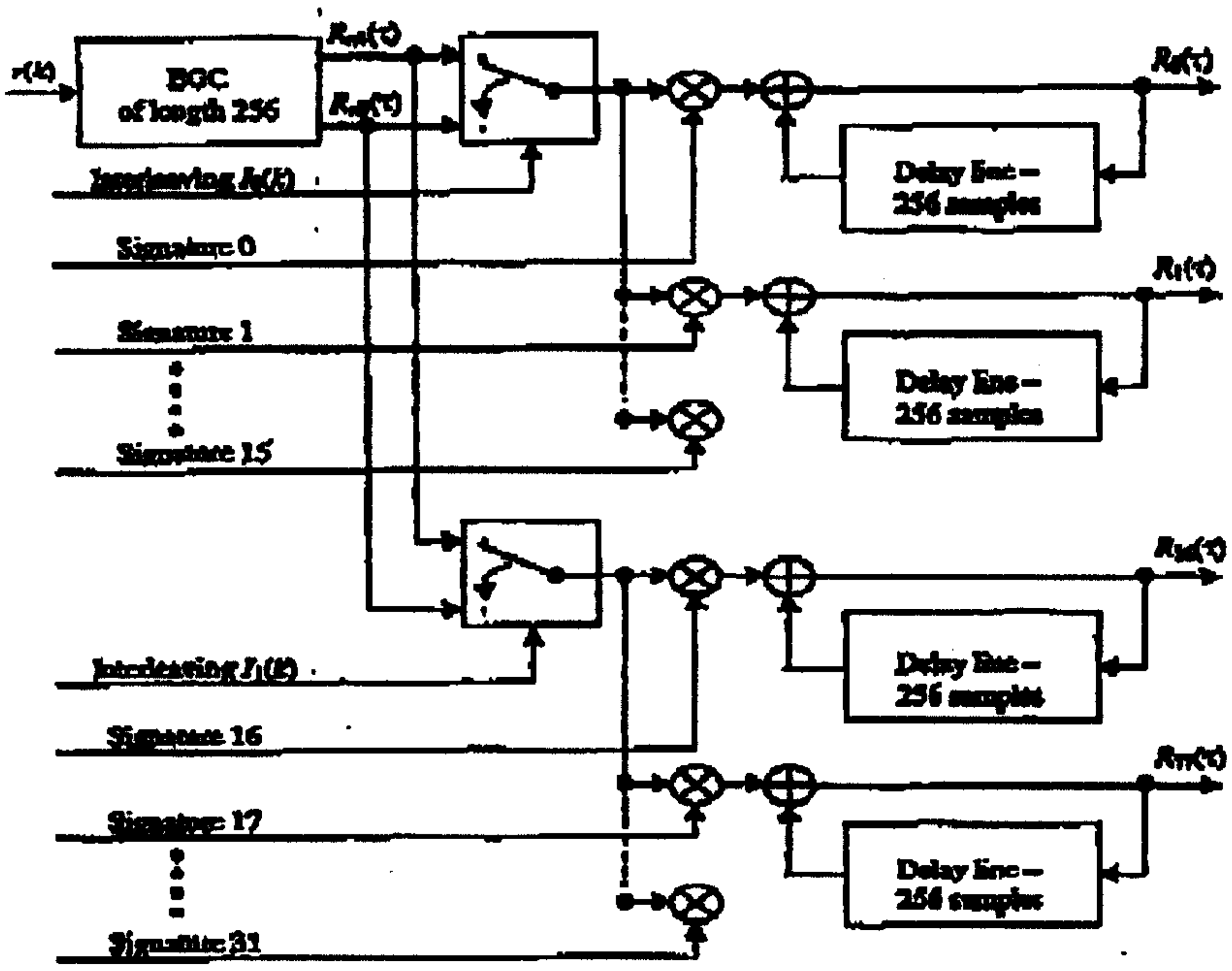


Figure 2: The bank of RACH preamble correlators with reduced memory, matched to 32 orthogonal Golay sequences of length 4096.

The interleaving function $I_0(k)$ is common for the 16 orthogonal preambles, while the interleaving function $I_1(k)$ is common for the other 16 orthogonal preambles. From Table 1 it can easily be seen that

$$I_0(k) = \{0, 0, 1, 1, 0, 0, 1, 1, 0, 0, 1, 1, 0, 0, 1, 1, \}, \text{ and } \quad I_1(k) = \{1, 1, 0, 0, 1, 1, 0, 0, 1, 1, 0, 0, 1, 1, 0, 0\}.$$

Each preamble has a unique "signature" sequence, which can also be easily derived from Table 1. For example,

$$\text{Signature\_0} = \text{Signature\_16} = \{1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, -1, -1\}.$$

The set of 256 cell-specific pairs of constituent Golay sequences $A(k)$ and $B(k)$ (corresponding to the set of 256 cell specific preamble spreading codes) is defined by (1), where the permutation vector P_n is common for all pairs and is given by

$$P_n = \{0, 2, 1, 5, 6, 4, 7, 3\}, \qquad (4)$$

while the corresponding 256 weighting vectors $W(v,n)$, $v = 0, 1, \ldots, 255$, are defined as the 8-bit binary representations of integers $\{0, 1, 2, \ldots, 255\}$, i.e.

$$W(v,n) = (-1)^{B_n(v)}, \quad v = 0, 1, \ldots, 255, \quad n = 1, 2, 3, \ldots, 8, \qquad (5a)$$

where $B_n(x)$ is the n-th bit in the 8-bits long binary representation of some positive integer x, i.e.

$$x = \sum_{n=1}^{8} B_n(x) \cdot 2^{n-1}. \qquad (5b)$$

Note that all 256 constituent pairs can be detected by using the same correlator shown in Figure 1, by adapting only the weighting coefficients W_n^*.

4 Implementation complexity

The implementation complexity of the bank of RACH preamble correlators is significantly reduced due to the use of EGC instead of preamble spreading code matched filter. Assuming that the number of new orthogonal preambles based on Golay complementary sequences (GCS) used is the same (16) as in the case of the current preambles based on concatenated orthogonal Gold sequences (OGS), the implementation complexity of the corresponding banks of correlators can be compared in the following way:

a) The number of adders is 32 (=16+16) for the GCS, compared to 271 (=255+16) adders for the OGS.
b) The number of multipliers is 24 (=8+16) for the GCS, compared to 272 (=256+16) multipliers for the OGS.
c) There is a multiplexer (switch) for GCS while there is no multiplexer for OGS.
d) The lengths of delay lines are the same in both cases.

5 Aperiodic autocorrelation properties

Besides the improved implementation efficiency, the new preambles based on Golay sequences offer much better performances in term of the maximum absolute aperiodic autocorrelation sidelobes (MAS), when compared with the current preamble codes based on concatenated orthogonal Gold sequences.

As a first example, the aperiodic auto-correlation function for one of the concatenated orthogonal Gold preambles generated with the old scheme for preamble spreading code $n=1$ is shown in Figure 3 in the annex. This should be compared with the new construction using Golay sequences with constituent sequences A and B defined by (1), (4) and, as an example, $W_n=\{1, -1, 1, -1, 1, -1, -1, 1\}$. The aperiodic auto-correlation function of this new code is shown in Figure 4 in the annex. As can be seen the Golay sequences have much better auto-correlation properties.

The MAS for all the preambles based on the above preamble spreading code are listed in Table 2. The benefits of the Golay sequences in terms of reduced MAS is clear.

Table 2: MAS for preambles corresponding to one particular preamble spreading code.

Golay sequences		Concatenated Orthogonal Gold sequences	
Number of occurrences	MAS	Number of occurrences	MAS
4	161	1	1024
4	181	4	1280
8	183	7	1536
-	-	2	1792
-	-	2	2048

The random access preambles are not completely asynchronous to the base station receiver because the UE has the basic information about base station timing, but with an uncertainty introduced by the round-trip propagation delay between the base station and UE. The current assumption in UTRA/FDD is that the round-trip delay is at most 255 chips to be able to the proposed simplified receiver structure, so the aperiodic auto-correlation function of random access preambles is actually of most interest only in the region +/- 255 chips around the main lobe. The maximum absolute values of aperiodic auto-correlation sidelobes in the region +/- 255 chips around the main lobe are shown in Table 3 for the previously described Golay and concatenated Orthogonal Gold sequences of length 4096.

Table 3: MAS in the +/- 255 chips region for preambles corresponding to one particular preamble spreading code.

Golay sequences		Concatenated Orthogonal Gold sequences	
Number of occurrences	MAS	Number of occurrences	MAS
16	31	1	731
-	-	2	737
-	-	3	743
-	-	3	755
-	-	6	761
-	-	1	767

From Table 3 it can be noticed that Golay sequences have about 25 times lower auto-correlation sidelobes than the concatenated Orthogonal Gold sequences, in the region +/- 255 chips around the main lobe.

It is clear that for the particular codes evaluate above, the Golay sequences are superior. Finally, the maximum absolute values of aperiodic auto-correlation sidelobes in the region +/- 255 chips around the main lobe are evaluated for *all* preambles. Both the Golay based 256 pairs of constituent sequences *A* and *B* defined by (4) and (5) for all 32 orthogonal preambles of length 4096 corresponding to each such pair of constituent sequences, and the current preambles based on concatenated Orthogonal Gold sequences have been investigated. The results are shown in Table 4.

Table 4: MAS in the +/- 255 chips region for all preambles.

Golay sequences		Concatenated Orthogonal Gold sequences
Number of occurrences	MAS	MAS
64	27	MAS values are plotted in Figure 5 in the annex. Average MAS is 669, largest MAS is 1080, smallest MAS is 286. 95% of MAS values are above 500.
128	29	
1280	31	
1024	33	
1600	35	
1280	37	
832	39	
512	41	
576	43	
256	45	
320	47	
192	49	
64	51	

Table 4 shows that all 8192 possible Golay preambles of length 4096, have extremely low maximum auto-correlation sidelobes. The average MAS is 37, and 65% of the MAS values are between 27 and 37. A simple, but rather fair, comparison between the two different preamble designs can be done by comparing the average MAS. The old concatenated orthogonal Gold preambles have an average MAS 18 times (669/37) higher than the Golay based preambles.

6 Conclusion

A new set of RACH preambles is proposed for inclusion in UTRA/FDD. The benefits of the preambles codes, based on Golay complementary sequences, are:

- The new preambles offer significantly more efficient preamble detector hardware implementation, measured in terms on the number of multipliers and adders required.
- The number of available preambles is doubled, to 8192.
- All 8192 of the new preambles have good auto-correlation properties, while the span for the old preambles is quite large and many of those codes exhibit very bad correlation properties.
- The new preambles have about 18 times lower aperiodic auto-correlation sidelobes than the present RACH preambles, offering potentially better Eb/No performance.

References

[1] S1.13, UTRA FDD Spreading and modulation.

[2] S.Z.Budisin, "Efficient pulse compressor for Golay complementary sequences", Electronics Letters, Vol.27, No.3, pp.219-220, Jan. 1991.

[3] M.J.E.Golay, "Complementary Series", IRE Trans. on Information Theory, Vol.IT-7, pp.82-87, April 1961.

Annex - Figures

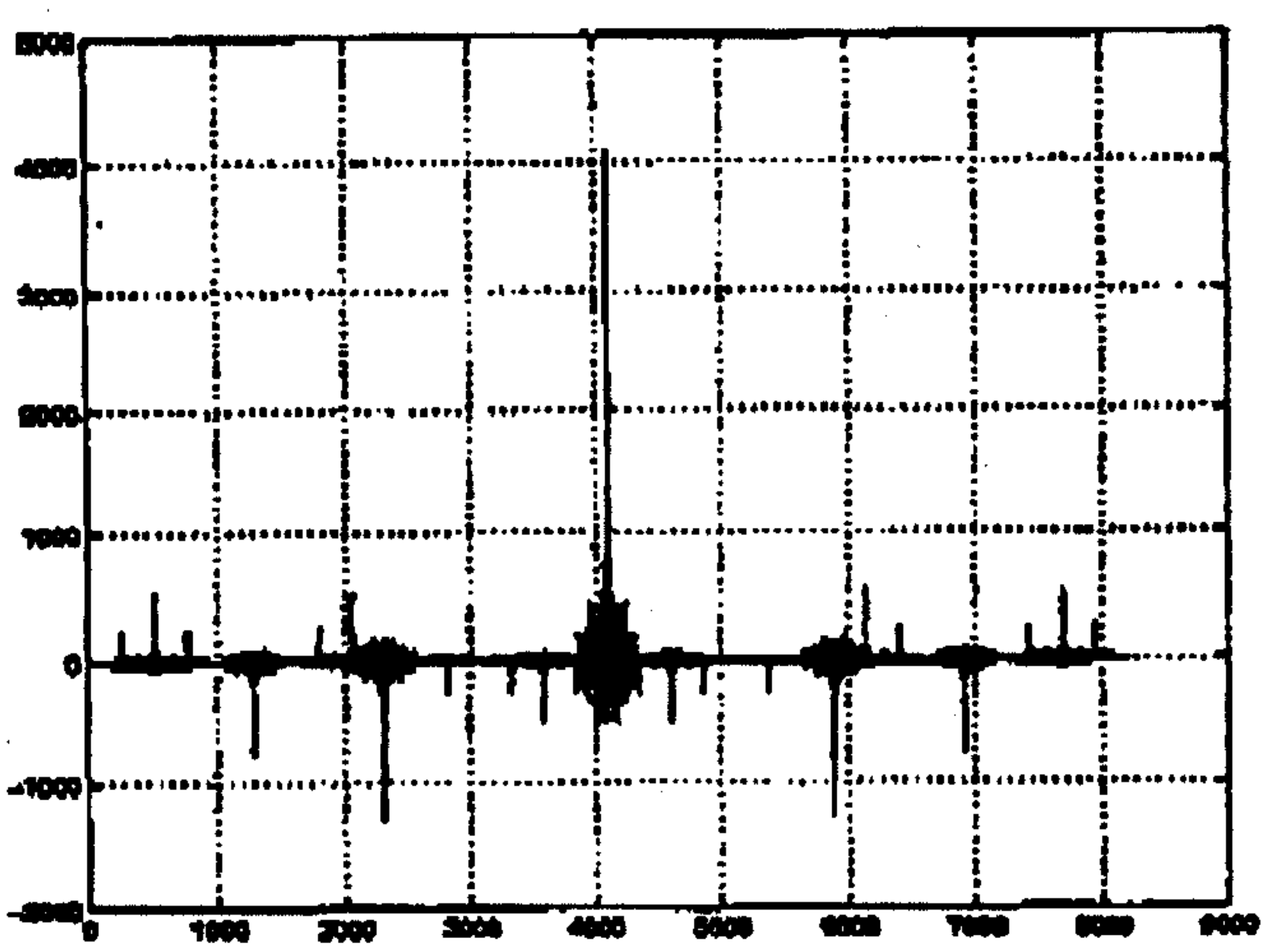


Figure 3: Aperiodic auto-correlation function for one of the present RACH preambles (signature + preamble spreading code).

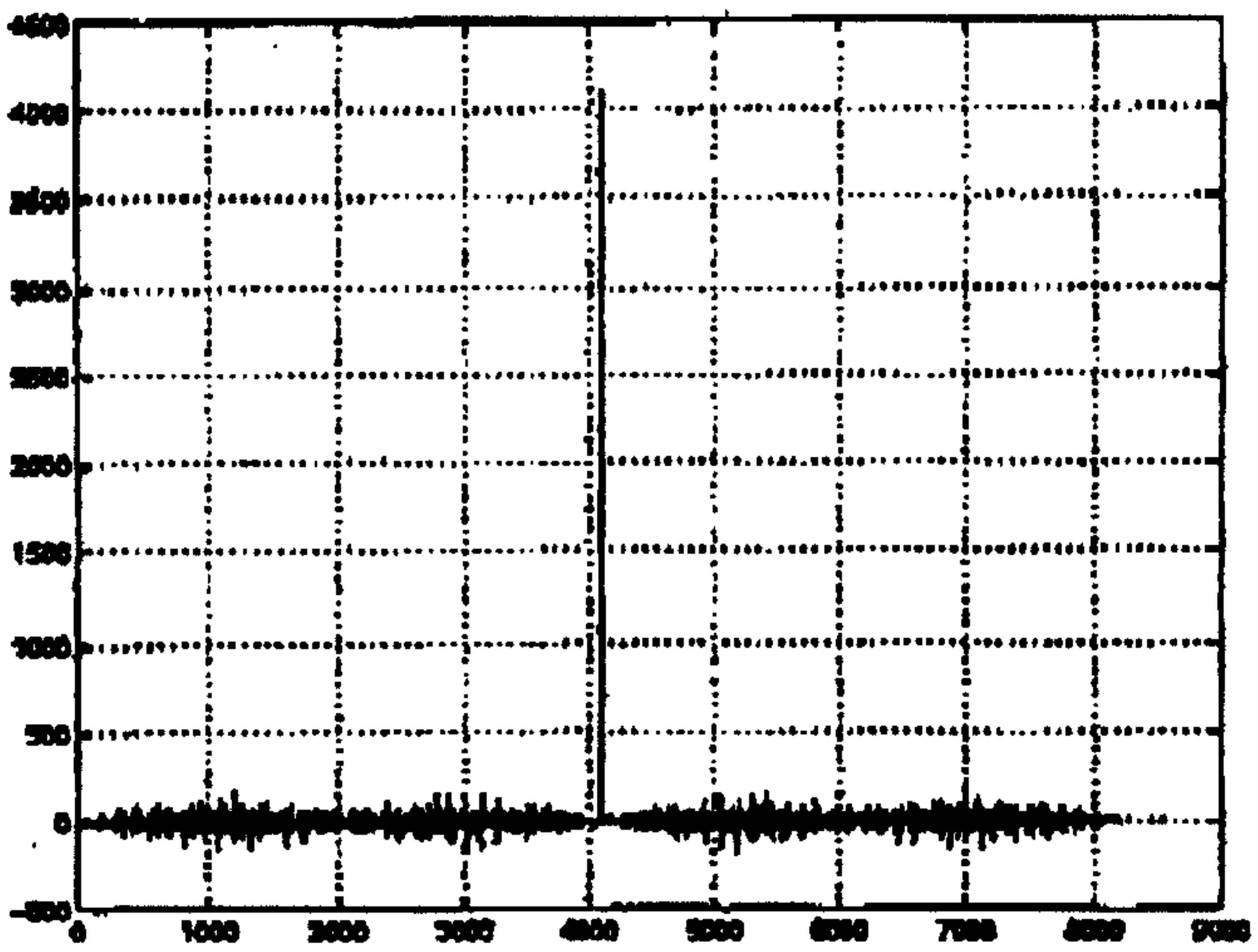


Figure 4: Aperiodic auto-correlation function for one of the new RACH preambles (Golay complementary sequence from Table 1)

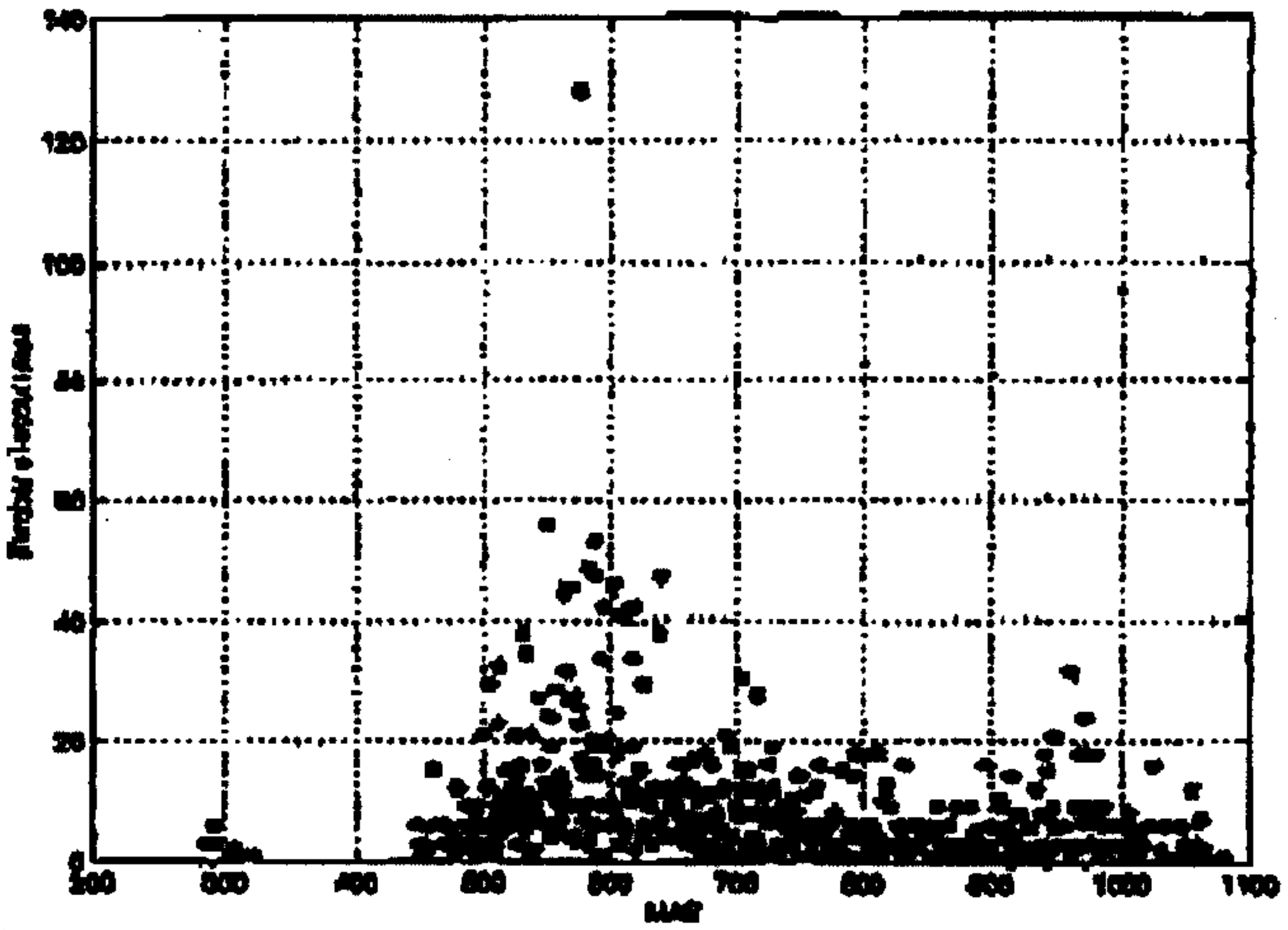


Figure 5: Distribution of MAS values for the old orthogonal Gold based preambles.

WHAT IS CLAIMED IS:

1. A method of producing an extended sequence from a pair of constituent Golay sequences A and B, comprising the steps of:

transforming the pair of constituent Golay sequences A and B to form at least one pair of transformed sequences which are also constituent Golay sequences; and

concatenating at least two of said pairs of constituent Golay sequences to produce the extended sequence.

2. A method as claimed in claim 1 wherein the step of transforming the pair of constituent Golay sequences A and B to form each pair of transformed sequences comprises a permutation of elements of the sequences.

3. A method as claimed in claim 2 wherein said permutation comprises a reversal of the order of elements in the sequences.

4. A method as claimed in claim 2 or 3 wherein said permutation comprises a reversal of a set of address bits identifying locations of elements in the sequences.

5. A method as claimed in claim 2 or 3 wherein said permutation comprises a reversal of some but not all of a set of address bits identifying locations of elements in the sequences.

6. A method as claimed in any of claims 2 to 5 wherein said permutation comprises a concatenation of subsets of elements of the sequences selected by decimation.

7. A method as claimed in claim 6 wherein there are two subsets of elements, in even and odd locations in the sequences, that are concatenated.

8. A method of producing a preamble for use on an access channel of a cellular communications system, wherein the preamble includes an extended sequence produced by the method of any of claims 1 to 7.

9. A method as claimed in claim 8 wherein each of the constituent Golay sequences A and B and each of the transformed sequences comprises 256 elements, and the preamble comprises 4096 elements.

10. A method as claimed in claim 9 wherein the extended sequence comprises the constituent Golay sequences A and B and seven different transformations of these sequences A and B.

11. A method of providing a preamble for an access channel of a CDMA (code division multiple access) communications system, comprising the steps of:

providing a pair of constituent Golay sequences A and B;

permuting elements of the pair of sequences A and B to form at least one pair of transformed sequences which are also constituent Golay sequences; and

concatenating said at least one pair of transformed sequences with the pair of constituent Golay sequences A and B for use as an extended sequence in the preamble.

12. A method as claimed in claim 11 wherein the preamble is provided by a concatenation of the pair of constituent Golay sequences A and B with a plurality of pairs of said transformed sequences according to different permutations of the elements of the pair of constituent Golay sequences A and B.

13. A method as claimed in claim 11 or 12 wherein the step of permuting elements of the pair of sequences A and B comprises a reversal of the order of elements in the sequences.

14. A method as claimed in any of claims 11 to 13 wherein the step of permuting elements of the pair of sequences A and B comprises a reversal of at least some of a set of address bits identifying locations of elements in the sequences.

15. A method as claimed in any of claims 11 to 13 wherein the step of permuting elements of the pair of sequences A and B comprises a concatenation of two subsets of elements of the sequences, the two subsets corresponding respectively to even and odd locations in the sequences.

16. Apparatus for use in carrying out the method of any of claims 1 to 15, comprising a memory for storing elements of each sequence, and address control means for addressing the memory for writing to or reading from the memory consecutively at locations according to the transformed sequences.

17. Apparatus as claimed in claim 16 wherein the address control means comprises a bidirectional counter for supplying memory addresses incremented in either of two opposite directions, and an address permutation unit for permuting said addresses in accordance with the transformed sequences and for supplying the permuted addresses to the memory.

18. A preamble for an access channel of a CDMA (code division multiple access) communications system, comprising a pair of constituent Golay sequences A and B and, concatenated with the pair of constituent Golay sequences A and B, at least one pair of transformed sequences which are also constituent Golay sequences, each pair of transformed sequences comprising a permutation of elements of the pair of sequences A and B.

19. A preamble as claimed in claim 18 comprising a plurality of pairs of said transformed sequences having different respective permutations of the elements of the pair of sequences A and B.

20. A preamble as claimed in claim 18 or 19 wherein a pair of said transformed sequences comprises the pair of sequences A and B with a reversed order of elements in the sequences.

21. A preamble as claimed in claim 18 or 19 wherein a pair of said transformed sequences comprises the pair of sequences A and B with elements in the sequences permuted in accordance with a reversed order of at least some of a set of address bits identifying locations of elements in the sequences.

22. A preamble as claimed in claim 18 or 19 wherein a pair of said transformed sequences comprises elements in odd locations of the pair of sequences A and B concatenated with elements in even locations in the pair of sequences A and B.

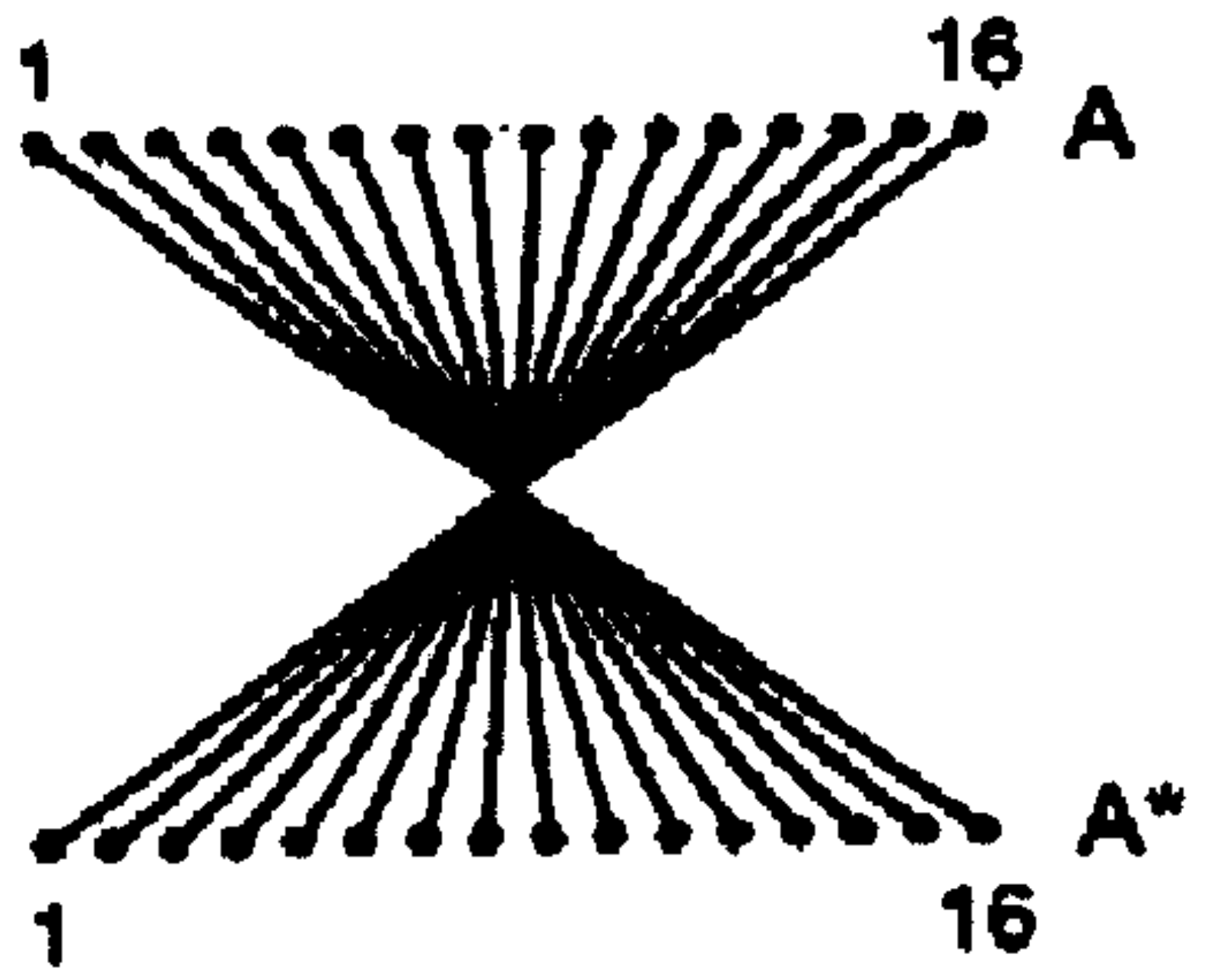


Fig. 1

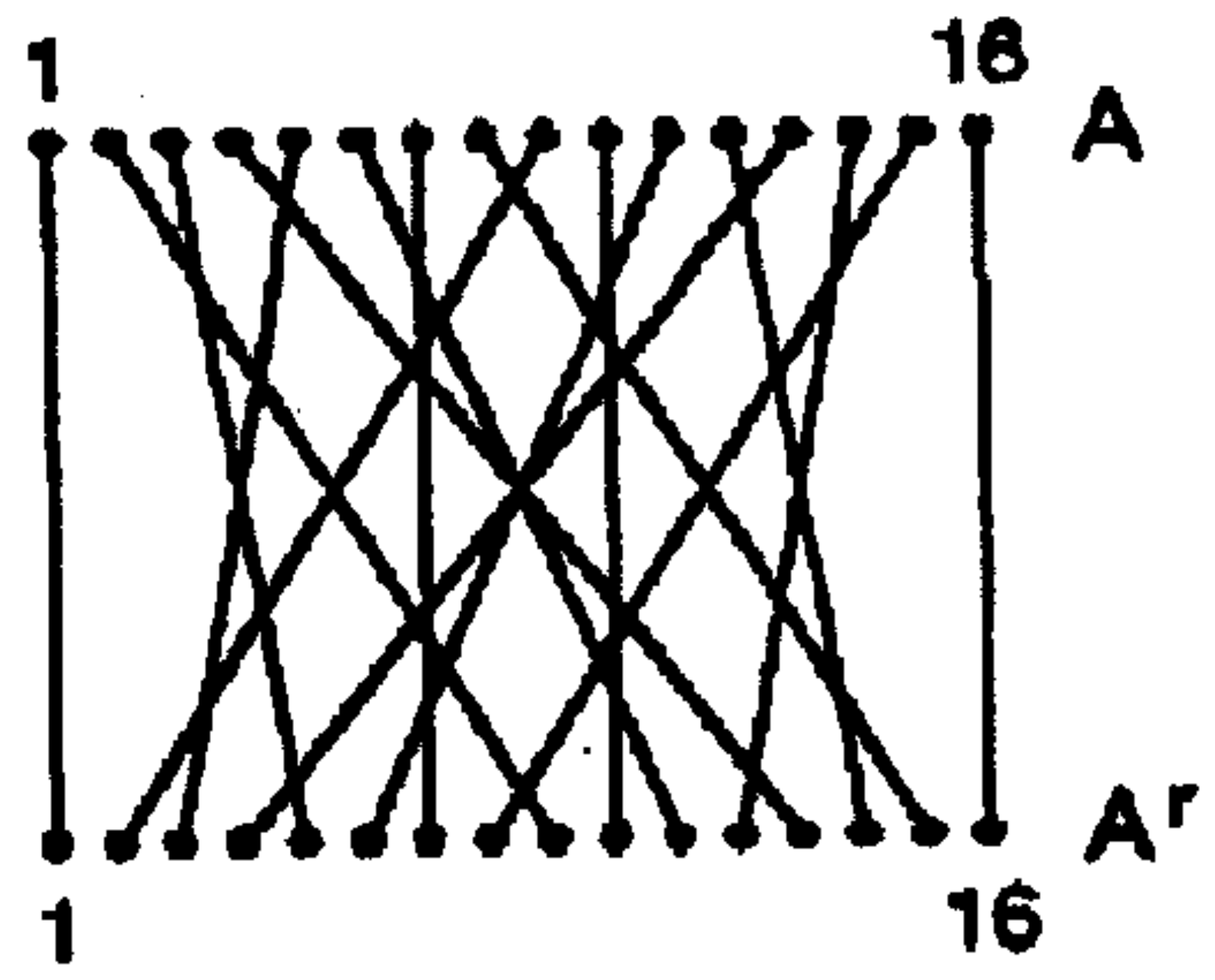


Fig. 2

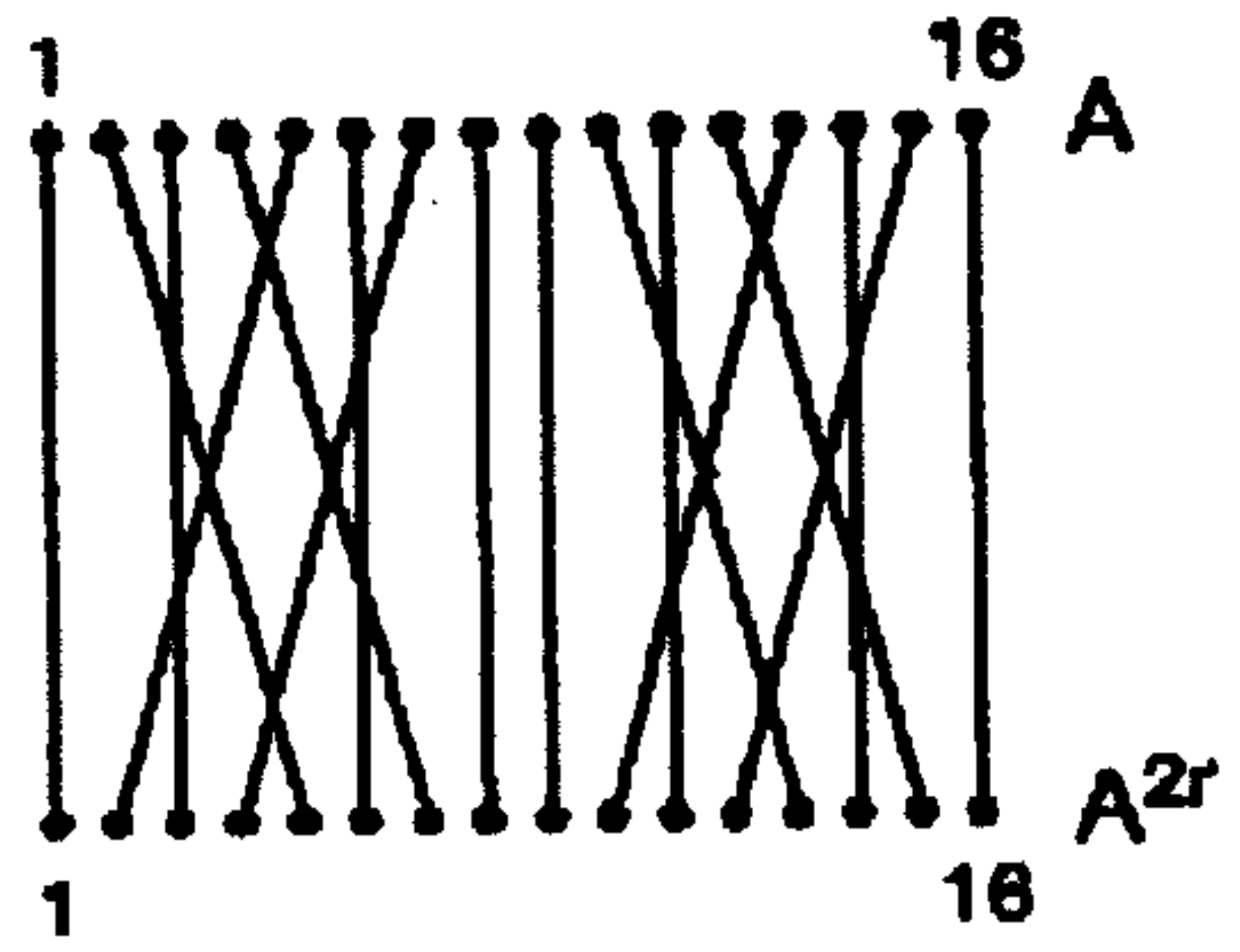


Fig. 3

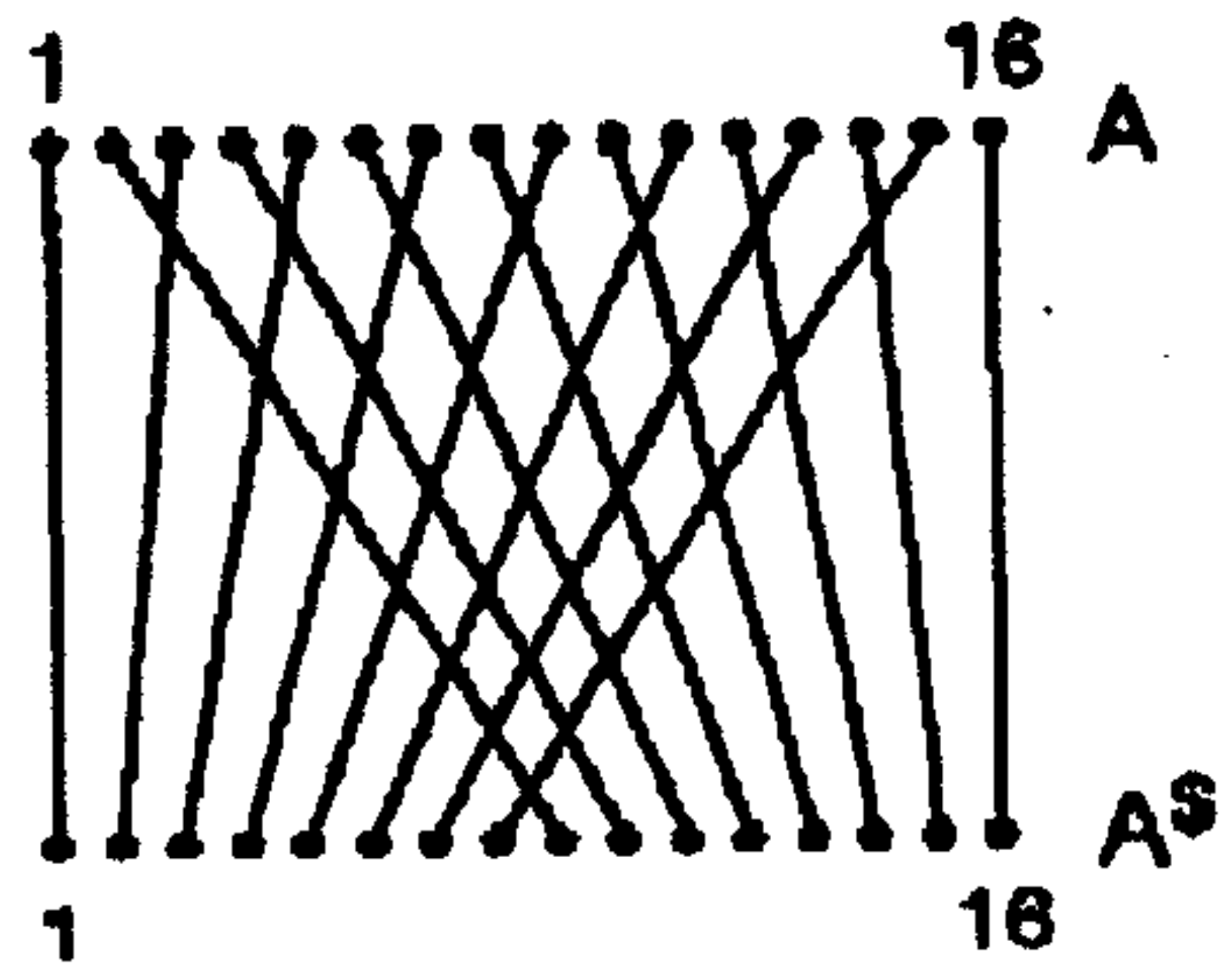


Fig. 4

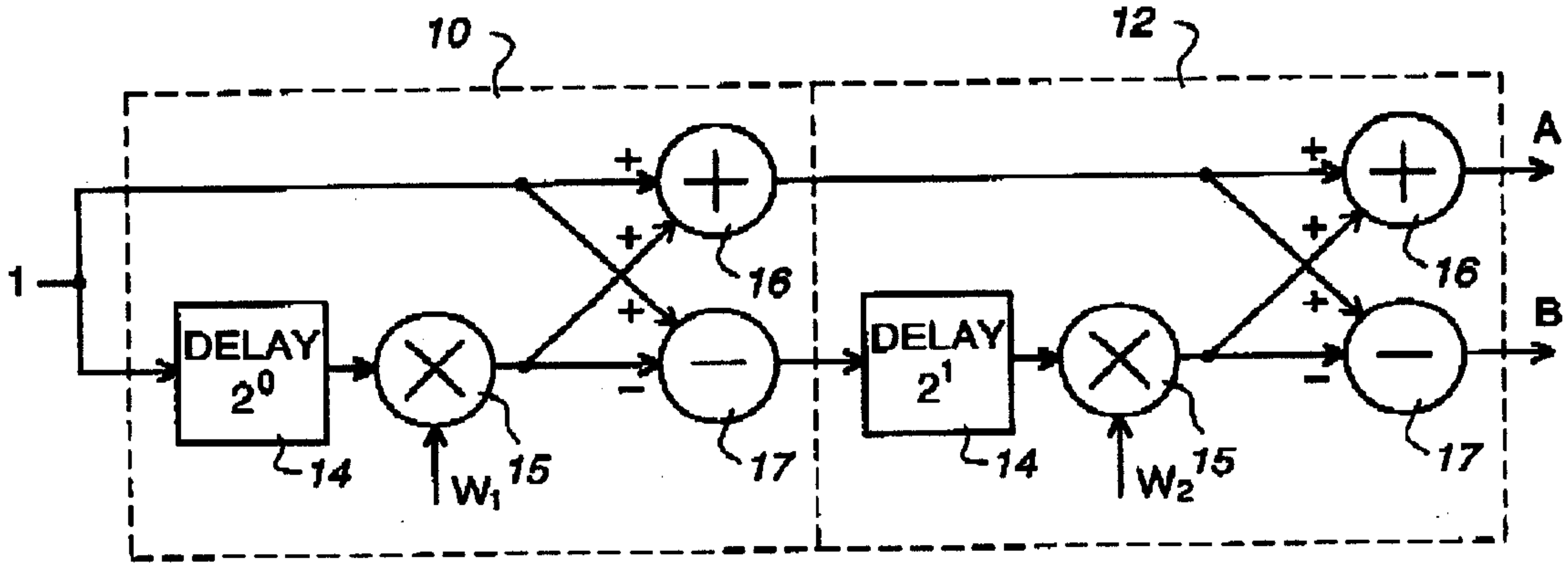


Fig. 5 PRIOR ART

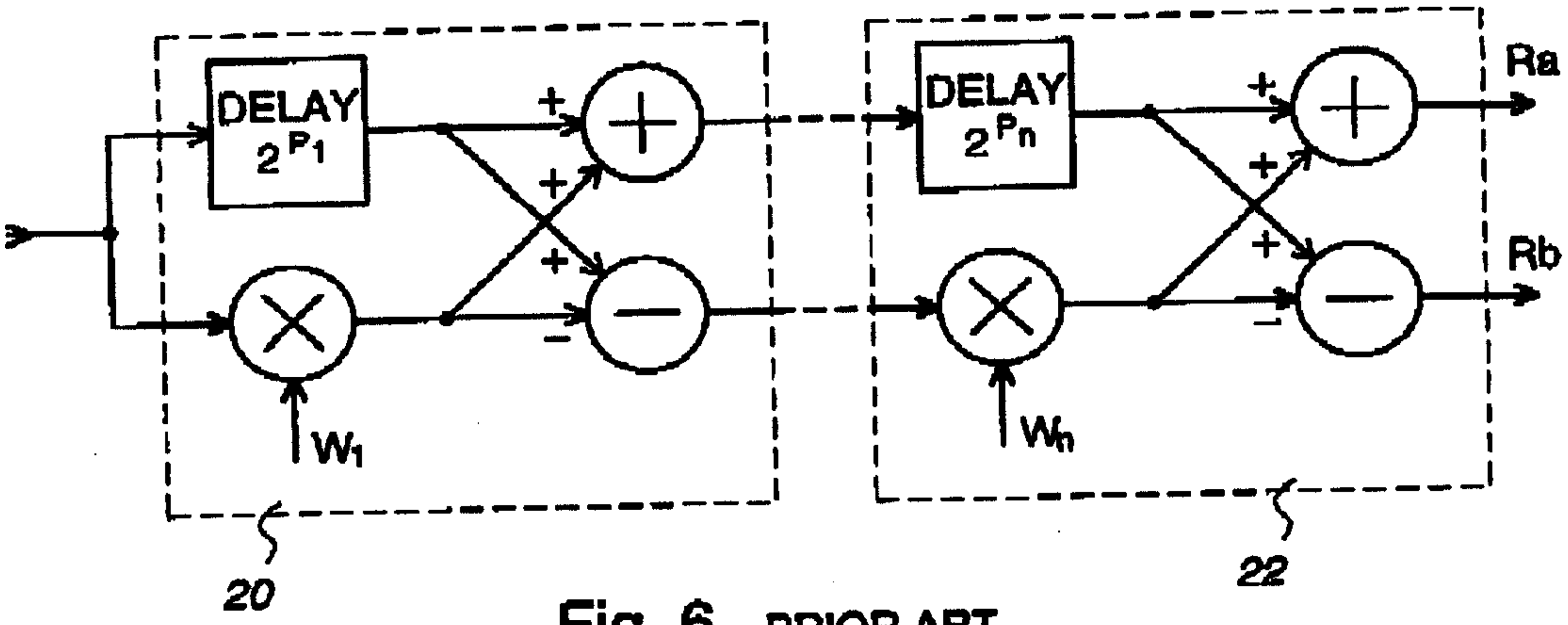


Fig. 6 PRIOR ART

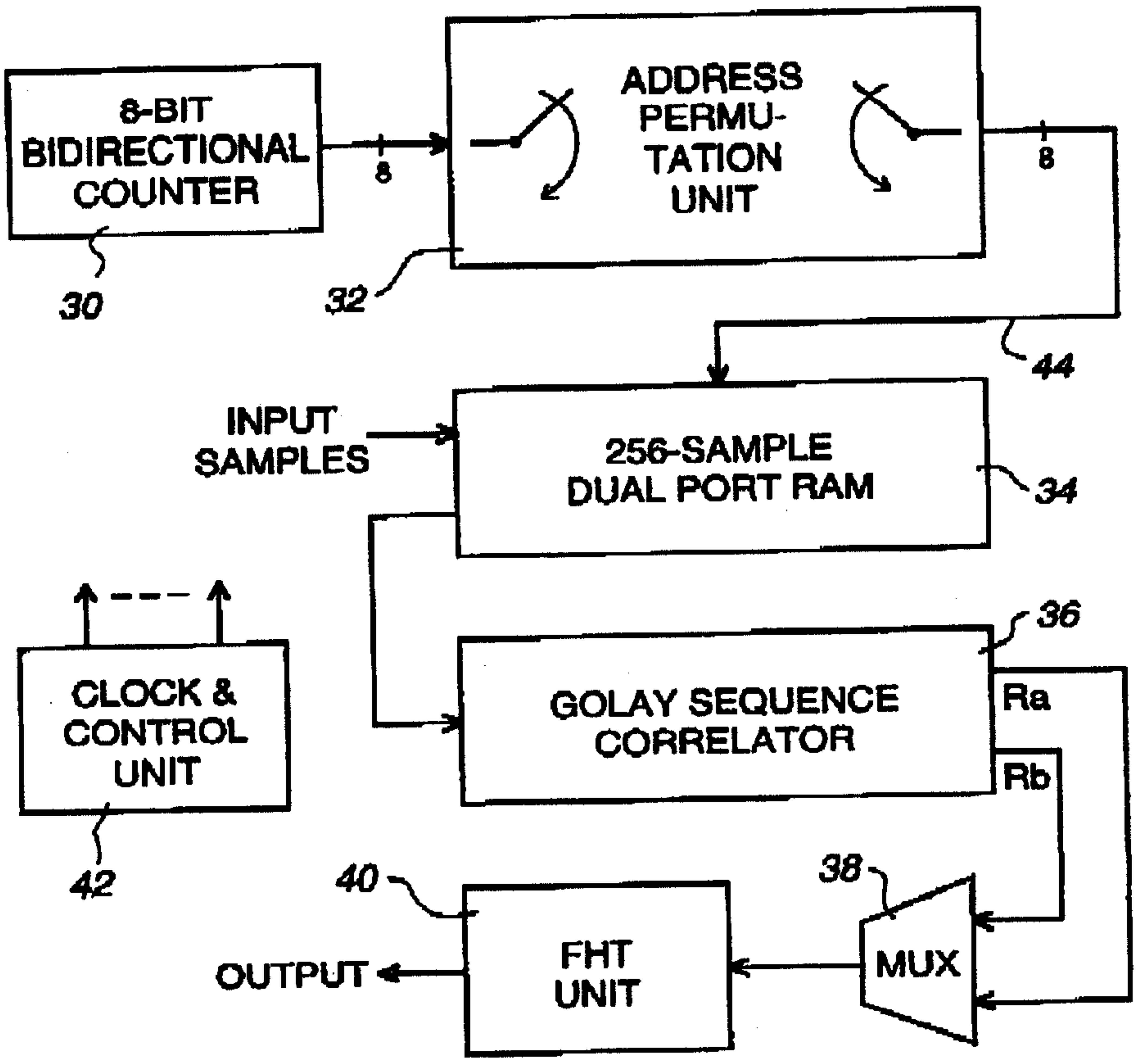
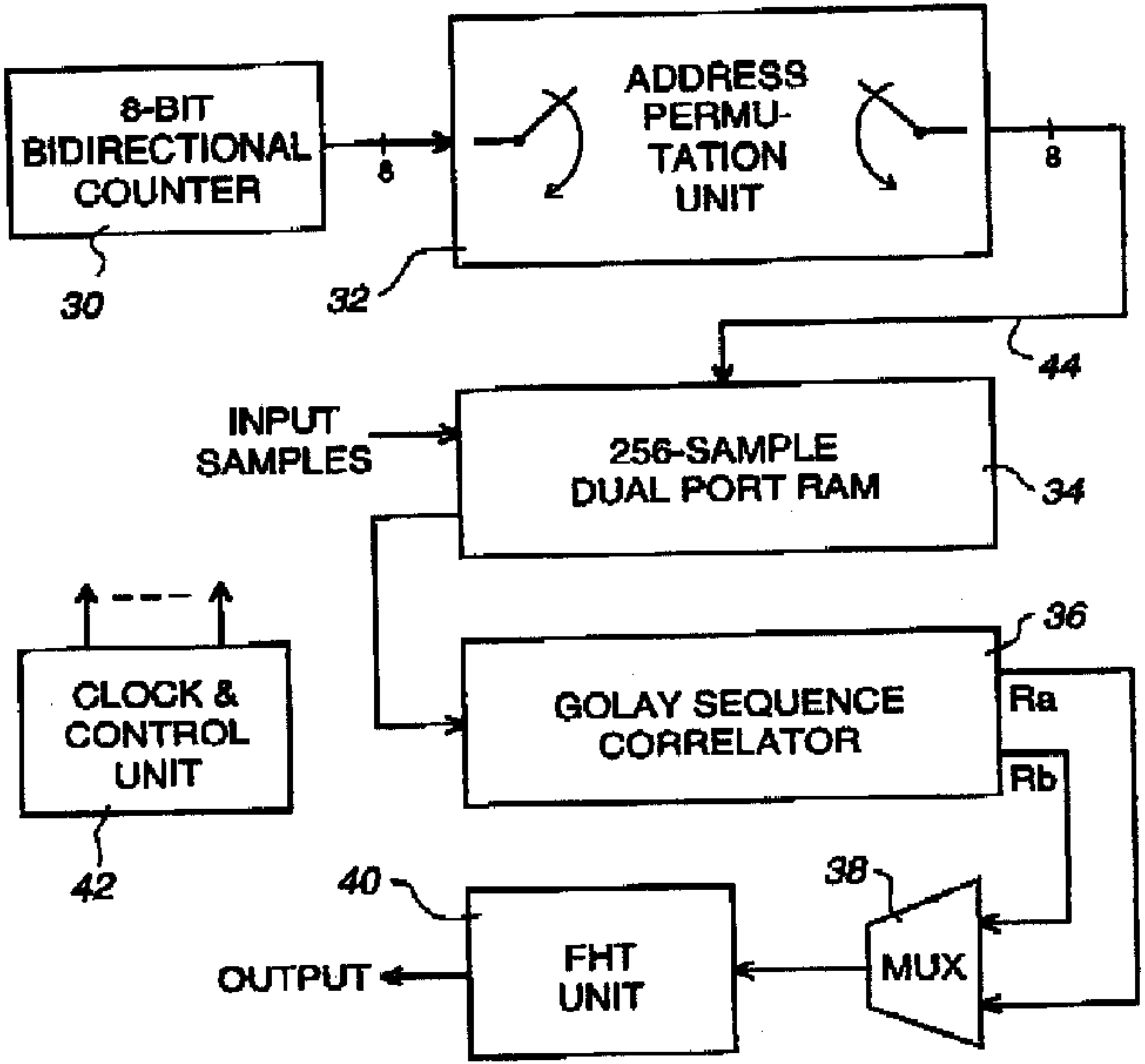


Fig. 7


8-BIT BIDIRECTIONAL COUNTER
8
ADDRESS PERMU-TATION UNIT
8
30
32
44
INPUT SAMPLES
256-SAMPLE DUAL PORT RAM
34
36
CLOCK & CONTROL UNIT
GOLAY SEQUENCE CORRELATOR
Ra
Rb
42
40
38
FHT UNIT
MUX
OUTPUT