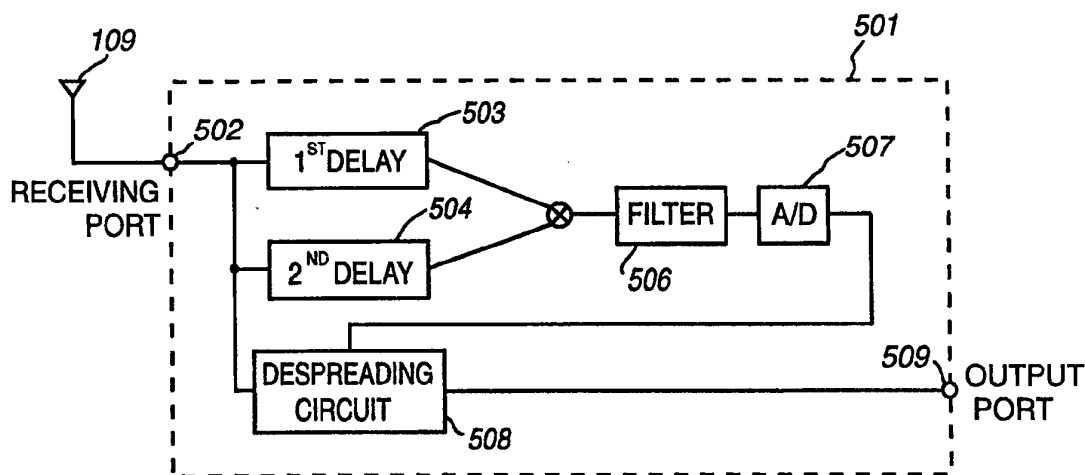




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(54) Title: DESPREADING/DEMODULATING DIRECT SEQUENCE SPREAD SPECTRUM SIGNALS



(57) Abstract

A spread-spectrum system in which the receiver (501) may decode the spread-spectrum signal without any need for a locally generated copy of the chip sequence used by the transmitter to encode the signal, and without the need for synchronizing operation of the receiver with the transmitter. The system may comprise a receiver (501) in which the incoming spread-spectrum signal is delayed by a plurality of delay lines (503, 504) and in which the signal and its delayed versions are multiplied (505) and filtered (506) to recover the original data. The delay imposed by each delayline (503, 504) may be small compared with a single bit-transmission time. Alternatively, the data may be prepared by the transmitter to account for delays at the receiver which are not small compared with a single bit-transmission time. In such case, the receiver may impose delays which are not small compared with a single bit-transmission time, and may review the data which is recovered by multiplication and filtering to reverse the preparation step performed at the transmitter.

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DESCRIPTIONDespreading/Demodulating Direct Sequence
Spread Spectrum SignalsBackground of the Invention1. Field of the Invention

This invention relates to despreading and demodulating direct sequence spread-spectrum signals.

2. Description of Related Art

In direct-sequence biphase spread-spectrum modulation, a pseudo-random chip sequence is used to encode data onto a carrier waveform. The resulting encoded signal is generally spread across a spectrum bandwidth which substantially exceeds the data-transfer rate, hence the term "spread-spectrum". The receiver produces a correlated signal in response to the received spread-spectrum signal when it is able to match the chip sequence to a sufficient degree. To do so, the receiver must generally generate the same pseudo-random chip sequence, synchronize its chip sequence to the transmitter's chip sequence, and maintain synchronization during transmission and reception of data.

The requirement of synchronization by the receiver has generally been a problem in the art. This requirement generally increases the difficulty of acquiring a spread-spectrum signal, maintaining synchronization with an acquired spread-spectrum signal, and in receiving the spread-spectrum signal in a very noisy environment. It can result, at the receiver, in additional circuit complexity, increased costs, and other operational constraints on the communication system. For example, in a noisy environment, the longer time required to achieve synchronization can introduce a severe drag on the efficiency of a communication system. Accordingly, it would be advantageous to have a spread-spectrum communication system in which the receiver may despread and

demodulate the transmitted spread-spectrum signal without the use of a locally generated copy of the chip sequence and without the need for synchronizing that copy with the transmitter.

5 Summary of the Invention

The invention provides a spread-spectrum system in which the receiver may decode the spread-spectrum signal without any need for a locally generated copy of the chip sequence used by the transmitter to encode the signal, and
10 without the need for synchronizing operation of the receiver with the transmitter. The system may comprise a receiver in which the incoming spread-spectrum signal is delayed by a plurality of (preferably two) delay lines, and in which the signal and its delayed versions are
15 multiplied and filtered to recover the original data. In a preferred embodiment, the delay imposed by each delay line may be small compared with a single bit-transmission time.

In a second embodiment, the data may be prepared by
20 the transmitter to account for delays at the receiver which are not small compared with a single bit-transmission time (i.e., more than one chip time and less than one bit time). The prepared data may comprise, for example, precomputed delays which account for transmission
25 delays over a substantial distance. In such case, the receiver may impose delays which are not small compared with a single bit-transmission time, and may review the data which is recovered by multiplication and filtering to reverse the preparation step performed at the transmitter.

30 In a third embodiment, the chip sequence may be recovered by operation of the receiver. This chip sequence may be applied to a baseband spread-spectrum signal, allowing recovery of the original data without filtering. In a preferred version of this embodiment, at
35 least part of the original data may be encoded using a

single chip sequence, which may be uninverted to indicate a "0" bit and may be inverted to indicate a "1" bit.

In a fourth embodiment, a carrier for the spread-spectrum signal may be recovered by operation of the receiver. This carrier signal may be used to demodulate information imposed on the original carrier.

Brief Description of the Drawings

Figure 1 shows a block diagram of a spread-spectrum communication transmitter and receiver as known in the art.

Figure 2 shows a block diagram of a spread-spectrum communication receiver.

Figure 3 shows a plot of the input and output signal/noise ratios of the receiver shown in figure 2.

Figure 4 shows an embodiment of the invention using analog autosynchronization.

Figure 5 shows an embodiment of the invention using digital autosynchronization.

Description of the Preferred Embodiment

Figure 1 shows a block diagram of a spread-spectrum communication transmitter and receiver as known in the art.

A spread-spectrum transmitter 101 may comprise an input port 102 for input data 103, a chip sequence transmitter generator 104, a modulator 105, and a transmitting antenna 106 for transmitting a spread-spectrum signal 107. A spread-spectrum receiver 108 may comprise a receiver antenna 109, a chip sequence receiver generator 110, a demodulator 111, and an output port 112 for output data 113. In a preferred embodiment, a single chip sequence 114 is identically generated by both the transmitter generator 104 and the receiver generator 110, and appears essentially random to others not knowing the spreading code upon which it is based. An extensive discussion of spread-spectrum communication, spreading

codes, and chip sequences, may be found in R. Dixon, SPREAD SPECTRUM SYSTEMS (1984).

Spread-Spectrum Receiver Without Chip Sequence Generator

Figure 2 shows a block diagram of a spread-spectrum
5 communication receiver.

In a preferred embodiment, the transmitter 101 has generated a carrier waveform (not shown) which has been phase modulated (e.g., biphasic modulated) with the chip sequence 114 and the input data 103 at a chipping rate
10 which is higher than a data transmission rate. The chip sequence 114 may comprise a maximal linear pseudo-random binary sequence. The input data 103 may be phase-shift keyed (PSK).

The receiver 201 may comprise a receiving port 202
15 coupled to the receiver antenna 109, which may comprise an output node of a circuit coupled to the receiver antenna 109 for amplification, filtering and other preprocessing functions. The receiving port 202 may be coupled to a first delay 203 and to a second delay 204. (Although the
20 drawing may show the receiving port 202 coupled to the first delay 203 and to the second delay 204 in parallel, it would be clear to those of ordinary skill in the art, after perusal of the specification, drawings and claims, that one of the first delay 203 and the second delay 204
25 will be longer, and thus that the second delay 204 may be coupled to an output of the first delay 203.)

The receiving port 202, the first delay 203 and the second delay 204 may be coupled in parallel to a multiplier circuit 205. The multiplier circuit 205 may be
30 coupled to a filter 206. The filter 206 may be coupled to the output port 112 of the receiver 201. In a preferred embodiment, the receiver 201 need not have any chip sequence receiver generator 110.

Operation of Spread-Spectrum Receiver

Operation of the receiver 201 is based on the property of maximal linear binary sequences that the modulo-two sum of the sequence with a phase-shifted version of itself will simply be a second phase-shifted version of the same sequence. The amount of the second phase shift depends upon the particular maximal linear binary sequence used. Thus, if a carrier which has been biphasic modulated is processed to develop three phase-distinct sequences, and the three phase-distinct sequences are multiplied, the third harmonic of the product may be recovered with the phase modulation removed.

Let t = time, $s(t)$ = the spread-spectrum signal 107, $a(t)$ = the maximal linear binary sequence, and w = carrier frequency.

Without considering transmitted data,

$$s(t) = a(t) \cos(wt). \quad (251)$$

Let R = chipping rate, j = first delay in chips, k = second delay in chips, $a_j(t)$ = $a(t)$ shifted j chips, and $a_k(t)$ = $a(t)$ shifted k chips.

Due to the phase-shifting effect of modulo-two addition,

$$a_k(t) = a(t) +_{\text{mod}2} a_j(t). \quad (252)$$

Equivalently, all three sequences uniformly sum (modulo-two) to the sequence of all zeros:

$$a(t) +_{\text{mod}2} a_j(t) +_{\text{mod}2} a_k(t) = 0. \quad (253)$$

Restating equation 253 for the phase-shifted versions of $a(t)$,

$$s(t + j/R) = a(t + j/R) \cos(wt + wj/R). \quad (254)$$

$$s(t + k/R) = a(t + k/R) \cos(wt + wk/R). \quad (255)$$

The output of the multiplier 205 is the product of the three phase-distinct versions of $s(t)$, the spread-spectrum signal 107:

$$\begin{aligned} & s(t) s(t + j/R) s(t + k/R) \\ & = \cos(wt) \cos(wt + wj/R) \cos(wt + wk/R), \end{aligned} \quad (256)$$

Phase modulation (e.g., biphasic modulation) can be removed because $a(t) +_{\text{mod}2} a_j(t) +_{\text{mod}2} a_k(t) = 0$, or

equivalently, where the sequences are represented by a series of +1 and -1 values in place of 1 and 0 values, the product $a(t) a_j(t) a_k(t)$ is uniformly +1.

$$\begin{aligned}
 & \cos(wt) \cos(wt + wj/R) \cos(wt + wk/R) \\
 5 \quad &= (1/2) [\cos(wj/R) + \cos(2wt + wj/R)] \cos(wt + wk/R) \\
 &= (1/4) \cos(wj/R - wt - wk/R) \\
 &\quad + (1/4) \cos(wj/R + wt + wk/R) \\
 &\quad + (1/4) \cos(wj/R + wt - wk/R) \\
 &\quad + (1/4) \cos(3wt + wj/R + wk/R). \quad (257)
 \end{aligned}$$

10 The output of the filter 206, which filters at $3w$, is therefore the $3w$ component of equation 257:

$$(1/4) \cos(3wt + wj/R + wk/R). \quad (258)$$

Alternatively, the filter 206 may filter at w to produce the w component of equation 257, which may be
15 processed in like manner as the $3w$ component.

$$(1/4) \cos(wt + wj/R + wk/R). \quad (259)$$

The values of j and k for which $a(t) +_{\text{mod}2} a_j(t) +_{\text{mod}2} a_k(t) = 0$ (equation 253) is true are not unique. Thus, they may be selected so that j and k are small compared
20 with a single bit-transmission time. If so chosen, the data-bit value for each of the three phase-distinct versions of the chip sequence is the same, and the data-bit values (either +1 or -1) are essentially cubed by the multiplier 205, and their value is therefore left
25 unchanged.

Let $d(t)$ = the input data 103.

Considering transmitted data,

$$s(t) = d(t) a(t) \cos(wt). \quad (260)$$

$$s(t + j/R) = d(t + j/R) a(t + j/R) \cos(wt + wj/R) \quad (261)$$

$$30 \quad s(t + k/R) = d(t + k/R) a(t + k/R) \cos(wt + wk/R) \quad (262)$$

After operation of both the multiplier 205 and the filter 206, the output is:

$$\begin{aligned}
 & (1/4) d(t) d(t + j/R) d(t + k/R) \cos(3wt + wj/R + \\
 & wk/R). \quad (263)
 \end{aligned}$$

35 Because the delays j and k are small compared with a bit-transmission time,

$$d(t) d(t + j/R) d(t + k/R) \approx_{\text{approx.}} [d(t)]^3 = d(t). \quad (264)$$

In a second embodiment, the input data 103 may be pre-encoded at the transmitter 101 so that it is properly decoded by operation of the multiplier 205 and the filter 206. In this alternative embodiment, it is not necessary
 5 to select the delays j and k which are small compared with a bit-transmission time.

Because the transmitter 101 knows the values of R , j and k , it may compute $d(t)$ such that

$$d(t) = d(t + j/R) = d(t + k/R), \quad (265)$$

10 for all t . Accordingly, the equation 265 will be uniformly and exactly true for all t .

Input and Output Signal/Noise Ratios

Figure 3 shows a plot of the input and output signal/noise ratios of the receiver shown in figure 2. The
 15 nonlinear operation of the multiplier 205 in multiplying the three phase-distinct versions of the spread-spectrum signal 107 takes place at a relatively low signal/noise ratio, and therefore reduces the signal/noise ratio still further. In a preferred embodiment, this reduction in
 20 signal/noise ratio is made up for by processing gain of the rest of the spread-spectrum communication system.

Let SN_i = input signal/noise ratio and SN_o = output signal/noise ratio:

$$SN_o = SN_i^3 / (3 SN_i^2 + 9 SN_i + 15). \quad (301)$$

25 Analog Autosynchronization

Figure 4 shows an embodiment of the invention using analog autosynchronization.

In this embodiment, a derived signal may be recovered by multiplying two phase-delayed copies of the received
 30 spread-spectrum signal 107,

$$g(t) = s(t + j/R) s(t + k/R) \quad (401)$$

The derived signal $g(t)$ has a component $g_1(t)$ which comprises twice the input carrier frequency modulated by the same binary sequence,

$$35 \quad g_1(t) = a(t) \cos(2\omega t) \quad (402)$$

and a component $g_2(t)$ which comprises twice the input carrier frequency modulated by the same binary sequence,

$$g_2(t) = a(t) \quad (403)$$

When multiplied by the received spread-spectrum signal
5 107, the original carrier waveform and its third harmonic are recovered,

$$s(t) g(t) = \cos(wt) + h(t) \cos(3wt) \quad (404)$$

In a preferred embodiment, the spread-spectrum signal
107 may be modulated with data $d_1(t)$, plus the underlying
10 carrier waveform may also be modulated with data $d_2(t)$.
For example, if the spread-spectrum signal 107 is
modulated with one of four spread-spectrum codes, it may
convey up to two bits of data per code; if the underlying
carrier waveform is also modulated by means of 4-ary
15 frequency-shift keying (FSK), it may also convey up to two
bits of data per modulation, for a total of four bits of
data.

In a preferred embodiment, the receiver 401 may
comprise a receiving port 402 coupled to the receiver
20 antenna 109, which may comprise an output node of a
circuit coupled to the receiver antenna 109 for
amplification, filtering and other preprocessing
functions. In a preferred embodiment, the receiving port
402 may be coupled to a first delay 403 and to a second
25 delay 404, either in parallel or in series, as noted with
regard to figure 2. The first delay 403 and the second
delay 404 may be coupled in parallel to a first multiplier
circuit 405. The receiving port 402 and the first
multiplier circuit 405 may be coupled to a second
30 multiplier circuit 406. The second multiplier circuit 406
may be coupled to a filter 407. The receiving port 402
and the filter 407 may be coupled to a third multiplier
circuit 408 for demodulating the carrier waveform. The
third multiplier circuit 408 may be coupled to the output
35 port 409 of the receiver 401.

Digital Autosynchronization

Figure 5 shows an embodiment of the invention using digital autosynchronization.

In this embodiment, the linear sequence $a(t)$ may be
5 computed from the three phase-distinct versions of the received spread-spectrum signal 107. The component $g_2(t)$ may be filtered from the derived signal $g(t)$ and used to despread the received spread-spectrum signal 107.

In a preferred embodiment, the receiver 501 may
10 comprise a receiving port 502 coupled to the receiver antenna 109, which may comprise an output node of a circuit coupled to the receiver antenna 109 for amplification, filtering and other preprocessing functions. The receiving port 501 may be coupled to a
15 first delay 503 and to a second delay 504, either in parallel or in series, as noted with regard to figure 2. The first delay 503 and the second delay 504 may be coupled in parallel to a multiplier circuit 505. (The multiplier circuit 505 may comprise an XOR circuit.) The
20 multiplier circuit 505 may be coupled to a filter 506. The filter 506 may be coupled to an A/D 507. The receiving port 502 and the A/D 507 may be coupled to a despreading circuit 508. The despreading circuit 508 may be coupled to the output port 509 of the receiver 501.

Alternative Embodiments

While preferred embodiments are disclosed herein, many variations are possible which remain within the concept and scope of the invention, and these variations would become clear to one of ordinary skill in the art after
30 perusal of the specification, drawings and claims herein.

For example, information which is transmitted from transmitter to receiver is referred to herein as "data", but it would be clear to those of ordinary skill in the art that these data could comprise both data and error-
35 correcting codes, control information, or other signals,

and that this would be within the scope and spirit of the invention.

For another example, while the invention is shown herein for a preferred embodiment using BPSK encoding of data in the received spread-spectrum signal, it would be clear to those of ordinary skill in the art, after perusal of this application, that other methods of data encoding, such as ternary phase shift keying, QPSK, or other known spread-spectrum techniques, would be workable, and are within the scope and spirit of the invention.

Claims

1. A method comprising the step of receiving a direct-sequence spread-spectrum signal without generating a chip sequence.
- 5 2. A method comprising the steps of
receiving a spread-spectrum signal which was encoded using a chip sequence; and
decoding said spread-spectrum signal without reference to a chip sequence.
- 10 3. A method comprising the steps of
receiving a spread-spectrum signal;
generating a plurality of phase-distinct versions of said spread-spectrum signal;
multiplying said plurality of phase-distinct
15 versions of said spread-spectrum signal to generate a product;
filtering said product.
- 20 4. A method as in claim 3, wherein said spread-spectrum signal is a direct-sequence spread-spectrum signal.
5. A method as in claim 3, wherein said spread-spectrum signal is a biphasic modulated spread-spectrum signal.
- 25 6. A method as in claim 3, wherein said spread-spectrum signal is a phase modulated spread-spectrum signal.
7. A method as in claim 3, wherein said spread-spectrum signal comprises phase-shift keyed data.

8. A method as in claim 3, wherein said spread-spectrum signal comprises biphase shift keyed data.

9. A method as in claim 3, wherein said step of generating comprises the steps of

5 generating a first delayed version of said spread-spectrum signal; and

 generating a second delayed version of said spread-spectrum signal.

10. A method as in claim 3, wherein said plurality of
10 phase-distinct versions of said spread-spectrum signal consist of the received spread-spectrum signal and exactly two phase-shifted versions of said received spread-spectrum signal.

11. A method as in claim 3, wherein said plurality of
15 phase-distinct versions of said spread-spectrum signal sum to zero when added modulo-two.

12. A method as in claim 3, wherein said step of filtering comprises the step of filtering said product with a center frequency substantially equal to a carrier
20 frequency of said spread-spectrum signal.

13. A method as in claim 3, wherein said step of filtering comprises the step of filtering said product with a center frequency of about three times a carrier frequency of said spread-spectrum signal.

25 14. In a spread-spectrum communication system, a composition of matter comprising a powered electromagnetic signal which is the multiplicative product of at least three phase-distinct versions of a received spread-spectrum signal.

15. In a spread-spectrum communication system, a composition of matter comprising a powered electromagnetic signal which is the multiplicative product of at least two phase-distinct versions of a received spread-spectrum
5 signal.

AMENDED CLAIMS

[received by the International Bureau on 20 April 1995 (20.04.95);
original claims 1-15 replaced by amended claims 1-15;
new claims 16-22 added (4 pages)]

1. A method of despreading a spread-spectrum
signal comprising the steps of:
receiving a spread-spectrum signal;
generating a plurality of phase-distinct
5 versions of said spread-spectrum signal; and
combining said plurality of phase-distinct
versions of said spread-spectrum signal to generate an
output signal without reference to a chip sequence used
to generate said spread-spectrum signal.

10 2. A method as in claim 1 wherein said combining
step comprises multiplying said plurality of
phase-distinct versions of said spread-spectrum signal.

15 3. A method as in claim 1, further comprising the
step of filtering said output signal.

20 4. A method as in claim 1, wherein said plurality
of phase-distinct versions of said spread-spectrum
signal consist of the received spread-spectrum signal
and exactly two phase-shifted versions of said received
spread-spectrum signal.

25 5. A method of despreading a spread-spectrum
signal comprising the steps of:
receiving a spread-spectrum signal, said
spread-spectrum signal comprising a spreading code;
delaying said received spread spectrum-signal
for a first delay period and generating a first delayed
30 replica thereby;
delaying said received spread-spectrum signal
for a second delay period and generating a second
delayed replica thereby, wherein said spreading code
modulo-two added with said spreading code delayed by

said first delay period results in said spreading code delayed by said second delay period; and

combining said spread-spectrum signal, said first delayed replica and said second delayed replica into an output signal.

6. A method as in claim 5, wherein said spread-spectrum signal comprises a phase modulated carrier.

7. A method as in claim 5, wherein said spread-spectrum signal comprises phase-shift keyed data.

8. A method as in claim 7, wherein said spread-spectrum signal comprises biphase shift keyed data.

9. A method as in claim 5 wherein said step of combining comprises multiplying together said spread-spectrum signal, said first delayed replica and said second delayed replica.

10. A method as in claim 5, wherein said spread-spectrum signal comprises a direct-sequence spread-spectrum signal.

11. A method as in claim 5, wherein said spread-spectrum signal, said first delayed replica and said second delayed replica sum to zero when added modulo-two.

12. A method as in claim 5 further comprising the step of filtering said output signal.

13. A method as in claim 12, wherein said step of filtering comprises the step of filtering said output

signal with a center frequency of about three times a carrier frequency of said spread-spectrum signal.

14. A method as in claim 12, wherein said step of
5 filtering comprises the step of filtering said output signal with a center frequency substantially equal to a carrier frequency of said spread-spectrum signal.

15. A method as in claim 5, wherein said
10 spread-spectrum signal comprises a biphase modulated carrier.

16. A method as in claim 5 wherein said spread-spectrum signal is modulated with a selected one of a
15 plurality of spread-spectrum codes.

17. A method as in claim 5 wherein said spread-spectrum signal comprises a carrier signal modulated by
20 frequency-shift keying.

18. A method as in claim 17 wherein a plurality of bits of data per modulation is conveyed by said
frequency-shift keying.

19. A method as in claim 5 wherein said first and
25 said second delay periods are small compared to a single-bit transmission time.

20. An apparatus for despreding a spread-spectrum
30 signal comprising:

a first delay element which delays a received spread-spectrum signal for a first delay period and having as an output a first delayed replica, said spread-spectrum signal comprising a spreading code;

35 a second delay element which delays a received spread-spectrum signal for a second delay period and having as an output a second delayed replica,

wherein said spreading code modulo-two added with said spreading code delayed by said first delay period results in said spreading code delayed by said second delay period; and

5 a combiner which combines said spread-spectrum signal, said first delayed replica and said second delayed replica into an output signal.

10 21. The apparatus of claim 20 wherein said combiner comprises a multiplier.

 22. The apparatus of claim 20 further comprising a filter coupled to said output signal.

STATEMENT UNDER ARTICLE 19

U.S. Patent No. 5,157,686, issued to Omura et al. (hereinafter "Omura") has been cited by the International Searching Authority. Omura does not teach or suggest the despreading of a spread-spectrum signal without the use of a reference chip code or sequence as presently claimed. Thus it would not have been obvious to a person skilled in the art to combine the Omura reference with other documents to arrive at the subject matter recited and claimed in the present invention.

Accordingly, the present invention clearly involves an inventive step over the Omura reference.

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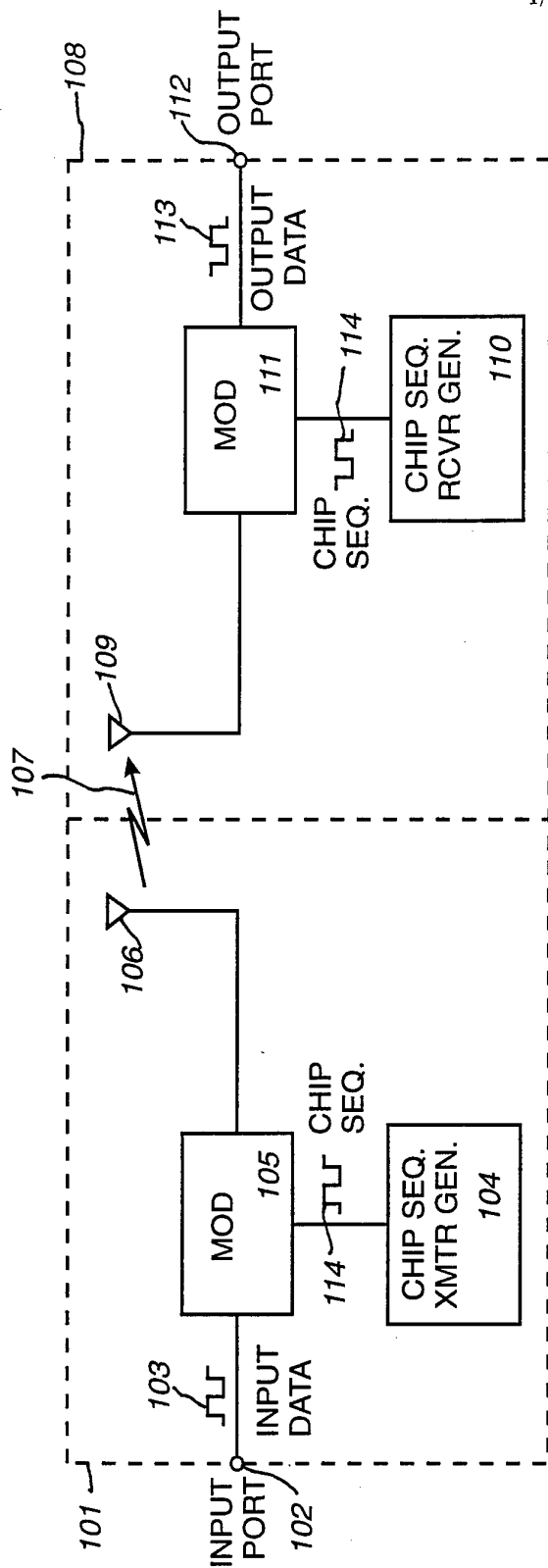


FIG. 1

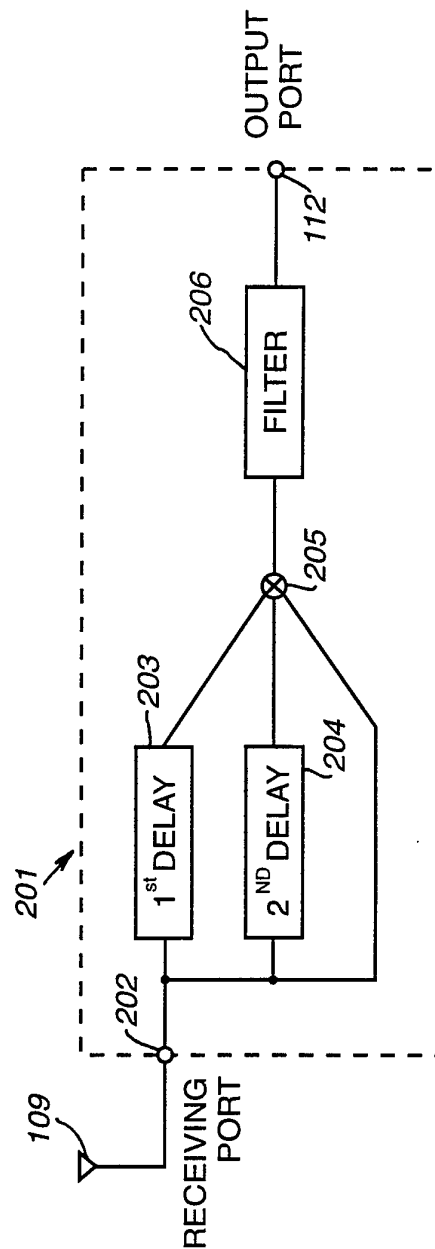
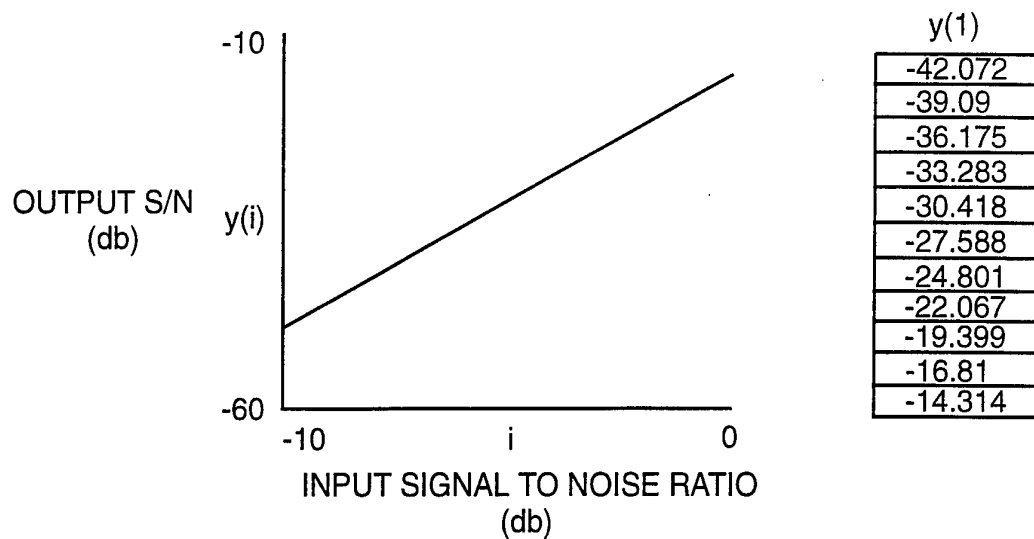
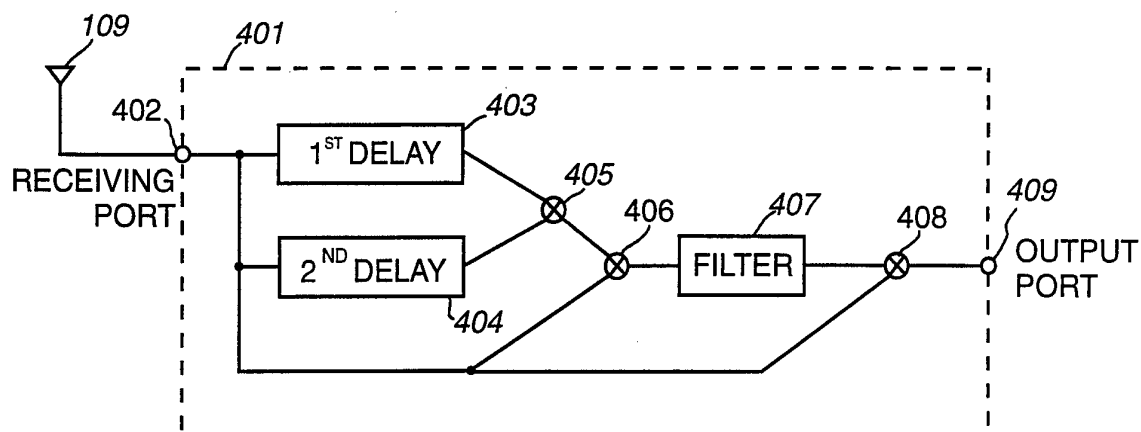
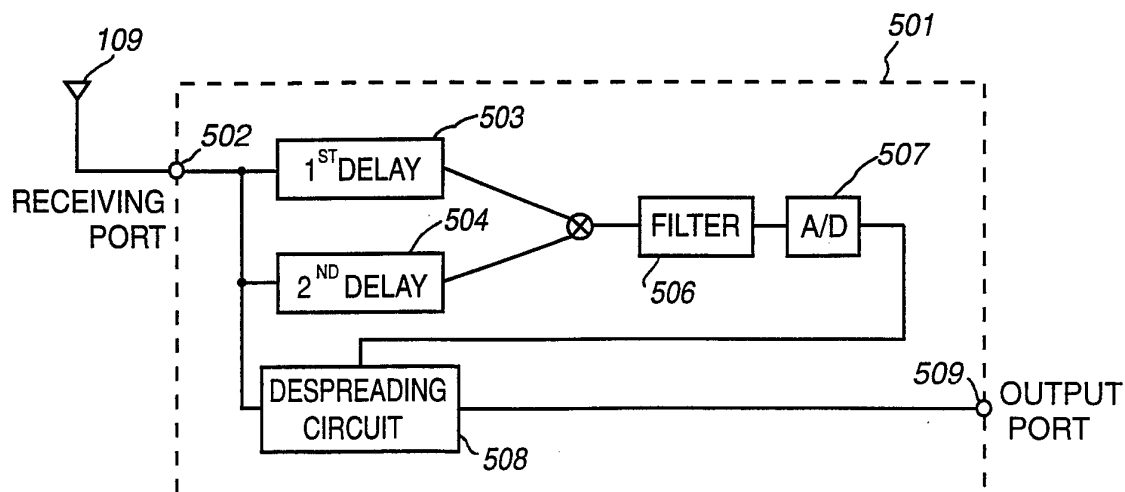


FIG. 2

2/2

**FIG. 3****FIG. 4****FIG. 5**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/12500

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04L 27/30

US CL :375/1

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)

U.S. : 375/1

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)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 5,157,686 (OMURA ET AL) 20 OCTOBER 1992, SEE FIGS. 1A, 6A AND 66, COL. 11, LINES 25-50.	1-15

☐ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be part of particular relevance	"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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Date of the actual completion of the international search

25 JANUARY 1995

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