(54) Title: RECIPROCAL MODE SAW CORRELATOR METHOD AND APPARATUS
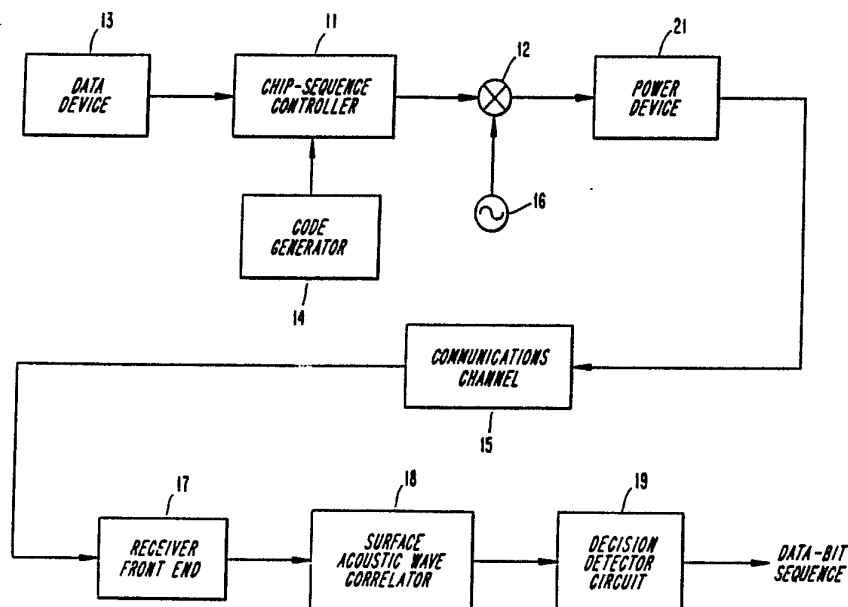
(57) Abstract

A surface-acoustic-wave correlator (18) for decoding a spread-spectrum signal having a data signal modulated with a plurality of chip sequences and reciprocal-chip sequences. A tapped-delay-line has a plurality of taps defining a tapped-delay-line structure matched to the chip sequence. In response to a plurality of first chips and second chips embedded in the spread-spectrum signal, the tapped-delay line generates TDL-chip sequences and inverse-TDL-chip sequences. A first transducer is acoustically coupled to the tapped-delay-line. In response to the spread-spectrum signal modulated by the chip sequence, the first transducer correlates a first group of the plurality of TDL-chip sequences and inverse-TDL-chip sequences and outputs a first correlation pulse. A second transducer is acoustically coupled to the tapped-delay-line. In response to the spread-spectrum signal modulated by the reciprocal-chip sequence, the second transducer correlates a second group of the plurality of TDL-chip sequences and inverse-TDL-chip sequences and outputs a second correlation pulse. In response to the first correlation pulse and the second correlation pulse, a decision circuit (19) outputs the first bit and the second bit, respectively.

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+ DESIGNATIONS OF "SU"

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DESCRIPTION

Reciprocal Mode Saw Correlator Method and Apparatus

BACKGROUND OF THE INVENTION

This invention relates to spread-spectrum communications, and more particularly to a spread-spectrum signal processing technique through the use of a single phase
5   shift encoded tapped-delay line surface-acousticwave correlator (SAWC) to demodulate multiple phase shift keyed (PSK) codes.

The effects of surface-acoustic waves applied to a piezoelectric material to convert electrical energy to
10 acoustic energy and vice versa for analog signal processing purposes have been known and practiced in the prior art for many years. This process, as applied to phase coded SAW correlators, consists, in its most basic form, of an input transducer and a phase coded tapped-delay line
15 matched to a phase shift encoded carrier. In general, this operation is carried out by applying an electrical signal to a transducer which consists of a sequence of metallized interdigital finger pairs deposited on the surface of a piezoelectric material. The transducer con-
20 verts this electrical signal to an acoustic wave which propagates down the surface of the substrate to the tapped-delay line. Acoustic energy is converted to elec-trical energy at the metallized delay-line taps. When the phase encoded wave matches the phase configuration of the
25 delay line taps, the electrical signals are added in phase with each other, and a correlation signal, which provides a signal to noise improvement, is generated and coupled to other electronic circuits through the busses of the tapped-delay line. Multiple correlations may be accom-
30 plished by placing separately encoded tapped-delay lines in parallel on the same substrate. Distinct correlation pulses will then occur upon application of matched phase shift encoded signals at the transducer input.

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The reciprocal properties of SAW devices allow for
this process to take place in reverse, where the tapped-
delay line is excited by a phase coded electrical signal,
and a correlation signal will occur at the output of the
5   transducer. These reciprocal properties have been dis-
cussed for many years in literature and conferences.
Certain kinds of devices and signal formats have shown
more promise in this area than others.   In 1973
J. Burnsweig of Hughes Corp. published a paper detailing
10   the use of linear FM pulse compression matched filters
operating in reciprocal manner ("Ranging and Data Trans-
mission Using Digital Encoded FM Chirp Surface Acoustic
Wave Filters", IEEE Transactions in Microwave Theory, Vol.
MTT-21, pp 272-279, April 1973). This approach involves
15   exciting the long tapped-delay line with the linear FM
encoded signal and utilizing the transducers, located a
certain distance away from each end of the delay line, as
the elements that coherently sum the waveform segments to
produce a compressed pulse. The reciprocal approach with
20   the linear FM chirp waveform was utilized to differentiate
between a "one" bit and a "zero" bit for satellite
ranging/data transmission applications.

While one and zero bit differentiation has been
applied toward a number of phase shift keyed (PSK) wave-
25   forms, most of these approaches appear to involve some
form of acoustoelectric convolver and a hybrid network.
The simpler approach presented in this invention employs
a SAW BPSK matched filter configuration with two trans-
ducers located near the ends of a phase coded tapped-
30   delay line. As briefly described above, the two trans-
ducers are typically utilized as inputs either to assist
in generating the BPSK sequence or serve as the input for
the BPSK encoded waveform, and the tapped-delay line
serves as the summing network to generate the correlation
35   peak. The reciprocal approach involves the use of the SAW
tapped-delay line as the input structure for a one bit
code and a reciprocal code representing the zero bit.

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Coherent summation of the BPSK sequence can be sensed, at a minimum within a chip width from one edge of the tapped-delay line. The summation can be sensed by an appropriate transducer structure that has dimensions corresponding to one chipwidth along with having the correct interdigital finger spacing for the center frequency.

OBJECTS AND SUMMARY OF THE INVENTION

An object of the invention is to provide a method for demodulating multiple data bits from a phase code sequence with a single tapped-delay-line surface-acoustic-wave correlator.

Another object of the invention is to provide a spread-spectrum receiver requiring no reference code synchronization.

A further object of the invention is to provide spread-spectrum demodulation through the use of single tapped-delay-line SAW correlators which may be manufactured with highly distinctive codes.

Another object of the invention is to provide a spread-spectrum demodulator which provides a lower bandwidth to processing gain ratio and more code variability than a linear FM chirp system. The BPSK encoded sequence is more robust with respect to bandwidth narrowing and some manufacturing tolerance variations compared with the linear FM chirp waveform.

According to the present invention, as embodied and broadly described herein, a system using a surface-acoustic-wave correlator for decoding a spread-spectrum signal having a data signal modulated with a plurality of chip sequences and reciprocal-chip sequences is provided comprising communications channel, data-sequence-generating means, chip-sequence-generating means, chip-sequence-controlling means, signal means, carrier-modulating means, power means, front-end means, tapped-delay-line means and decision means. The data-sequence-generating means, chip-sequence-generating means, chip-sequence-controlling

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means, signal means, carrier-modulating means, power
means, front-end means, tapped-delay-line means and deci-
sion means may be embodied as a data device, a code gen-
erator, a chip-sequence controller, a signal source, a
5   product device, a power device, a receiver-front end, a
tapped-delay line and a decision/detector circuit,
respectively.

The data device generates a data-bit sequence having
first bits and second bits. The code generator repeti-
10   tively generates a chip sequence having a plurality of
first chips and second chips. The chip-sequence con-
troller outputs the chip sequence in response to each
first bit, and outputs the reciprocal-chip sequence in
response to each second bit. By reciprocal-chip sequence
15   is meant a time reversed version of the chip sequence. The
signal source generates a carrier signal. The product
device generates the spread-spectrum signal by phase modu-
lating the carrier signal with the chip sequence and
reciprocal-chip sequence. The power device sends the
20   spread-spectrum signal over the communications channel,
and optionally helps to limit a power level of the spread-
spectrum signal to less than a predetermined-threshold
level at the tapped-delay line.

The receiver-front end receives the spread-spectrum
25   signal. The tapped-delay line has a first end and a
second end. The tapped-delay line also has a plurality of
taps defining a tapped-delay-line structure phase-matched
to the chip sequence. The tapped-delay line generates a
plurality of TDL-chip sequences and inverse-TDL-chip
30   sequences, in response to each of the plurality of first
TDL chips and second TDL chips embedded in the spread-
spectrum signal, respectively. A TDL chip is defined as
a segment of the carrier signal of length equivalent to a
period of each chip generated by the chip generator, with
35   a first TDL chip having a first phase, and a second phase
of a second TDL chip shifted with reference to the first
phase.

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A first transducer is coupled acoustically to the first end of the tapped-delay line. The first transducer correlates a first sequence of the plurality of TDL chips and inverse-TDL chips generated by the tapped-delay line and outputs a first correlation pulse, in response to the spread-spectrum signal modulated by the chip sequence. A second transducer is coupled acoustically to the second end of the tapped-delay line. The second transducer correlates a second sequence of the plurality of TDL chips and inverse-TDL chips generated by the tapped-delay line and outputs a second correlation pulse, in response to the spread-spectrum signal modulated by the reciprocal-chip sequence.

A decision/detector circuit outputs the first bit and the second bit in response to detecting the first correlation pulse and the second correlation pulse, respectively.

Additional objects and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention also may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 illustrates a system using the reciprocal SAWC in a spread-spectrum receiver according to the present invention;

FIG. 2A is an equivalent block diagram for a SAWC BPSK matched filter showing a chip sequence generated by a 1-bit;

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FIG. 2B shows the correlation values at the 1-bit transducer;

FIG. 2C shows the correlation values at the 0-bit transducer;

FIG. 3A is an equivalent block diagram for a SAWC BPSK matched filter showing a chip sequence generated by a 0-bit;

FIG. 3B shows the correlation values at the 0-bit transducer; and

FIG. 3C shows the correlation values at the 1-bit transducer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention disclosed in this patent is related to the inventions disclosed in U.S. patent application entitled "Spread Spectrum Correlator", by Robert C. Dixon and Jeffrey S. Vanderpool and having Serial No. 07/390,315 and Filing Date of August 7, 1989, in U.S. patent application entitled "Asymmetric Spread Spectrum Correlator" by Robert C. Dixon and Jeffrey S. Vanderpool and having Serial No. 07/389,914 and Filing Date of August 7, 1989, and in U.S. patent application entitled "SAWC Phase Detection Method and Apparatus" by Robert C. Dixon and having Serial No. 07/556,147 and Filing Date of July 23, 1990, which are incorporated herein by reference.

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals indicate like elements throughout the several views. The present invention includes a system using a surface-acoustic-wave correlator for decoding a spread-spectrum signal having a data signal modulated with a plurality of chip sequences and reciprocal-chip sequences. The system comprises a communications channel, data-sequence-generating means, chip-sequence-generating means, chip-sequence-controlling means, signal means,

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carrier-modulating means, power means, front-end means, tapped-delay-line means and decision means.

As illustratively shown in FIG. 1, the data-sequence-generating means, chip-sequence-generating means, chip-sequence-controlling means, signal means, carrier-modulating means, power means, front-end means, tapped-delay-line means and decision means, by way of example, may be embodied as a data device 13, a code generator 14, a chip-sequence controller 11, an RF signal source 16, a phase modulator 12, a power device 21, a receiver-front end 12, a surface-acoustic-wave correlator 18, and a decision/detector circuit 19, respectively.

The chip-sequence controller 11 is coupled to the data device 13 and the code generator 14. The phase modulator 12 is coupled to the RF signal source 16 and the chip-sequence controller 11. The power device 21 is coupled to the product device 12.

The receiver-front end 17 is coupled to the communications channel 15. The surface-acoustic-wave correlator 18 is coupled to the receiver-front end 17. The decision/detector circuit is coupled to the surface-acoustic-wave correlator 18.

The data device 13 outputs a data-symbol sequence. The data-symbol sequence usually includes information to be communicated by the spread-spectrum signal. The data-symbol sequence may have each data symbol represent two or more data bits. In a binary case, the data-symbol sequence has each data symbol represent one data bit, and accordingly, the data-symbol sequence is known as a data-bit sequence. The data-symbol sequence, for example, may be a data-bit sequence having first bits and second bits, which are the 1-bit and 0-bit. As an example, the data device 13 may be a computer terminal, a device which has converted analog inputs such as voice, audio or video, to data, or any other source where data are to be transmitted from a transmitter to a receiver.

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The code generator 14 repetitively generates a chip
sequence having a plurality of first chips and second
chips.   The first chips and second chips are commonly
known as 1s and 0s.   The repetitively generated chip
5   sequence is known as the spreading sequence for generating
the spread-spectrum signal.   In a preferred embodiment,
the chip sequence is a pseudo-noise (PN) code.   The code
generator 14 may employ shift registers having appropriate
taps for generating the chip sequence.

10   For the binary case, the chip-sequence controller 11
outputs the chip sequence from the code generator 14 in
response to each first bit received from the data device
13, and outputs the reciprocal-chip sequence in response
to each second bit received from the data device 13.
15   Accordingly, the chip-sequence controller 11 outputs a
concatenated plurality of chip sequences and reciprocal-
chip sequences, in response to a concatenated plurality of
first bits and second bits from data device 13.

For the binary case, the chip-sequence controller 11
20   causes a shift register containing the chip sequence to
shift in a forward direction for each first bit, and in
the reciprocal (opposite) direction for each second bit.
Thus, chip-sequence controller 11 outputs a chip sequence
in the case of a data 1-bit, and a reciprocal-chip
25   sequence for data 0-bit.

By reciprocal-chip sequence is meant a time reversed
version of the chip sequence.   By way of example, if the
chip sequence is 110101, then the reciprocal-chip sequence
is 101011.   Preferably, a complete sequence of the repeti-
30   tively generated chip sequence or reciprocal-chip sequence
is outputted from the chip-sequence controller 11 for each
data symbol.   A chip sequence optionally may be generated
coherently with each data symbol of the data-symbol
sequence, and each data symbol determines whether a chip
35   sequence or its reciprocal is generated.

The signal source 16 generates a carrier signal.   The
term "carrier signal" is defined herein to be any signal

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at an RF, intermediate frequency (IF), or other frequency
at which the surface-acoustic-wave correlator 18 operates.
The center frequency of the carrier signal is matched to
the surface-acoustic-wave correlator 18 used at the
5   receiver.

The carrier-modulating means is coupled to the chip-
sequence-controlling means and the signal source 16, and
may be embodied as a product device or, as illustrated in
FIG. 1, a phase modulator 12. The phase modulator 12
10   generates the spread-spectrum signal by phase modulating
the carrier signal from the signal source 16 with the
plurality of chip sequences and reciprocal-chip sequences
from the chip-sequence controller 11, causing phase shifts
in the carrier signal corresponding to each state transi-
15   tion of the chip sequence. The spread-spectrum signal is
the carrier signal modulated with the output from the
chip-sequence controller 11. The phase modulator 12 out-
puts the spread-spectrum signal to the power device 21.

The power device 21 sends the spread-spectrum signal
20   over the communications channel 15, and limits a power
level of the spread-spectrum signal to less than a pre-
determined-threshold level at the input to the surface-
acoustic-wave correlator 18. The power device 21 is
optional, and includes any power amplifier and/or power
25   limiter. Typically, the power device 21 is coupled to a
communications channel from the surface-acoustic-wave
correlator 18. The transmitter power is adjusted to help
maintain the power level at the input to the surface-
acoustic-wave correlator 18 to below a predetermined-
30   threshold level which prevents the surface-acoustic-wave
correlator 18 from operating in a non-linear range. In
some commercially available devices, the predetermined-
threshold level has been found to be less than 20 dBm.

The communications channel 15 may be any medium where
35   the spread-spectrum signal may propagate or travel.

The receiver-front end 17 receives the spread-
spectrum signal from the communications channel 15. The

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receiver-front 17 end includes any antenna, amplifier
and/or impedance matching circuitry coupling the surface-
acoustic-wave correlator 18 to the communications
channel 15.

5   The present invention includes a phase coded surface-
acoustic-wave correlator 18 for demodulating a received
spread-spectrum signal. The surface-acoustic-wave cor-
relator 18 comprises tapped-delay-line means, first
transducer means and second transducer means. As illus-
10   tratively shown in FIGS. 2A and 3A, the tapped-delay-line
means, first transducer means and second transducer means
may be embodied as tapped-delay line 30, first transducer
36, and second transducer 37. The spread-spectrum signal
has a data signal embedded in a carrier signal by phase
15   modulating the carrier signal with a chip sequence and a
reciprocal-chip sequence, as previously described. The
received spread-spectrum signal is applied to the tapped-
delay-line bus, which serves as the surface-acoustic-wave
correlator 18 input. The tapped-delay line bus converts
20   the electrical signal received to an acoustic signal.
When a phase-matched-chip sequence is received at the
surface-acoustic-wave correlator 18, an output transducer
will output a correlation pulse, which is applied to the
detection means, which may be embodied as an amplitude
25   and/or phase detector 19.
        In a tapped-delay line, as the electrical signal is
converted to acoustical energy, an acoustic wave propa-
gates on the surface of a substrate, with each chip width
section of the wave adding in or out of phase with the
30   delay line fingers. When the acoustic waves reach the
output transducers at each end of the tapped-delay line,
the phase components of the wave are summed to create a
correlation pulse whose amplitude is in direct proportion
to the number of phase matches of the delay line. The
35   output transducers convert this acoustic energy to elec-
trical energy and output the correlation pulse in the
form of an amplitude modulated RF signal of frequency

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equivalent to the center frequency of the surface-acoustic-wave correlator 18 and the received spread-spectrum signal.

More particularly, as shown in FIGS. 2A and 3A, the
5 tapped-delay-line 25 has a plurality of taps defining a tapped-delay-line structure. In the exemplary arrangement shown, the tapped-delay line 30 has five taps 31, 32, 33, 34, 35. The tapped-delay-line structure has the taps adjusted to provide a phase match with a received spread-
10 spectrum signal modulated by the chip sequence or reciprocal-chip sequence.

The tapped-delay line 30 has a first end and a second end. The first transducer 36 is acoustically coupled to the first end of the tapped-delay line 30. The second
15 transducer 37 is acoustically coupled to the second end of the tapped-delay line 30. The tapped-delay line 30 generates a plurality of TDL-chip sequences and inverse-TDL-chip sequences, in response to each chip of the plurality of first chips and second chips embedded in the spread-
20 spectrum signal, respectively.

FIGS. 2A, 2B, and 2C illustrate the case for a received spread-spectrum signal being a 1-bit, which is represented by the chip sequence 11101. The received spread-spectrum signal is applied to the tapped-delay-
25 line bus, which serves as the input to the tapped-delay line 30. Each 1-chip of the chip sequence 11101 generates in the tapped-delay line a tapped-delay-line-chip sequence (TDL-chip sequence), 11101, and each 0-chip generates in the tapped-delay line an inverse-TDL-chip sequence, 00010.
30 The generation of each TDL-chip sequence and inverse-TDL-chip sequence is delayed in time by the time equivalent of one chip. FIG. 2B shows a group of TDL-chip sequences and an inverse-TDL-chip sequences as they propagate as acoustic waves toward the first end of the tapped-delay line
35 30. The group shown in FIG. 2B is in response to the chip sequence 11101, which represents the 1-bit. FIG. 2B shows the output 61 of the first transducer 36, illustrated as

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a 1-bit transducer, which is the sum of the chips at any point in time. The 1-chips add in-phase with the TDL structure and are given a value of +1 and the 0-chips add out-of-phase with the TDL structure and are given a value

5 of -1. The output 61 shows that the first transducer 36 generates a maximum value of 5, and accordingly the first correlation pulse when the total of the output 61 reaches 5.

FIG. 2C shows a group of TDL-chip sequences and an

10 inverse-TDL-chip sequence as they propagate as acoustic waves toward the second end of the tapped-delay line 30. The group shown in FIG. 2C is in response to the chip sequence 11101, which represents the 1-bit. The output 51 of the second transducer 37, illustrated as a 0-bit trans-

15 ducer, is the sum of the chips at any point in time. The 1-chips add in-phase with the TDL structure and are given a value of +1 and the 0-chips add out-of-phase with the TDL structure and are given a value of -1. The output 51 shows that the second transducer 37 does not generate the

20 maximum level, since the levels are below a maximum value.

The decision/detector circuitry 19 detects which output of the first transducer 36 and second transducer 37 produced the maximum value, and thereby outputs a 1-bit if the maximum value is from the first transducer 36.

25 FIGS. 3A, 3B, and 3C illustrate the case for a received spread-spectrum signal being a 0-bit, which is represented by the reciprocal-chip sequence 10111. The received spread-spectrum signal is applied to the tapped-delay-line bus, which serves as the input to the tapped-

30 delay line 30. Each 1-chip of the chip sequence 10111 generates a tapped-delay-line-chip sequence (TDL-chip sequence), 11101, and each 0-chip generates an inverse-TDL-chip sequence, 00010. The generation of each TDL-chip sequence and inverse-TDL-chip sequence is delayed in

35 time by the time equivalent of one chip. FIG. 3B shows a group of TDL-chip sequences and an inverse-TDL-chip sequence as they propagate as acoustic waves toward the

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second end of the tapped-delay line 30. The group shown
in FIG. 3B is in response to the reciprocal-chip sequence
10111, which represents the 0-bit. The output 51 of the
second transducer 37 is the sum of the chips at any point
5   in time. The 1-chips add as a +1 and the 0-chips add as
a -1, as stated previously. The output 51 shows that the
second transducer 37 generates a maximum level of 5, and
accordingly the second correlation pulse when the total of
the output 51 reaches 5.

10   FIG. 3C shows a group of TDL-chip sequences and an
inverse-TDL-chip sequence as they propagate as acoustic
waves toward the first end of the tapped-delay line 30.
The group shown in FIG. 3C is in response to the
reciprocal-chip sequence 10111, which represents the
15   0-bit. The output 61 of the first transducer 36 is the
sum of the chips at any point in time. The 1-chips add as
a +1 and the 0-chips add as a -1, as stated previously.
The output 61 shows that the first transducer 36 does not
generate the maximum value, since the values are below the
20   maximum value.

The decision/detector circuitry 19 detects which out-
put of the first transducer 36 and second transducer 37
produces the maximum value, and thereby outputs a 0-bit if
the maximum value is from the second transducer 37.

25   Accordingly, the first transducer 36 correlates a
first group of the plurality of TDL-chip sequences and
inverse-TDL-chip sequences generated by the tapped-delay
line 30 and outputs a first correlation pulse, in response
to the spread-spectrum signal modulated by the chip
30   sequence. The first transducer 36 at the first end of the
tapped-delay line 30 produces a first correlation pulse
representing a data 1-bit, in response to the received
spread-spectrum signal modulated with the chip sequence.
Similarly, the second transducer 37 correlates a second
35   group of the plurality of TDL-chip sequences and inverse-
TDL-chip sequences generated by the tapped-delay line 30
and outputs a second correlation pulse, in response to the

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spread-spectrum signal modulated by the reciprocal-chip
sequence. The second transducer 37 at the second end of
the tapped-delay line produces a second correlation pulse
representing a data 0-bit in response to the received
5   spread-spectrum signal modulated with the reciprocal-chip
sequence.

A decision/detector circuit 19 outputs the first bit
and the second bit in response to detecting the first
correlation pulse and the second correlation pulse at the
10 outputs of the first transducer 36 and second transducer
37, respectively.

The present invention further includes a method using
a surface-acoustic-wave correlator having a tapped-delay
line for encoding a spread-spectrum signal having a data
15 signal modulated with a plurality of chip sequences and a
reciprocal-chip sequences. The method comprises the steps
of: generating a plurality of TDL-chip sequences and
inverse-TDL-chip sequences with the tapped-delay line in
response to a plurality of first chips and second chips
20 embedded in the spread-spectrum signal matching the taps
of the tapped-delay line; correlating a first group of the
plurality of TDL-chip sequences and inverse-TDL-chip
sequences generated by the tapped-delay line; outputting
a first correlation pulse from a first transducer in
25 response to the spread-spectrum signal being modulated by
the chip sequence; correlating a second group of the
plurality of TDL-chip sequences and inverse-TDL-chip
sequences generated by the tapped-delay-line; outputting
a second correlation pulse from the second transducer in
30 response to the spread-spectrum signal being modulated by
the reciprocal-chip sequence; and outputting from a deci-
sion circuit the first bit and the second bit in response
to the first correlation pulse and the second correlation
pulse being outputted from the first transducer and the
35 second transducer, respectively.

It will be apparent to those skilled in the art that
various modifications can be made to the system using a

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surface-acoustic-wave correlator or other analog corre-
lators, including but not limited to charged-coupled
devices, for decoding a spread-spectrum signal of the
instant invention with out departing from the scope or
5 spirit of the invention, and it is intended that the
present invention cover modifications and variations of
the system using the surface-acoustic-wave correlator
provided they come in the scope of the appended claims and
their equivalence.   Such modifications and variations
10 include, but are not limited to, applying the surface-
acoustic-wave correlator to communications systems employ-
ing other type of phase modulation such as QPSK and M-ary
PSK.

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<u>Claims</u>

     1. A system using a surface-acoustic-wave correlator
for decoding a spread-spectrum signal having a data signal
modulated with a plurality of chip sequences and
5 reciprocal-chip sequences, comprising:

     a communications channel;

     data-sequence-generating means for generating a data-
bit sequence having first bits and second bits;

     chip-sequence-generating means for repetitively gen-
10 erating a chip sequence having a plurality of first chips
and second chips;

     chip-sequence-controlling means coupled to said data-
sequence-generating means and said chip-sequence-generat-
ing means, responsive to each first bit for outputting the
15 chip sequence, and responsive to each second bit for out-
putting the reciprocal-chip sequence;

     signal means for generating a carrier signal;

     carrier-modulating means coupled to said signal means
and said chip-sequence-controlling means, responsive to
20 the chip sequence and the reciprocal-chip sequence, for
generating the spread-spectrum signal by phase modulating
the carrier signal; power means coupled to said carrier-
modulating means and responsive to the spread-spectrum
signal for sending the spread-spectrum signal over said
25 communications channel;

     front-end means coupled to said communications chan-
nel for receiving the spread-spectrum signal and generat-
ing a limiting signal;

     tapped-delay-line means having a first end, a second
30 end, and a plurality of taps defining a tapped-delay-line
structure matched to the chip sequence, responsive to the
plurality of first chips and second chips embedded in the
spread-spectrum signal for generating a plurality of TDL-
chip   sequences   and   inverse-TDL-chip   sequences,
35 respectively;

     first transducer means, acoustically coupled to said
first end of said tapped-delay-line means, responsive to

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the spread-spectrum signal modulated by the chip sequence
for correlating a first group of the plurality of TDL-
chip sequences and inverse-TDL-chip sequences generated by
said tapped-delay-line means and outputting a first corre-
5   lation pulse;

second transducer means, acoustically coupled to said
second end of said tapped-delay-line means, responsive to
the spread-spectrum signal modulated by the reciprocal-
chip sequence for correlating a second group of the
10   plurality of TDL-chip sequences and inverse-TDL-chip
sequences generated by said tapped-delay-line means and
outputting a second correlation pulse;

decision means coupled to said first transducer means
and said second transducer means, responsive to the first
15   correlation pulse and the second correlation pulse for
outputting the first bit and the second bit, respectively;
and

wherein said power means responsive to the limiting
signal limits a power level of the spread-spectrum signal
20   to signal less than a predetermined level at said tapped-
delay-line means.

2.   The surface-acoustic-wave correlator as set forth
in claim 1 wherein:

said tapped-delay-line means includes a tapped-delay
25   line having a first end and a second end;

said first transducer means includes a first trans-
ducer acoustically coupled to said first end of said
tapped-delay-line means, responsive to the spread-spectrum
signal modulated by the chip sequence for correlating a
30   first group of the plurality of TDL-chip sequences and
inverse-TDL-chip sequences generated by said tapped-delay
line and outputting a first correlation pulse; and

second transducer means includes a second transducer
acoustically coupled to said second end of said tapped-
35   delay-line means, responsive to the spread-spectrum signal
modulated by the reciprocal-chip sequence for correlating

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a second group of the plurality of TDL-chip sequences and
inverse-TDL-chip sequences generated by said tapped-delay
line and outputting a second correlation pulse end.

3.   A surface-acoustic-wave correlator for decoding
5 a spread-spectrum signal having a data signal modulated
with a plurality of chip sequences and reciprocal-chip
sequences, comprising:
        tapped-delay-line means having a plurality of taps
defining a tapped-delay-line structure matched to the chip
10 sequence, responsive to a plurality of first chips and
second chips embedded in the spread-spectrum signal for
generating a plurality of TDL-chip sequences and inverse-
TDL-chip sequences, respectively;
        first transducer means responsive to the spread-
15 spectrum signal modulated by the chip sequence for
correlating a first group of the plurality of TDL-chip
sequences and inverse-TDL-chip sequences generated by said
tapped-delay-line means and outputting a first correlation
pulse;
20   second transducer means responsive to the spread-
spectrum signal modulated by the reciprocal-chip sequence
for correlating a second group of the plurality of TDL-
chip sequences and inverse-TDL-chip sequences generated by
said tapped-delay-line means and outputting a second cor-
25 relation pulse; and
        decision means responsive to the first correlation
pulse and the second correlation pulse for outputting the
first bit and the second bit, respectively.

4.   The surface-acoustic-wave correlator as set forth
30 in claim 3 wherein:
        said tapped-delay-line means includes a tapped-delay
line having a first end and a second end;
        said first transducer means includes a first trans-
ducer acoustically coupled to said first end of said
35 tapped-delay-line means, responsive to the spread-spectrum

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signal modulated by the chip sequence for correlating a
first group of the plurality of TDL-chip sequences and
inverse-TDL-chip sequences generated by said tapped-delay
line and outputting a first correlation pulse; and
5   second transducer means includes a second transducer
acoustically coupled to said second end of said tapped-
delay-line means, responsive to the spread-spectrum signal
modulated by the reciprocal-chip sequence for correlating
a second group of the plurality of TDL-chip sequences and
10 inverse-TDL-chip sequences generated by said tapped-delay
line and outputting a second correlation pulse.

          5. The surface-acoustic-wave correlator as set forth
in claim 3 further including:
          a power device for limiting a power level of the
15 spread-spectrum signal to less than a predetermined-
threshold level at said tapped-delay-line means.

          6. A surface-acoustic-wave correlator for decoding
a spread-spectrum signal having a data signal modulated
with a plurality of chip sequences and reciprocal-chip
20 sequences, comprising:
          a tapped-delay-line having a first end, a second end,
and a plurality of taps defining a tapped-delay-line
structure matched to the chip sequence, responsive to a
plurality of first chips and second chips embedded in the
25 spread-spectrum signal for generating TDL-chip sequences
and inverse-TDL-chip sequences, respectively;
          a first transducer, acoustically coupled to said
first end of said tapped-delay-line, responsive to the
spread-spectrum signal modulated by the chip sequence for
30 correlating a first group of the plurality of TDL-chip
sequences and inverse-TDL-chip sequences generated by said
tapped-delay-line means and outputting a first correlation
pulse;
          a second transducer, acoustically coupled to said
35 second end of said tapped-delay-line, responsive to the

20

spread-spectrum signal modulated by the reciprocal-chip sequence for correlating a second group of the plurality of TDL-chip sequences and inverse-TDL-chip sequences generated by said tapped-delay-line means and outputting 5 a second correlation pulse; and

a decision circuit coupled to said first transducer and said second transducer, responsive to the first correlation pulse and the second correlation pulse for outputting the first bit and the second bit, respectively.

10   7. The surface-acoustic-wave correlator as set forth in claim 6 further including:

a power device for limiting a power level of the spread-spectrum signal to less than a predetermined-threshold level at said tapped-delay line.

15   8. A method using a surface-acoustic-wave correlator for decoding a spread-spectrum signal having a data signal modulated with a plurality of chip sequences and reciprocal-chip sequences, comprising the steps of:

generating a data-bit sequence having first bits and 20 second bits;

generating repetitively a chip sequence and a reciprocal-chip sequence having a plurality of first chips and second chips;

generating a carrier signal;

25   modulating the carrier signal with the chip sequence and the reciprocal-chip sequence in response to each first bit and each second bit of the data-bit sequence, respectively;

sending the spread-spectrum signal over a communica-30 tions channel;

receiving the spread-spectrum signal; generating with a tapped-delay line having a plurality of taps defining a tapped-delay-line structure matched to the chip sequence, a TDL-chip sequence and an inverse-TDL-chip sequence in

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response to each of the first chips and second chips embedded in the spread-spectrum signal, respectively;

correlating a first group of the plurality of TDL-chip sequences and inverse-TDL-chip sequences generated by
5 said tapped-delay line at a first transducer;

outputting a first correlation pulse from said first transducer in response to the spread-spectrum signal modulated by the chip sequence and producing a correlation of the first group of the plurality of TDL-chip sequences and
10 inverse-TDL-chip sequences generated by said tapped-delay line;

correlating a second group of the plurality of TDL-chip sequences and inverse-TDL-chip sequences generated by said tapped-delay-line means at a second transducer;
15 outputting a second correlation pulse from said second transducer in response to the spread-spectrum signal modulated by the reciprocal-chip sequence and producing a correlation of the second group of the plurality of TDL-chip sequences and inverse-TDL-chip sequences gen-
20 erated by said tapped-delay line; and

deciding the first bit and the second bit in response to the levels of the first correlation pulse and the second correlation pulse, respectively.

9.   The method as set forth in claim 8 further
25 including the step of:

limiting a power level of the spread-spectrum signal to less than a predetermined level at said tapped-delay line.

10. A method using a surface-acoustic-wave correla-
30 tor for decoding a spread-spectrum signal having a data signal modulated with a plurality of chip sequences and a reciprocal-chip sequences, comprising the steps, using said surface-acoustic-wave correlator, of:

generating with a tapped-delay line having a plural-
35 ity of taps defining a tapped-delay-line structure matched

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to the chip sequence, a TDL-chip sequence and an inverse-TDL-chip sequence in response to each of the first chips and second chips embedded in the spread-spectrum signal, respectively;
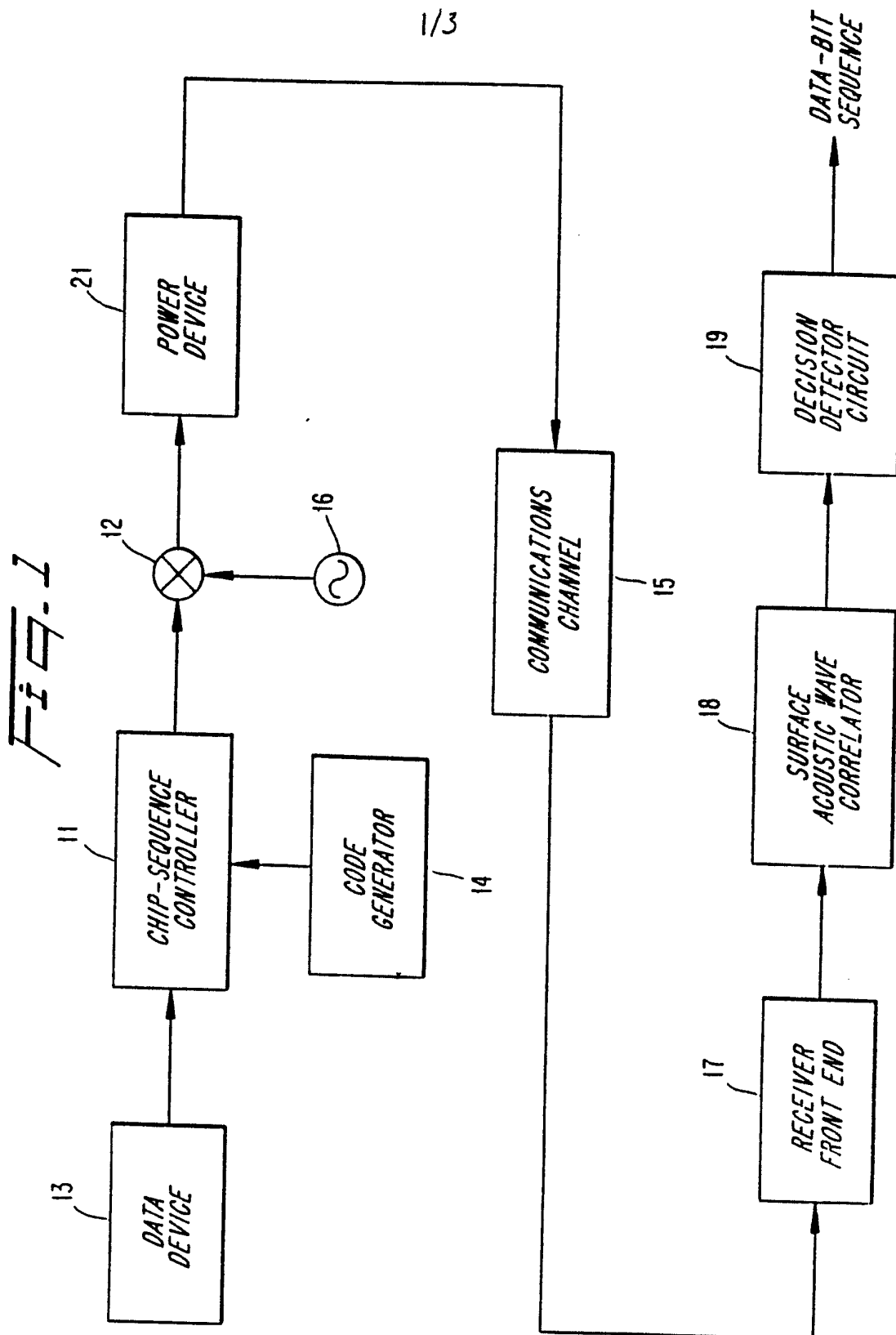
5   correlating from a first transducer a first group of the plurality of TDL-chip sequences and inverse-TDL-chip sequences generated by said tapped-delay line;
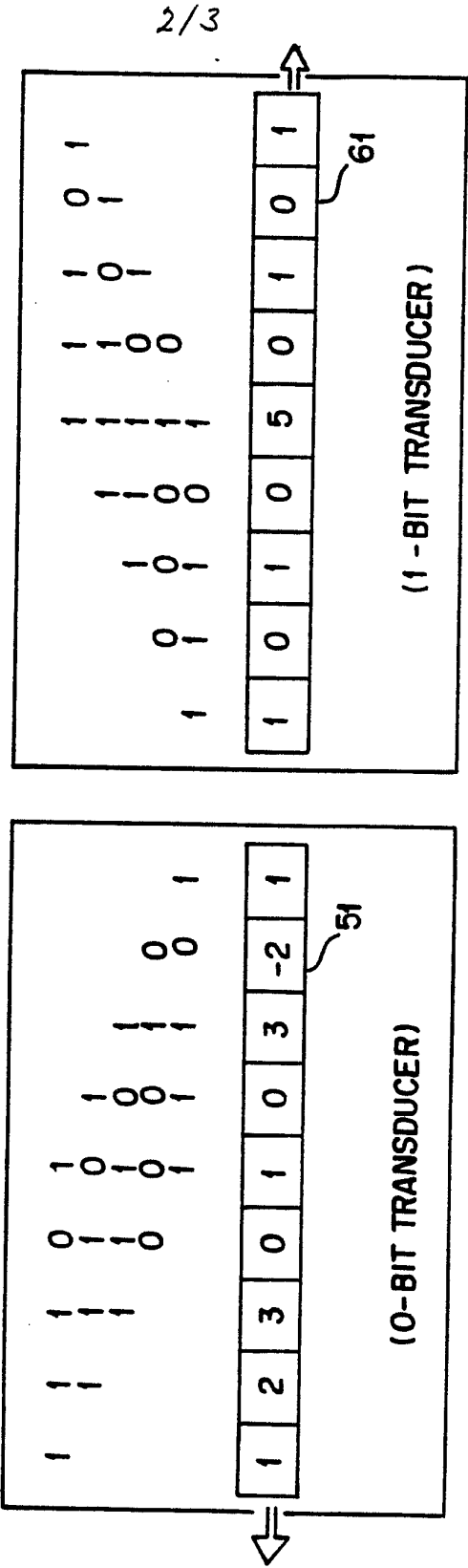
outputting a first correlation pulse from said first transducer in response to the spread-spectrum signal modu-

10   lated by the chip sequence and producing a correlation of the first group of the plurality of TDL-chip sequences and inverse-TDL-chip sequences;

correlating from a second transducer a second group of the plurality of TDL-chip sequences and inverse-TDL-

15   chip sequences;

outputting a second correlation pulse from said second transducer in response to the spread-spectrum signal modulated by the reciprocal-chip sequence and producing a correlation of the second group of the

20   plurality of TDL-chip sequences and inverse-TDL-chip sequences; and

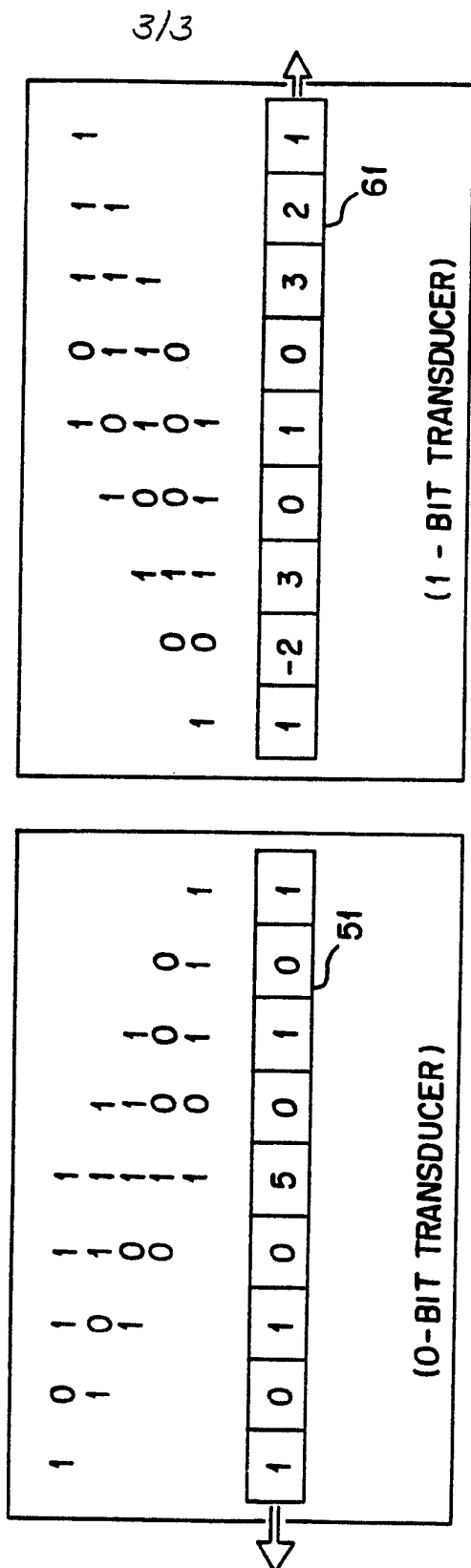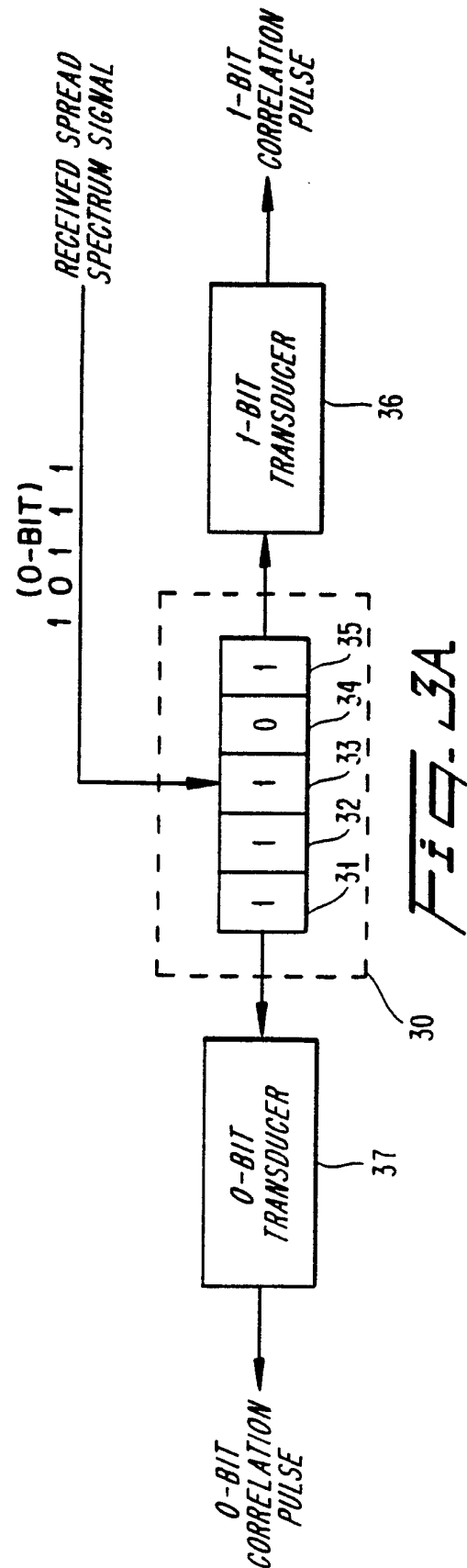deciding the first bit and the second bit in response to the levels of first correlation pulse and the second correlation pulse, respectively.

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Fig.1

RECEIVED SPREAD SPECTRUM SIGNAL

(I-BIT)
I I I O I

I-BIT
TRANSDUCER
36

I-BIT
CORRELATION
PULSE

I	O	I	I	I
31	32	33	34	35

30

0-BIT
TRANSDUCER
37

0-BIT
CORRELATION
PULSE

Fig. 2A

I	0	I	I	O	I	0	I	I
	I		I O	I I O	I O O I	O I O I	I O I	O I
					I I I I	I I O O	I I O	I O
						I	O I	I
							O	I

1	O	I	O	5	O	I	O	1
61

(1 - BIT TRANSDUCER)

Fig. 2C

I		I		I O		O		I
	I		I O	O I	I O I	O I I	O O	I
				O I I	I I I	I O O I		
					I I I			

1	2	3	O	I	0	1	3	-2	1
51

(0-BIT TRANSDUCER)

Fig. 2B

RECEIVED SPREAD
SPECTRUM SIGNAL

I-BIT
CORRELATION
PULSE

I-BIT
TRANSDUCER

36

(0-BIT)
1 0 1 1 1

1	1	1	0	1

31 32 33 34 35

Fig. 3A

30

0-BIT
TRANSDUCER

37

0-BIT
CORRELATION
PULSE

1   1 1 1   0 1 1 0   1 0 1 0 1   0 1 1   0 1   1 0

1	-2	3	0	1	0	3	2	1

61

(1 - BIT TRANSDUCER)

Fig. 3C

1   0 1   0 1   1 0 1   1 1 1 1   1 0 1 0 1   0 1   0 1   1

1	0	1	0	5	0	1	0	1

51

(0-BIT TRANSDUCER)

Fig. 3B

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/05316

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 6

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5) HO4B 15/00 US:375/1

II. FIELDS SEARCHED

Minimum Documentation Searched 7	
Classification System	Classification Symbols
US	375/1

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched 8

III. DOCUMENTS CONSIDERED TO BE RELEVANT 9

Category *	Citation of Document, 11 with indication, where appropriate, of the relevant passages 12	Relevant to Claim No. 13
A, P	US, A, 5,016,255 (Dixon et al.) 14 MAY 1991.	1-10
A, P	US, A, 5,022,047 (Dixon et al.) 04 JUNE 1991.	1-10

* Special categories of cited documents: 10

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"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

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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
20 DECEMBER 1991	10 JAN 1992
International Searching Authority	Signature of Authorized Officer
ISA/US	DAVID CAIN NGUYEN NGOC-HO INTERNATIONAL DIVISION

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