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3 PHASE DETECTION USING NEURAL NETWORKS
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5 STATEMENT OF GOVERNMENT INTEREST

6 The invention described herein may be manufactured and used by
7 or for the Government of the United States of America for
8 governmental purposes without the payment of any royalties
9 thereon or therefor.
10

11 BACKGROUND OF THE INVENTION

12 (1) Field of the Invention

13 This invention generally relates to the detection of a
14 signal and more specifically to a method and apparatus for
15 estimating and utilizing phase discontinuities to better detect
16 the presence of a corrupted signal in background noise.

17 (2) Description of the Prior Art

18 In many applications involving energy transmitted through
19 some medium to be reflected off an object, the signals
20 representing the received reflected energy are characterized by
21 phase discontinuities and background noise. In a sonar system,
22 a transmitted acoustic energy pulse travels through the water,
23 reflects off an object and returns to a receiver. Typically
24 the object is not uniform in shape so energy may reflect along
25 a number of different axes from the object. Moreover, each of
26 these reflections may travel back to the receiver through

1 diverse paths caused by reflections from different thermal
2 layers in the water, the water surface or the sea bottom.
3 Consequently the reflected signal is corrupted with phase
4 discontinuities caused by the diverse arrival times of these
5 reflections along paths of different length. Moreover, it is
6 often made more difficult to detect the signal because the
7 reflected signal is further burdened with noise accumulated as
8 the signal propagates through the medium.

9 As known, various approaches have been used to recover the
10 true or coherent transmitted signal. For example, a single
11 quadrature receiver has been used to integrate a received
12 signal over an integration interval corresponding to its pulse
13 width with some success. However, it has been demonstrated
14 that a priori knowledge of phase discontinuities in the
15 received signal can significantly enhance the probability of
16 signal detection by such a detection modality. That is,
17 knowledge of the phase discontinuities would enable a parallel
18 quadrature receiver or other signal processing circuit to
19 optimize its operation over coherent intervals within the
20 received signal structure. Processing in such receivers over
21 such coherency intervals would enhance the probability of
22 detection over the probabilities achieved with a single
23 quadrature receiver.

24 Neural networks have also been used to detect phase by
25 detecting persistent patterns of phase in a time varying or
26 oscillatory signal. United States Letters Patent No. 5,146,541

1 (1992) to Speidel discloses a signal phase pattern sensitive
2 neural network system that employs duplicate inputs from each
3 of its sensors to the processing elements of a first layer of a
4 neural network. One input is always phase shifted relative to
5 the other. This system employs a modification of a
6 conventional Kohonen competitive learning rule that is applied
7 by the processing and learning elements of a second layer of
8 the neural network. Partitioned segments are then processed
9 and a third layer of the neural network that comprises
10 processing elements connected to the second layer, processes
11 the different segments to identify a desired characteristic of
12 the incoming signal.

13 Thus the prior art discloses a need for defining coherency
14 intervals in a received signal characterized by phase
15 discontinuities in the signal and by background noise. The
16 prior art also discloses the use of neural networks for
17 discerning patterns in phase. However, there remains a need
18 for an apparatus and a method for detecting signal phase
19 discontinuities that may occur at random times, determining the
20 presence and duration of coherency intervals within the
21 received signals and utilizing these coherency intervals to
22 enhance detection capabilities.

SUMMARY OF THE INVENTION

Therefore it is an object of this invention to provide a method and apparatus for detecting phase changes that can occur at random times within a received signal.

Another object of this invention is to provide a phase detector utilizing a neural network to recognize phase changes that occur at random times within a signal.

Still another object of this invention is to provide a method and apparatus utilizing neural networks for recognizing phase changes that occur within a signal corrupted by background noise.

Yet another object of this invention is to provide a method and apparatus utilizing neural networks and parallel quadrature receivers for enhancing the ability to detect a signal that is degraded by a combination of multiple reflections of a reflected signal and by noise sources.

In accordance with this invention a received signal representing reflected energy and characterized by signal discontinuities and noise is preprocessed into a signal having a predetermined format. Neural networks analyze the formatted signal to determine the likelihood of phase discontinuities in the reflected signal within different test intervals. This information defines coherency intervals that control the integration operation of parallel quadrature receivers for processing the received signal. The outputs of the quadrature

1 receivers are then combined to indicate the presence or absence
2 of the reflected transmitted signal.

3 4 BRIEF DESCRIPTION OF THE DRAWINGS

5 The appended claims particularly point out and distinctly
6 claim the subject matter of this invention. The various
7 objects, advantages and novel features of this invention will
8 be more fully apparent from a reading of the following detailed
9 description in conjunction with the accompanying drawings in
10 which like reference numerals refer to like parts, and in
11 which:

12 FIG. 1 is a block diagram depicting the apparatus
13 constructed in accordance with this invention;

14 FIG. 2 is a block diagram of a preprocessor shown in FIG.
15 1;

16 FIG. 3 is a block diagram of an integration time generator
17 shown in FIG. 1; and

18 FIG. 4 is a block diagram of a quadrature receiver shown
19 in FIG. 1.

20 21 DESCRIPTION OF THE PREFERRED EMBODIMENT

22 FIG. 1 depicts an energy transmitter 10, such as a sonar
23 transmitter, for directing an energy pulse through a medium
24 along a path 12 as a wave EP. Typically this energy pulse will
25 be a sinusoidal pulse with constant frequency having a
26 predetermined pulse width. It may be focused or radiated

1 omnidirectionally. The resulting energy travels through the
2 medium, and a portion of the energy reflects from an object 14.
3 In many applications the energy reflects from multiple
4 surfaces. FIG. 1 shows facets 14A and 14B for purposes of
5 explanation. In the specific embodiment of FIG. 1 the energy
6 reflects from the facet 14A along a nominally direct path 16 to
7 a receiver 18. The receiver 18 receives the reflected energy
8 from the facet 14B after it passes along a path 20 involving
9 multiple reflections as, for example, off the surface of water
10 at 20A, the sea bottom at 20B or some intermediate layer at
11 20C. As known, the incoherent combination of these multiple
12 reflections, that arrive at the receiver 18 at different
13 unknown times, produces phase discontinuities in any signal
14 representing the reflected energy. Moreover, the signal will
15 be corrupted by noise that combines with the transmitted and
16 reflected energy.

17 The receiver 18 is a component of the phase detection
18 apparatus 22 shown in FIG. 1. The receiver 18 additionally
19 will receive a signal corresponding to the transmitted pulse
20 from the transmitter 10 for storage and use by the phase
21 detection apparatus 22.

22 The received analog signal representing the reflected
23 energy with its phase discontinuities and background noise from
24 the receiver 18 is coupled to a preprocessing unit 24. The
25 preprocessing unit 24 converts the analog signal into a digital
26 form that constitutes a predetermined format. Generally this

1 conversion occurs in accordance with conventional sampling
2 theory.

3 A neural network set 26 in FIG. 1 comprises a plurality of
4 neural networks 26(1), 26(2)... 26(n). Each of the independent
5 neural networks is constructed to analyze an incoming signal
6 for the likelihood of phase discontinuities occurring over the
7 signal duration. The analysis intervals may be arbitrary, or
8 they may be predefined depending on the design of each neural
9 network.

10 As described later, the preprocessing unit 24 may filter
11 the received signal and produce a representation of the signal
12 in a format that is more suitable for processing. The received
13 signal is preprocessed in accordance with the specific analysis
14 requirements for each neural network in set 26.

15 An integration time generator 28 receives all the outputs
16 from the neural network set 26. It acts to fuse the resulting
17 information based upon the collective outputs at a particular
18 analysis interval to determine whether it is likely that a
19 phase discontinuity exists in any such interval. The
20 integration time generator 28 utilizes this information to
21 identify actual coherency intervals that, by virtue of not
22 being likely to contain a phase discontinuity, are likely to
23 have a coherent signal.

24 These actual coherency intervals control a set 30 of
25 parallel quadrature receivers 30(1) through 30(k) where k
26 indicates the number of multiple intervals to be processed

1 simultaneously. Each of the quadrature receivers 30(1) through
2 30(k) integrates the received signal in the preprocessed format
3 over a corresponding actual coherency interval. Thus the
4 parallel quadrature receivers 30 operate with a priori
5 knowledge of the phase discontinuities and integrate the signal
6 only over actual coherency intervals in which the digitized
7 signal from the receiver is assumed to be coherent. A detector
8 32 sums the quadrature receiver outputs and generates a SIGNAL
9 DETECTED output when the sum exceeds a predetermined threshold.

10 An optional signal processor 34 may then utilize this
11 information to perform still other processing.

12 Now referring to FIG. 2, the preprocessing unit 24
13 receives a signal $S(t)+n(t)$ where $S(t)$ represents the time
14 dependent reflected signal and $n(t)$ represents corrupting
15 noise. In this particular embodiment an analog-to-digital
16 (A/D) converter 36 samples and digitizes the received signal.
17 An optional filter 38 can provide one or more functions, such
18 as bandpass filtering, low or high pass filtering, amplitude
19 limiting or clipping. The digitized and filtered signal is
20 transferred to a received signal storage unit 40A of memory 40
21 and provides a digitized representation of the total signal
22 $\{S(t)+n(t)\}$ in the corresponding interval during which the
23 input is active. As previously indicated the digitized signal
24 constitutes a predetermined format of the signal.

25 The memory 40 also includes a transmitted pulse storage
26 unit 40B that receives signals representing the transmitted

1 pulse which are coupled from the transmitter 10 of FIG. 1. The
2 receipt and storage of such transmitted signals and the use of
3 such information for the learning operation of neural networks
4 is known in the art.

5 A preprocessing unit 24 can include additional
6 preprocessors 42(1) and 42(2) through 42(j). Each additional
7 preprocessor in the additional preprocessor set 42 could be
8 dedicated to producing a signal of a different format as
9 required by each neural network. Such additional preprocessors
10 in the additional preprocessor set 42 could produce Fourier
11 transforms, wavelets and the like. Each would be selected on
12 the basis of its ability to enhance the likelihood that a
13 neural network could be configured to operate on that signal
14 with a likelihood of detecting a phase discontinuity.

15 Each neural network in the neural set 26 of FIG. 1 is
16 uniquely constructed once a particular feature (e.g.,
17 amplitude, frequency or phase) and a particular format for the
18 input signal have been defined. In this invention where phase
19 discontinuities are to be detected, a number of different
20 signal formats can be processed to obtain the desired phase
21 information. Some of the individual neural networks, for
22 example, might process Fast Fourier Transform information
23 related to the received signal and obtained from one of the
24 additional preprocessors 42(1) through 42(j) in FIG. 2 to
25 analyze the incoming signal as a complex signal. Also,
26 different neural networks might establish testing intervals at

1 different times and for different durations to identify the
2 likelihood of a phase discontinuity. Still other neural
3 networks could be utilized as sliding windows that would
4 process overlapping groups of subintervals or time partitions.

5 In essence, and as generally known, each neural network
6 compares the signal feature associated with the received signal
7 with the feature of the known transmitted pulse thereby to
8 determine whether it is likely that, based on the respective
9 analysis performed, the received signal is coherent over the
10 respective testing interval.

11 FIG. 3 depicts the integration time generator 28 in more
12 detail. A timing generator 44 defines a number of successive
13 tentative coherency time intervals at some particular temporal
14 resolution. An integration processor 46 then receives, during
15 each tentative coherency interval established by the timing
16 generator 44, the corresponding outputs from the neural network
17 set 26. The integration processor 46 combines the resulting
18 signals in any number of fashions. A typical application might
19 include an "M of N" voting function; that is, if "M of N" tests
20 indicate coherency during a particular tentative coherency
21 interval, the integration processor 46 establishes that
22 interval as an actual coherency interval that is appropriate
23 for integration. The result of this process is the generation
24 of an integration time map 48 that, for each tentative
25 coherency interval, indicates whether the received signal has a
26 likelihood of coherency during a particular interval such that

1 one of the quadrature receivers in the quadrature receiver set
2 30 should operate over the interval. Although FIG. 3 depicts a
3 particular embodiment, it will be apparent that the integration
4 time generator 28 could be varied to analyze the outputs of the
5 neural networks in a different fashion.

6 FIG. 4 depicts a typical quadrature receiver 30(k) as one
7 of the parallel quadrature receivers in the set 30 operating on
8 its respective part of the integration time map. The
9 quadrature receiver 30(k) includes an in-phase (sine wave)
10 multiplier 50 and a quadrature (cosine wave) multiplier 52 that
11 process the incoming signal over each actual coherency
12 interval. The sinusoidal multipliers are characterized by the
13 frequency of the transmit signal. In accordance with known
14 quadrature receiver operation, an in-phase integrator 54 and
15 squarer 56 sequentially process the signal from the multiplier
16 50 to be an input to a summing circuit 58. Similarly a
17 quadrature integrator 60 and squarer 62 process the output from
18 the quadrature multiplier 52 to be applied as a second input to
19 the summing circuit 58. The resulting output from the
20 quadrature receiver 30(k) becomes one of the inputs to the
21 detector 32 in FIG. 1.

22 Still referring to FIG. 1, in this specific embodiment,
23 the detector 32 comprises a detector processor 64 for combining
24 (e.g., summing) the outputs of the parallel quadrature receiver
25 set 30 and a threshold circuit 66. Thus the detector 32
26 produces a SIGNAL DETECTED signal whenever the processed

1 outputs of the quadrature receiver set 30 exceeds a certain
2 threshold established by the threshold circuit 66.

3 Generally, therefore, the transmitter 10 in FIG. 1
4 generates an acoustic pulse that travels along a path 12 to
5 reflect from facets on the object 14. When the receiver 18 in
6 FIG. 1 is on, the input is either noise $n(t)$ or signal embedded
7 in noise $S(t)+n(t)$. In an ideal case without the presence of
8 background noise, the reflected signal is characterized by
9 several intervals of constant phase and amplitude interrupted
10 by phase discontinuities caused as a result of the different
11 arrival times of the reflected energy. More realistically,
12 background noise, such as white Gaussian noise, is present.
13 The signal phase and amplitude may be affected by the noise to
14 such an extent that the discontinuities in phase are not
15 readily discernible.

16 The preprocessing unit 24 and neural networks 26 analyze
17 this signal to identify the times when the signal phase
18 changes. Specifically each neural network processes a received
19 signal at different subintervals or testing intervals in an
20 attempt to detect phase discontinuities. The resulting timing
21 of likely phase discontinuities establishes coherency intervals
22 where the phase is constant. These actual coherency intervals
23 then control the receivers of the parallel quadrature receiver
24 set 30 that perform piece-wise integrations on the received
25 signal from the preprocessing unit 24. Stated differently, the
26 quadrature receivers utilize the actual coherency intervals to

1 perform the piece-wise integration over intervals of constant
2 phase to enhance the probability of detection.

3 Each neural network 26(1) through 26(n) implements well
4 known back propagation architectures or other appropriate
5 supervised learning paradigms. Each network is trained to
6 determine if a phase change occurs within an assigned or
7 corresponding testing interval. In one configuration, for
8 example, the number of neural network outputs corresponds to a
9 number of partitions or analysis intervals. Each output is
10 either at a "1" or "0" indicating the presence of a phase
11 change versus no phase change. Thus the combination of the
12 neural network outputs estimates integration times which in
13 turn define coherency intervals over which the parallel
14 quadrature receiver set 30 processes the received waveform.
15 For example, if the neural network outputs indicate that a
16 phase change has occurred at $t/2$ then the integration time
17 generator 28 would set the integration intervals to 0 to $t/2$
18 and $t/2$ to t . Thus the use of the neural networks in the
19 neural network set 26 enhances the likelihood of detecting
20 phase discontinuities; and the integration time generator 28
21 limits processing by the receivers of quadrature receiver set
22 30 to subintervals in which there is a strong likelihood that
23 the signal is coherent.

24 This invention has been disclosed in terms of certain
25 embodiments. It will be apparent that many modifications can
26 be made to the disclosed apparatus without departing from the

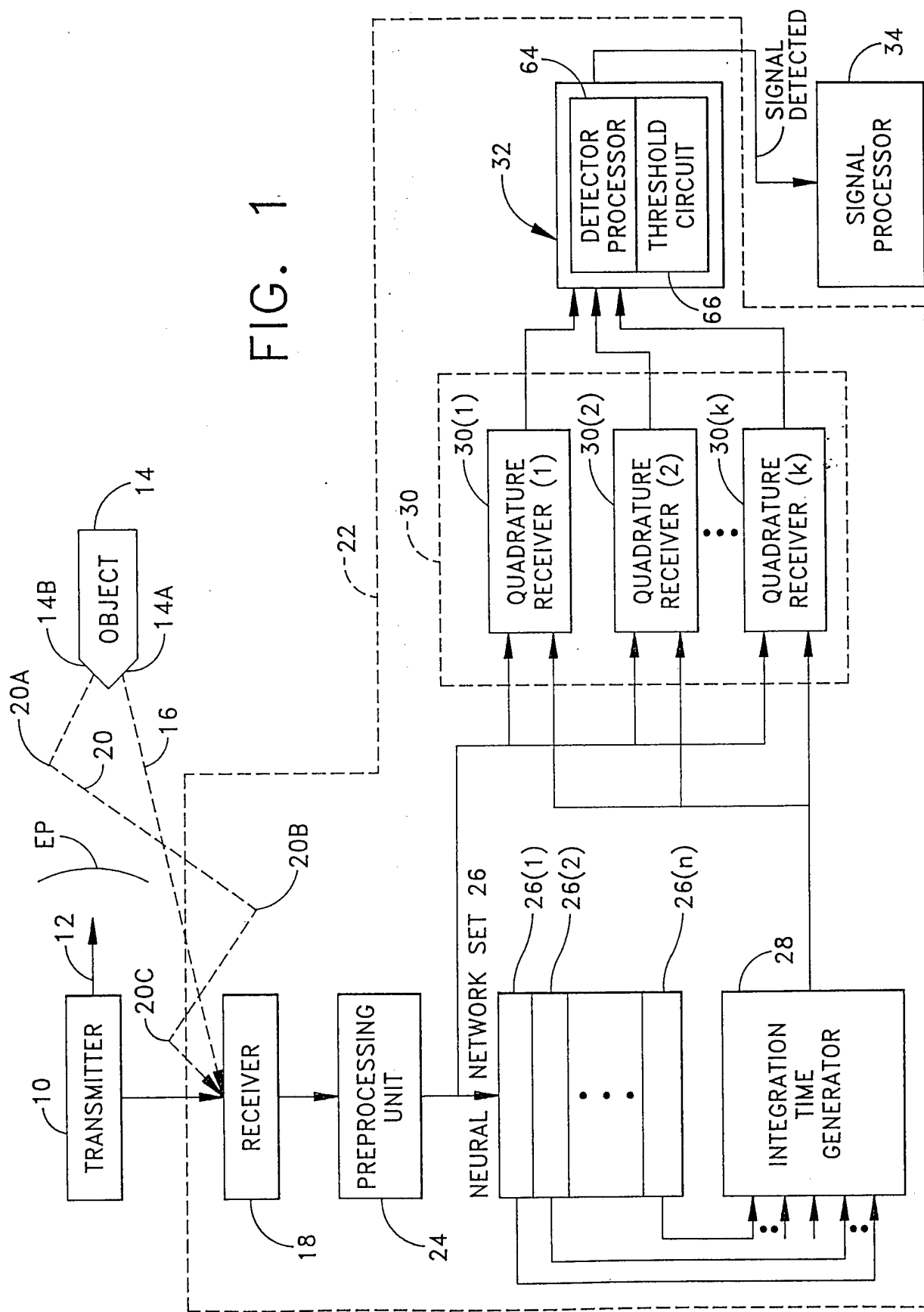
1 invention. Therefore, it is the intent
2 to cover all such variations and modifications as come within
3 the true spirit and scope of this invention.

1 Navy Case No. 77624

2
3 PHASE DETECTION USING NEURAL NETWORKS

4
5 ABSTRACT OF THE DISCLOSURE

6 A likelihood of detecting a reflected signal characterized
7 by phase discontinuities and background noise is enhanced by
8 utilizing neural networks to identify coherency intervals. The
9 received signal is processed into a predetermined format such
10 as a digital time series. Neural networks perform different
11 tests over arbitrary testing intervals to determine the
12 likelihood of a phase discontinuity occurring in any such
13 interval. An integration time generator subsequently uses this
14 information to define a series of contiguous coherency
15 intervals over the duration of the received signal. These
16 coherency intervals are then used for piece-wise processing of
17 the received signal by parallel quadrature receivers. The
18 outputs are combined and processed for detecting the presence
19 of the reflected signal.



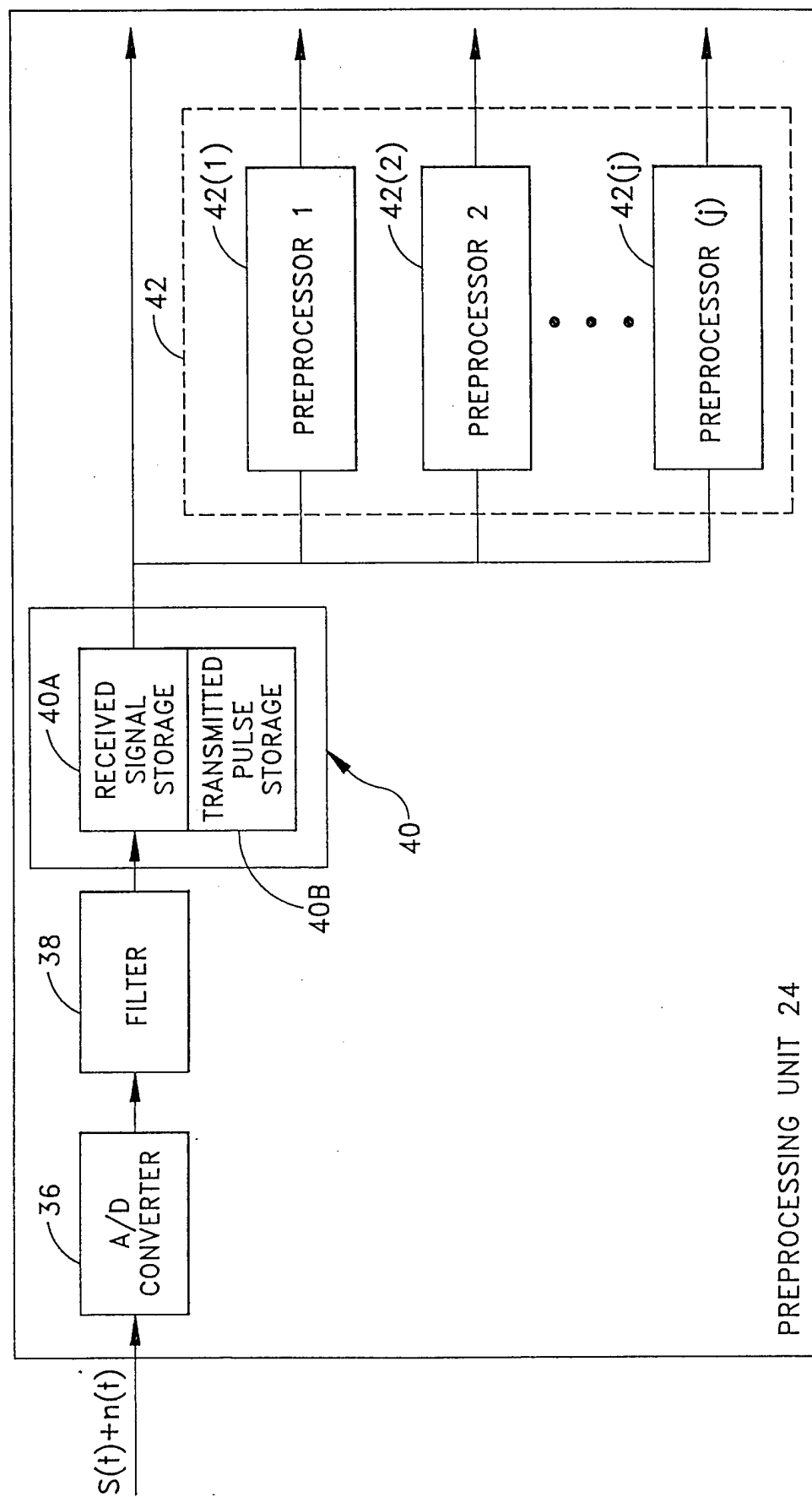


FIG. 2

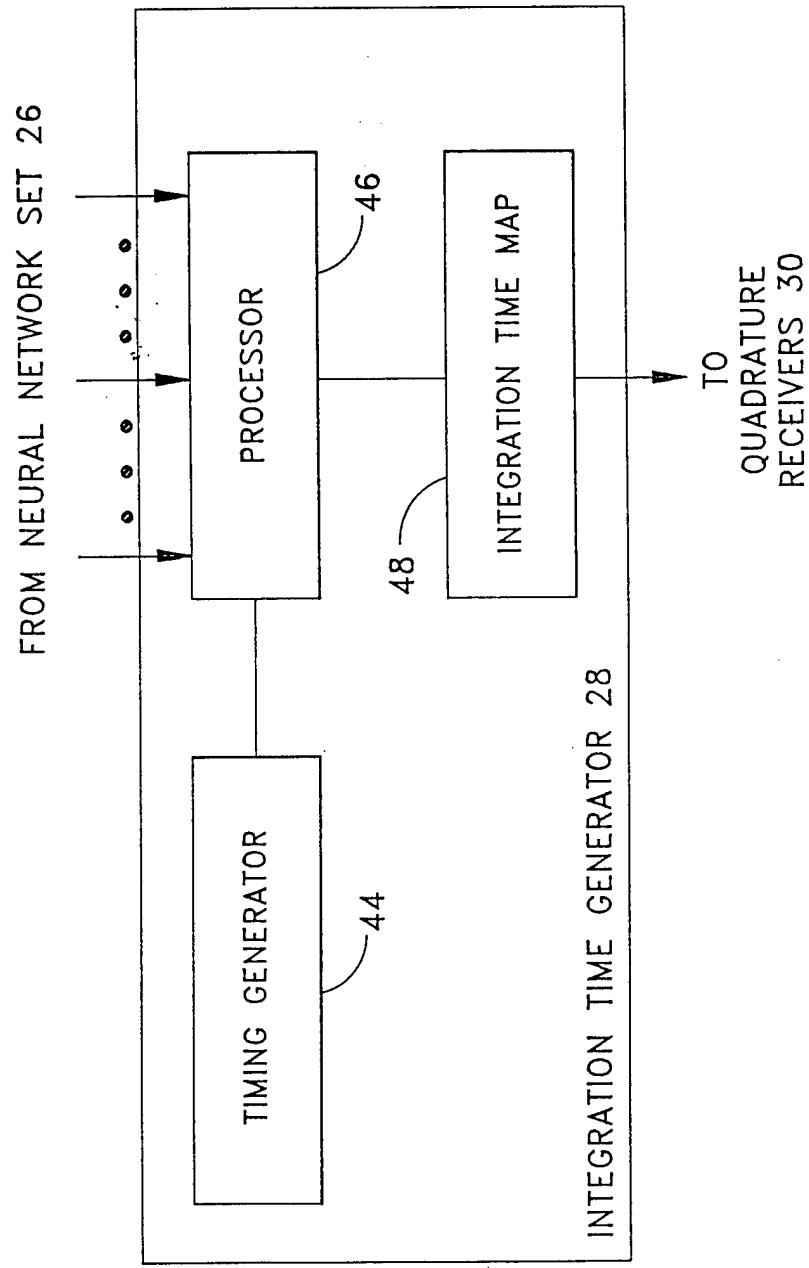


FIG. 3

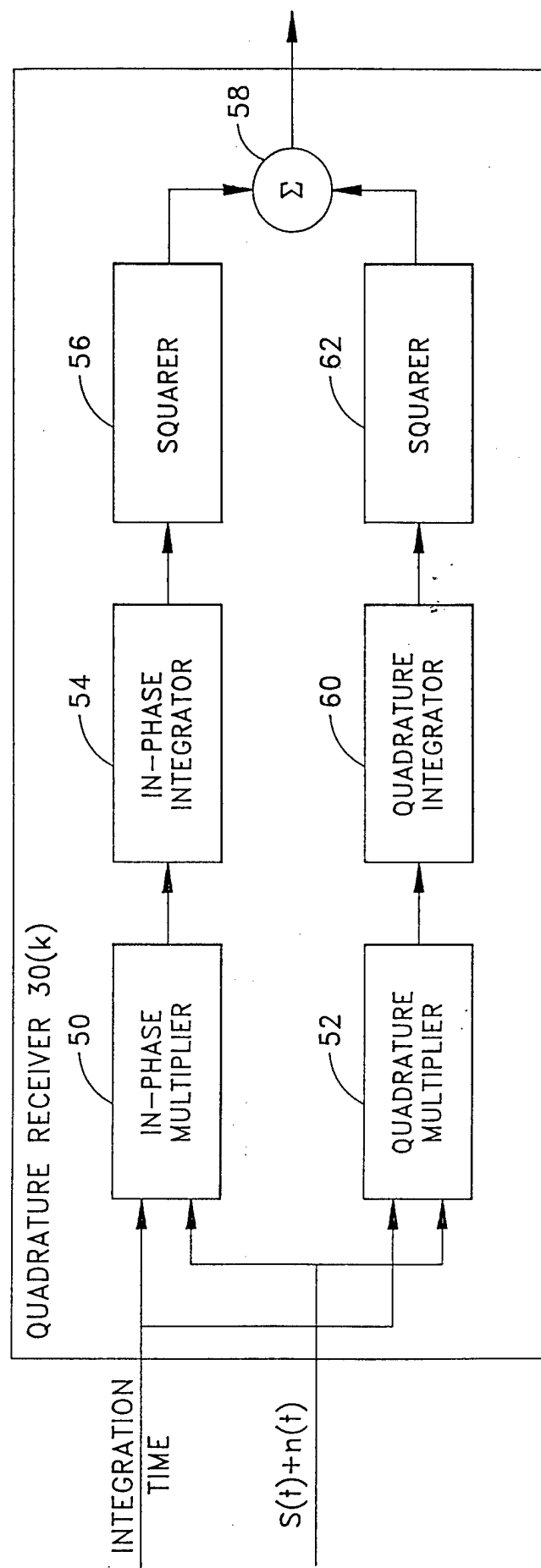


FIG. 4