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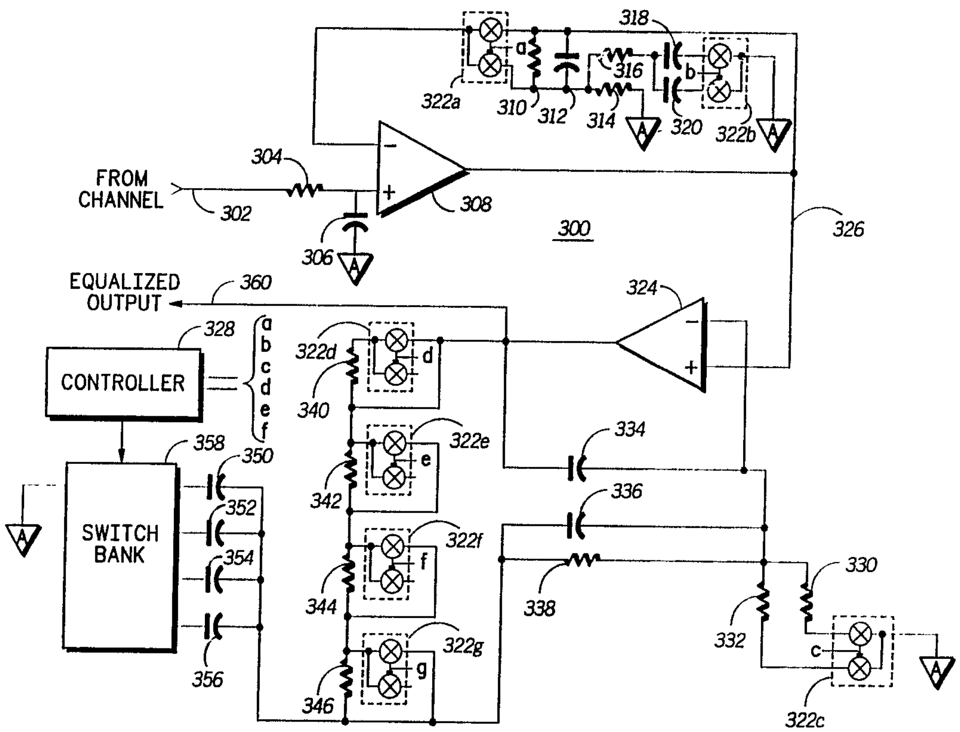
(54) Title: METHOD AND APPARATUS FOR RECEIVED SIGNAL EQUALIZATION



(57) Abstract

A bipolar return-to-zero signal received from a communication channel (302) is sampled (402) to provide signal information that is processed (328 and Fig. 5) to determine signal variation information. In accordance with this signal variation information, at least one operational parameter (a-g) of an equalization system (300) is varied.

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METHOD AND APPARATUS FOR RECEIVED SIGNAL EQUALIZATION

TECHNICAL FIELD

This invention relates generally to digital signal equalizers, and more specifically to those digital signal equalizers capable of varying operational parameters so as to optimize reception of a received signal.

BACKGROUND

One of the most persistent and difficult problems associated with the design and proper operation of a digital communication system is the effectiveness of equalization of the communication channel. As a practical matter, virtually every transmission media employed as a communication channel introduces some distortion into the signals travelling through the media. Typically, such distortion is caused by impedance mismatches, imperfect transmission characteristics of the media, or adverse transmission environments. For example, the communication channel commonly used by digital data services (DDS) comprises an unloaded four-wire communication channel that attenuates and band-limits information passing through the channel by an amount that varies depending upon the physical size of the wire, and the length of the communication channel. Accordingly, it is common for DDS receivers to employ some type of equalization in an attempt to counteract the effects of the channel on the received information.

Known equalizers operate based upon a model of the communication channel. Clearly, the better the model, the more effective the equalization. However, since one model may not effectively equalize all communication channels, it is common to adjust the gain and bandwidth performance of the equalizer in a stepwise manner so as to maximize received signal amplitude. Regrettably, this process cannot effectively compensate for all possible channel variations, and may lead to equalizer adjustments that do not optimally receive information from the communication channel. Accordingly, a need exists for a more effective communication channel equalizer and more effective equalization techniques.

SUMMARY of the INVENTION

Briefly, according to the invention, a signal received from a communication channel is sampled to provide signal information that is processed to provide a measure of signal variation. In accordance with this signal variation information, at least one operational parameter of an equalization means is varied.

BRIEF DESCRIPTION of the DRAWINGS

Figure 1 is an illustration of an ideal "eye" pattern.

Figure 2 is an illustration of a typical "eye" pattern.

Figure 3 is a block diagram of a signal equalizer suitable for use in the present invention.

Figure 4 is a block diagram of an equalization system in accordance with the present invention.

Figures 5a-5c are flow diagrams illustrating the operation of the equalization system of Figure 4.

DESCRIPTION of the PREFERRED EMBODIMENT

Referring to Figure 1, a bipolar return-to-zero signal received from an ideal communication channel forms an undistorted "eye" pattern symmetrically positioned about a reference (zero) level. Typically, the signal bit is sampled at a sampling point 10 so as to maximize received signal amplitude. This practice facilitates a correct decision as to what information level was transmitted (i.e., logical +1, logical -1, or logical zero).

Regrettably, Figure 2 illustrates a more typical "eye" pattern representing information received from a non-ideal communication channel. As can be seen, the phase and amplitude of the received information has been distorted by the communication channel. Depending upon the particular channel used, and the transmission environment, the decision as to what information level was transmitted may be reduced to a mere guess, which may frustrate the effective communication of information.

Referring to Figure 3, a block diagram of an equalizer 300 suitable for use with the present invention is shown. Operationally, a preferably bipolar return-to-zero signal 302 is received from a communication channel and buffered via a preferably active (308) preamplification network (304-320) that has various resistors and capacitors switched (322a and 322b) into and out-of the network so as to buffer or amplify the signal received from the communication channel.

The buffered/amplified signal 326 is filtered in a preferably active (324) filter network (330-358) that has a filter pole adjusted by switching various resistors and capacitors into and out-of the filter network (322c-322g and 358). In this way, at least one operational characteristic of the equalizer is varied by a controller 328, which preferably comprises an Intel 8031 or functional equivalent. Adjusting the filter pole modifies the equalizer bandwidth and will affect the phase and amplitude of the information signal received by all processing stages (i.e., receiver and/or decoder) following the equalizer 300.

All of the switches 322a-322g and a switching bank 358 are preferably controlled by the controller 328 with instructions stored in a memory or the like. In this way, the output 360 of the equalizer 300 is compensated to the distortion introduced by the communication channel, which in the preferred embodiment comprises an unloaded four-wire communication channel.

Naturally, the band-limits and filter pole variation possible will depend upon the values of the various resistors and capacitors used in any particular implementation of the equalizer 300. However, the resistor and capacitor values for the preferred embodiment are listed below in Table 1.

Table 1

Resistor 304	2.21 k ohms
Capacitor 306	.001 μ farads
Resistor 310	10 k ohms

Capacitor 312	470 Pico farads
Resistor 314	10 k ohms
Resistor 316	107 ohms
Capacitor 318	.05 μ farads
Capacitor 320	.0047 μ farads
Resistor 330	2.49 k ohms
Resistor 332	10 k ohms
Capacitor 334	470 Pico farads
Capacitor 336	680 Pico farads
Resistor 338	10 k ohms
Resistor 340	1.118 k ohms
Resistor 342	2.37 k ohms
Resistor 344	4.75 k ohms
Resistor 346	9.53 k ohms
Capacitor 350	.027 μ farads
Capacitor 352	.022 μ farads
Capacitor 354	.01 μ farads
Capacitor 356	.0047 μ farads

Referring to Figure 4, a block diagram of an equalization system 400 in accordance with the present invention is seen to employ the equalizer 300 of Figure 3. Accordingly, a bipolar return-to-zero signal 302 is received from the communication channel and the equalized 360 version thereof is sampled by a sample and hold circuit 402. In the preferred embodiment, sampling is performed at or near the zero-crossing points (10' of Figure 2) where the signal variation(s) of the received information is most pronounced (reasons for the preferred sampling point will hereinafter become more apparent). The equalized signal 360 is also processed by at least one peak detector 404, which preferably operates to determine at least one threshold level that may be used by receiver (and/or decoder) circuitry 406 to decide the information level of the received bipolar return-to-zero signal (i.e., logical +1, logical -1, or logical zero) which may be optionally rectified by conventional techniques (i.e., logical 1 or logical zero). Accordingly, the peak detector preferably operates to set the threshold at a point representing approximately the mid-point between a a reference level and a peak amplitude value achieved by the received signal.

According to the invention, the threshold level and received signal samples are selectively (408) routed to an analog-to-digital convertor 410, which provides representative digitized information to the controller 328. Using this information, the controller operates to determine some measure of signal variation. In the preferred embodiment, at least statistical variance information concerning the received signal is determined. Optionally, peak signal value, RMS value, average absolute value, or other such signal variation criteria may be used in accordance with the teachings of the present invention. In this way, the controller 328 may vary, program or otherwise adjust the equalizer 300 (via switch control lines a-g) in accordance with the variance information so as to set the equalizer to a setting corresponding to the minimum variance of the received signal. Those skilled in the art will appreciate that, ideally, signal variations (e.g., statistical variance) at the received signal zero-crossing should be zero (see Figure 1). However, in a practical embodiment, the received signal will vary (i.e., a non-zero variance) at the peak and the zero-crossing area such that some non-zero determinable signal variation value can be determined. The present invention prefers to determine statistical variance information and vary, adjust, or program one or more operational parameters of the equalizer so as to equalize the received signal at the point of minimum signal variation. Although either sampling point (10 or 10') may be used, the sampling point 10' is preferred since the signal variation(s) (e.g., statistical variance) is more pronounced at the zero-crossings, and therefore, greater resolution in the setting of the equalizer may be achieved.

Referring to Figures 5a-5c, the operation of the equalization system of Figure 4 may be explained. The procedure begins in step 500, where a counter and equalizer setting register are initialized (preferably to zero) using techniques known in the art. Following initialization, the threshold level is read by the controller 328 (step 502) as described in conjunction with Figure 4. Next, a wait state (step 504) is executed to allow a proper settling time interval to pass before the received signal is sampled (preferably at the zero-crossing point 10') (step 506). Steps 508 and 510 respectively accumulate a sum of the sample values and a sum of the squared sample values. That is, the current sample is accumulated with prior samples to form a sum of the samples. Also, the sample is mathematically squared (i.e., $(\text{sample})^2$) and accumulated with prior squared samples to form a sum of the squared samples. These accumulations will be later employed to determine the signal variation (i.e., statistical variance) information used to set the equalizer.

Decision 512 determines whether sampling is completed. According to the invention, a suitable number of samples must be taken in order to be able to accurately determine the bit error ratio of the received signal. If more samples are required, the counter is incremented and another sample is processed. Conversely, when sampling has been completed for the currently equalizer setting (as determined by the equalizer setting register), the routine proceeds to Figure 5b, where the statistical variance (step 518) is determined by applying known relationships to the sum of samples and sum of squared samples. After the signal variation information is known it is stored together with the peak value for the sample in any suitable memory or storage media.

The routine continues by decision 522 determining whether the variance information has been determined for all possible equalizer settings. If the maximum equalizer setting has not been reached, the equalizer setting register is incremented (step 524) and the counter is reset (step 526) before control is passed to step 514 of Figure 5a. Conversely, is the received signal variation information is known for all equalizer settings, the stored peak value information is sorted (checked) to find those peak values between two threshold limits (step 528). For those samples having a peak value in accordance with step 528, the signal variation (preferably statistical variance) information associated with those samples are evaluated (step 530) and the equalizer 300 has one or more operational parameters programmed, varied, or adjusted (step 532) so as to operate to equalize received signals based upon the lowest (minimum) signal variation criteria found. By adjusting the equalizer 300 in this manner, the bit error rate (BER) of the received information is enhanced, corresponding to a more optimum equalizer setting than was heretofore available through conventional equalization techniques.

What is claimed is:

CLAIMS

1. A method of equalizing a signal received from a communication channel, comprising the steps of:

(a) receiving the bipolar return-to-zero signal from the communication channel to provide a received signal;

(b) sampling at least a portion the received signal to provide signal information;

(c) processing the signal information to determine signal variation information;

(d) varying at least one operational parameter of an equalization means in accordance with the signal variation information.

2. The method of claim 1, wherein step (c) further comprises processing the signal information to determine statistical variance information.

3. The method of claim 1, wherein step (c) further comprises processing the signal information to determine peak value information.

4. The method of claim 3, wherein step (c) further comprises processing the signal information to determine signal variation information from signal information determined to reside within an range of the peak value information.

5. The method of claim 1, wherein step (b) further comprises sampling at least a portion the received signal substantially at signal zero-crossing points to provide the signal information.

6. A method of equalizing a signal received from a communication channel, comprising the steps of:

(a) receiving a bipolar return-to-zero signal from the communication channel to provide a received signal;

(b) sampling at least a portion the received signal to provide signal information;

(c) processing the signal information to determine signal variation information;

(d) varying at least one operational parameter of an equalization means in accordance with the signal variation information so as to set the equalization means operating point in accordance with a minimum signal variation point.

7. The method of claim 6, wherein step (c) further comprises processing the signal information to determine statistical variance information.

8. The method of claim 6, wherein step (c) further comprises processing the signal information to determine peak value information.

9. The method of claim 8, wherein step (c) further comprises processing the signal information to determine signal variation information from signal information determined to reside within an range of the peak value information.

10. The method of claim 6, wherein step (b) further comprises sampling at least a portion the received signal substantially at signal zero-crossing points to provide the signal information.

11. A signal equalization system, comprising:

means for receiving a bipolar return-to-zero signal from a communication channel to provide a received signal;

means for sampling at least a portion the received signal to provide signal information;

means for processing the signal information to determine signal variation information; and

means for varying at least one operational parameter of an equalization means in accordance with the signal variation information.

12. The signal equalization system of claim 11, which includes means for receiving or decoding the received signal.

13. The signal equalization system of claim 11, which includes means for processing the signal information to determine peak value information.

14. The signal equalization system of claim 11, which includes means for processing the signal information to determine signal variation information from signal information determined to reside within an range of the peak value information.

15. The signal equalization system of claim 11, wherein the sampling means further comprises means for sampling at least a portion the received signal substantially at signal zero-crossing points to provide the signal information.

16. A signal equalization system, comprising:

means for receiving a bipolar return-to-zero signal from a communication channel to provide a received signal;

means for sampling at least a portion the received signal to provide signal information;

means for processing the signal information to determine signal variation information; and

means for varying at least one operational parameter of an equalization means in accordance with the signal variation information so as to set the equalization means operating point in accordance with a minimum signal variation point.

17. The signal equalization system of claim 16, which includes means for receiving or decoding the received signal.

18. The signal equalization system of claim 16, which includes means for processing the signal information to determine peak value information.

19. The signal equalization system of claim 16, which includes means for processing the signal information to determine signal variation information from signal information determined to reside within an range of the peak value information.

20. The signal equalization system of claim 11, wherein the sampling means further comprises means for sampling at least a portion the received signal substantially at signal zero-crossing points to provide the signal information.

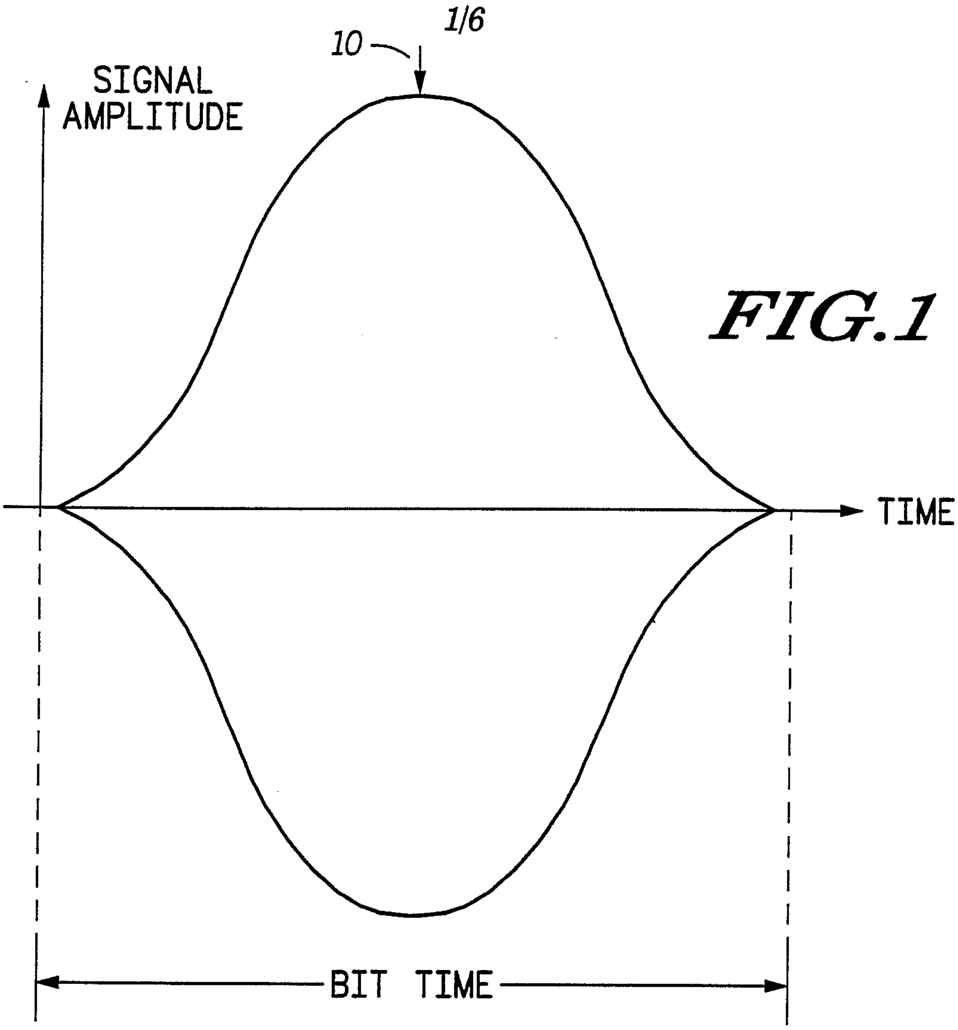
10
SIGNAL
AMPLITUDE
TIME
BIT TIME

FIG.1

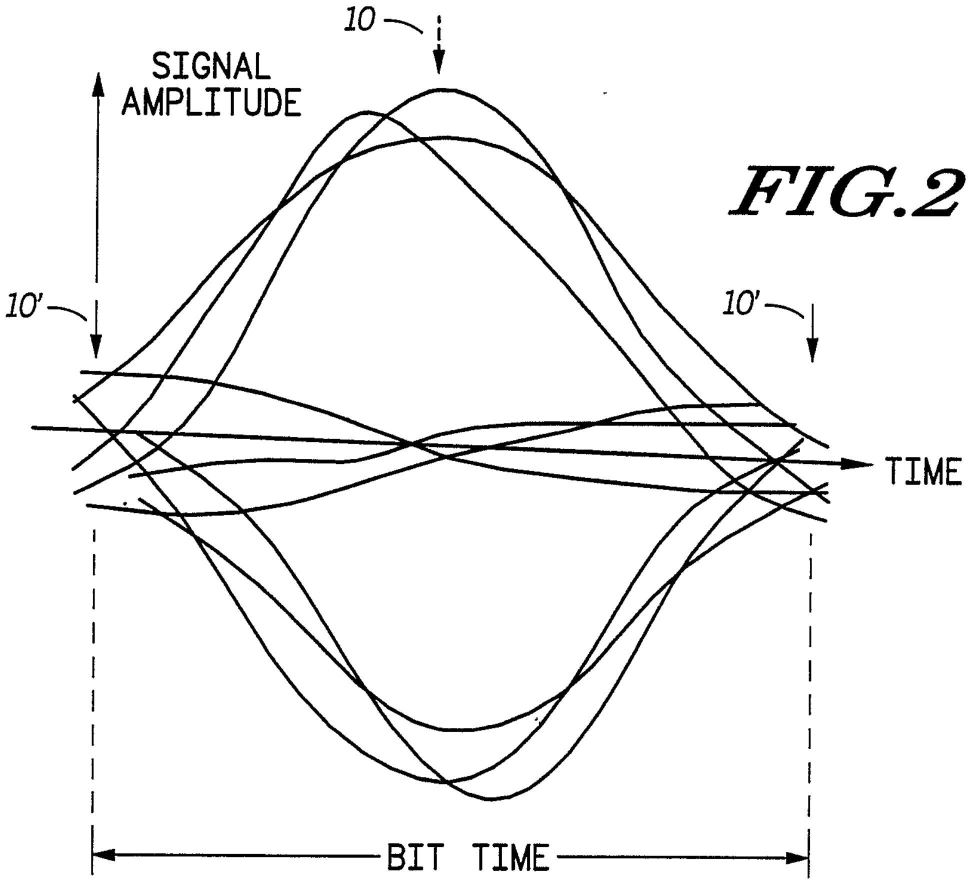
10
SIGNAL
AMPLITUDE
10'
10'
TIME
BIT TIME

FIG.2

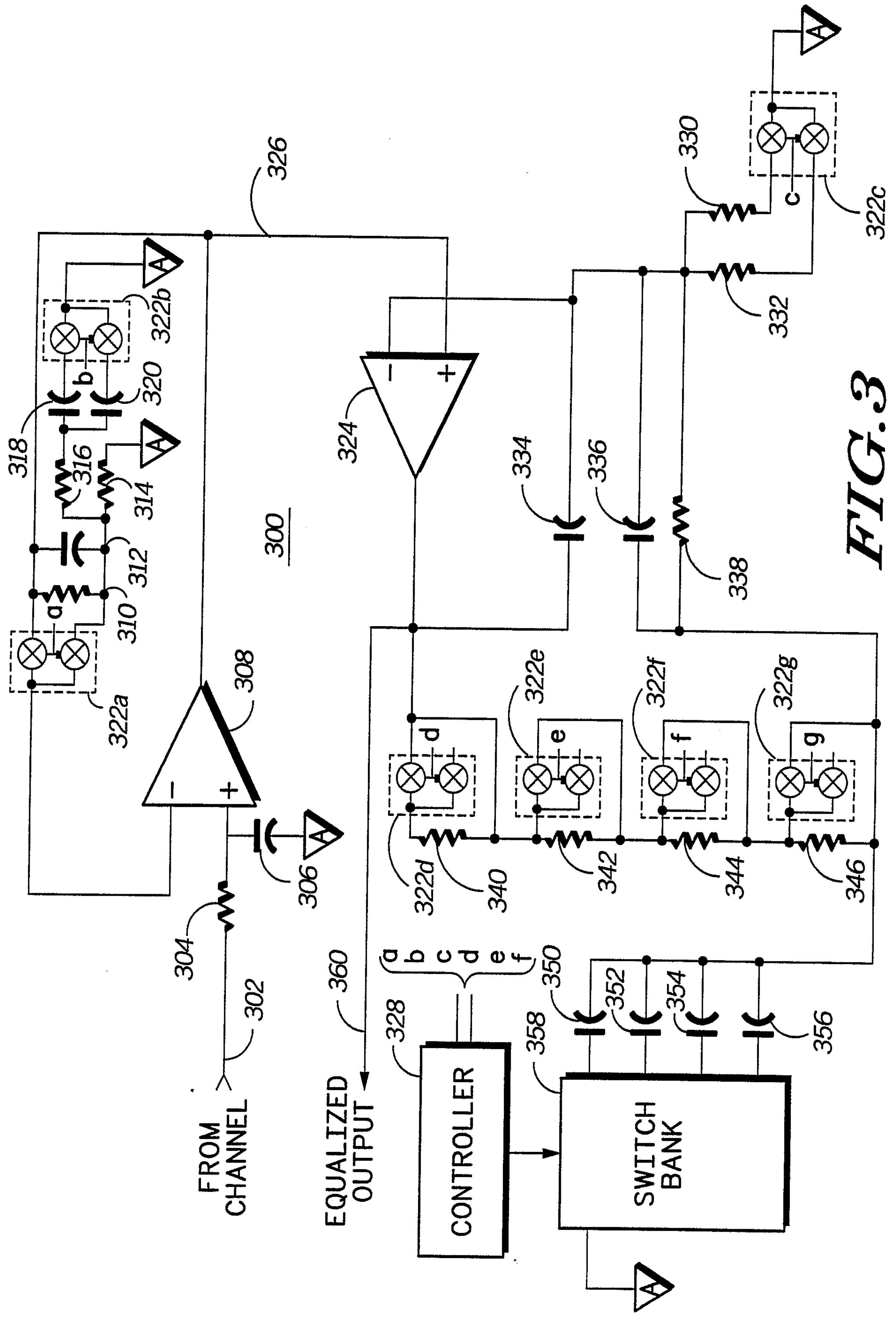
FROM CHANNEL
EQUALIZED OUTPUT
CONTROLLER
SWITCH BANK
300
302
304
306
308
310
312
314
316
318
320
322a
322b
322c
322d
322e
322f
322g
324
326
328
330
332
334
336
338
340
342
344
346
350
352
354
356
358
360
a
b
c
d
e
f
g

FIG.3

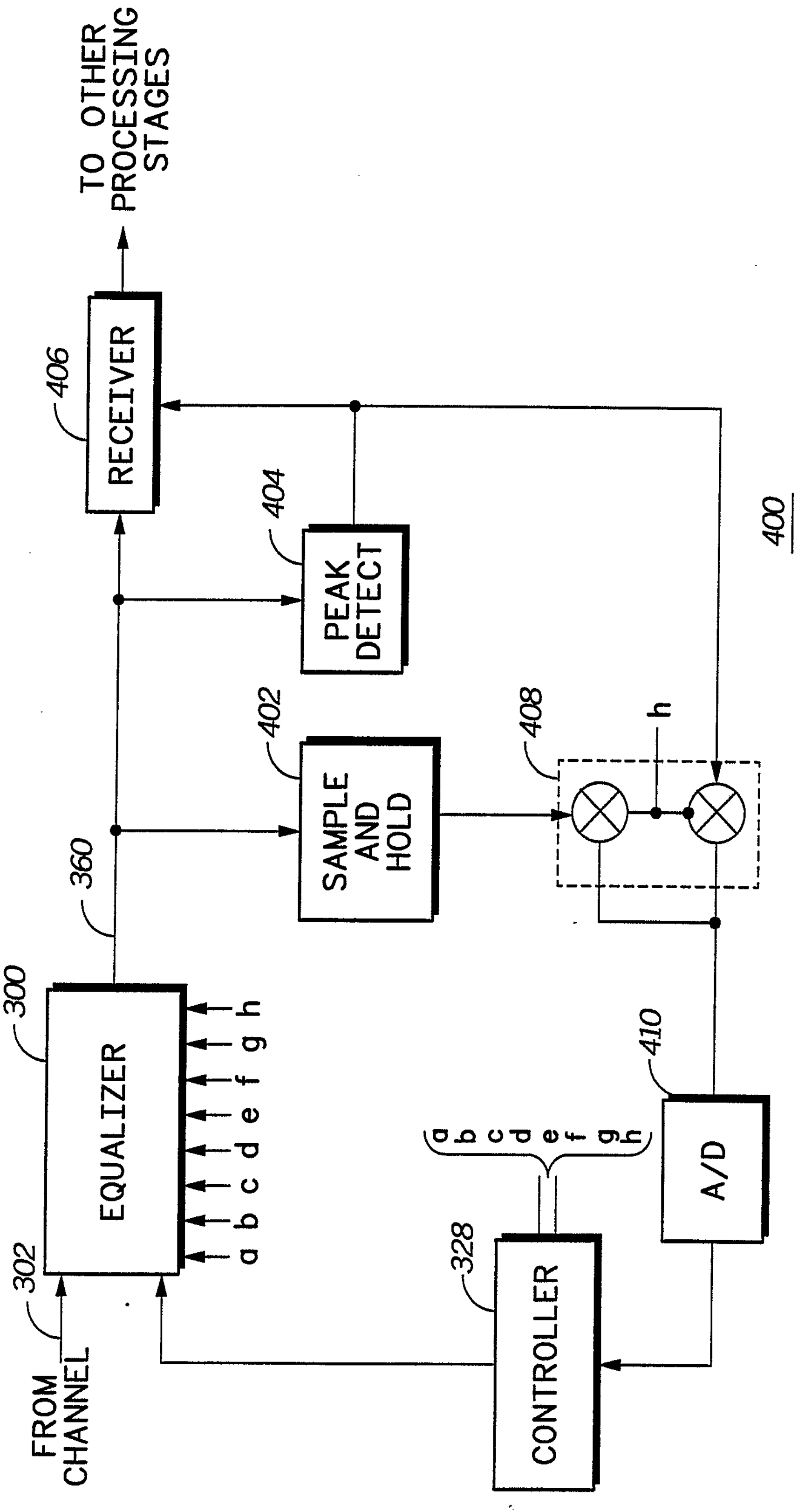
TO OTHER PROCESSING STAGES
406
RECEIVER
404
PEAK DETECT
402
SAMPLE AND HOLD
408
h
360
300
EQUALIZER
a b c d e f g h
302
FROM CHANNEL
410
A/D
328
CONTROLLER
a b c d e f g h
400

FIG. 4

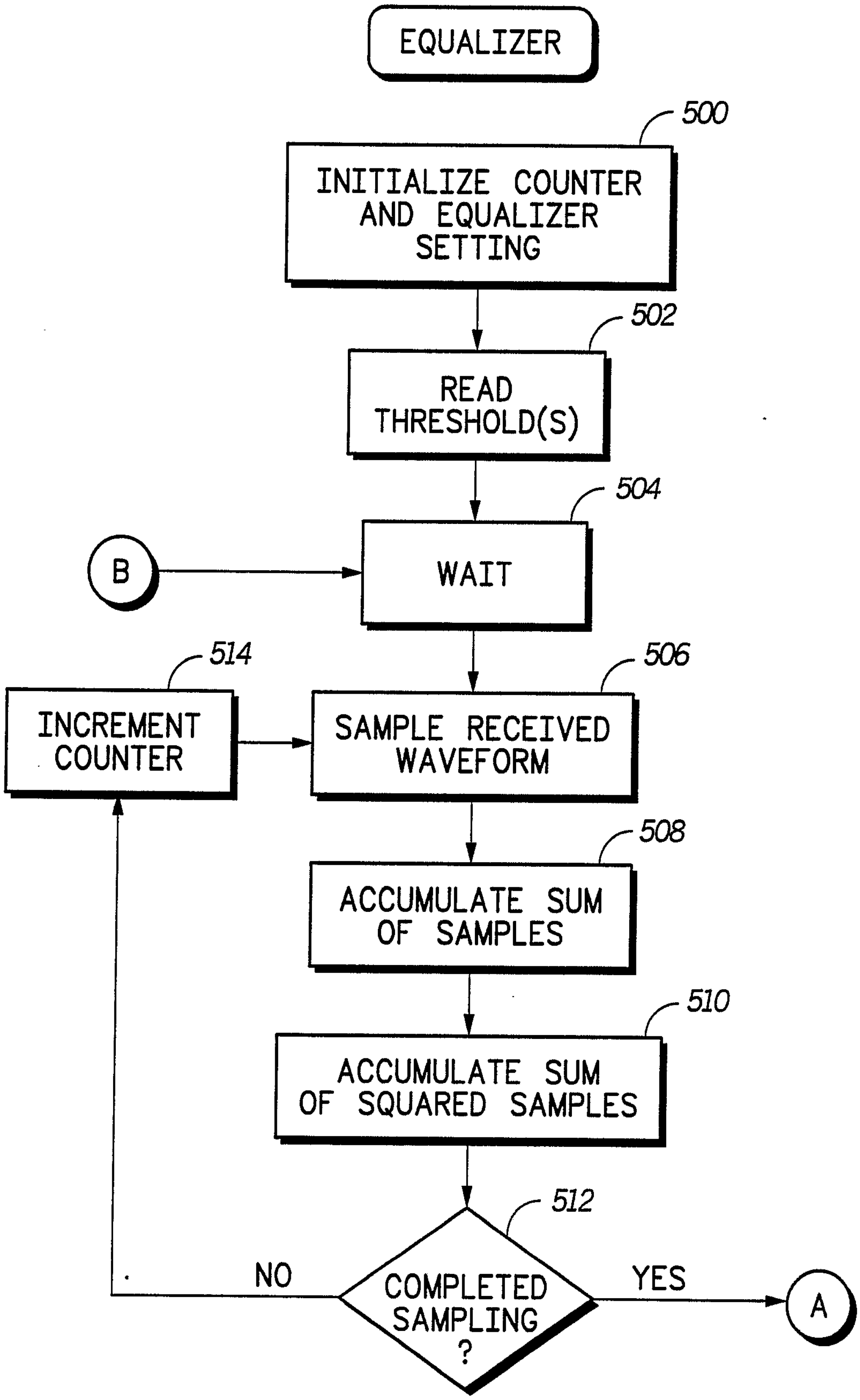
EQUALIZER
500
INITIALIZE COUNTER AND EQUALIZER SETTING
502
READ THRESHOLD(S)
504
B
WAIT
514
INCREMENT COUNTER
506
SAMPLE RECEIVED WAVEFORM
508
ACCUMULATE SUM OF SAMPLES
510
ACCUMULATE SUM OF SQUARED SAMPLES
512
NO
COMPLETED SAMPLING ?
YES
A

FIG. 5A

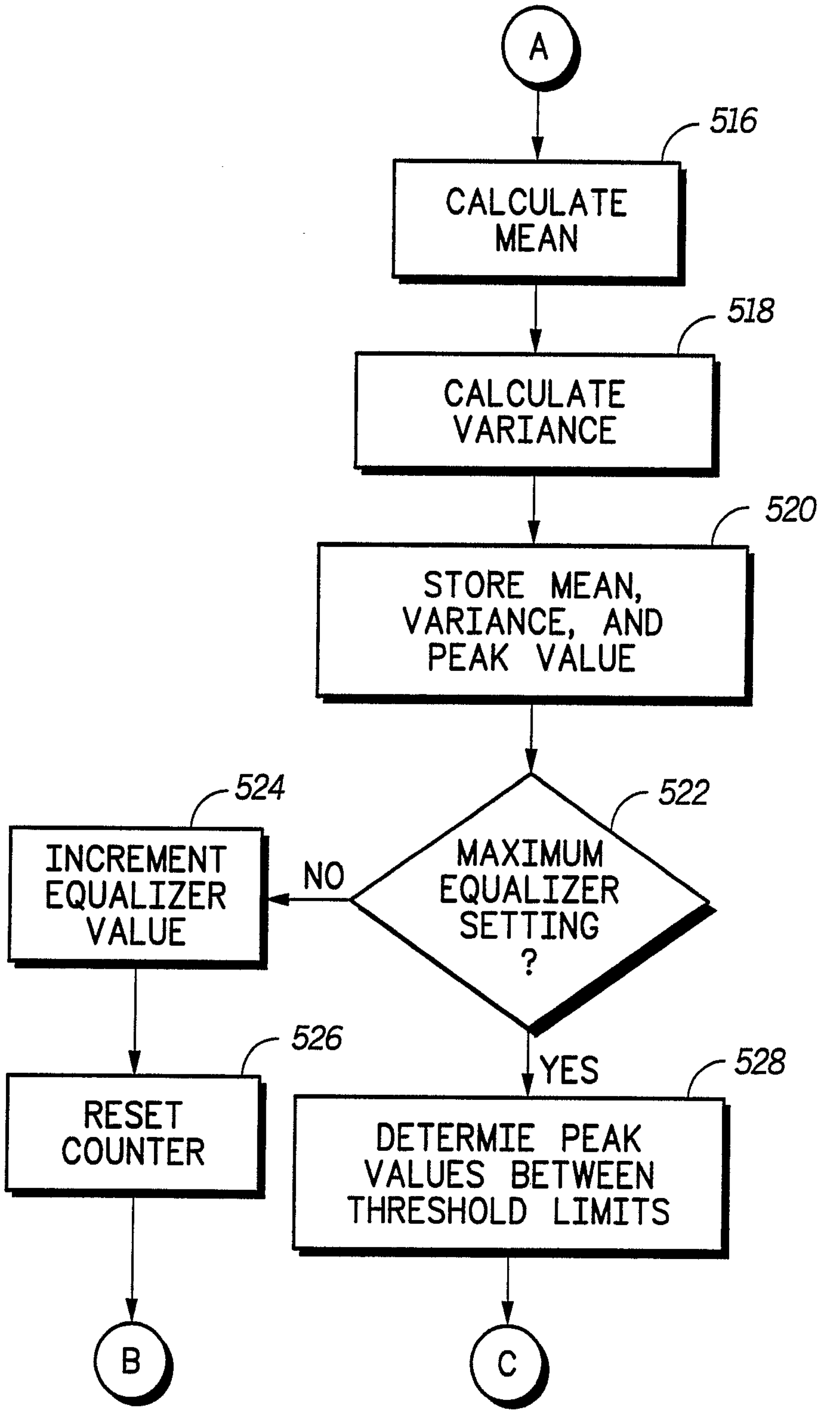
A
516
CALCULATE MEAN
518
CALCULATE VARIANCE
520
STORE MEAN, VARIANCE, AND PEAK VALUE
522
MAXIMUM EQUALIZER SETTING ?
NO
524
INCREMENT EQUALIZER VALUE
526
RESET COUNTER
B
YES
528
DETERMIE PEAK VALUES BETWEEN THRESHOLD LIMITS
C

FIG.5B

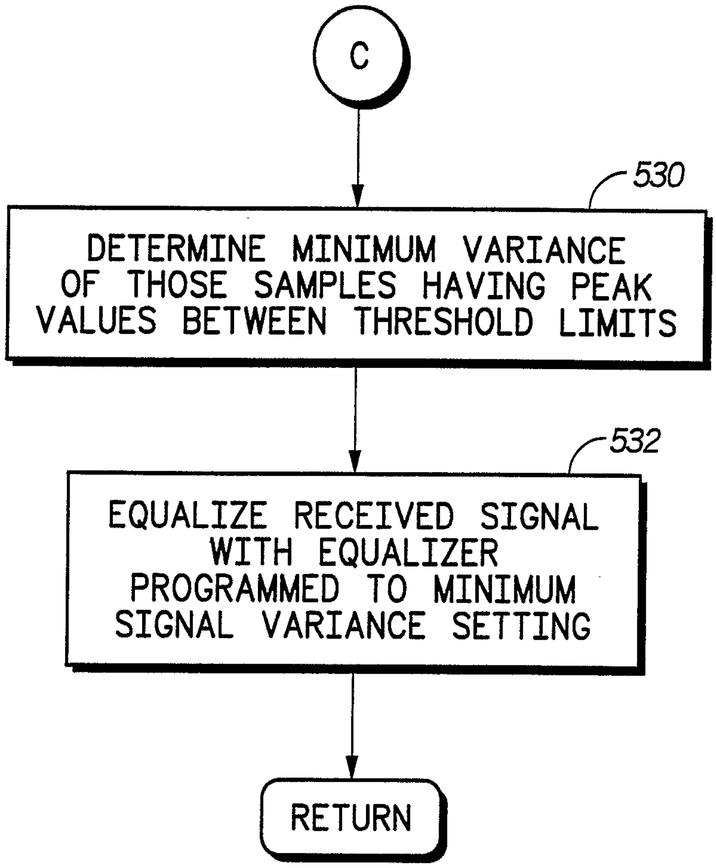
C
530
DETERMINE MINIMUM VARIANCE OF THOSE SAMPLES HAVING PEAK VALUES BETWEEN THRESHOLD LIMITS
532
EQUALIZE RECEIVED SIGNAL WITH EQUALIZER PROGRAMMED TO MINIMUM SIGNAL VARIANCE SETTING
RETURN

FIG.5C

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/04654

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

INT. CL.(5): H03H 7/30
US CL : 375/12; 333/18; 364/724.2

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
U.S	375/11,12,14,18,99,101; 33/18,28R, 379/39,414,398; 364/724.2

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]
Y	US, A, 4,943,789 (SURIE) 24 JANUARY 1990 See fig. 1, and column 4, lines 52-67.	1-20
Y	US, A, 4,545,060 (ARNON) 01 OCTOBER 1985 See abstract.	1-20
Y	US, A, 3,638,122 (GIBSON) 25 JANUARY 1972 See abstract.	1-20

* 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

"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

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
01 OCTOBER 1991	30 OCT 1991
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ISA/US	For STEPHEN CHIN NGUYEN NGOC-HO INTERNATIONALDIVISION