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

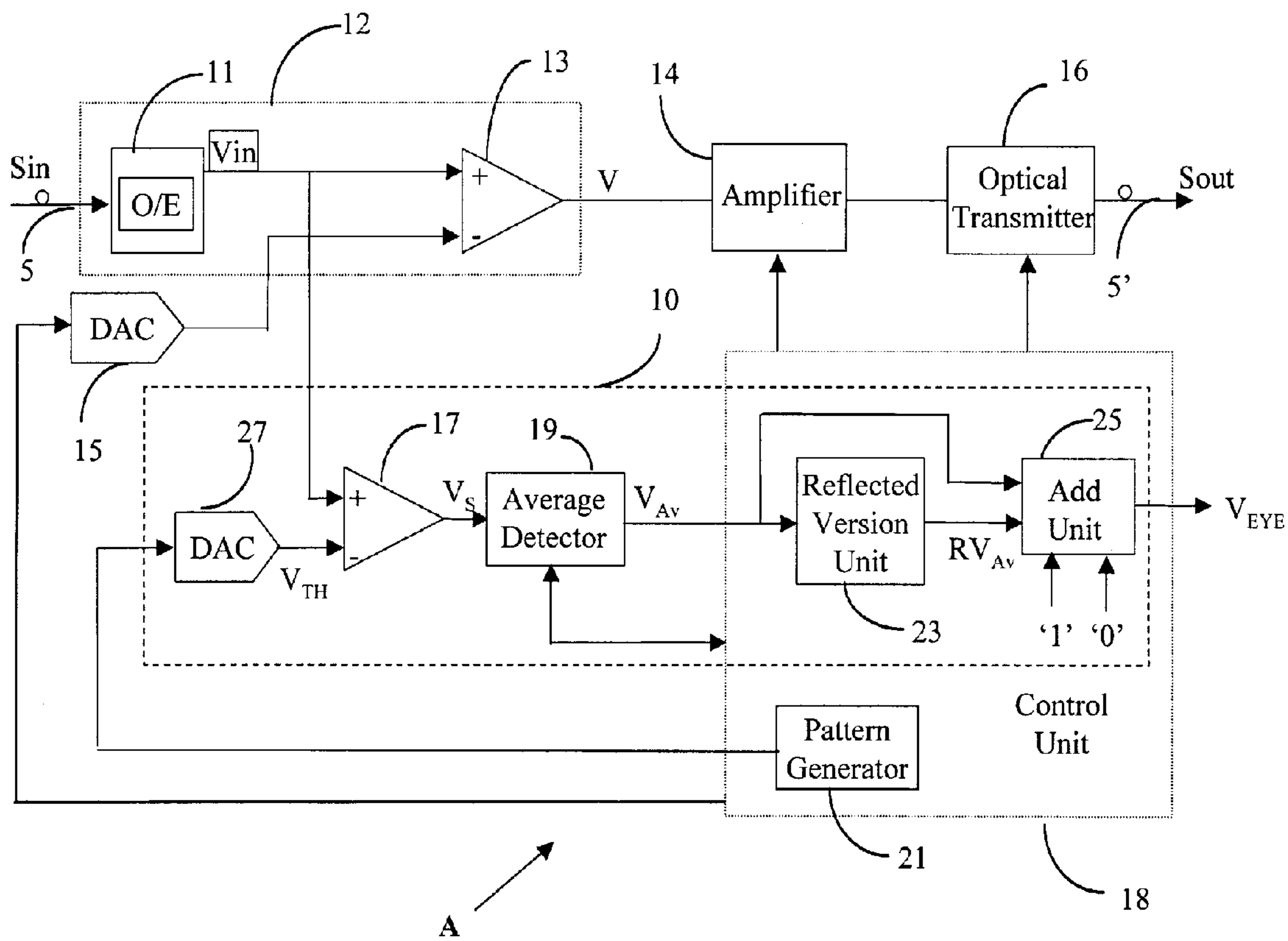
(21) (A1) **2,249,800**
(22) 1998/10/06
(43) 2000/04/06

(72) ANSLOW, Peter Jeremy, GB
(72) HABEL, Richard Achille, GB
(72) SOLHEIM, Alan Glen, GB
(71) NORTEL NETWORKS CORPORATION, CA

(51) Int.Cl.^{6} H04B 10/08

(54) **MONITEUR DE QUALITE OPTIQUE POUR REGENERATEUR 2R**

(54) **EYE QUALITY MONITOR FOR A 2R REGENERATOR**



(57) The method of monitoring the quality of an optical signal at the site of a 2R or 1R regenerator, without performing a clock recovery operation, is based on slicing the recovered voltage with a threshold voltage, manipulated according to a pattern, and averaging the output of the slicer. An eye diagram is simulated by a diagram representing the average voltage versus the threshold voltage.

ABSTRACT

The method of monitoring the quality of an optical signal at the site of a 2R or 1R regenerator, without performing a clock recovery operation, is based on slicing the recovered voltage with a threshold voltage, manipulated according to a pattern, and averaging the output of the slicer. An eye diagram is simulated by a diagram representing the average voltage versus the threshold voltage.

EYE QUALITY MONITOR FOR A 2R REGENERATOR

BACKGROUND OF THE INVENTION

Field of the Invention

The invention is directed to monitoring the quality of a signal received over an optical network, and in particular, to an eye quality monitor for a data regenerator.

Background Art

Optical signals suffer between the transmitter and receiver from two principally different groups of degradations that will cause bit errors: noise and distortion. The causes, behavior and remedies for these groups are different. The primary sources of noise are the receiver noise (i.e. shot, thermal), optical bandwidth, interferometric cross-talk, laser noise, reflections, etc.

Distortion is defined as any inaccurate replication of a signal transmitted over a communication link, and could be referred to any network element (NE) along the link. The pulse distortion in a fiber optic system may, for example, be caused by some parts of the light pulses following longer paths (modes) than other parts. The primary sources for distortion are chromatic dispersion, inter-symbol interference, non-linearity of the elements and transmission medium, receiver frequency response, etc. In addition, in amplified wavelength division multiplexed (WDM) systems, the transmission characteristics vary from one channel to another due to the non-flat gain and noise profile of erbium-doped fiber amplifiers (EDFAs). Distortion can be measured by assessing the difference between the wave shape of the original signal and that of the signal at the network element of interest, after it has traversed the transmission link.

In the last decade, the transmission rates of data signals have increased very rapidly, along with the demand for receivers with high sensitivity. For high rate transmission, such as rates over 10 Gb/s, the signal corruption introduced by the transmission channel is a critical parameter. Numerous methods have been proposed to overcome the difficult problem of measuring or estimating the signal quality. However, they are often based on the same basic principles, or use the same equipment, and differ mainly in how the primary measurement is analyzed.

Some signal quality monitoring methods require detection, synchronization, demultiplexing, and then some analysis of the sampled signal. Even in the best cases, the results are uncertain and it is difficult to ascertain if the monitoring method mimics the behavior of the final receiver.

Other methods are based on power monitoring of each channel. As these are averaging methods, they do not sense the pulse distortion. Moreover, the precision required in the spectral measurement is prohibitive in itself.

The extent of signal degradations may be directly measured using an eye closure diagram, which is the graphic pattern produced on an oscilloscope when the detected signal is applied to the vertical input of an oscilloscope and is synchronized with the instrument time base. Changes in the eye opening indicate intersymbol interference, amplitude irregularities, or timing problems. For a binary signal, the eye diagram has a single eye, which is open or closed to an extent determined by the signal degradation. An open eye pattern is desired.

Currently, the time base of the oscilloscope is triggered using a clock signal necessarily extracted from the transmission in order to capture the eye diagram. Consequently, a network provider cannot measure the quality of the optical signal without a clock extract circuit. This prior art method also fails to separate the eye closure due to distortion from that due to noise.

A receiver regenerates the signal presented to it by interpreting the levels of the received signal according to a decision level, defined also as threshold level, or as a slicing level. Generally, binary data regenerators are provided with a fixed threshold level selected so as to yield the best error rate at a predetermined signal power level.

When the extent of signal degradations must be assessed, the current way of doing so is to recover the clock at the site of the regenerator, thus destroying bit rate transparency. Such methods not only increase the complexity, and hence the cost of the equipment at the regenerator site, but also are dependent on the rate of the signal traveling along the link.

For example, United States Patent No. 4,823,360 (Tremblay et al., issued April 18, 1989 and assigned to Northern Telecom Limited) discloses a device for measuring quality of a signal travelling along an optical fiber, using eye closure. The device described in this U.S. patent provides the receiver with three threshold levels for recovering data. Two of the thresholds V1 and V2 are obtained by setting them above and below the center of the eye for a preset error rate, and the third threshold is provided in a selected relationship to the other two. If V1 and V2 are set for equal 'error' rates, then the central circuit operates near the middle of the eye and hence with a negligible true error rate.

The technique described in the '360 patent is based on recovering the signal clock, i.e. implies knowing the rate of the channel. In addition, the measurement does not give an indication as to the separate contribution of the noise and the distortion.

However, not all regenerators installed in a transmission link are provided with means for recovering the clock. From this point of view, regenerators may be classified as 1R, that only regenerate the signal, 2R that regenerate and reshape the signal, and 3R, that regenerate, reshape and retime the signal. 2R regenerators are used, for example, at sites where the transmission signal needs to be converted from one wavelength (e.g. 1.3 μm short reach) to another (e.g. a wavelength on the ITU grid suitable for dense WDM).

There is a need to measure the quality of an optical signal, while maintaining bit rate transparency, so that the measurements may be applied to signals of various rates.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a method and apparatus for measuring the quality of a signal of a communication network, that alleviate totally or in part the drawbacks of the current methods and apparatuses.

It is another object of the invention to provide a method and apparatus for measuring the quality of a signal in a communication network which are bit rate transparent.

Still another object of the invention is to obtain a measurement of the quality of the optical signal, which can be used to assign the cause of errors to noise or to distortion.

According to one aspect of the invention, there is provided a method of monitoring the quality of an optical signal at a regenerator site, without performing a clock recovery operation, comprising, generating a threshold voltage V_{TH} to take a plurality of values according to a pattern, applying the threshold voltage V_{TH} on a first input of a slicer, and applying an input voltage V_{in} on a second input of the slicer to obtain a slicer output voltage V_S, the input voltage V_{in} being an electrical equivalent of the optical signal, for the plurality of threshold voltages, obtaining a corresponding plurality of associated parameters; and processing all the associate parameters as a function of all the threshold voltages to simulate an eye diagram of the optical signal.

According to a further aspect of the invention, there is provided an eye quality monitor for a data regenerator for providing a simulated eye diagram of an optical signal without performing a clock recovery operation, comprising a pattern generator for generating a threshold voltage V_{TH} according to a pattern, a slicer, for receiving a the threshold voltage V_{TH} on a first input and an input voltage V_{in} on a second input, and generating a slicer output voltage V_S, the input voltage V_{in} being an electrical equivalent of the optical signal, an average detector for providing an associated average voltage V_{AV} of the slicer output voltage V_S corresponding to the a threshold voltage V_{TH}, and means for processing the average voltages V_{AV}, to simulate an eye diagram of the optical signal.

An important advantage of the present invention is that the quality of the signal can be measured with no need to recover the bit rate of the signal, which is very important in the case of 2R receivers, where the clock is not available. This results in important savings on equipment at such receivers.

Another advantage of the invention is that it can be applied to various signal rates and is independent of the technology used. Thus, the method can be applied to the existing SONET technology, and also to emerging optical transport networks (OTN).

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of the preferred embodiments, as illustrated in the appended drawings, where:

Figure 1 shows the block diagram of a repeater site equipped with an eye quality monitor according to the invention;

Figures 2A to 2C show the time diagrams for a triangular input signal applied to the eye quality monitor of Figure 1;

Figure 3 shows the ideal transfer function of the eye monitor, i.e. the variation of the output voltage from the eye monitor with the threshold voltage for a triangular input signal;

Figures 4A and 4B show how the eye diagram is reconstructed for a triangular input signal;

Figures 5A to 5C show the simulated eye monitor transfer function for transmitted signals with various degrees of dispersion and noise. Figure 5A refers to an undistorted signal, Figure 5B, to a signal with eye closure due to dispersion, and Figure 5C, to a signal with eye closure due to polarization mode dispersion (PMD);

Figure 6A to 6C show reconstructed eye diagrams for the signals in Figures 5A to 5C;

Figure 7 is another embodiment of the eye monitor according to the invention; and

Figure 8 is still another embodiment of the eye monitor according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 shows an eye monitor **10** provided at a regenerator site A for measuring the quality of the eye of an optical signal S_{in}. In this Figure, an incoming optical signal S_{in} arrives at site A over a fiber span **5** and an outgoing optical signal S_{out} leaves site A over fiber span **5'**. Site A is equipped with an optical receiver **12**, an amplifier **14** and an optical transmitter **16**, which form a 2R regenerator, adapted only to regenerate and reshape the signal. As such, no clock recovery circuitry is provided at site A. Receiver **12** comprises an optical-to-electrical converter **11**, for converting S_{in} into the electrical equivalent input signal V_{in}. A comparator

13 compares V_{in} with a decision level to separate the signal from noise. The recovered electrical signal V is then amplified in amplifier **14**. Optical transmitter **16** receives the amplified variant of V, modulates it over an optical carrier and transmits the optical outgoing signal S_{out} over fiber **5'**.

Site A is also equipped with a control unit **18** which provides the decision level for receiver **12** and controls operation of receiver **12**, amplifier **14**, and transmitter **16**. A digital-to-analog converter (DAC) **15** converts the slicing signal output by control unit **18** into the decision level for receiver **12**.

Receiver **12**, amplifier **14** and transmitter **16** are illustrated for showing the connection of the eye monitor **10**.

Eye monitor **10** comprises a slicer **17** and an average detector **19**. The slicer **17** receives a threshold voltage V_{TH} on the negative input and input signal V_{in} and on the positive input. The slicer output V_S of the slicer **17** is above logic 'zero' whenever V_{in} is higher than the threshold voltage V_{TH}.

Average detector **19** receives V_S and provides the mean value V_{AV} of slicer output V_S over a given interval. This mean value decreases when the number and duration of pulses in V_S decreases. In general, the closer V_{TH} is to the maximum value of V_{in}, the shorter the time when V_{in} is above V_{TH}, which results in shorter pulses for V_S. Shorter V_S pulses means lover V_{AV} values.

Figures 2A to 2C show time diagrams for a triangular input signal V_{in} applied to the eye quality monitor of Figure 1, and Figure 3 illustrates the ideal transfer function of the eye monitor, i.e. the variation of V_{AV} with the threshold voltage V_{TH} for a triangular input signal.

When slicing level V_{TH} is at a level of 50% of the level of a logic "1", the mean value of V_S is 0.5. This is shown in Figure 2A. If the slicing level is moved up to 75% of the "1" level, the mean of V_S becomes 0.375, as shown in Figure 2B. If the slicing level is moved up to 99.9% of the "1" level, the mean of V_S becomes 0.25, shown in Figure 2C.

Figure 3 illustrates a V_{AV} - V_{TH} diagram for a triangular input signal. Both V_{AV} and V_{TH} are normalized with respect to the "1" level of V_{in}. A value of V_{AV} = .875 is approximated for a threshold V_{TH} corresponding to

V_{TH} = 0 ("long 0s threshold) and a V_{AV} = .125 is approximated to a threshold corresponding to V_{TH} = 1 ("long 1s threshold"). The points marked with A, B and C correspond to the mean values of V_S in Figure 2A, 2B and respectively 2C.

To obtain the V_{AV} - V_{TH} diagram, the threshold voltage V_{TH} is linearly swept across the entire range of the output of average detector **19**, V_{AV}. A pattern generator **21** also shown in Figure 1, gives various values to the threshold voltage V_{TH} according to a pattern. In this example, pattern generator **21** is illustrated as being part of control unit **18**, where it can be implemented in software. Pattern generator **21** may also be provided as an independent unit, so that a threshold voltage V_{TH} as necessary for the invention may be obtained by any other known means.

The signal at the output of block **19** is shown in Figure 4A, illustrating diagrams a, b, c and d obtained with the same procedure of linearly increasing the threshold voltage form 0% to 100% of V_{AV}, and repeating this pattern. These diagrams are similar to the V_{AV} - V_{TH} diagram shown in Figure 3, with the abscissa and the ordinate axes interchanged, and the values of V_{AV} scaled by a factor of 2. The diagrams are preferably one bit apart.

The average voltage thus obtained is input to a reflected version unit **23** that provides a variant of the average voltage, "reflected" with respect to the V_{TH} axis of coordinates. This reflected variant is denoted herein with RV_{AV}. A succession of reflected variants is also illustrated on Figure 4B, where diagrams denoted with a', b' and respectively c', are reflected versions of diagrams a, b and c.

To construct the eye of the signal, the output of the average detector **19** and the output of the reflected version unit **23** are added in add unit **25**, together with lines "1" and "0" at 100% and at 0% respectively. The output of the add unit **25** is the reconstructed eye for V_{in}, which is denoted on Figure 1 with V_{EYE}.

The reflected variants may be obtained in any suitable way, in software or in hardware. It is to be understood that the reflected variants may be obtained by linearly decreasing the threshold voltage V_{TH} across the entire range of the average voltage V_{AV}, rather than calculating the reflected variants.

It is to be understood that units **23** and **25** can also be implemented as separate units, or can be implemented in control unit **18**, as shown in Figure 1. Preferably, control unit **18** is a microcontroller. A DAC **27** is also needed to convert the digital value of V_{TH} into the analog value applied at the input of slicer **17**.

Figures 5A-5C shows the transfer function V_{TH} - V_{AV} of the slicer measured with and without noise, and for input signals V_{in} with various grades of distortion. The transfer functions in Figure 5A are prepared for an undistorted of V_{in}. The transfer functions in Figure 5B are for a V_{in} with dispersion, and in Figure 5C, for a V_{in} with polarization mode dispersion (PMD).

Figure 6A to 6C show simulated eye diagrams for the signals V_{in} used for preparing the transfer characteristics of the slicer shown in Figures 5A to 5C, i.e. for an undistorted signal, a signal with dispersion and a signal with PMD. Superimposed on the eye diagrams for V_{in} are the reconstructed eyes V_{EYE} from the invention both with and without noise added to the signal V_{in}.

The results could be communicated by control unit **18** to the network management system, or they could be used to raise an alarm when the signal quality is under a provisioned value. This provisioned value may be any parameter defining the size of the eye.

Other implementations of the eye quality monitor are also possible based on similar principles, as shown in Figures 7 and 8.

Figure 7 shows another embodiment of the eye monitor according to the invention. The output V_S of slicer **17** is applied to a frequency counter **31**, which counts the number of times V_{in} rises above V_{TH} in a given period. The threshold V_{TH} is varied to cover the entire range of V_{in}, using a microcontroller shown at **18**. The output of the microcontroller **18** is converted into an analog value by a DAC **25**, so that V_{TH} takes as many values as necessary for a given resolution. The values measured by the frequency counter **31** are provided to microcontroller **18**.

As in the previous case, a transfer characteristic is plotted, this time a 'frequency count (F)'-'threshold voltage (V_{TH})' diagram, by varying V_{TH} for a given V_{in} and measuring the corresponding values of the frequency counter **31**. F is plotted in relative units with respect to the maximum value of the counter for the respective V_{in}. V_{TH} is plotted relative to the peak-to-peak voltage.

The transfer characteristics are interpreted to determine a measure of the distortion of the eye. This method is still under investigation for determining what other parameters of V_{in} may be determined on F- V_{TH} diagrams.

Figure 8 shows the block diagram of still another embodiment of the eye quality monitor according to the invention. In this embodiment, the optical incoming signal V_{in} is fed to one input of slicers **17** and **17'**, the second input of the slicers receiving a corresponding threshold V_1, V_2. V_1 and V_2 are received from microcontroller **18** and a respective first and second DAC **25** and **25'**. The output V_{S1} of slicer **17** and output V_{S2} of slicer **17'** are fed to an exclusive OR gate **35**, and the output V_S of the XOR gate is averaged to obtain V_{AV} in average detector **19**. As is well known, the output of XOR gate **35** becomes 'logic 1' whenever one input is 'logic 1' and the other is 'logic 0', and the output is 'logic 0' whenever the inputs are both 'logic 1' or 'logic 0'.

Appropriate manipulation of thresholds V_1 and V_2 results in an average output V_{AV} that estimates the probable eye shape of the optical signal with sufficient accuracy for determining the quality of transmission.

One method of exploring various aspects of the eye diagram of V_{in} according to the embodiment of Figure 8 is performed by first setting V_1 to a voltage above signal V_{in}, therefore setting one input to XOR gate **35** permanently low. Threshold V_2 is then set so that the output of average detector **19** V_{AV} is 0.5. In other words, V_S is 'logic 1' for half the time and "0" for half the time. The value measured will correspond to the '50% level' on the eye diagram.

Next, threshold V_2 is set to a voltage above signal V_{in} and the settings for V_1 required for values of V_{AV} of 0.125 and 0.875 are determined. The values measured correspond to the 87.5% level and the 12.5% level on the eye diagram.

V_2 is then returned to the value corresponding to a V_{AV} of 0.5, and V_1 is swept between the 0.125 and 0.875 values while measuring the averaged output at each point.

An estimation of the average eye shape may now be obtained by plotting various values of the V_1 vs $(0.25+ V_S)*2$ when $V_1 > V_2$ and V_1 vs $(0.25- V_{out})*2$ when $V_1 < V_2$.

Still another way of obtaining information about the eye of V_{in} is to scan V_1 and V_2 through the eye with a small offset of for example 2%.

WE CLAIM

1. A method of monitoring the quality of an optical signal at a regenerator site, without performing a clock recovery operation, comprising:

generating a threshold voltage V_{TH} to take a plurality of values according to a pattern;

applying said threshold voltage V_{TH} on a first input of a slicer, and applying an input voltage V_{in} on a second input of said slicer to obtain a slicer output voltage V_S, said input voltage V_{in} being an electrical equivalent of said optical signal;

for said plurality of threshold voltages, obtaining a corresponding plurality of associated parameters; and

processing all said associate parameters as a function of all said threshold voltages to simulate an eye diagram of said optical signal.

2. A method as claimed in claim 1, wherein said parameter is an associated average voltage providing the average value of said slicer output voltage V_S.

3. A method as claimed in claim 2, further comprising:

normalizing all said threshold voltages, and said associated average voltages with respect to the logic 1 level of said input voltage V_{in};

plotting a $V_{AV} - V_{TH}$ diagram using said normalized threshold voltages and said normalized associated average voltages;

comparing said V_{AV} -V_{TH} diagram with a reference V_{AV} -V_{TH} diagram to distinguish the effect of the noise from the effect of the distortion on said optical signal.

4. A method as claimed in claim 2, wherein said step of generating comprises:

providing a maximum threshold voltage above the maximum value of said input voltage V_{in} for obtaining a long one's value, and providing a minimum threshold voltage less than the minimum value of said input voltage V_{in} for obtaining a long zero's value;

linearly increasing said threshold voltage from said minimum to said maximum threshold voltage; and

repeating said step of linearly increasing at predetermined intervals.

5. A method as claimed in claim 2, wherein said step of obtaining a corresponding plurality of associated average voltages comprises determining an associated average voltage for each value assumed by said threshold voltage.

6. A method as claimed in claim 5, wherein said step of processing comprises:

providing a reflected version of each said associated average voltage to obtain a corresponding plurality of reflected versions;

normalizing each said threshold voltage, said associated average voltage and said reflected version with respect to the logic 1 level of said input voltage V_{in}; and

for each threshold voltage, adding said normalized associated average voltage with said normalized reflected versions to obtain said simulated eye diagram.

7. A method as claimed in claim 6, further comprising:

providing a maximum threshold voltage above the maximum value of said input voltage V_{in} for obtaining a long one's value, and providing a minimum threshold voltage less than the minimum value of said input voltage V_{in} for obtaining a long zero's value; and

adding said long zero's value and said long one's value on said simulated eye diagram.

8. A method as claimed in claim 6, wherein said step of providing a reflected version comprises:

determining a maximum of said average voltage, and

determining said reflected version for said threshold voltage by ascertaining a symmetrical value for said associated average voltage with respect to said maximum average voltage.

9. A method as claimed in claim 2, wherein said threshold voltage V_{TH} is generated in a digital format, is converted to an analog format, and is applied on said first input of said slicer in said analog format.

10. A method as claimed in claim 1, wherein said associated parameter is a count indicating the interval when said input voltage is above said threshold voltage.

11. An eye quality monitor for a data regenerator for providing a simulated eye diagram of an optical signal without performing a clock recovery operation, comprising:

a pattern generator for generating a threshold voltage V_{TH} according to a pattern;

a slicer, for receiving a said threshold voltage V_{TH} on a first input and an input voltage V_{in} on a second input, and generating a slicer output voltage V_S, said input voltage V_{in} being an electrical equivalent of said optical signal;

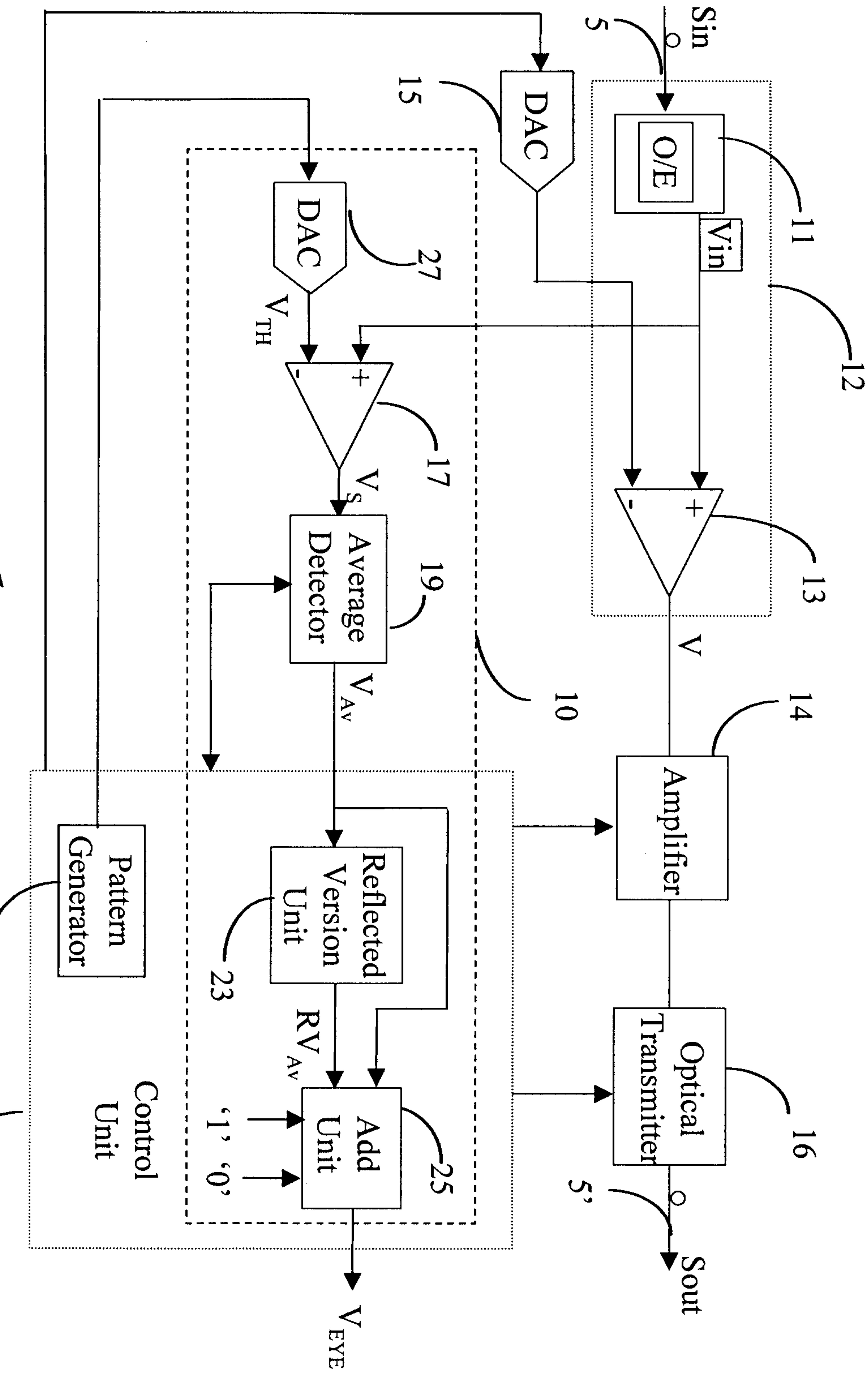
an average detector for providing an associated average voltage V_{AV} of said slicer output voltage V_S corresponding to said a threshold voltage V_{TH}; and

means for processing said average voltages V_{AV}, to simulate an eye diagram of said optical signal.

12. An eye quality monitor as claimed in claim 10, wherein said means for processing comprises

a reflected version unit for providing a reflected version of each said associated average voltage to obtain a corresponding plurality of reflected versions; and

an add unit for adding a normalized value of said associated average voltage with a normalized value of said reflected version, for each threshold voltage, to obtain said simulated eye diagram.


Sin
5
O/E
11
Vin
12
DAC
15
+
-
13
V
14
Amplifier
Optical
Transmitter
16
5'
Sout
DAC
27
V_{TH}
+
-
17
V_S
Average
Detector
19
V_{AV}
10
Reflected
Version
Unit
23
RV_{AV}
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Unit
25
'1' '0'
V_{EYE}
Pattern
Generator
21
Control
Unit
18
A

FIGURE 1

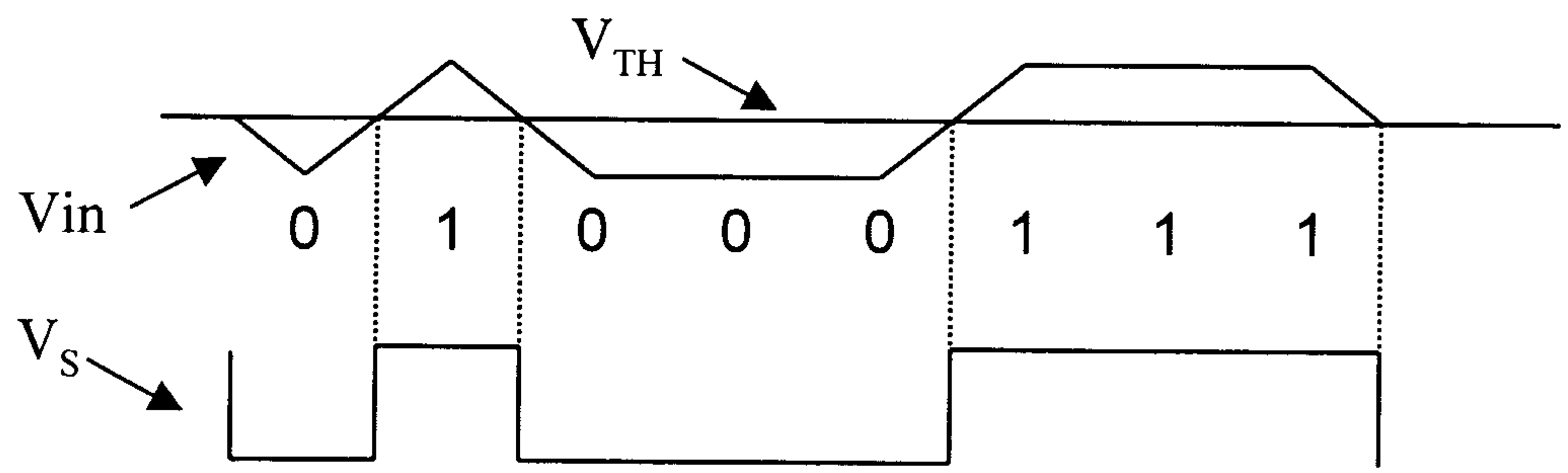


FIGURE 2A

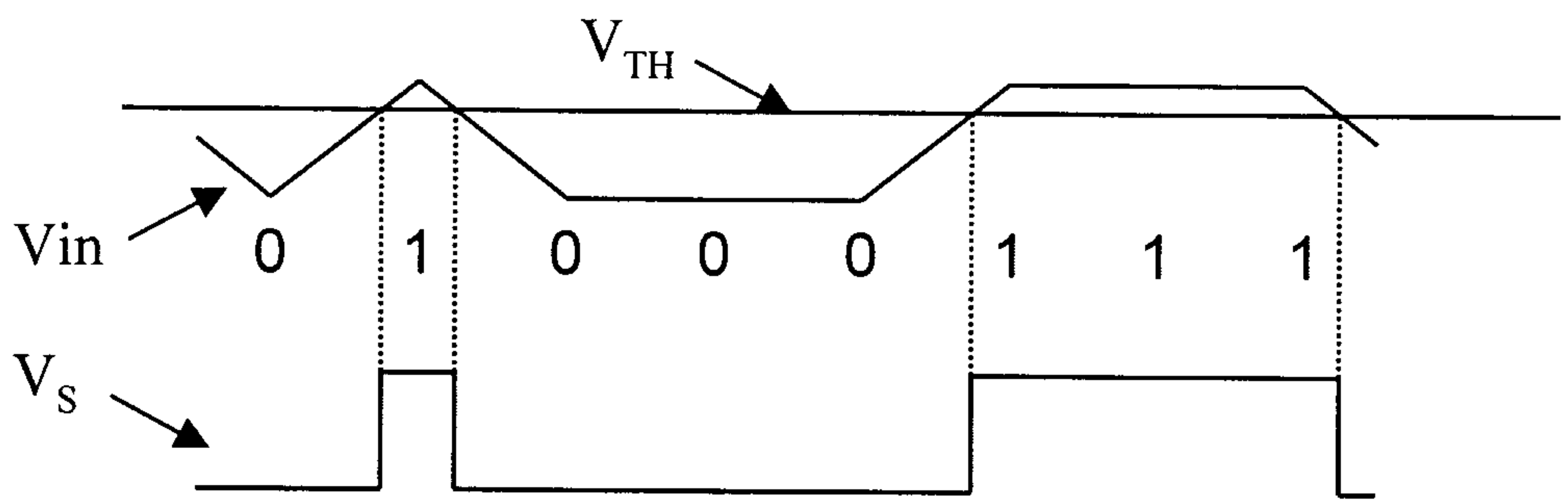


FIGURE 2B

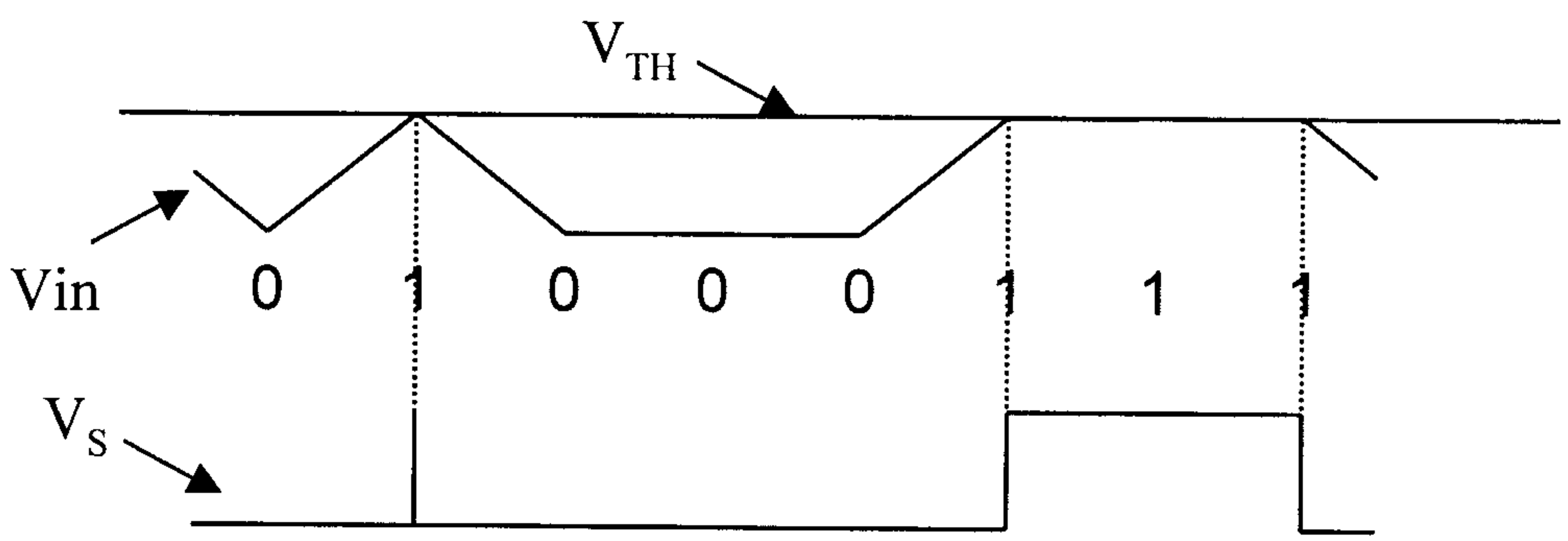
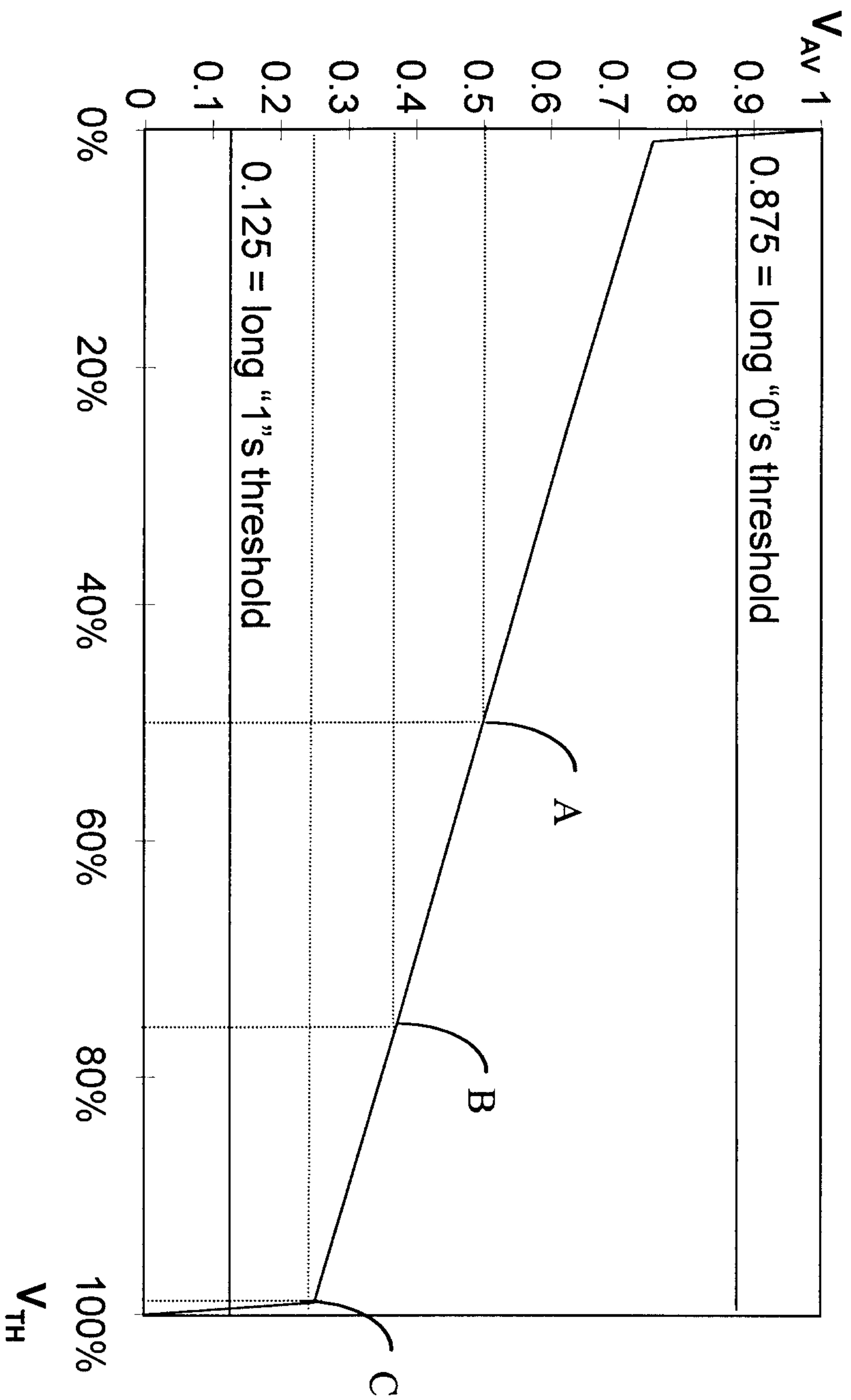


FIGURE 2C



V_{AV}
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0%
20%
40%
60%
80%
100%
V_{TH}
0.875 = long "0"s threshold
0.125 = long "1"s threshold
A
B
C

FIGURE 3

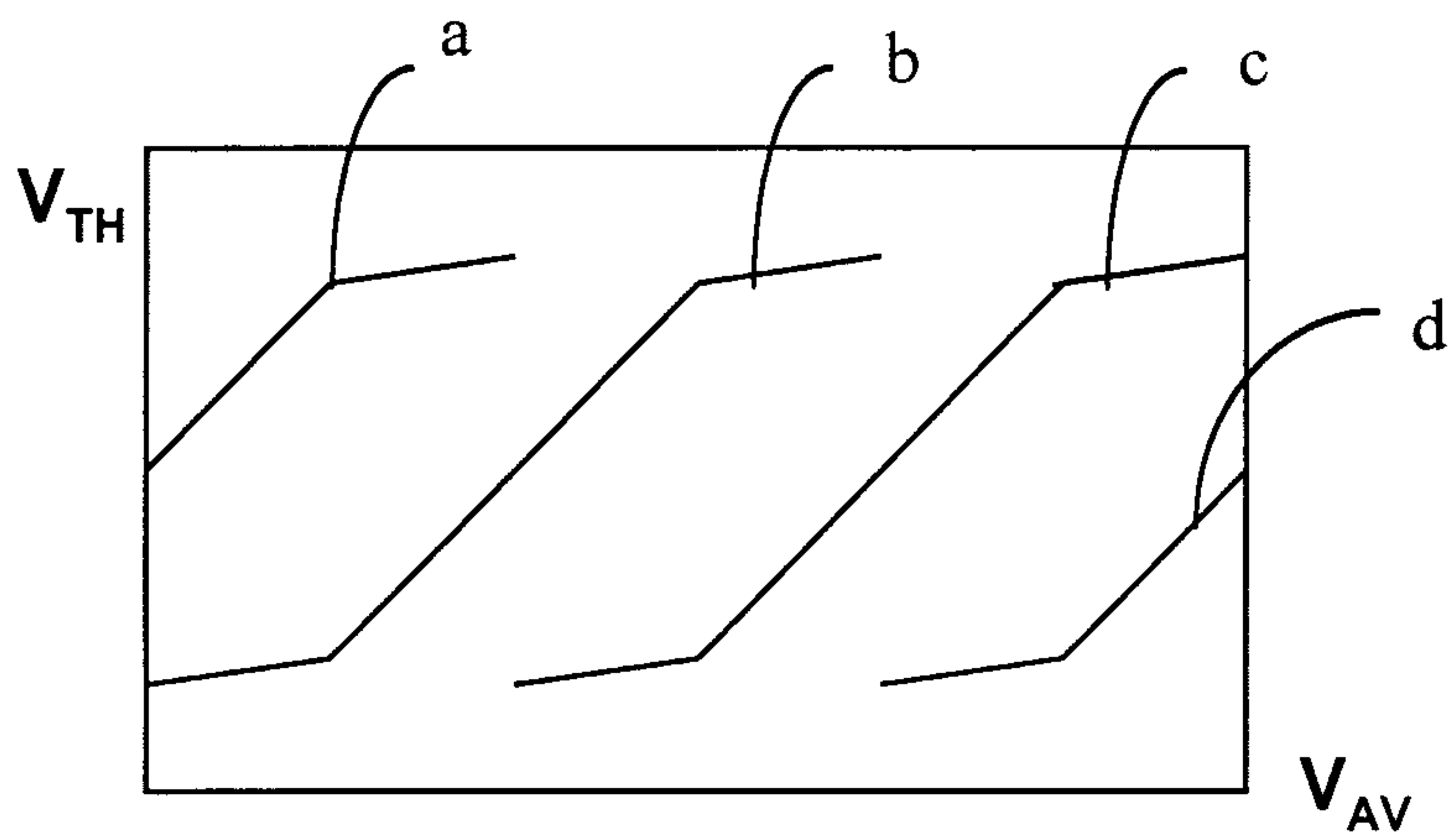


FIGURE 4A

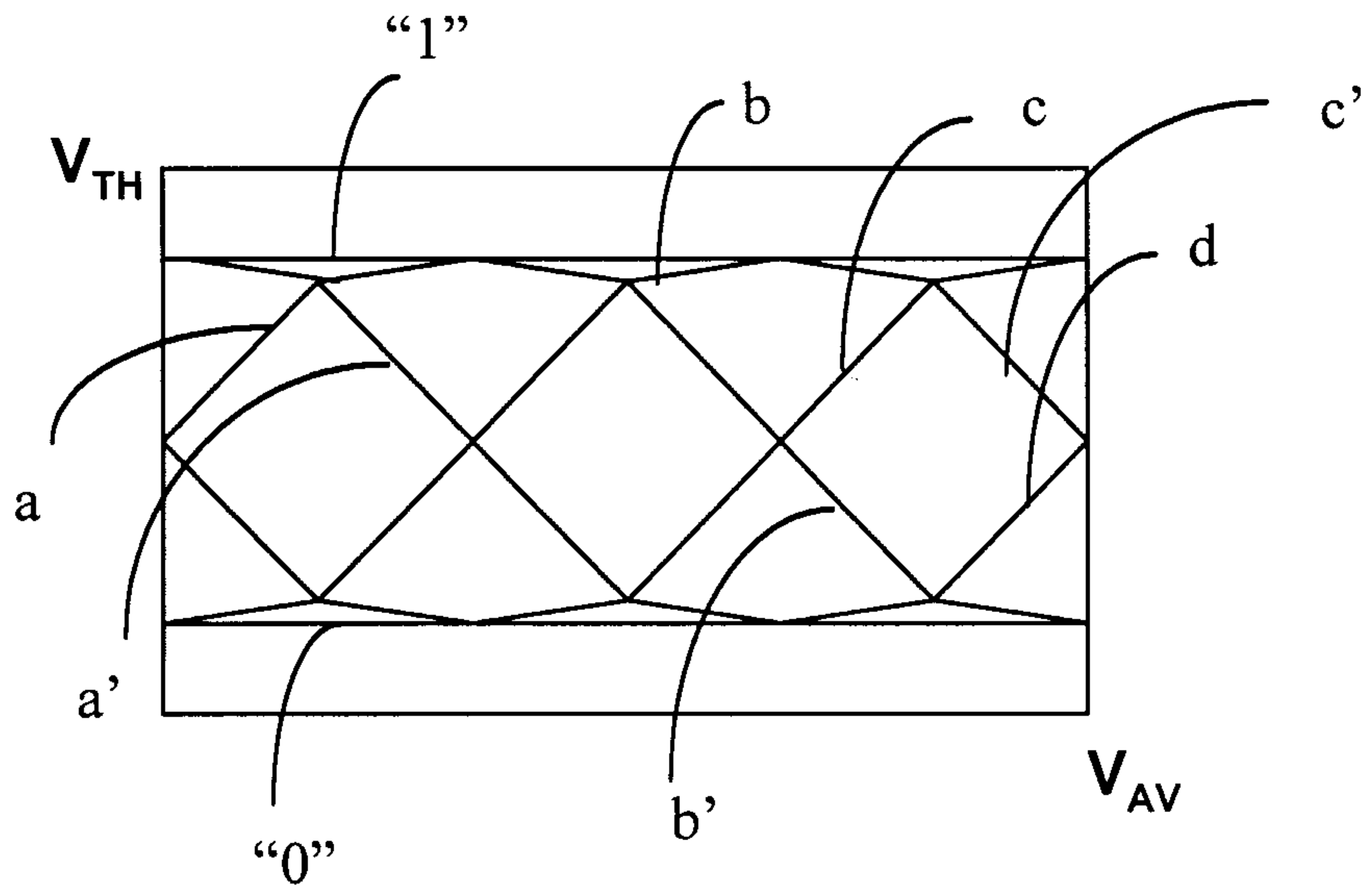


FIGURE 4B

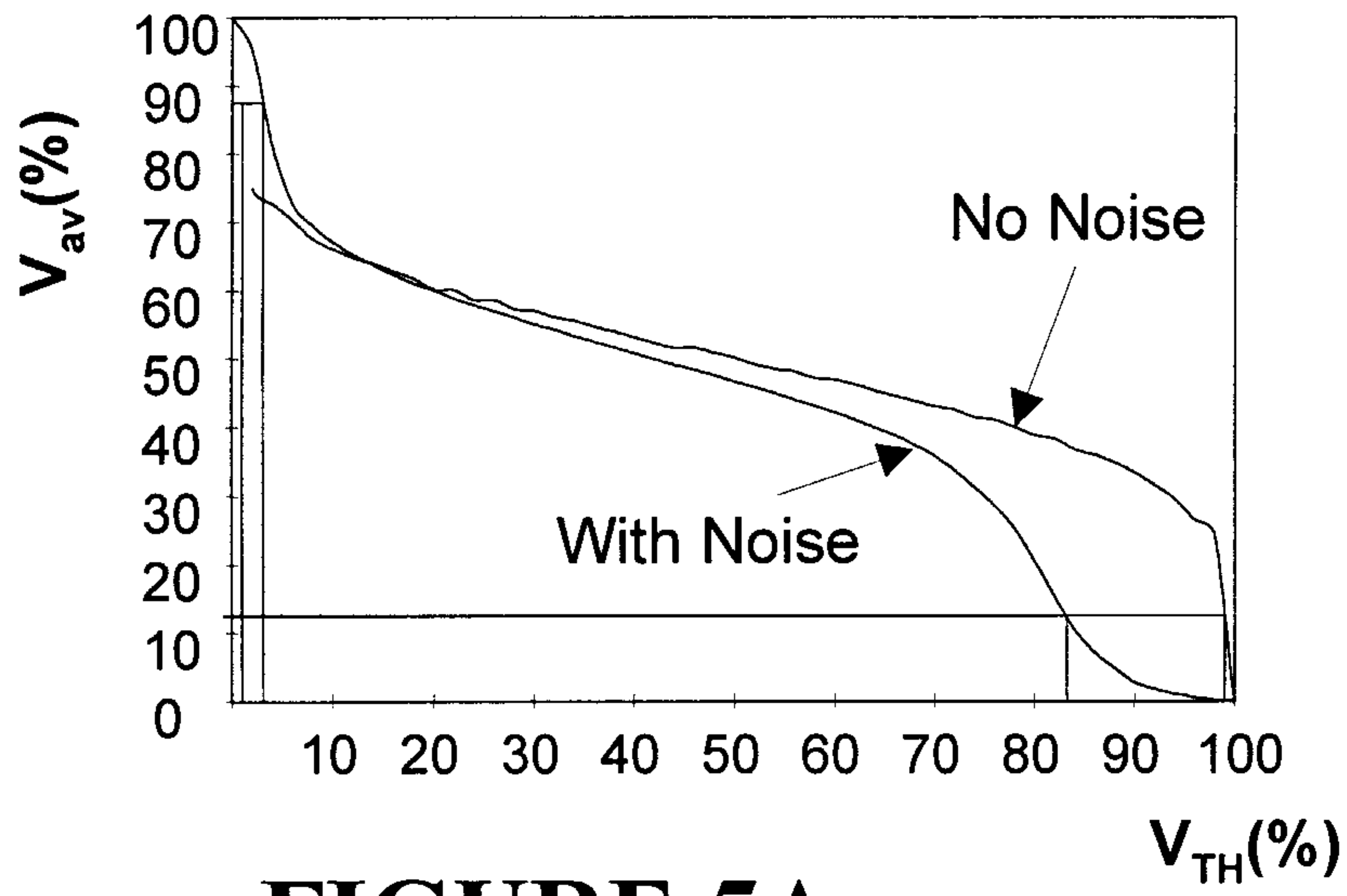


FIGURE 5A

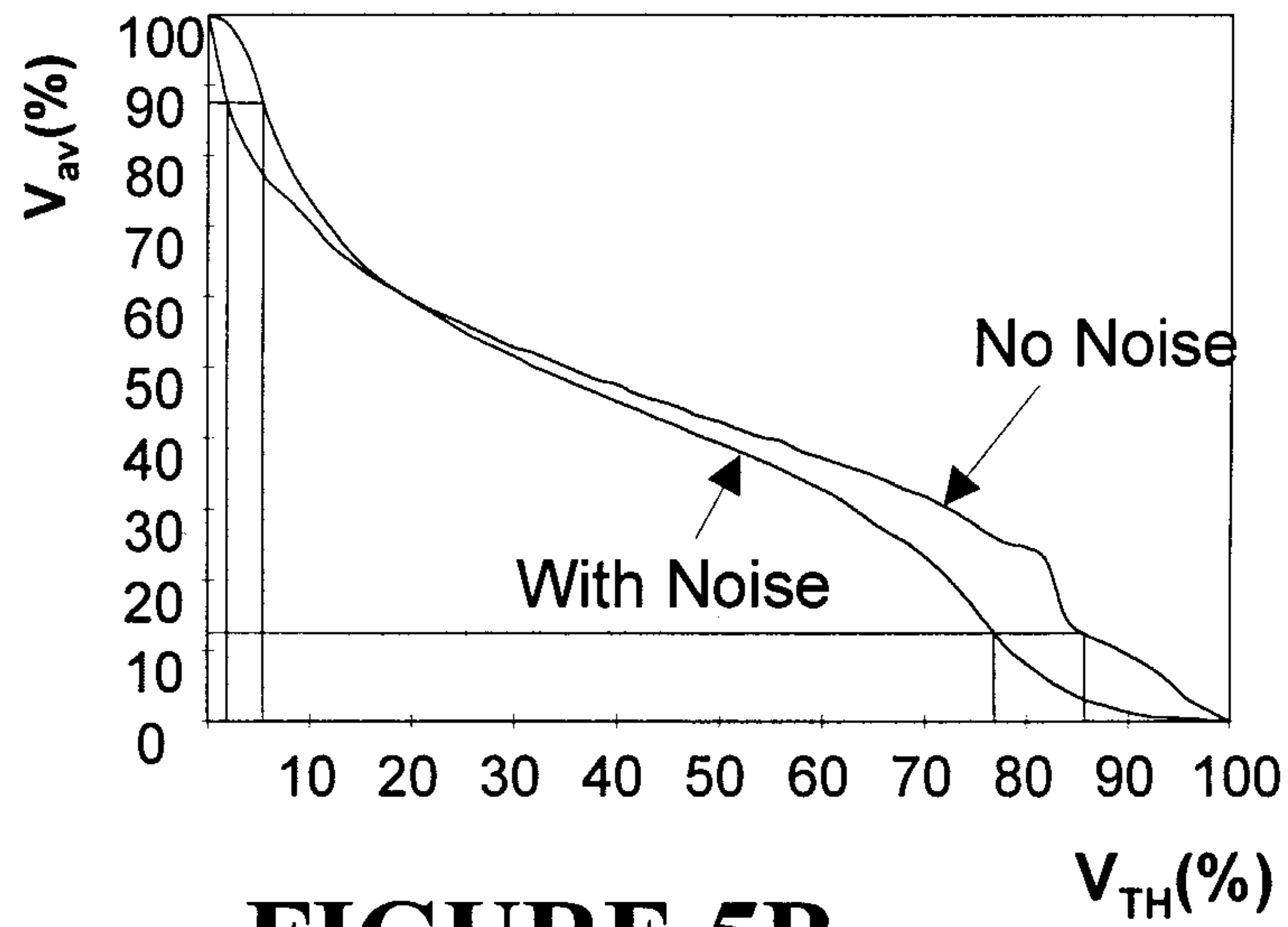


FIGURE 5B

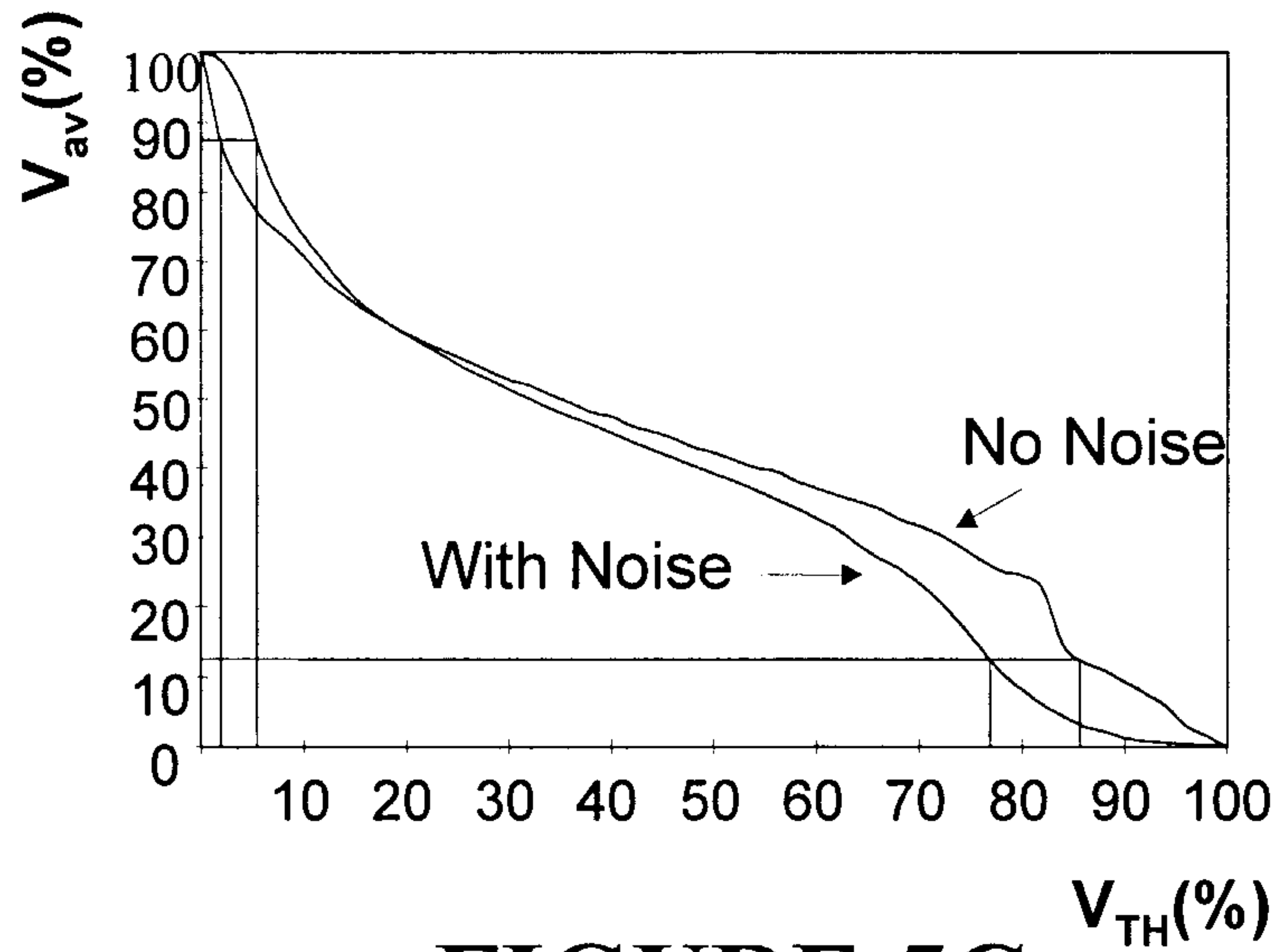


FIGURE 5C

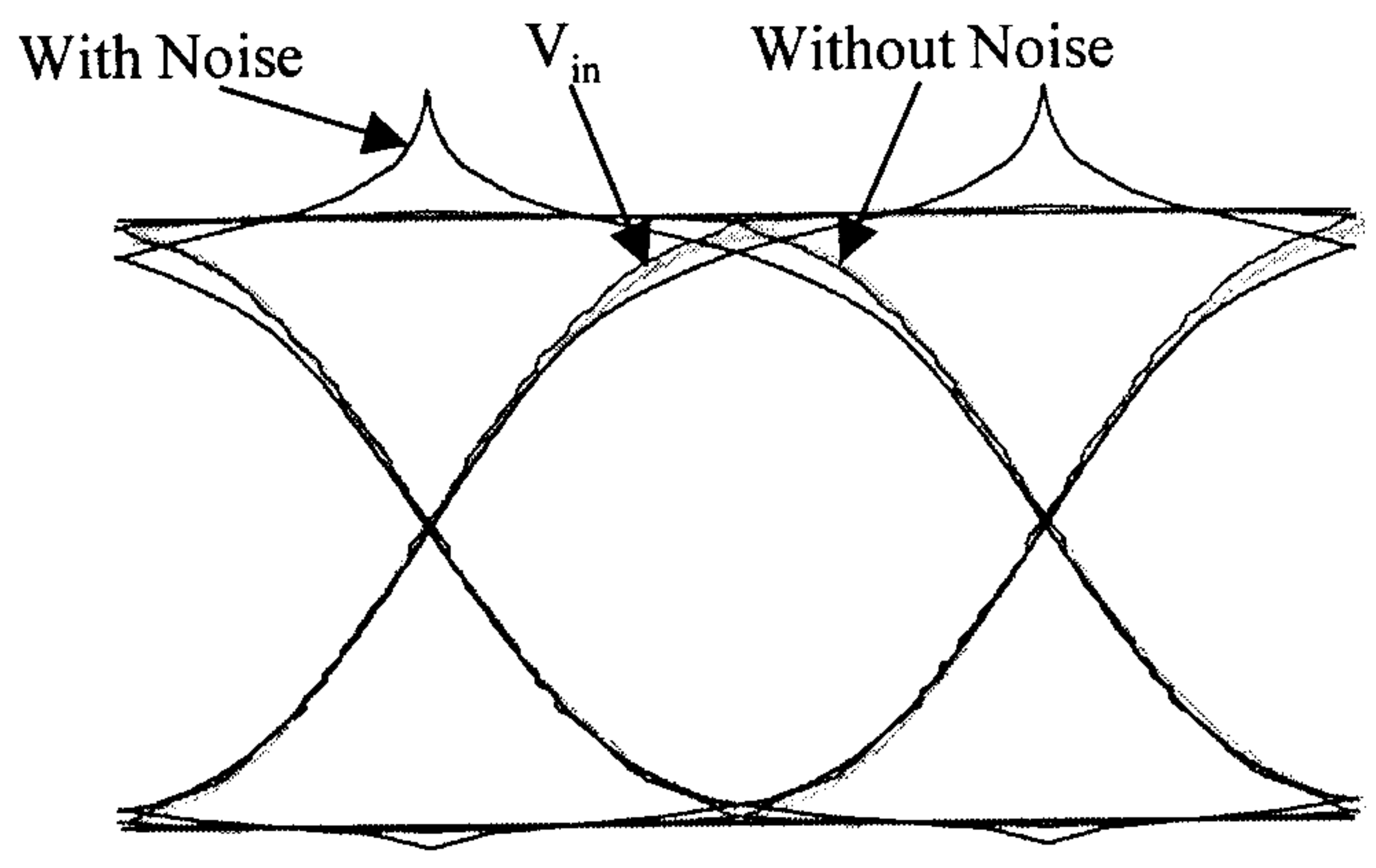


FIGURE 6A

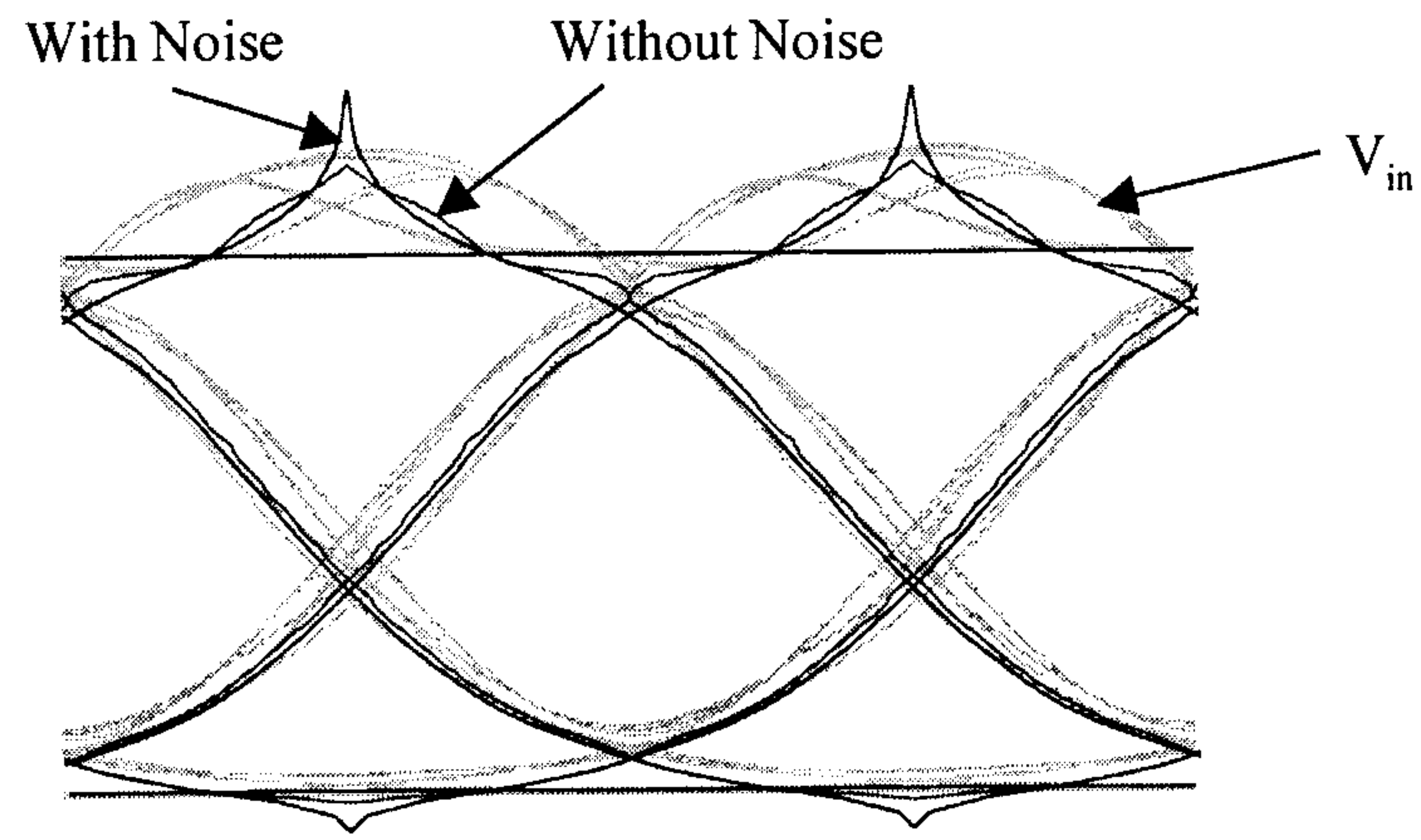


FIGURE 6B

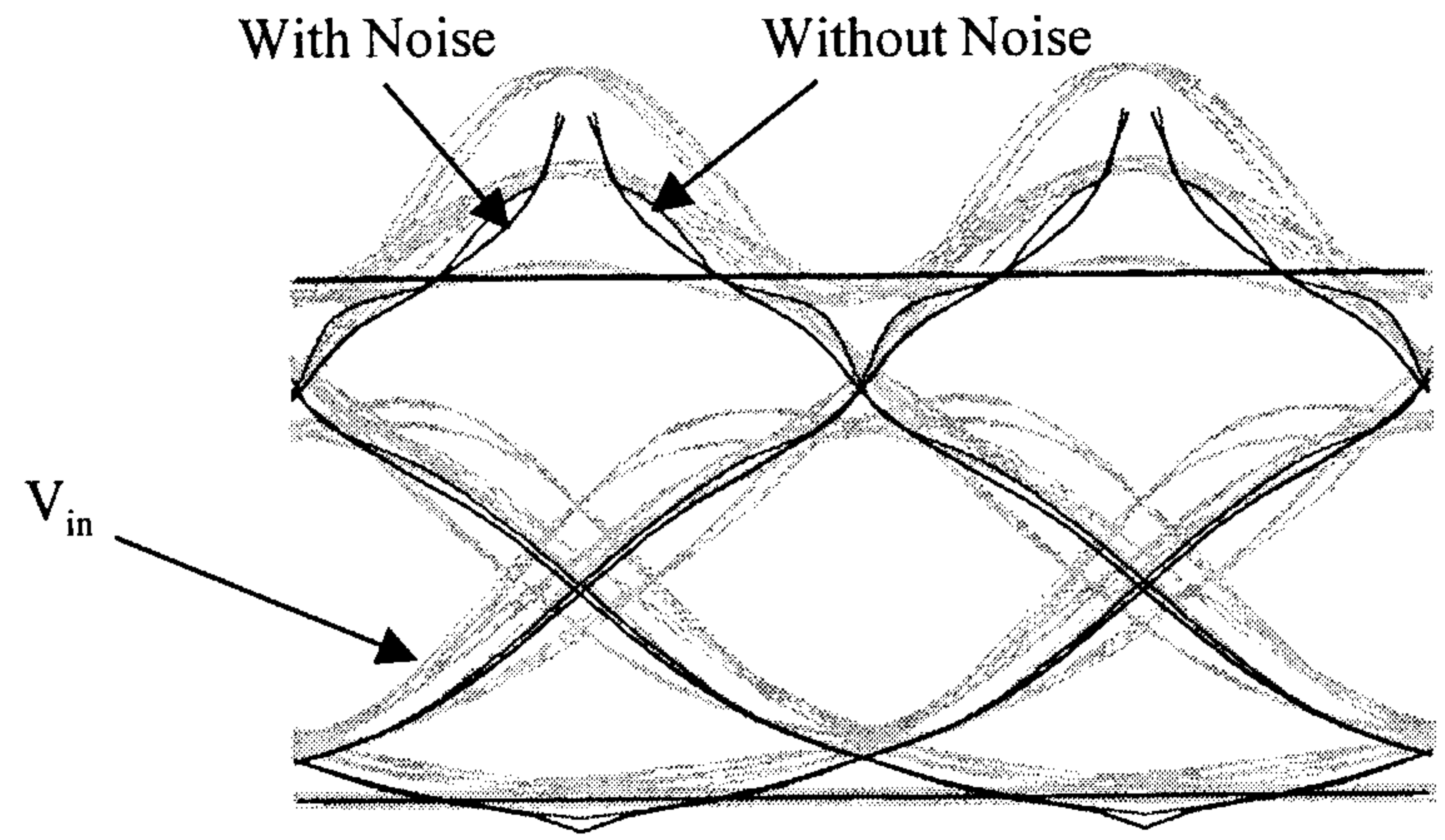


FIGURE 6C

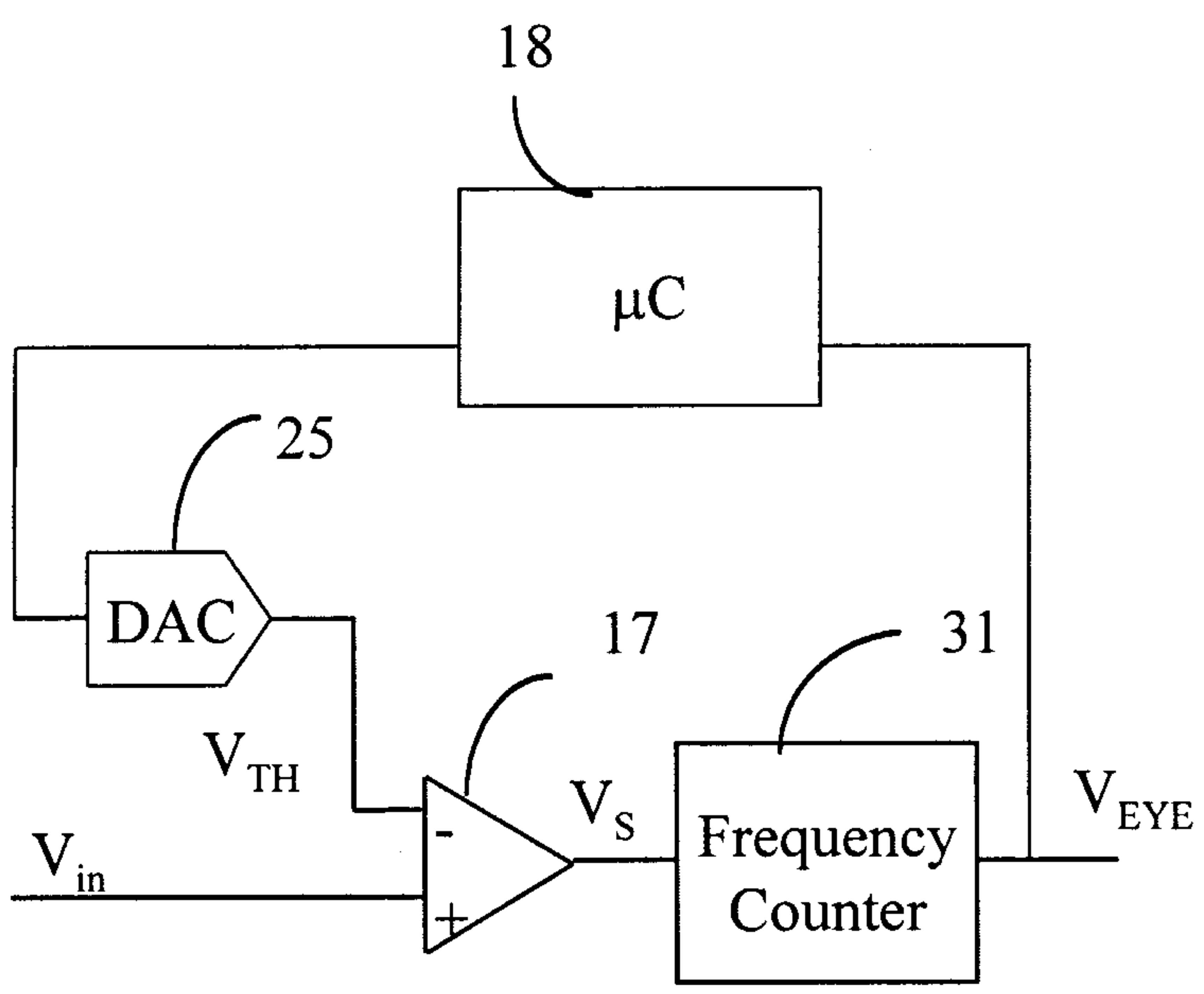


FIGURE 7

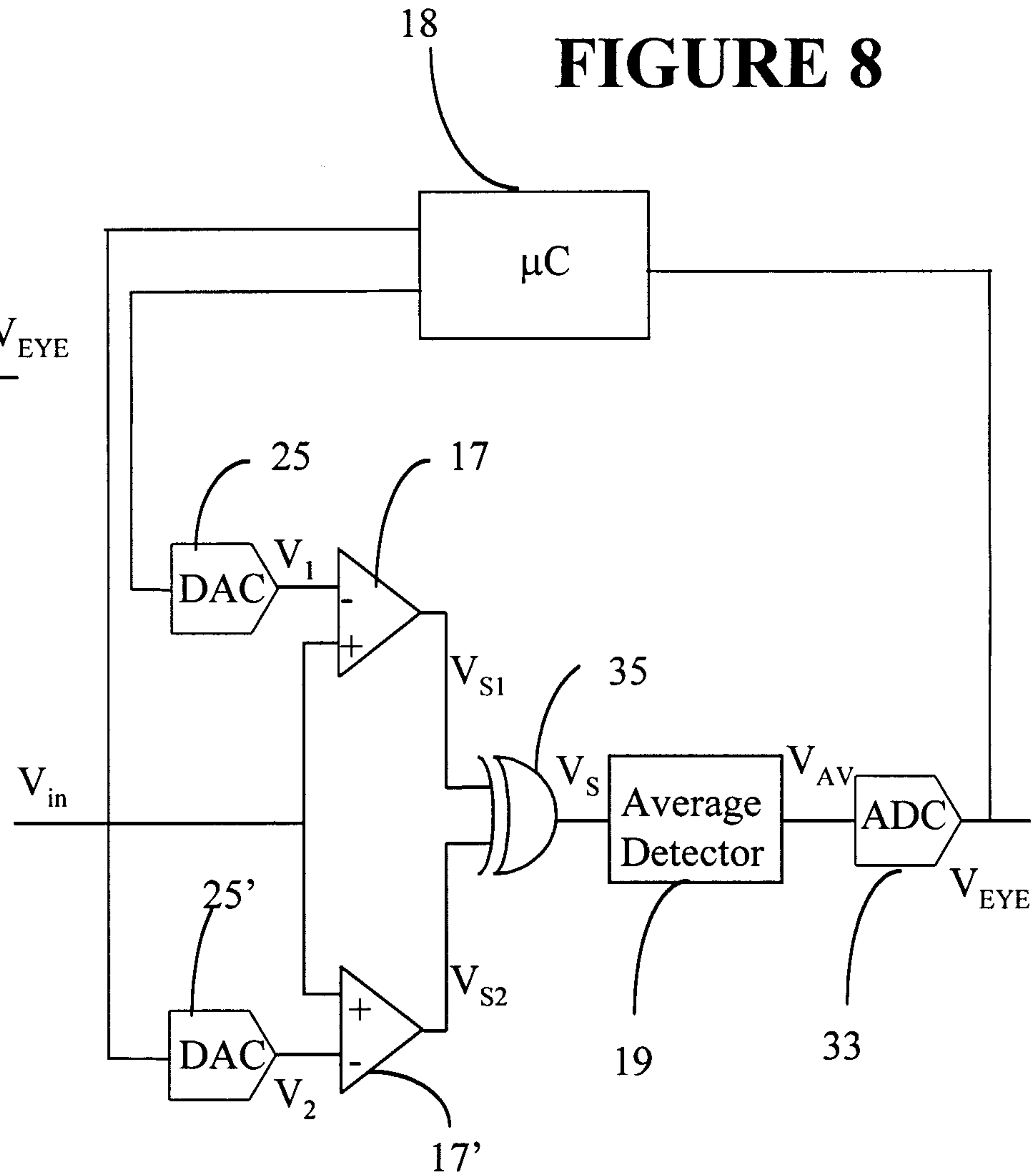


FIGURE 8