(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 386 879 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
05.05.2021 Bulletin 2021/18

(51) Int Cl.:
G01T 3/06 *(2006.01)*

(21) Application number: **11001589.8**

(22) Date of filing: **25.02.2011**

(54) NEUTRON IMAGE DETECTING METHOD AND NEUTRON IMAGE DETECTOR USING ITS METHOD

Neutronenbilddetektionsverfahren und das Verfahren nutzender Neutronenbilddetektor

Procédé de détection d'image à neutrons et détecteur d'image à neutrons utilisant ce procédé

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **26.02.2010 JP 2010042209**

(43) Date of publication of application:
16.11.2011 Bulletin 2011/46

(73) Proprietors:
- **Japan Atomic Energy Agency**
  Naka-gun,
  Ibaraki 319-1184 (JP)
- **Hoshin Electronics Co., Ltd.**
  Miyamae-ku
  Kawasaki-shi
  Kanagawa 216-0006 (JP)

(72) Inventors:
- **NAKAMURA, Tatsuya**
  Kawasaki-shi
  Kanagawa 216-0006 (JP)
- **KATAGIRI, Masaki**
  Kawasaki-shi
  Kanagawa 216-0006 (JP)
- **EBINE, Masumi**
  Kawasaki-shi
  Kanagawa 216-0006 (JP)
- **BIRUMACHI, Atsushi**
  Kawasaki-shi
  Kanagawa 216-0006 (JP)
- **YORIBAYASHI, Yutaka**
  Kawasaki-shi
  Kanagawa 216-0006 (JP)

(74) Representative: **Strehl Schübel-Hopf & Partner**
Maximilianstrasse 54
80538 München (DE)

(56) References cited:
US-A1- 2007 096 028 **US-B1- 6 590 957**

- **HOSOYA T ET AL: "Development of a new detector and DAQ systems for iBIX", NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH. SECTION A: ACCELERATORS, SPECTROMETERS, DETECTORS, AND ASSOCIATED EQUIPMENT, ELSEVIER BV * NORTH-HOLLAND, NL, vol. 600, no. 1, 21 February 2009 (2009-02-21), pages 217-219, XP025936847, ISSN: 0168-9002, DOI: 10.1016/J.NIMA.2008.11.123 [retrieved on 2008-12-06]**
- **KATAGIRI M ED - UNNO YOSHINOBU ET AL: "Development status of position-sensitive neutron detectors for J-PARC in JAERI-a comprehensive overview", NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH. SECTION A, ELSEVIER BV * NORTH-HOLLAND, NL, vol. 529, no. 1-3, 21 August 2004 (2004-08-21), pages 254-259, XP004527298, ISSN: 0168-9002, DOI: 10.1016/J.NIMA.2004.04.154**

Printed by Jouve, 75001 PARIS (FR)

Description

BACKGROUND OF INVENTION

[0001] The present invention relates to a neutron image detecting method for creating one-dimensional or two-dimensional neutron images at a high speed and with increased position accuracy, and relates to a neutron image detector using this method. The present invention can be applied to various purposes for the measurement of intense pulsed neutrons in a high-intensity photon accelerator facility (e.g. J-PARC), the evaluation of various dynamic behaviors in nuclear reactors and fusion reactors, the non-destructive inspection using high permeability of neutrons, and the physical property measurement of new materials.

[0002] As for the two-dimensional neutron image detector used for neutron scattering experiments using neutron sources generated by a nuclear reactor or an accelerator, what have been used include such a detector as being formed by combining a neutron scintillator or a fluorescent neutron detecting sheet formed together with a fluorescent material and a neutron convertor with a wavelength shifting fiber (refer to Patent Literatures 1 and 2, and Non-Patent Literature 1). Such two-dimensional image detector is characterized in that the position information is obtained by using a cross-fiber reading method, including proven methods such as a method for determining the incident position by using a coincidence counting method using such a sheet configuration that a couple of wavelength shifting fiber bundles are arranged diagonally on the upper surface and the bottom surface of the fluorescent material sheet or the scintillator plate, a method for determining the incident position by using a coincidence counting method using such a sheet configuration that couple of wavelength shifting fiber bundles are arranged diagonally on the back surface of the scintillator by improving the cross-fiber reading method, and a method using such a sheet configuration that a couple of wavelength shifting fiber bundles are arranged diagonally and that scintillators are arranged on its upper surface and bottom surface.

[0003] In relation to the method for determining the incident position of neutrons by using a median point calculating method in the same way as the present invention, what is known as Anger-type camera method uses such a method in that gamma-rays or fluorescent lights from the neutron scintillator are detected directly by a number of photomultiplier tubes, and the incident position is determined by a median point calculating method on the basis of the digitized values of the fluorescent light intensity by using Analog/Digital Converter (hereinafter referred to as ADC) (for example, refer to Patent Literature 3).

[0004]

[Patent Literature 1] JP 2000-187007 A
[Patent Literature 2] JP 2002-71816 A
[Patent Literature 3] JP 2009-8695 A

[0005] [Non-Patent Literature 1] Nucl. Instr. and Meth., A439 (1999) PP. 311-320.

[0006] Further, Nucl. Instr. and Meth., A529 (2004) pp. 254-259 discloses a neutron image detection method from which the pre-characterising part of claim 1 starts out. Related methods are disclosed in Nucl. Instr. and Meth., A600 (2009) pp. 217-219 and in US 2007/0096028 A1.

SUMMARY OF INVENTION

[0007] In those conventional two-dimensional image detectors, the fluorescent light emitted from the scintillator is converted to the electric signal by the photomultiplier tube, and then the analog pulse signal is output after amplifying the integrated signal waveform by using the waveform shaping amplifier, and the peak value of the obtained analog pulse signal waveform is digitized, and the position showing the maximum value at the corresponding optical fiber or wavelength shifting fiber is finally determined to be the incident position. As those conventional detectors requires ADC circuit for obtaining the digital values, there is such a disadvantage that the signal processing circuit becomes complicated and requires an extraordinary high cost.

[0008] In those conventional one-dimensional detectors, one-dimensional neutron image is obtained in that the fluorescent light emitted from the scintillators each separated at regular intervals by reflecting plates are made led into the photomultiplier tubes by using the optical fibers, and then the signal induced by the fluorescent light is made integrated, and finally the signal having a signal value equal to or larger than the predetermined value is counted to be identifying a single neutron incident.

[0009] In those neutron image detectors, as there is no boundary between adjacent pixels due to their configuration in which the wavelength shifting fibers are arranged on a plane, and, in case of using optical fibers, as the fluorescent lights emitted from the fluorescent light sheet are leaked at the gaps at the reflecting plates and made scattered and diffused, and then are incident into two or more wavelength shifting fibers or optical fibers, uncommon circuit technology is required to determine the exact incident position. Thus, as described above, ADC circuit is required principally to determine the incident position, and, there is resultantly such a disadvantage that the signal processing circuit becomes complicated and requires an extraordinary high cost. In addition, the accuracy in determining the incident position is not satisfactory.

[0010] The light transmission efficiency is several percent when the fluorescent light emitted from the scintillator is transmitted through the wavelength shifting fiber or the optical fiber to the photomultiplier tube. This requires a number of photons sufficiently enough to shape and amplify the waveform of the signal from the photomultiplier tube, and convert the amplified waveform into the digital signal by using ADC circuit, which may lead to such a disadvantage that the detection efficiency for neutrons decreases.

[0011] In order to redeem those disadvantages, a method for determining the incident position of neutron by using a pattern of the photon signals output from the individual wavelength shifting fibers by using a photon counting method is developed and used, which still have such a problem that the exact incident position of neutron can not determined precisely.

[0012] In addition, in the above described method in that gamma-rays or fluorescent lights from the neutron scintillator are detected directly by a number of photomultiplier tubes, and the incident position is determined by a median point calculating method on the basis of the digitized values of the fluorescent light intensity by using ADC, as ADC is required to be used for obtaining the digital value, there is such a disadvantage that the signal processing circuit becomes complicated and requires an extraordinary high cost.

[0013] The invention solving the above problems is defined by the appended claims. The neutron image detection method according to the present invention is defined according to claim 1.

[0014] Another aspect of the neutron image detection method according to the present invention is based on the concept in that, in the neutron image detection method for collecting a fluorescent light generated by a neutron incident at a designated position interval on a vertical axis and a horizontal axis, respectively, in two-dimensional geometry and determining an incident position of the neutron by detecting the collected fluorescent light, wherein

the fluorescent light is detected by photon counting method;

a pulse signal generated by an individual photon is extracted on the basis of a clock signal generated with the same time interval as the time width of the pulse signal generated by a single photon;

a count-value distribution is obtained on a vertical axis and a horizontal axis, respectively, in terms of incident position as variable determined by a single neutron incident by counting the pulse signal output;

a neutron incident position is determined on a vertical axis and a horizontal axis, respectively, by calculating a median point on a vertical axis and a horizontal axis, respectively, on the basis of the obtained count-value distribution.

[0015] Yet another aspect of the neutron image detection according to the present invention is based on the concept in that, the neutron image detection method for collecting a fluorescent light from a scintillator generating a fluorescent light upon a neutron incident at a designated position interval on a vertical axis and a horizontal axis, respectively, in two-dimensional geometry and determining an incident position of the neutron by detecting the collected fluorescent light or detecting the fluorescent light directly in two-dimensional geometry wherein

the fluorescent light is detected by photon counting method;

a pulse signal generated by an individual photon is extracted on the basis of a clock signal generated with the same time interval as the time width of the pulse signal generated by a single photon;

a two-dimensional count-value distribution is obtained in terms of incident position as variable determined by a single neutron incident by counting the pulse signal output, or obtained by detecting directly the fluorescent light;

a neutron incident position is determined on a vertical axis and a horizontal axis, respectively, on the basis of the obtained two-dimensional count-value distribution.

[0016] The above described position calculation can be performed in an extremely high speed by applying exactly FPGA (Field Programmable Gate Array) having a relatively large number of input pins, enabled by today's progressive integrated-circuit technologies. By applying the median point calculation, the incident position of neutron can be determined precisely.

[0017] As the neutron image detection method according to the present invention include a sophisticated scheme for calculating the incident position of neutron, it will e appreciated that such a large number of expensive Analog/Digital Converters (ADC) as found in the prior art may not be used, but that the such scheme may be realized by a small-sized, inexpensive and dedicated hardware device. Thus, it will be appreciated that the neutron image detector according to the present invention may be significantly inexpensive, and also that the performance speed for creating the neutron image may be significantly fast.

BRIEF DESCRIPTION OF DRAWINGS

[0018]

FIG.1 is a schematic diagram showing the configuration of the median point calculating circuit in the one-dimensional neutron image detector.

FIG. 2A is a first half of the flow chart of the median point calculation in the one-dimensional neutron image detector and FIG. 2B is a last half of the flow chart thereof.

FIG. 3 is an illustrative diagram showing the calculation example of the median point calculation in the one-dimensional neutron image detector.

FIG. 4 is a schematic diagram showing the configuration of the median point calculating circuit in the two-dimensional neutron image detector.

FIG. 5A is a first half of the flow chart of the median point calculation in the two-dimensional neutron image detector, and FIG. 5B is a last half of the flow chart thereof.

FIG. 6 is a graph showing an example of the peak analysis result of the median point calculation in the two-dimensional neutron image detector.

FIG. 7 is a three-dimensional representation of the peak analysis result of the median point calculation in the two-dimensional neutron image detector.

FIG. 8 is a schematic diagram showing the configuration of the median point calculating circuit in the two-dimensional neutron image detector using two-dimensional processing method.

FIG. 9A is a first half of the flow chart of the median point calculation in the two-dimensional neutron image detector using two-dimensional processing method, and FIG. 9B is a last half of the flow chart thereof.

FIG. 10A is a first half of schematic diagram showing the configuration of the median point calculating circuit having a photon signal discriminating function in the two-dimensional neutron image detector, and FIG. 10B is a last half of the schematic diagram thereof.

FIG. 11A is a first half of the flow chart of the median point calculation having a photon signal discriminating function in the two-dimensional neutron image detector, and FIG. 11B is a last half of the flow chart thereof.

FIG. 12 is a graph showing an example of the peak analysis result by the median point calculating circuit having a photon signal discriminating function in the two-dimensional neutron image detector in case of changing the number of photons.

FIG. 13 is a graph showing an example of the improvement in the peak position resolution by the median point calculating circuit having a photon signal discriminating function in the two-dimensional neutron image detector in case of changing the number of photons.

FIG. 14A is a first half of the schematic diagram showing the configuration of the median point calculating circuit having a function for compensating the non-linearity in photon countings in the two-dimensional neutron image detector using ZnS:Ag as a material for the scintillator, and FIG. 14B is a last half of the schematic diagram thereof.

FIG. 15A is a first half of the flow chart of the median point calculation having a function for compensating the non-linearity in photon countings in the two-dimensional neutron image detector using ZnS:Ag as a material for the scintillator, and FIG. 15B is a last half of the flow chart thereof.

FIG. 16 is a graph showing the result of measuring the wave-height distribution characteristic of the photons detected by the photomultiplier in the fluorescent light from the neutron detecting sheet commercially available from AST in England.

FIG. 17 is an explanatory drawing showing the principle for compensating the non-linearity in photon countings in the two-dimensional neutron image detector using ZnS:Ag as a material for the scintillator.

FIG. 18 is a graph showing an example of calculating the correction amount in the photon count number for compensating the non-linearity in photon countings in the two-dimensional neutron image detector using ZnS:Ag as a material for the scintillator.

FIG. 19 is a schematic diagram showing the circuit configuration for removing the multiple countings due to after-glow by forcing time-delay after the median point calculation in the two-dimensional neutron image detector using ZnS:Ag as a material for the scintillator.

FIG. 20A is a first half of the flow chart of the operation in the multiple countings removing circuit shown in FIG. 19, and FIG. 20B is a last half of the flow chart thereof.

FIG. 21 is a graph showing the example of the actual measurement of the count values in case of changing the delay time in the multiple countings removing circuit shown in FIG. 19.

FIG. 22 is a graph showing the actual measurement data illustrating the relation between the multiple countings fraction due to after-glow and the delay time based on the experimental values obtained by forcing time-delay after the median point calculation in the two-dimensional neutron image detector using ZnS:Ag as a material for the scintillator.

FIG. 23 is a graph showing the example of calculating the multiple countings due to after-glow based on the wave-height distribution in the scintillator using ZnS:Ag fluorescent material.

FIG. 24 is a graph showing the relation between the optimal delay time and the photon count number based on the experimental result for the delay time.

FIG.25 is a schematic diagram showing the configuration of the median point calculating circuit for calculating the median point without using a circuit for multiplying the photon synchronization signal and the corresponding position number values.

FIG. 26 is a flow chart of the calculation process in the median point calculating circuit shown in FIG. 25.

FIG. 27 is an illustrative diagram showing the calculation example of the median point calculating circuit shown in FIG. 25.

FIG. 28 is a schematic diagram showing the configuration of the median point calculating circuit in the neutron image detector having a semi-transparent scintillator and a wavelength shifting fiber.

FIG. 29A is a first half of the flow chart of the operation in the median point calculating circuit shown in FIG. 28, and FIG. 29B is a last half of the flow chart thereof.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[Embodiment]

(Embodiment 1)

[0019] As Embodiment 1, FIG. 1 illustrates a schematic diagram showing the configuration of the median point calculating circuit in the one-dimensional neutron image detector using a scintillator and a wavelength shifting fiber. FIG. 2A and FIG. 2B show flow charts of the median point calculation in case that the generated fluorescent light incident into five wavelength shifting fibers upon the incidence of a neutron. In the flowcharts separated into A and B generally throughout the specification, A represents the first half of the whole flow chart and B represents the last half of the flow chart of the whole flow chart. Note that the end row of blocks of the flow chart A are found as the first raw row of blocks of the flow chart B in order to make it easier to understand the connectivity between the first half and the last half of the whole flow chart. FIG. 3 illustrates an illustrative diagram showing the calculation example of the median point calculation based on the basic principle of the present invention. The one-dimensional neutron image detector using a scintillator and a wavelength shifting fiber in this embodiment has the structure shown below.

[0020] ZnS:Ag/$^{10}B_2O_3$ scintillator having a thickness of 0.3mm is used as the neutron scintillator that emits the fluorescent light upon the incidence of a neutron. The wavelength of the fluorescent light emitted from ZnS:Ag-based fluorescent material has distributed from 390nm to 520nm, of which the center is 450nm. The life-time of the short life-time component of the fluorescent light from ZnS:Ag-based fluorescent material to be used for detecting neutrons substantially is about 0.3 μ s. BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The shape of the wavelength shifting fiber is made in a right square having one side length of 0.5mm. The one-dimensional neutron image detector having the effective sensing width of 32mm is formed by arranging 64 wavelength shifting fibers in one-dimensional geometry, and by arranging ZnS:Ag/$^{10}B_2O_3$ scintillator above a bundle of those wavelength shifting fibers.

[0021] As for the optical detector for detecting the emitted fluorescent light experienced with wavelength shifting by the wavelength shifting fibers, H7546 commercially available from HAMAMATSU PHOTONICS K.K. may be used, that is a 64-channnel photomultiplier tube, each channel having an effective sensitive area of 2mm x 2mm. The individual photon electric signals output from this photomultiplier tube are amplified by the photon signal amplifiers, each composed of a high-speed amplifier, and then the individual amplified signals are formed as the photon digital pulse signals by the photon signal discriminating circuit composed of individual discriminator circuits.

[0022] When detecting the fluorescent lights emitted from the wavelength shift fibers by using the 64-channel photomultiplier tube in the above configuration, the photon signal amplifier and the photon signal discriminating circuit having an ability to detect the fluorescent lights using the photon counting method are used. As for the photon signal amplifier, a couple of ICs, AD8001 commercially available from Analog Devices Inc. are used as high-speed ICs for the individual circuit and the overall amplifier is formed as an amplifier having a 60-times-amplifying gain with its amplifier bandwidth of 200MHz. As for the photon signal discriminating circuit, AD8611 also commercially available from Analog Devices Inc. is used as the high-speed discriminator IC. Owing to applying the electronic circuit so configured as described above, the photon digital pulse signal having a pulse time width of about 5ns can be obtained as a single signal per photon.

[0023] Next, the photon digital pulse signal generated by the photon output from the individual photomultiplier tube is extracted as the signal synchronized to the clock signal having a cycle time adapted to its pulse time width by using the signal synchronization circuit composed of the gate circuit, and then the synchronized photon signal is obtained. The frequency of the clock signal is made 100MHz, generating the same pulse time width of 5ns because the pulse time width of the photon pulse signal is 5ns.

[0024] The logical "OR" operation is applied to the synchronized photon signals, each synchronized to one another, for all of 64 channels by "OR" circuit at first, and then, the timing when the pulse signal arrives at first to the input to "OR" circuit among the photon digital pulse signals obtained by detection and signal processing upon the incident of a neutron is defined to be the neutron incident time, and is made input to the count-time generating circuit. The count-time generating circuit supplies this first-arriving pulse signal as the start-time signal to the multi-channel photon digital counting circuit, which starts the counting operations at the individual channels.

[0025] The circuit for observing the predetermined count out time in the count-time generating circuit starts at the same time, and then this circuit generates a stop signal upon the predetermined count time reached and sends the stop signal to the multi-channel photon digital counting circuit, that terminates the counting operation and finally decides the counting values. In this embodiment, the count time is defined to be 1 μ s corresponding to three times of 0.3 μ s, which is the short life-time component of the fluorescent light from ZnS:Ag fluorescent material, so that almost all the short life-time component of the fluorescent light may be utilized. Thus, the photon count-value distribution at the center of the neutron incident position upon the single neutron incident into the scintillator is obtained in which the total amount of distributed photons is proportional to the amount of fluorescent light.

[0026] In the present invention, the incident position in one-dimensional geometry is determined by calculating a median point on the basis of the obtained photon count-value distribution. One embodiment of the median point calculation is described by referring to FIG. 3. In the calculation example below, assume that the fluorescent lights enter 5 (five) wavelength shifting fibers at the fiber positions 3 to 5. At first, the integrated count value A obtained by counting for the single neutron by using the wavelength shifting fibers is obtained by summing the count values at the positions 3 to 7, which makes 11 in this calculation example. Next, the median point count value summation B is obtained. This summed value is calculated by summing the values, each obtained individually by multiplying the position number value and the photon count value counted at the relevant position corresponding to its position number value. The median point count value summation makes 54 in this calculation example. The neutron incident position obtained in case of applying the median point calculating method is defined as a quotient obtained by dividing the median point count value summation B by the integrated count value A, that is, B/A=54/11=4.9. In case of representing the coordinate value of the incident position in terms of integer number, position 5 is obtained as the incident position by round-off calculation. In case of an increased accuracy in the incident position, a real value of 4.9 may be used as the coordinate value of the incident position.

[0027] Note that the weight values for the photon count values at the individual positions are uniformly made equal to 1 in the above calculation example, though it is allowed that the uneven weight values may be used in order to increase the position accuracy in case that the detection characteristics for the fluorescent light is not uniform.

(Embodiment 2)

[0028] As Embodiment 2, FIG. 4 illustrates a schematic diagram showing the configuration of the median point calculating circuit in the two-dimensional neutron image detector using a scintillator and a wavelength shifting fiber. FIG. 5 A and FIG. 5B show flow charts of the median point calculation in case that the generated fluorescent light incident into five wavelength shifting fibers for the vertical axis and the horizontal axis, respectively, upon the incidence of a neutron. The two-dimensional neutron image detector using a scintillator and a wavelength shifting fiber in this embodiment has the structure shown below.

[0029] $ZnS:Ag/^{10}B_2O_3$ scintillator having a thickness of 0.3mm is used as the neutron scintillator that emits the fluorescent light upon the incidence of a neutron. The wavelength of the fluorescent light emitted from ZnS:Ag has distributed from 390nm to 520nm at the center of 450nm. The life-time of the short life-time component of the fluorescent light from ZnS:Ag-based fluorescent material to be used for detecting neutrons substantially is about 0.3 μ s. BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The shape of the wavelength shifting fiber is made in a right square having one side length of 0.5mm.

[0030] A bundle of wavelength shifting fibers for fetching count values along the vertical axis is formed by arranging 64 wavelength shifting fibers in one-dimensional geometry. A bundle of wavelength shifting fibers for fetching count values along the horizontal axis is formed by arranging 64 wavelength shifting fibers in one-dimensional geometry on the bundle of wavelength shifting fibers for fetching count values along the vertical axis in one-dimensional geometry in the diagonal direction. $ZnS:Ag/^{10}B_2O_3$ scintillator is formed above the bundle of those wavelength shifting fibers. Owing to this structure, a two-dimensional neutron detector having the dimension of the effective sensitive area of 32mm in height and 32mm in width may be formed. As for the optical detector for detecting the emitted fluorescent light experienced with wavelength shift by the wavelength shifting fibers, H7546 commercially available from HAMAMATSU PHOTONICS K.K. may be used, that is a 64-channnel photomultiplier tube for the horizontal axis and the vertical axis, respectively, each channel having an effective sensitive area of 2mm x 2mm. The individual photon electric signals output from the photomultiplier tubes for the horizontal axis and the vertical axis, respectively, are amplified by the photon signal amplifiers, each composed of a high-speed amplifier for the horizontal axis and the vertical axis, respectively, and then the individual amplified signals are formed as the photon digital pulse signals for the horizontal axis and the vertical axis, respectively, by the photon signal discriminating circuit composed of individual discriminator circuits.

[0031] When detecting the fluorescent lights emitted from the wavelength shift fibers by using the 64-channel photomultiplier tube in the above configuration, the photon signal amplifier and the photon signal discriminating circuit having an ability to detect the fluorescent lights using the photon counting method are used. As for the photon signal amplifier, a couple of ICs, AD8001 commercially available from Analog Devices Inc. are used as high-speed ICs for the individual circuit and the overall amplifier is formed as an amplifier having a 60-times-amplifying gain with its amplifier bandwidth of 200MHz. As for the photon signal discriminating circuit, AD8611 also commercially available from Analog Devices Inc. is used as the high-speed discriminator IC. Owing to applying the electronic circuit so configured as described above, the photon digital pulse signal having a pulse time width of about 5ns can be obtained as a single signal per photon.

[0032] Next, the photon digital pulse signal generated by the photon output from the individual photomultiplier tube is extracted as the signal synchronized to the clock signal having a cycle time adapted to its pulse time width by using the signal synchronization circuit composed of the gate circuit, and then the synchronized photon signal is obtained. The frequency of the clock signal is made 100MHz, generating the same pulse time width of 5ns because the pulse time width of the photon pulse signal is 5ns.

[0033] The arithmetic "OR" operation is applied to the synchronized photon signals output for the vertical axis and the horizontal axis, respectively, each synchronized to one another, for all of 64 channels by "OR" circuit at first, and then, the timing when the pulse signal arrives at first to the input to "OR" circuit among the photon digital pulse signals obtained by detection and signal processing upon the incident of a neutron is defined to be the neutron incident time, and is made input to the count-time generating circuit . The count-time generating circuit supplies this first-arriving pulse signal as the start-time signal to the multi-channel photon digital counting circuit for the vertical axis and the horizontal axis, respectively, which start the counting operations at the individual channels. The circuit for observing the predetermined count out time in the count-time generating circuit starts at the same time, and then this circuit generates a stop signal upon the predetermined count time reached and sends the stop signal to the multi-channel photon digital counting circuits for the vertical axis and the horizontal axis, respectively, that terminate the counting operation and finally decides the counting values for the vertical axis and the horizontal axis, respectively. In this embodiment, the count time is defined to be 1 μ s corresponding to three times of 0.3μ s, that is the short life-time component of the fluorescent light from ZnS:Ag fluorescent material, so that almost all the short life-time component of the fluorescent light may be utilized. Thus, the photon count-value distribution at the center of the neutron incident position upon the single neutron incident into the scintillator is obtained in which the total amount of distributed photons is proportional to the amount of fluorescent light.

[0034] In the present invention, the incident position in two-dimensional geometry is determined by calculating a median point on the basis of the obtained photon count-value distribution. In one embodiment of the median point calculation, the neutron incident position in two-dimensional geometry on the vertical axis and the horizontal axis, respectively, is obtained individually by using the same method as described by referring to FIG. 3 in Embodiment 1. The position signals for the vertical axis and the horizontal axis, each obtained independently, are supplied to the coincidence counting circuit that judges whether the position signal for the vertical axis and the position signal for the horizontal axis establish coincidence by observing that those signals arrive during a predetermined time window. If their coincidence is proved to be valid, the neutron incident position signal is made output as the neutron signal, and if proved to be invalid, the neutron incident position signal is not made output. The coincidence count time (coincidence time) is defined to be 1 μ s corresponding to three times of 0.3 μ s, which is the short life-time component of the fluorescent light from ZnS:Ag fluorescent material.

[0035] Note also in the description of this embodiment that the weight values for the photon count values at the individual positions are uniformly made equal to 1 in the above calculation example, though it is allowed that the uneven weight values may be used in order to increase the position accuracy in case that the detection characteristics for the fluorescent light is not uniform.

[0036] In order to estimate the characteristics in determining the neutron incident position of the two-dimensional neutron image detector in this embodiment, neutron irradiation experiment was conducted by using cold neutrons having a wavelength of 4 A° at CHOP, Pulsed Neutron Instrument with Disk Chopper, at JRR-3 Research Reactor, Japan Atomic Energy Agency. A Cd(Cadmium)-based collimator plate having a hole having a diameter of 1.1mm is placed in front of the neutron image detector of this embodiment, and the collimated neutron beam having a diameter of 1.1mm is made irradiated. FIG. 6 shows the comparison between the result obtained by applying the median point calculating method according to the present invention to the photon count distribution obtained by the neutron beam and the result obtained by applying the pattern matching method in the prior art to the same photon count distribution obtained as above. This figure is the result of viewing the two-dimensional incident position distribution in the horizontal-axis direction.

[0037] The position resolution calculated by the pattern matching method in the prior art is 1.08mm while the position resolution calculated by the median point calculating method according to the present invention is 0.92mm, which proves that the position resolution can be improved by 0.16mm. In the prior art method, the peak profile on the count-value distribution is observed to be shifted asymmetrically to the left side and the peak position is also shifted by the displacement corresponding to the gap between the adjacent wavelength shifting fibers, though the peak profile in the method according to the present invention is observed to be proximate to symmetrical Gaussian distribution, and its peak position is also observed to be located at the center of the distribution. FIG. 7 shows the three-dimensional image of the neutron peak obtained by the prior art method and the three-dimensional image of the neutron peak obtained by the median point calculating method according to the present invention. As described above, it is proved that the peak profile is improved and that the count-value distribution is symmetrical in the omni-directions in three-dimensional geometry in the method according to the present invention.

(Embodiment 3)

[0038] As Embodiment 3, FIG. 8 illustrates a schematic diagram showing the configuration of the median point calculating circuit in the two-dimensional neutron image detector for determining the incident position of the neutron by detecting the fluorescent light from the scintillator directly in two-dimensional geometry. Each of FIG. 9A and FIG. 9B illustrates a flow chart of the median point calculation based on the basic principle of the median point calculation in two-dimensional geometry according to the present invention. The two-dimensional neutron image detector using a scintillator in this embodiment has the structure shown below.

[0039] $ZnS:Ag/^{10}B_2O_3$ scintillator having a thickness of 0.3mm is used as the neutron scintillator that emits the fluorescent light upon the incidence of a neutron. The wavelength of the fluorescent light emitted from ZnS:Ag has distributed from 390nm to 520nm at the center of 450nm. The life-time of the short life-time component of the fluorescent light from ZnS:Ag-based fluorescent material to be used for detecting neutrons substantially is about 0.3 μ s.

[0040] As the signal processing is applied to the photon count values in the present invention, in case of detecting the photons by using the photomultiplier tube that is a photoelectric detector sensitive to the light from the scintillator, the photomultiplier measures a bunch of photons, which makes it difficult to obtain the designated accuracy in the photon count-value distribution, which will be described in detail in Embodiment 5. In order to solve this problem, an optical plate used for attenuating the light intensity and also diffusing the light beam is provided in front of the photomultiplier tube. As the light-intensity attenuation rate for the wavelength shifting fiber having a high detection efficiency as described in Embodiments 1 and 2 is 4%, the light-intensity attenuation rate in this embodiment is made 1/25 so as to be the same level of light-intensity attenuation rate. Though this embodiment uses the fluorescent light emitted from the scintillator and attenuated by the optical plate used for attenuating the light intensity and also diffusing the light beam, it is allowed to using an optical guide method in which the fluorescent light may be attenuated by a few ten percents and detected by the photomultiplier tube.

[0041] As for the photomultiplier tube to be used, H7546 commercially available from HAMAMATSU PHOTONICS K.K. may be used, that is a 64-channnel photomultiplier tube, each channel having an effective sensitive area of 2mm x 2mm.

[0042] As the size of the overall effective sensitive area of the 64-channnel photomultiplier tube is 18.1mm x 18.1mm, the size of the neutron scintillator and the light-intensity attenuation filter is made to be 20mm x 20mm.

[0043] When detecting the fluorescent lights by using the 64-channel photomultiplier tube, the photon signal amplifier and the photon signal discriminating circuit having an ability to detect the fluorescent lights using the photon counting method are used. As for the photon signal amplifier, a couple of ICs, AD8001 commercially available from Analog Devices Inc. are used as high-speed ICs for the individual circuit and the overall amplifier is formed as an amplifier having a 60-times-amplifying gain with its amplifier bandwidth of 200MHz. As for the photon signal discriminating circuit, AD8611 also commercially available from Analog Devices Inc. is used as the high-speed discriminator IC. Owing to applying the electronic circuit so configured as described above, the photon digital pulse signal having a pulse time width of about 5ns can be obtained as a single signal per photon.

[0044] Next, the photon digital pulse signal generated by the photon output from the individual photomultiplier tube is extracted as the signal synchronized to the clock signal having a cycle time adapted to its pulse time width by using the signal synchronization circuit composed of the gate circuit, and then the synchronized photon signal is obtained. The frequency of the clock signal is made 100MHz, generating the same pulse time width of 5ns because the pulse time width of the photon pulse signal is 5ns.

[0045] The arithmetic "OR" operation is applied to the synchronized photon signals output, each synchronized to one another, for all of 64 channels by "OR" circuit at first, and then, the timing when the pulse signal arrives at first to the input to "OR" circuit among the photon digital pulse signals obtained by detection and signal processing upon the incident of a neutron is defined to be the neutron incident time, and is made input to the count-time generating circuit. The count-time generating circuit supplies this first-arriving pulse signal as the start-time signal to the multi-channel photon digital counting circuit, which starts the counting operations at the individual channels. The circuit for observing the predetermined count out time in the count-time generating circuit starts at the same time, and then this circuit generates a stop signal upon the predetermined count time reached and sends the stop signal to the multi-channel photon digital counting circuit, that terminates the counting operation and finally decides the counting values. In this embodiment, the count time is defined to be 1 μ s corresponding to three times of 0.3 μ s, that is the short life-time component of the fluorescent light from ZnS:Ag fluorescent material, so that almost all the short life-time component of the fluorescent light may be utilized.

[0046] Thus, the photon count-value distribution at the center of the neutron incident position upon the single neutron incident into the scintillator can be obtained in which the total amount of distributed photons is proportional to the amount of fluorescent light, as shown in "Two-dimensional View" illustrated in two-dimensional geometry at the most upper part of FIG. 8

[0047] In the present invention, the incident position in one-dimensional geometry is determined by calculating a median point on the basis of the obtained photon count-value distribution. One embodiment of the median point calculation is described by referring to the flow chart of the median point calculation using two-dimensional processing method shown in FIG. 9A and FIG. 9B. In this calculation example, the position having the maximum count value is obtained at first. In the calculation example below, assume that the position having the maximum count value is position 5 (five). Next, the median point calculation is executed for the distinctive 4 (four) directions originated at the position 5 as the center, i.e. horizontal direction, diagonal direction 1, diagonal direction

2 and vertical direction.

[0048] For the diagonal direction 1 and the diagonal direction 2, their diagonal components are made separated into the horizontal-axis component and the vertical-axis component, each contributing scalar components to form the diagonal component. Using the obtained components, their own average values for the individual vertical-axis and horizontal-axis components are calculated as the incident position on the horizontal axis and the incident position on the vertical axis, respectively, and then made output as the neutron incident position.

[0049] Note that the weight values for the photon count values at the individual positions are uniformly made equal to 1 in the above calculation example, though it is allowed that the uneven weight values may be used in order to increase the position accuracy in case that the detection characteristics for the fluorescent light is not uniform.

(Embodiment 4)

[0050] As Embodiment 4, FIG. 10A and FIG. 10B illustrate schematic diagrams showing the configuration of the median point calculating circuit in the two-dimensional neutron image detector using a scintillator and a wavelength shifting fiber according to the present invention. FIG. 11A and FIG. 11B show flow charts of the median point calculation in case that the generated fluorescent light incident into five wavelength shifting fibers for the vertical axis and the horizontal axis, respectively, upon the incidence of a neutron.

[0051] The two-dimensional neutron image detector using a scintillator and a wavelength shifting fiber in this embodiment has the same structure as Embodiment 2. Note that the additional function including the median-point calculating circuit and its down stream in the present invention will be now described.

[0052] At first, the neutron incident position in two-dimensional geometry on the vertical axis and the horizontal axis, respectively, is determined individually by the median point calculation on the basis of the photon count-value distribution obtained by using the same method as Embodiment 2. The integrated value for the horizontal-axis count values and the an integrated value for the horizontal-axis count values, both obtained at median point calculation, are extracted for the signals to be used for discrimination, respectively. Next, comparing the integrated value for the horizontal-axis count values with the preset discrimination value for the horizontal axis, if the integrated value for the horizontal-axis count values is equal to or larger than the preset discrimination value for the horizontal axis, in which the output of AND circuit is turned "ON", then the incident position on the horizontal axis is made transmitted to the coincidence counting circuit. Similarly, comparing the integrated value for the vertical-axis count values with the preset discrimination value for the vertical axis, if the integrated value for the vertical-axis count values is equal to or larger than the preset discrimination value for the vertical axis, in which the output of AND circuit is turned "ON", then the incident position on the vertical axis is made transmitted to the coincidence counting circuit. The position signals for the vertical axis and the horizontal axis, each transmitted as described above, are supplied to the coincidence counting circuit that judges whether the position signal for the vertical axis and the position signal for the horizontal axis establish coincidence by observing that those signals arrive during a predetermined time window. If their coincidence is proved to be valid, the neutron incident position signal is made output as the neutron signal, and if proved to be invalid, the neutron incident position signal is not made output. The coincidence count time (coincidence time) is defined to be 1 μ s corresponding to three times of 0.3μ s, that is the life time of the short life-time component of the fluorescent light from ZnS:Ag fluorescent material.

[0053] In this embodiment, the present values for the position signals for the vertical axis and the horizontal axis, respectively, are determined and then, the position signals are judged individually to be valid if the individual position signals are equal to or larger than the individual preset values. However, it is allowed that a single present discrimination value for the photon count value is used to be compared with the sum of the integrated value for the horizontal-axis count values and the integrated value for the vertical-axis count values in order to validate the position signal for the horizontal axis and the position signal for the vertical axis.

[0054] In order to estimate the characteristics in determining the neutron incident position of the two-dimensional neutron image detector in this embodiment, neutron irradiation experiment was conducted by using cold neutrons having a wavelength of 4Å at CHOP, Pulsed Neutron Instrument with Disk Chopper, at JRR-3 Research Reactor, Japan Atomic Energy Agency. A Cd(Cadmium)-based collimator plate having a hole having a diameter of 1.1mm is placed in front of the neutron image detector of this embodiment, and the collimated neutron beam having a diameter of 1.1mm is made irradiated. FIG. 12 illustrates the measurement and signal processing result of the neutron beam measured by using the median point calculating method according to the present invention in case that the preset discrimination values for the photon count value for the integrated value for the horizontal-axis count values and the integrated value for the vertical-axis count values, respectively, are made identical to each other, and that the preset discrimination value is made change from 2 to 6. This figure is the result of viewing the two-dimensional incident position distribution in the horizontal-axis direction. This figure shows the changes of the peak profile in case that the preset discrimination values for the photon count value for the integrated value for the horizontal-axis count values and the integrated value for the vertical-axis count values, respectively, are made change from 2 to 6. It is proved that the peak profile does not change substantially even if the preset discrimination value for the photon count value changes, and that, as the preset discrimination value for the photon count value changes, the peak area decreases and the detection efficiency for the neutron decreases.

[0055] FIG. 13 shows the analysis result of the position resolution for the peak profile for the preset discrimination value for the photon count value, the present discrimination value being changed from 2 to 7. The position resolution for the preset discrimination value for the photon count value being 6 is 0.81mm while the position resolution for the preset discrimination value being 2 is 1.04mm, which proves that the position resolution can be improved by 0.23mm.

(Embodiment 5)

[0056] As Embodiment 5, FIG. 14A and FIG.14B illustrate schematic diagrams showing the configuration of the median point calculating circuit in the two-dimensional neutron image detector combining a semi-transparent scintillator manufactured by mixing ZnS:Ag fluorescent material, and ^{6}LiF or $^{10}B_2O_3$ as a neutron converter and a wavelength shifting fiber according to the present invention. FIG. 15A and FIG. 15B show flow charts of the median point calculation in case that the generated fluorescent light incident into five wavelength shifting fibers for the vertical axis and the horizontal axis, respectively, upon the incidence of a neutron.

[0057] The two-dimensional neutron image detector using a scintillator and a wavelength shifting fiber in this embodiment has the same structure as Embodiment 2. Note that the additional function including the signal synchronization circuit and its down stream in the present invention will be now described.

[0058] What will be described below is a case of using a semi-transparent scintillator as a neutron scintillator manufactured by mixing ZnS:Ag fluorescent material, and ^{6}LiF or $^{10}B_2O_3$ as a neutron converter. The neutron detecting sheet commercially available from AST in England is used as the neutron scintillator, which is manufactured by using ZnS:Ag as fluorescent material, and mixing ZnS:Ag and ^{6}LiF with a mixing ratio of 4:1 by binder material. The thickness of the neutron scintillator is 0.45mm. FIG. 16 shows an example of the measurement result of the photon pulse-height distribution characteristics by detecting the fluorescent light from the neutron scintillator by the photomultiplier tube. It is proved that the number of photons to be used at the median point calculation distributes in the range almost in double-figures from 2 (two) to about 100 (one hundred) when the photon digital signal is generated upon the neutron incident detected by the wavelength shifting fiber, as this neutron scintillator is semi-transparent.

[0059] In such a case as described above, if photons are generated in a very short period of time, the number of photons to be measured may not be measured precisely because several photons are super-positioned on one another in a designated time window. FIG. 17 shows the nonlinearity in photon countings and its compensation method by classifying such photon superposition phenomena into three cases; extremely many photons generated, several photons generated, and photons generated intermittently.

[0060] In case that the number of photons is large, as shown in FIG. 17, the discrimination output provides a single digital pulse having a long pulse width, and after that, several photon signals appear intermittently. The photon count number corresponding to the long pulse width of the digital pulse is obtained by using the signal synchronization circuit with the clock signals. However, the super-positioned photons can not be measured precisely.

[0061] Based on the fact that the life-time of the fluorescent light generated from the fluorescent material is known, and that the relation between the discrimination levels in the photon signal discriminating circuit and the continuous pulse width of the digital pulse output from the photon signal discriminating circuit, the exact number of photons implied by the super-positioned photon signal pulses is estimated by using the life-time of the fluorescent light. In case that the number of fluorescent lights is relatively small as shown at the center part of FIG. 17, the exact number of photons can be also estimated by compensating the measured number of photons.

[0062] Referring to the short life-time component of the fluorescent light from ZnS:Ag fluorescent material, 0.3 μ s, the exact number of photons implied by the super-positioned photon signal pulses was estimated based on the relation between the relation between the discrimination levels in the photon signal discriminating circuit and the continuous pulse width of the digital pulse output from the photon signal discriminating circuit. A simple exponential function is used as the life-time decay curve. The discrimination level is so defined that the photon digital signal may accommodate the separately identifiable photon signal output from the amplifier with 90% fraction.

[0063] FIG. 18 shows the relation between the exact number of incident photons to be estimated according to the above described conditions and the measured number of synchronized and output photons. As the ideal relation between those entities is shown as the proportional line in FIG. 18, the difference between the proportional line and the estimated curve is the number of photons to be used for compensation. For example, assuming that the exact number of incident photons is 60, the compensated number to the actually measured number of photons is 33, which is almost equal to the actually measured number, 27.

[0064] In practical applications, in order to compensate the non-linearity, some compensation and conversion formula or conversion table may be used for the median point calculation as shown in the flow chart of median point calculation in FIG. 15 at the linearity compensation circuit shown in FIG. 14, and some false pulse may be generated corresponding to the input photon count numbers as shown in FIG. 17 illustrating an explanatory drawing for the principle of compensating the non-linearity.

(Embodiment 6)

[0065] As Embodiment 6, FIG. 19 illustrates a schematic diagram showing the circuit configuration for removing the multiple countings due to after-glow (The life-time of the short life-time component of the fluorescent light is 70 μ s) after the median point calculation with the time-delay circuit in the two-dimensional neutron image detector combining a semi-transparent scintillator manufactured by mixing ZnS:Ag fluorescent material, and ^{6}LiF or $^{10}B_2O_3$ as a neutron converter and a wavelength shifting fiber according to the present invention. FIG. 20A and FIG. 20B show flow charts of the process performed in the circuit configuration example when of the median point calculation in case that the generated fluorescent light incident into five wavelength shifting fibers for the vertical axis and the horizontal axis, respectively, upon the incidence of a neutron.

[0066] The two-dimensional neutron image detector using a scintillator and a wavelength shifting fiber in this embodiment has the same structure as Embodiment 2. Note that the additional function including the median-point calculating circuit and its down stream in the present invention will be now described.

[0067] What will be described below is a case of using a semi-transparent scintillator as a neutron scintillator manufactured by mixing ZnS:Ag fluorescent material, and ^{6}LiF or $^{10}B_2O_3$ as a neutron converter in the similar manner to Embodiment 5. The neutron detecting sheet commercially available from AST in England is used as the neutron scintillator, which is manufactured by using ZnS:Ag as fluorescent material, and mixing ZnS:Ag and ^{6}LiF with a mixing ratio of 4:1 by binder material. The thickness of the neutron scintillator is 0.45mm. Refer to FIG. 16 for the example of the measurement result of the photon pulse-height distribution characteristics by detecting the fluorescent light from the neutron scintillator by the photomultiplier tube. It is proved that the number of photons to be used at the median point calculation distributes in the range almost in double-figures from 2 (two) to about 100 (one hundred) when the photon digital signal is generated upon the neutron incident detected by the wavelength shifting fiber, as this neutron scintillator is semi-transparent.

[0068] In such a case as described above, the larger the number of photons, the more after-glow remain in the ZnS:Ag fluorescent material, and therefore, the remaining after-glow component causes multiple countings (two or more neutron incident countings are obtained per neutron incident) in case of applying the signal processing using such a photon counting method as the present invention.

[0069] In order to remove such multiple countings, it is required to make the signal processing circuit into a ready state for counting the subsequent neutron incident after completing the previous neutron incident counting. It is possible to remove such multiple countings not by making the processing circuit into a ready state immediately, but by delaying the initiation of the ready state of the processing circuit with an optimal delay time by using the delay circuit.

[0070] The probability for the multiple countings can be obtained by actual measurement by changing the actual delay time to initiating the ready state of the processing circuit and by observing the multiple countings by using the actual neutron image detector. FIG. 21 shows the relation between the delay time and the actual number of neutron countings as the raw data in the experimental result. The measurement condition assumes such a basic case that one or more photons enter the horizontal axis and one or more photons enters the vertical axis at the neutron image detector. It is observed that the neutron counting per 100 seconds is 8200 for the delay time of 2 μ s though the neutron counting is 7000 for the enough delay time of 20 μ s. It is proved that a fraction of multiple countings to the overall countings is 16% for the delay time of 2μ s.

[0071] FIG. 22 shows a fitting curve showing the relation between the fraction of multiple countings and the delay time on the basis of raw data described above. According to the figure, the fraction of multiple countings gets to as large as 16% in case of applying the delay time of 2 μ s unconditionally. On the other hand, the fraction of multiple countings is as low as 1% in case of applying the delay time of 20μ s, which fails to establish neutron image detection with a higher counting rate because of the increased dead time.

[0072] In order to solve such a problem as described above in the present invention, the delay time is so defined as to correspond to the optimal number of photon count value on the basis of the overall number of measured photons in the experiment. As shown in the circuit configuration illustrated in FIG. 19 and the signal flow chart illustrated in FIG. 20A and FIG. 20B, the delay time is so preset at the median point calculating circuit as to correspond to the sum of the integrated value for the vertical-axis photon count values and the integrated value for the horizontal-axis photon count values, and the initiation of the ready state for detecting the subsequent neutron incident is delayed by the delay time.

[0073] The delay time to be preset is determined by analyzing the experimental result as described below. The relation between the delay time and the fraction of multiple countings to the overall countngs is required at first, which can be prepared by using the relational expression in FIG. 22 as described above.

[0074] The relation between the overall photon countings and the multiple photon countings is obtained by normalizing the fraction of multiple countings so that the fraction of multiple countings may be 0.16 for 2 (two) photons, assuming that the fraction of multiple countings is proportional to a square of the number of photons and using the photon distribution in the ZnS-based scintillator as shown in FIG. 16. The measurement condition assumes such a basic case that one or more photons enter the horizontal axis and one or more photons enters the vertical axis at the neutron image detector. FIG. 23 shows the relation between the obtained number of photons and the probability, that is, occurrence rate of multiple countings.

[0075] Assuming that the fraction of multiple countings in the relational expression between the fraction of multiple countings obtained by referring to FIG. 22 is identical to the occurrence rate of multiple countings in the relational expression between the occurrence rate of multiple countings and the number of photons obtained by referring to FIG. 23, the relation between the number of photons and the required delay time can be obtained by combining those relational expressions. FIG. 24 shows the computational result. It is proved that the delay time of 2 μs can be applied for the number of photons, 20 or smaller, and that the delay time should be increased linearly as the number of photon count number increases from 20 and more.

[0076] By means that this relational expression is implemented as the table or the relational expression into the delay-time preset circuit shown in FIG. 19, such a neutron image detector can be realized so that the delay time may be adjusted in response to the measured number of photons on the basis of the flow chart shown in FIG. 20. Owing to this configuration and process, it will be appreciated that such a two-dimensional neutron image detector having such a performance as being compliant to high-rate counting measurement can be obtained so that the counting loss may be as low as possible, the multiple countings due to the after-glow in the ZnS:Ag fluorescent material may be removed.

(Embodiment 7)

[0077] As Embodiment 7, FIG. 25 illustrates a schematic diagram showing the configuration of the median point calculating circuit in the one-dimensional neutron image detector using a scintillator and a wavelength shifting fiber. FIG. 26 shows a flow chart of the median point calculation in case that the generated fluorescent light incident into five wavelength shifting fibers upon the incidence of a neutron. FIG. 27 shows a calculation example for the median point calculation based on the principle of mapping the synchronized photon signal to the position number value in calculating the median point without using the multiplication circuit.

[0078] The one-dimensional neutron image detector using a scintillator and a wavelength shifting fiber in this embodiment has the same structure as Embodiment 1. Note that the additional function including the signal synchronization circuit and its down stream in the present invention will be now described.

[0079] In the median point calculating circuits described above in Embodiments 1 to 6, as described in the calculation example for the median point calculating circuit shown in FIG. 3, the integrated count value of photons for the individual position is obtained by adding operation to the number of photons at the individual position on the basis of the photon count value at the individual incident position stored at the multi-channel photon digital counting circuit. Next, multiplication operation of the photon count value at the individual position and the corresponding position number value is performed and the resultant products are summed to obtain the photon median point count value summation. Those calculations require complicated circuits and computational times, and thus, it takes a longer time to determine the incident position on the basis of overall median point calculations, which fails to establish neutron image detection with a higher counting rate because of the increased dead time.

[0080] The logical "OR" operation is applied to all the synchronized photon signals, each synchronized to one another, for all of 64 channels by "OR" circuit at first, and then, the timing when the pulse signal arrives at first to the input to "OR" circuit among the photon digital pulse signals obtained by detection and signal processing upon the incident of a neutron is defined to be the neutron incident time, and is made input to the count-time generating circuit. The count-time generating circuit supplies this first-arriving pulse signal as the start-time signal to the multi-channel photon digital counting circuit which starts the counting operations at the individual channels and summing operation for those count values, and also supplies this start-time signal to the position number value integrating circuit in order to start integrating operation for the position number values.

[0081] All the synchronized photon signals are input to the multi-channel photon digital counting circuit, and resultantly the integrated count value of photons can be obtained. At the same time, all he synchronized photon signals are input also to the photon synchronization signal-to position number converting circuit. The photon synchronization signal-to position number converting circuit generates the position number value corresponding to the individual incident position for the photon synchronization signal. The individual position number values generated above are input to the position number value integrating circuit, and resultantly the photon median point count value summation can be obtained.

[0082] The circuit for observing the predetermined count out time in the count-time generating circuit starts at the same time, and then this circuit generates a stop signal upon the predetermined count time reached and sends the stop signal to the multi-channel photon digital counting circuit, that terminates the counting operation and finally decides the photon count integrated value and the photon median point count value summation.

[0083] In this embodiment, the count time is defined to be 1 μs corresponding to three times of 0.3 μs, that is the life time of the short life-time component of the fluorescent light from ZnS:Ag fluorescent material, so that almost all the short life-time component of the fluorescent light may be utilized.

[0084] Next, the neutron incident position can be obtained by dividing the obtained photon median point summation by the photon count integrated value by using a division circuit.

[0085] By referring to FIG. 27, a calculation example for the median point calculation according to the present invention now will be described. In the calculation example below, assume that the fluorescent lights enter 5 (five) wavelength shifting fibers at the fiber positions 3 to 5. At first, the integrated count value A obtained by counting for the single neutron by using the wavelength shifting fibers is obtained by summing the count values at the positions 3 to 7, which makes 11 in this calculation example.

[0086] Next, the median point calculation summation B is obtained. The position number values from 3 to 7 are generated by the synchronized photon signals corresponding to the fiber positions 3 to 7, respectively. The individual generated position number values are made input to the position number value integrating circuit, in which the median point calculation summation B is obtained as 54 by summing its input values as shown in the figure. The neutron incident position obtained in case of applying the median point calculating method is defined as a quotient obtained by dividing the median point count value summation B by the integrated count value A, that is, B/A=54/11=4.9. In case of representing the coordinate value of the incident position in terms of integer number, position 5 is obtained as the incident position by round-off calculation. In case of an increased accuracy in the incident position, a real value of 4.9 may be used as the coordinate value of the incident position. The incident position obtained in this embodiment is identical to the result obtained in the embodiment referring to FIG. 3.

[0087] Owing to the above described configuration and process, it will be appreciated to provide such a one-dimensional neutron image detector or a two-dimensional neutron image detector as enabling to obtain the incident position by the median point calculation without using any complicated multiplying circuit and integrating circuit.

(Embodiment 8)

[0088] As Embodiment 8, FIG. 28 illustrates a schematic diagram showing the configuration of the median point calculating circuit in the two-dimensional neutron image detector combining a semi-transparent scintillator manufactured by mixing ZnS:Ag fluorescent material, and ^{6}LiF or $^{10}B_2O_3$ as a neutron converter and a wavelength shifting fiber according to the present invention. FIG. 15A and FIG. 15B show flow charts of the median point calculation in case that, assuming a couple of neutrons incident simultaneously, in which one neutron having a higher intensity of the fluorescent light, that is, a larger integrated number of photons is defined as "Neutron 1" and the other neutron is defined as "neutron 2", the fluorescent light corresponding to Neutron 1 incident into five wavelength shifting fibers for the vertical axis and the horizontal axis, respectively, and the fluorescent light corresponding to Neutron 2 incident into three wavelength shifting fibers for the vertical axis and the horizontal axis, respectively, and then, those neutrons are discriminated.

[0089] The two-dimensional neutron image detector using a scintillator and a wavelength shifting fiber in this embodiment has the same structure as Embodiment 2. Note that the additional function including the signal synchronization circuit and its down stream in the present invention will be now described.

[0090] What will be described below is a case of using a semi-transparent scintillator as a neutron scintillator manufactured by mixing ZnS:Ag fluorescent material, and ^{6}LiF or $^{10}B_2O_3$ as a neutron converter. The neutron detecting sheet commercially available from AST in England is used as the neutron scintillator, which is manufactured by using ZnS:Ag as fluorescent material, and mixing ZnS:Ag and ^{6}LiF with a mixing ratio of 4:1 by binder material. The thickness of the neutron scintillator is 0.45mm. FIG. 16 shows an example of the measurement result of the photon pulse-height distribution characteristics by detecting the fluorescent light from the neutron scintillator by the photomultiplier tube. It is proved that the number of photons to be used at the median point calculation distributes in the range almost in double-figures from 2 (two) to about 100 (one hundred) when the photon digital signal is generated upon the neutron incident detected by the wavelength shifting fiber, as this neutron scintillator is semi-transparent.

[0091] As the photons are detected at two positions in the vertical axis and the horizontal axis, respectively, at the neutron image detector in case that a couple of photons are generated simultaneously (within a time window for measuring photons) at distinctive positions, it is impossible to identify the detection positions, and thus the neutron signals are not provided in general. Therefore, counting loss may occur especially in case of the measurement with a higher counting rate.

[0092] In the present invention, in case of using ZnS:Ag as fluorescent material and ^{6}LiF as a neutron converter, the number of generated photons upon the incident of a neutron is as many as 2 to 100. In case that the number of photons generated by the incident of a neutron varies from one neutron to another neutron when a couple of neutrons incident, the count values for the vertical axis and the horizontal axis for the individual neutrons are compared with each other, respectively, a group of count values having relatively larger values and a group of count values having relatively smaller values are identified respectively to correspond to the individual neutrons in order to discriminate a couple of neutrons.

[0093] In this embodiment, by referring to FIG. 29A and FIG. 29B, a flow of the median point calculation by discriminating a couple of neutrons as well as the associated circuit operation will be described below.

[0094] Assume that a couple of neutrons, Neutron 1 and Neutron 2, incident simultaneously, and that the number of photons generated by Neutron 1 is larger than the number of photons generated by Neutron 2. Under those assumptions, the number of fibers detecting the photons generated by Neutron 1 in the horizontal axis and the vertical axis, respectively, is 5 (five), and the number of fibers detecting the photons generated by Neutron 2 in the horizontal axis and the vertical axis, respectively, is 3 (three).

[0095] In the subsequent processes, in the similar manner to Embodiment 2, the photon count-value distributions in the horizontal axis and the vertical axis, respectively can be obtained by using the multi-channel photon digital counting circuit. In this embodiment, a couple of neutron photon distributions associated with Neutron 1 and Neutron 2 are identified at the two distinctive positions in the photon count-value distribution in the horizontal axis. Similarly, a couple of neutron photon distributions associated with Neutron 1 and Neutron 2 are identified at the two distinctive positions in the photon count-value distribution in the vertical axis.

[0096] Next, the count values for the two incident positions in the horizontal axis are summed by using the horizontal-axis two-neutron judgment circuit, and then, the whole sum NA of photons and the whole sum NB of photons are obtained, respectively. By comparing the whole sum NAof photons with the whole sum NB of photons, the larger one is identified to be the count-value distribution due to Neutron 1, and the smaller one is identified to be the count-value distribution due to Neutron 2. In case that those whole sums are indistinctive or almost identical to each other, the neutron signal output is made NULL. In this embodiment, as the whole sum NA is larger than the whole sum NB, the whole sum NA is judged to be contributed by Neutron 1, and the whole sum NB is judged to be contributed by Neutron 2.

[0097] Similarly, the count values for the two incident positions in the vertical axis are summed by using the vertical-axis two-neutron judgment circuit, and then, the whole sum NC of photons and the whole sum ND of photons are obtained, respectively. By comparing the whole sum NC of photons with the whole sum ND of photons, the larger one is identified to be the count-value distribution due to Neutron 1, and the smaller one is identified to be the count-value distribution due to Neutron 2. In case that those whole sums are indistinctive or almost identical to each other, the neutron signal output is made NULL. In this embodiment, as the whole sum ND is larger than the whole sum NC, the whole sum ND is judged to be contributed by Neutron 1, and the whole sum NC is judged to be contributed by Neutron 2.

[0098] Next, using the median point calculating circuit for horizontal-axis high count integrated value and the median point calculating circuit for horizontal-axis low count integrated value, and dividing operation is applied to the median-point summation and the whole sum of photon count values, a couple of neutron incident positions XA and XB are obtained. According to the judgment result described above, the neutron incident point XA is determined to be contributed by Neutron 1 and the neutron incident point XB is determined to be contributed by Neutron 2.

[0099] Next, using the median point calculating circuit for vertical-axis high count integrated value and the median point calculating circuit for vertical-axis low count integrated value, and dividing operation is applied to the median-point summation and the whole sum of photon count values, a couple of neutron incident positions YC and YD are obtained. According to the judgment result described above, the neutron incident point YD is determined to be contributed by Neutron 1 and the neutron incident point YC is determined to be contributed by Neutron 2.

[0100] In order to verify the coincidence of the neutron incident positions XA and YC, both being contributed by Neutron 1 associated with a larger number of photons, the coincidence measurement is performed by using the coincidence counting circuit. If their coincidence is verified to be valid, the neutron incident position signal (X1, Y1) is provided as Neutron 1 signal, and if their coincidence is verified to be invalid, then the neutron incident position signal is not provided. The coincidence count time (coincidence time) is defined to be 1 μs corresponding to three times of 0.3 μ s, that is the life time of the short life-time component of the fluorescent light from ZnS:Ag fluorescent material.

[0101] In order to verify the coincidence of the neutron incident positions XB and YD, both being contributed by Neutron 2 associated with a smaller number of photons, the coincidence measurement is performed by using the coincidence counting circuit. If their coincidence is verified to be valid, the neutron incident position signal (X2, Y2) is provided as Neutron 2 signal, and if their coincidence is verified to be invalid, then the neutron incident position signal is not provided. The coincidence count time (coincidence time) is defined to be 1 μs corresponding to three times of 0.3 μ s, that is the life time of the short life-time component of the fluorescent light from ZnS:Ag fluorescent material.

[0102] Owing to the above described signal processing, as a couple of neutrons can be discriminated so as to provide their distinctive position signals upon a couple of neutrons incident simultaneously into the neutron image detector, it will be appreciated that such a detector with lower counting loss may be realized even if the neutron incident with a higher counting rate.

[0103] Although two wavelength shifting fibers has been arranged on one pixel in the examples described above, it becomes possible to realize a larger area detector and reduce the cost of a two-dimensional image detector as a whole by arranging three or more wavelength shifting fibers on one pixel and connecting them to photomultiplier tubes. In an example of three fibers, the first and third fibers are connected to photomultiplier tube 1, and the second fiber is connected to photomultiplier 2. Further, in an example of four fibers, the first and third fibers are connected to photomultiplier tube 1, and the second and fourth fibers are connected to photomultiplier 2. Even if five or more fibers are used, It is possible to construct a two-dimensional image detector in a similar manner.

[0104] In the following, the text included in the Figures is repeated.

[FIG. 2A]

[0105] Neutron incident into scintillator and fluorescent light generated
Generated fluorescent light incident into five wavelength shifting fibers as an embodiment
Detecting position P1
Detecting position P2
Detecting position P3
Detecting position P4
Detecting position P5
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Clock Generating Circuit
Clock Signal
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts photon signal arriving at first by using OR circuit and generates start signal
Start Signal
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Generates photon counting time and, generates stop signal when counting ends Stop Signal
Obtains Photon count value A in the counting time
Obtains Photon count value B in the counting time
Obtains Photon count value C in the counting time
Obtains Photon count value D in the counting time
Obtains Photon count value E in the counting time

[FIG. 2B]

[0106] Generates photon counting time and, generates stop signal when counting ends Stop Signal
Obtains Photon count value A in the counting time
Obtains Photon count value B in the counting time
Obtains Photon count value C in the counting time
Obtains Photon count value D in the counting time
Obtains Photon count value E in the counting time
Obtains whole sum D of Photons by summing all the count values as in A+B+C+D+E=N
Calculates W1 by P1xA=W1
Calculates W2 by P2xB=W2
Calculates W3 by P3xC=W3
Calculates W4 by P4xD=W4
Calculates W5 by P5xE=W5
Calculates median-point summation H by W1+W2+W3+W4+W5=W
Divides median-point summation E by whole sum D of Photons Obtains Neutron Incident Position at X by median-point calculation

[FIG. 5A]

[0107] Neutron incident into scintillator and fluorescent light generated
Generated fluorescent light incident into five X-axis wavelength shifting fibers as an embodiment
Generated fluorescent light incident into five Y-axis wavelength shifting fibers as an embodiment
Detecting position P1
Detecting position P2
Detecting position P3
Detecting position P4
Detecting position P5
Executes the same procedures as for X-axis
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube

Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Photon Synchronization Signal for Y-axis
Clock Generating Circuit
Clock Signal
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts photon signal arriving at first by using OR circuit and generates start signal
Start Signal
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Generates photon counting time and, generates stop signal when counting ends Stop Signal
Obtains Photon count value A in the counting time
Obtains Photon count value B in the counting time
Obtains Photon count value C in the counting time
Obtains Photon count value D in the counting time
Obtains Photon count value E in the counting time
Obtains whole sum D of Photons by summing all the count values as in A+B+C+D+E=N
Calculates W1 by P1xA=W1
Calculates W2 by P2xB=W2
Calculates W3 by P3xC=W3
Calculates W4 by P4xD=W4
Calculates W5 by P5xE=W5

(FIG. 5B]

[0108] Obtains whole sum D of Photons by summing all the count values as in A+B+C+D+E=N
Calculates W1 by P1xA=W1
Calculates W2 by P2xB=W2
Calculates W3 by P3xC=W3
Calculates W4 by P4xD=W4
Calculates W5 by P5xE=W5
Calculates median-point summation H by W1+W2+W3+W4+W5=W
Divides median-point summation E by whole sum D of Photons
Obtains Neutron Incident Position X by median-point calculation
Obtains Neutron Incident Position at Y by median-point calculation
Judges coincidence by coincidence counting circuit
Concludes non-neutron signal
Concludes neutron incident position at X, Y

[FIG. 11A]

[0109] Neutron incident into scintillator and fluorescent light generated
Generated fluorescent light incident into five X-axis wavelength shifting fibers as an embodiment
Generated fluorescent light incident into five Y-axis wavelength shifting fibers as an embodiment
Detecting position P1
Detecting position P2
Detecting position P3
Detecting position P4
Detecting position P5
Executes the same procedures as for X-axis
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with Its wavelength shifted into electric signal by using photomultiplier tube
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it Into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Photon Synchronization Signal for Y-axis
Clock Generating Circuit
Clock Signal
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon dig-

ital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts photon signal arriving at first by using OR circuit and generates start signal
Start Signal
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Generates photon counting time and, generates stop signal when counting ends Stop Signal
Obtains Photon count value A in the counting time
Obtains Photon count value B in the counting time
Obtains Photon count value C in the counting time
Obtains Photon count value D in the counting time
Obtains Photon count value E in the counting time

[FIG. 11B]

[0110] Obtains whole sum D of Photons by summing all the count values as in A+B+C+D+E=N
Calculates W1 by P1xA=W1
Calculates W2 by P2xB=W2
Calculates W3 by P3xC=W3
Calculates W4 by P4xD=W4
Calculates W5 by P5xE=W5
Calculates median-point summation H by W1+W2+W3+W4+W5=W
Divides median-point summation E by whole sum D of Photons
Obtains Neutron Incident Position X by median-point calculation
Obtains Neutron Incident Position Y by median-point calculation
Obtains integrated value of count values
Obtains integrated value of count values
Concludes non-neutron signal
Compare integrated count values with preset discrimination value for the horizontal axis
Preset discrimination value for the horizontal axis
Concludes non-neutron signal
Compare integrated count values with preset discrimination value for the vertical axis
Preset discrimination value for the vertical axis
Judges coincidence by coincidence counting circuit
Concludes non-neutron signal
Concludes neutron incident position at X, Y

[FIG. 15A]

[0111] Neutron incident into scintillator and fluorescent light generated
Generated fluorescent light incident into five X-axis wavelength shifting fibers as an embodiment
Generated fluorescent light incident into five Y-axis wavelength shifting fibers as an embodiment
Detecting position P1
Detecting position P2
Detecting position P3
Detecting position P4
Detecting position P5
Executes the same procedures as for X-axis
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Photon Synchronization Signal for Y-axis
Clock Generating Circuit
Clock Signal
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Performs linearity compensation calculation in case that 2 or more signals continuously arrive
Performs linearity compensation calculation in case that 2 or more signals continuously arrive
Performs linearity compensation calculation in case that 2 or more signals continuously arrive
Performs linearity compensation calculation in case that 2 or more signals continuously arrive
Performs linearity compensation calculation in case that 2 or more signals continuously arrive
Extracts photon signal arriving at first by using OR circuit

and generates start signal
Start Signal
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit

[FIG. 15B]

[0112] Extracts photon signal arriving at first by using OR circuit and generates start signal
Start Signal
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Generates photon counting time and, generates stop signal when counting ends Stop Signal
Obtains Photon count value A in the counting time
Obtains Photon count value B in the counting time
Obtains Photon count value C in the counting time
Obtains Photon count value D in the counting time
Obtains Photon count value E in the counting time
Obtains whole sum D of Photons by summing all the count values as in A+B+C+D+E=N
Calculates W1 by P1xA=W1
Calculates W2 by P2xB=W2
Calculates W3 by P3xC=W3
Calculates W4 by P4xD=W4
Calculates W5 by P5xE=W5
Calculates median-point summation H by W1+W2+W3+W4+W5-W
Divides median-point summation E by whole sum D of Photons
Obtains Neutron Incident Position X by median-point calculation
Obtains Neutron Incident Position Y by median-point calculation
Concludes neutron incident position at X, Y

[FIG. 20A]

[0113] Neutron incident into scintillator and fluorescent light generated
Generated fluorescent light incident into five X-axis wavelength shifting fibers as an embodiment
Generated fluorescent light incident into five Y-axis wavelength shifting fibers as an embodiment
Detecting position P1
Detecting position P2
Detecting position P3
Detecting position P4
Detecting position P5
Executes the same procedures as for X-axis
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Photon Synchronization Signal for Y-axis
Clock Generating Circuit
Clock Signal
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts photon signal arriving at first by using OR circuit and generates start signal
Start Signal
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Generates photon counting time and, generates stop signal when counting ends Stop Signal
Obtains Photon count value A in the counting time
Obtains Photon count value B in the counting time

Obtains Photon count value C in the counting time
Obtains Photon count value D in the counting time
Obtains Photon count value E in the counting time

[FIG. 20B]

[0114] Obtains whole sum D of Photons by summing all the count values as in A+B+C+D+E=N
Calculates W1 by P1xA=W1
Calculates W2 by P2xB=W2
Calculates W3 by P3xC=W3
Calculates W4 by P4xD=W4
Calculates W5 by P5xE=W5
Calculates median-point summation H by W1+W2+W3+W4+W5=W
Divides median-point summation E by whole sum D of Photons
Obtains Neutron Incident Position X by median-point calculation
Obtains Neutron Incident Position Y by median-point calculation
Obtains integrated value SX of count values for the horizontal axis
Obtain the sum of integrated value SX of count values for the horizontal axis and integrated value SY of count values for the vertical axis; SX+SY=SS
Obtains integrated value SY of count values for the vertical axis
Judges coincidence by coincidence counting circuit
Concludes non-neutron signal
Concludes neutron incident position at X, Y

[FIG. 26]

[0115] Neutron incident into scintillator and fluorescent light generated
Generated fluorescent light incident into five wavelength shifting fibers as an embodiment
Detecting position P1
Detecting position P2
Detecting position P3
Detecting position P4
Detecting position P5
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with Its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Clock Generating Circuit
Clock Signal
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts photon signal arriving at first by using OR circuit and generates start signal
Converts Photon Synchronization Signal to Position Number Value Signal by using Photon Synchronization Signal-to Position Number Converting Circuit Converts Photon Synchronization Signal to Position Number Value Signal by using Photon Synchronization Signal-to Position Number Converting Circuit Converts Photon Synchronization Signal to Position Number Value Signal by using Photon Synchronization Signal-to Position Number Converting Circuit Converts Photon Synchronization Signal to Position Number Value Signal by using Photon Synchronization Signal-to Position Number Converting Circuit Converts Photon Synchronization Signal to Position Number Value Signal by using Photon Synchronization Signal-to Position Number Converting Circuit
Calculates whole sum N of photon count values by summing individual photon synchronization signals for the individual positions all together by using Multi-Channel Photon Digital Counter and Integrating Circuit
Start Signal
Stop Signal
Start Signal
Generates Photon Count Time, and then Generates Stop Signal when counting ends
Stop Signal
Calculates median-point summation W by adding position numbers by using Position Number Value Integrating Circuit every time when photon synchronization signal for the individual position comes in.
Divides median-point summation E by whole sum D of Photons
Obtains Neutron Incident Position X by median-point calculation

[FIG. 29A]

[0116] Neutron1 incident into scintillator and fluorescent light generated (with maximum Photon numbers)
Neutron2 incident into scintillator and fluorescent light generated (with minimum Photon numbers)

Generated fluorescent light incident into 5 (five) X-axis wavelength shifting fibers as an embodiment
Generated fluorescent light incident into 3 (three) X-axis wavelength shifting fibers as an embodiment
Generated fluorescent light incident into 5 (five) Y-axis wavelength shifting fibers as an embodiment
Generated fluorescent light incident into 3 (three) Y-axis wavelength shifting fibers as an embodiment
Detecting position P1-5 for horizontal axis
Detecting position P11-13 for horizontal axis
Detecting position P11-13 for vertical axis
Detecting position P21-25 for vertical axis
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with Its wavelength shifted into electric signal by using photomultiplier tube
Converts Fluorescent light with its wavelength shifted into electric signal by using photomultiplier tube
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Amplifies electric signal and converts it into photon-digital signal at photon signal discriminating circuit
Photon Synchronization Signal for Y-axis
Clock Generating Circuit
Clock Signal
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts Photon synchronization signal from photon digital signal by using signal synchronization circuit
Extracts photon signal arriving at first by using OR circuit and generates start signal
Start Signal
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Counts Photon synchronization signal by using photon counting circuit
Generates photon counting time and, generates stop signal when counting ends
Stop Signal
Obtains Photon count distribution A in the counting time
Obtains Photon count distribution B in the counting time
Obtains Photon count distribution C in the counting time
Obtains Photon count distribution D in the counting time

[FIG. 29B]

[0117] Generates photon counting time and, generates stop signal when counting ends Stop Signal
Obtains Photon count distribution A in the counting time
Obtains Photon count distribution B in the counting time
Obtains Photon count distribution C in the counting time
Obtains Photon count distribution D in the counting time
Obtain whole sum NAof Photons by summing count values
Obtain median point whole sum WA of Photons as a result of calculation
Obtain whole sum NB of Photons by summing count values
Obtain median point whole sum WB of Photons as a result of calculation
Obtain whole sum NC of Photons by summing count values
Obtain median point whole sum WC of Photons as a result of calculation Obtain whole sum ND of Photons by summing count values
Obtain median point whole sum WD of Photons as a result of calculation
Compares whole sum NA of Photons with whole sum NB of Photons
In case that NA is NB, concludes non-neutron signal output
Obtains neutron incident position XA by diving median point whole sum WA by whole sum NA of Photons
Obtains neutron incident position XB by diving median point whole sum WA by whole sum NA of Photons
Obtains neutron incident position YC by diving median point whole sum WC by whole sum NC of Photons
Obtains neutron incident position YD by diving median point whole sum WD by whole sum ND of Photons
Compares whole sum NC of Photons with whole sum ND of Photons
In case that NC is ND, concludes non-neutron signal output
In case that NA is larger than NB, regards NA as neutron-1 induced signal and NB as neutron-2 signal
Horizontal-axis incident position judgment circuit
Vertical-axis incident position judgment circuit
In case that ND is larger than NC, regards ND as neutron-1 induced signal and NC as neutron-2 signal
Horizontal-axis XA
Horizontal-axis XB
Vertical-axis YD
Vertical-axis YC
Judges whether XA and YD for neutron-1 establish coincidence by using coincidence counting circuit
Concludes non-neutron signal
Judges whether XB and YC for neutron-2 establish coincidence by using coincidence counting circuit
Concludes non-neutron signal
Concludes neutron-1 incident position at X1 (XA), Y1

(YD)
Concludes neutron-2 incident position at X2 (XB), Y2 (YC)

Claims

1. A neutron image detection method for collecting fluorescent light generated by a neutron incident at a designated position interval in one-dimensional geometry and determining an incident position of the neutron by detecting the collected fluorescent light, wherein
the fluorescent light is detected by a photon counting method;
wherein
a pulse signal generated by an individual output photon is extracted;
a count-value distribution is obtained in terms of incident position as variable, upon a single neutron incident, by counting the pulse signal output; and
a neutron incident position is determined by calculating a median point on the basis of the obtained count-value distribution,
characterised in that the pulse signal generated by an individual output photon is extracted on the basis of a clock signal generated with the same time interval as the time width of the pulse signal generated by a single photon.

2. A neutron image detection method in accordance with claim 1, further comprising collecting the fluorescent light generated by a neutron incident at a designated position interval on a vertical axis and a horizontal axis, respectively, in two-dimensional geometry, wherein
a count-value distribution is obtained on the vertical axis and the horizontal axis, respectively, in terms of incident position as variable; and
the neutron incident position is determined on the vertical axis and the horizontal axis, respectively, by calculating a median point on the vertical axis and the horizontal axis, respectively, on the basis of the obtained count-value distributions.

3. A neutron image detection method in accordance with claim 1, further comprising collecting the fluorescent light from a scintillator generating the fluorescent light upon a neutron incident at a designated position interval on a vertical axis and a horizontal axis, respectively, in two-dimensional geometry and determining the incident position of the neutron by detecting the collected fluorescent light or detecting the fluorescent light directly in two-dimensional geometry, wherein
a two-dimensional count-value distribution is obtained in terms of incident position as variable, upon a single neutron incident, by counting the pulse signal output, or obtained by detecting directly the fluorescent light; and
the neutron incident position is determined on the vertical axis and the horizontal axis, respectively, on the basis of the obtained two-dimensional count-value distribution.

4. A neutron image detection method in accordance with claim 1, further comprising collecting the fluorescent light from a scintillator generating the fluorescent light upon a neutron incident, by using optical fibers or wavelength shifting fibers arranged at a designated position interval in parallel in one-dimensional geometry and determining the incident position of the neutron by detecting the collected fluorescent light or detecting the fluorescent light with its wavelength shifted, wherein
the count-value distribution is obtained in terms of incident position relative to an individual optical fiber or an individual wavelength shifting fiber as variable, upon a single neutron incident, by counting the pulse signal output by a counting circuit; and
the neutron incident position is determined by calculating the median point on the basis of the obtained count-value distribution.

5. A neutron image detection method in accordance with claim 1, further comprising collecting the fluorescent light from a scintillator generating the fluorescnt light upon a neutron incident, by using an optical fiber or a wavelength shifting fiber arranged at a designated position interval on a vertical axis and a horizontal axis, respectively, in parallel in two-dimensional geometry, making one fluorescent light amount a value collected for the vertical axis and making the other fluorescent light amount a value collected for the horizontal axis orthogonal to the vertical axis of the optical fiber or the wavelength shifting fiber, and determining the incident position of the neutron by detecting the fluorescent light collected by the optical fiber or the wavelength shifting fiber on the vertical axis and the horizontal axis by using a vertical light detector and a horizontal light detector, wherein
the pulse signal generated by an individual photon output by the individual light detector is extracted on the basis of the clock signal generated with the same time interval as the time width of the pulse signal generated by a single photon;
the count-value distribution is obtained on the vertical axis and the horizontal axis, respectively, in terms of incident position relative to an individual optical fiber or an individual wavelength shifting fiber as variable, upon a single neutron incident, by counting the pulse signal output by a counting circuit; and
the neutron incident position is determined on the vertical axis and the horizontal axis, respectively, by calculating the median point on the vertical axis and

the horizontal axis, respectively, on the basis of the obtained count-value distribution.

6. A neutron image detection method in accordance with claim 1, further comprising collecting the fluorescent light from a scintillator generating the fluorescent light upon a neutron incident, by using an optical fiber or a light guide arranged at a designated position interval on a vertical axis and a horizontal axis, respectively, in parallel in two-dimensional geometry, and determining the incident position of the neutron by detecting the collected fluorescent light by a light detector arranged in two-dimensional geometry or detecting the fluorescent light directly by a two-dimensional light detector, wherein
a two-dimensional count-value distribution is obtained in terms of incident position relative to an individual optical fiber or an individual wavelength shifting fiber as variable, upon a single neutron incident, by counting the pulse signal output by a counting circuit, or obtained by detecting the fluorescent light directly by the two-dimensional light detector; and
the neutron incident position is determined on the vertical axis and the horizontal axis, respectively, on the basis of the obtained two-dimensional count-value distribution.

7. A neutron image detection method in accordance with any of claims 4 to 6 wherein, to enable changing a discrimination level of a neutron signal:

    when the pulse signal is extracted on the basis of the clock signal generated with the same time interval as the time width of the pulse signal generated by a single photon and the generated pulse signal is counted, the pulse signal obtained in synchronism with the used clock signal is counted during a designated count time by a counting circuit;
    an integrated count value for a horizontal-axis count distribution and an integrated count value for a vertical-axis count distribution are obtained;
    a horizontal-axis signal is made valid if the integrated count value for the horizontal axis is equal to or greater than a preset discrimination value for the horizontal axis, and a vertical-axis signal is made valid if the integrated count value for the vertical axis is equal to or greater than a preset discrimination value for the vertical axis; and the neutron signal is output if and only if both the horizontal-axis signal and the vertical-axis signal are valid.

8. A neutron image detection method in accordance with any one of Claims 4 to 6, further comprising using a circuit for adding a predetermined number of pulse signals according to the number of consecutive pulse signals so that a neutron incident position may be determined by compensating the non-linearity in the photon counting in case of counting multiple photons simultaneously if the pulse signal obtained in synchronism with the used clock signal is consecutive, when the pulse signal is extracted on the basis of the clock signal generated with the same time interval as the time width of the pulse signal generated by a single photon, and a generated pulse signal is counted by a counting circuit.

9. A neutron image detection method in accordance with Claim 5, wherein
a semi-transparent scintillator manufactured by mixing ZnS:Ag fluorescent material, and ^{6}LiF or $^{10}B_2O_3$ is used as a neutron converter, which has such a characteristic that a population of fluorescent light emitted responsive to a single incident neutron distributes widely owing to the scintillator being semitransparent, further that when a couple of neutrons are incident simultaneously into distinctive positions at the two-dimensional neutron image detector during a predetermined count time, an integrated count number of vertical-axis count-number distribution and an integrated count number of horizontal-axis count-number distribution are obtained, and then
a vertical-axis incident position and a horizontal-axis incident position, respectively, of a couple of neutrons incident simultaneously are determined separately by combining a larger vertical-axis integrated count number with a larger horizontal-axis integrated count number, and combining a smaller vertical-axis integrated count number with a smaller horizontal-axis integrated count number.

10. A neutron image detection method in accordance with any one of Claims 4 to 8, wherein
a semi-transparent scintillator manufactured by mixing ZnS:Ag fluorescent material, and ^{6}LiF or $^{10}B_2O_3$ is used as a neutron converter, which has such a characteristic that a population of fluorescent light emitted responsive to a single incident neutron distributes widely owing to the scintillator being semitransparent, further comprising that a count-value distribution on a vertical axis and a horizontal axis, respectively is obtained relative to an individual optical fiber or an individual wavelength shifting fiber upon a neutron incident into the scintillator; an integrated count value for a horizontal-axis count distribution and an integrated count value for a vertical-axis count distribution are obtained on the basis of the obtained count-value distribution, and then the whole sum of count values is calculated as a sum of the integrated count value for the horizontal axis and the integrated count value for the vertical axis; and a counting operation by a count circuit is suspended during a time period predetermined on the basis of

the whole sum of count values so that multiple countings due to after-glow in ZnS:Ag fluorescent material may be removed.

11. A neutron image detection method in accordance with any one of Claims 4 to 10, wherein:

the method further comprises that the pulse signal generated by an individual photon output from a light detector corresponding to an individual detection position is extracted on the basis of the clock signal generated with the same time interval as the time width of the pulse signal generated by a single photon, and the generated pulse signal is defined to be a synchronization signal;
the whole sum of photon count values is obtained by integrating the synchronization signal at the individual position, and at the same time, a position number value corresponding to the individual position is generated by the synchronization signal for the individual position;
the whole sum of a medium point calculation value is obtained by integrating the generated position number values; and
the median position is obtained by dividing the obtained whole sum of the medium point calculation value by the whole sum of photon calculation values.

Patentansprüche

1. Neutronenbild-Erfassungsverfahren zum Aufnehmen von Fluoreszenzlicht, das von einem einfallenden Neutron erzeugt wird, mit bestimmtem Positionsintervall in eindimensionaler Geometrie und zum Bestimmen der Einfallsposition des Neutrons durch Erfassen des aufgenommenen Fluoreszenzlichts, wobei
das Fluoreszenzlicht durch ein Photonenzählverfahren erfasst wird;
wobei:

ein von einem individuellen Ausgangsphoton erzeugtes Impulssignal gewonnen wird;
durch Zählen der Impulssignalausgabe bei Einfall eines einzelnen Neutrons eine Zählwertverteilung in Abhängigkeit der Einfallsposition als Variable gewonnen wird; und
durch Berechnen eines Medianpunkts aufgrund der gewonnenen Zählwertverteilung eine Neutroneneinfallsposition bestimmt wird,
dadurch gekennzeichnet, dass das von einem individuellen Ausgangsphoton erzeugte Impulssignal aufgrund eines Taktsignals abgeleitet wird, das mit gleichem Zeitintervall wie der Zeitbreite des von einem einzelnen Photon erzeugten Impulssignals erzeugt wird.

2. Neutronenbild-Erfassungsverfahren nach Anspruch 1, wobei das Fluoreszenzlicht aufgenommen wird, das von einem einfallenden Neutron erzeugt wird, mit einem bestimmten Positionsintervall entsprechenderweise auf einer vertikalen Achse und einer horizontalen Achse in zweidimensionaler Geometrie, wobei
entsprechenderweise auf der vertikalen Achse und der horizontalen Achse eine Zählwertverteilung in Abhängigkeit der Einfallsposition als Variable gewonnen wird; und
die Neutroneneinfallsposition entsprechenderweise auf der vertikalen Achse und der horizontalen Achse bestimmt wird, indem entsprechenderweise auf der vertikalen Achse und der horizontalen Achse aufgrund der gewonnenen Zählwertverteilungen ein Medianpunkt berechnet wird.

3. Neutronenbild-Erfassungsverfahren nach Anspruch 1, wobei das Fluoreszenzlicht von einem Szintillator aufgenommen wird, der das Fluoreszenzlicht bei Einfall eines Neutrons mit einem bestimmten Positionsintervall entsprechenderweise auf einer vertikalen Achse und einer horizontalen Achse in zweidimensionaler Geometrie erzeugt, und die Einfallsposition des Neutrons bestimmt wird, indem das aufgenommene Fluoreszenzlicht erfasst wird, oder das Fluoreszenzlicht direkt in zweidimensionaler Geometrie erfasst wird, wobei
bei Einfall eines einzelnen Neutrons eine zweidimensionale Zählwertverteilung in Abhängigkeit der Einfallsposition als Variable gewonnen wird, indem die Impulssignalausgabe gezählt wird oder das Fluoreszenzlicht direkt erfasst wird; und
die Neutroneneinfallsposition entsprechenderweise auf der vertikalen Achse und der horizontalen Achse aufgrund der gewonnenen zweidimensionalen Zählwertverteilung bestimmt wird.

4. Neutronenbild-Erfassungsverfahren nach Anspruch 1, wobei das Fluoreszenzlicht von einem Szintillator, der das Fluoreszenzlicht bei Neutroneneinfall erzeugt, unter Verwendung von optischen Fasern oder Wellenlängen-verschiebenden Fasern aufgenommen wird, die in eindimensionaler Geometrie mit einem bestimmten Positionsintervall parallel angeordnet sind, und die Einfallsposition des Neutrons durch Erfassen des aufgenommenen Fluoreszenzlichts oder Erfassen des in seiner Wellenlänge verschobenen Fluoreszenzlichts bestimmt wird, wobei
bei Einfall eines einzelnen Neutrons die Zählwertverteilung in Abhängigkeit der Einfallsposition bezüglich einer einzelnen optischen Faser oder einer einzelnen Wellenlängen-verschiebenden Faser als Variable gewonnen wird, indem die Impulssignalausgabe von einer Zählschaltung gezählt wird; und

die Neutroneneinfallsposition durch Berechnen des Medianpunkts aufgrund der gewonnenen Zählwertverteilung bestimmt wird.

5. Neutronenbild-Erfassungsverfahren nach Anspruch 1, wobei das Fluoreszenzlicht von einem Szintillator, der das Fluoreszenzlicht bei Neutroneneinfall erzeugt, unter Verwendung einer optischen Faser oder einer Wellenlängen-verschiebenden Faser, die in zweidimensionaler Geometrie entsprechenderweise auf einer vertikalen Achse und einer horizontalen Achse mit bestimmtem Positionsintervall parallel angeordnet sind, aufgenommen wird, eine Fluoreszenzlichtmenge als für die vertikale Achse aufgenommener Wert und die andere Fluoreszenzlichtmenge als für die horizontale Achse orthogonal zur vertikalen Achse der optischen Faser oder der Wellenlängen-verschiebenden Faser aufgenommener Wert verwendet wird und die Einfallsposition des Neutrons durch Erfassen des von der optischen Faser oder der Wellenlängen-verschiebenden Faser auf der vertikalen Achse und der horizontalen Achse aufgenommenen Fluoreszenzlichts unter Verwendung eines Vertikallichtdetektors und eines Horizontallichtdetektors bestimmt wird, wobei
das von einer einzelnen Photon-Ausgabe durch den einzelnen Lichtdetektor erzeugte Impulssignal aufgrund des Taktsignals abgeleitet wird, das mit dem gleichen Zeitintervall wie dem von einem einzelnen Photon erzeugten Impulssignal erzeugt wird;
bei Einfall eines einzelnen Neutrons die Zählwertverteilung entsprechenderweise auf der vertikalen Achse und der horizontalen Achse in Abhängigkeit der Einfallsposition bezüglich einer einzelnen optischen Faser oder einer einzelnen Wellenlänge-verschiebenden Faser als Variable gewonnen wird, indem die Impulssignalausgabe von einer Zählschaltung gezählt wird; und
die Neutroneneinfallsposition entsprechenderweise auf der vertikalen Achse und der horizontalen Achse durch Berechnen des Medianpunkts auf der vertikalen Achse und der horizontalen Achse jeweils aufgrund der gewonnenen Zählwertverteilung bestimmt wird.

6. Neutronenbild-Erfassungsverfahren nach Anspruch 1, wobei das Fluoreszenzlicht von einem Szintillator, der das Fluoreszenzlicht bei Neutroneneinfall erzeugt, unter Verwendung einer optischen Faser oder eines Lichtleiters gewonnen wird, die bzw. der mit bestimmtem Positionsintervall entsprechenderweise auf der vertikalen Achse und der horizontalen Achse parallel in zweidimensionaler Geometrie angeordnet ist, und die Einfallsposition des Neutrons durch Erfassen des gewonnenen Fluoreszenzlichts von einem in zweidimensionaler Geometrie angeordneten Lichtdetektor oder durch Erfassen des Fluoreszenzlichts direkt von einem zweidimensionalen Lichtdetektor bestimmt wird, wobei
bei Einfall eines einzelnen Neutrons eine zweidimensionale Zählwertverteilung in Abhängigkeit der Einfallsposition bezüglich einer einzelnen optischen Faser oder einer einzelnen Wellenlängen-verschiebenden Faser als Variable gewonnenen wird, indem die Impulssignalausgabe von einer Zählschaltung gezählt wird oder indem das Fluoreszenzlicht direkt von dem zweidimensionalen Lichtdetektor erfasst wird; und
die Neutroneneinfallsposition entsprechenderweise auf der vertikalen Achse und der horizontalen Achse aufgrund der gewonnenen zweidimensionalen Zählwertverteilung bestimmt wird.

7. Neutronenbild-Erfassungsverfahren nach einem der Ansprüche 4 bis 6, wobei, um einen Ansprechpegel für ein Neutronensignal ändern zu können:

wenn das Impulssignal aufgrund des Taktsignals abgeleitet wird, das mit dem gleichen Zeitintervall wie der Zeitbreite des von einem einzelnen Photon erzeugten Impulssignals erzeugt wird, und das erzeugte Impulssignal gezählt wird, das synchron mit dem verwendeten Taktsignal gewonnene Impulssignal während einer bestimmten Zählzeit von einer Zählschaltung gezählt wird;
ein integrierter Zählwert für eine Horizontalachsen-Zählverteilung und ein integrierter Zählwert für eine Vertikalachsen-Zählverteilung gewonnen werden;
ein Horizontalachsen-Signal gültig gemacht wird, wenn der integrierte Zählwert für die horizontale Achse gleich oder größer als ein vorbestimmter Ansprechwert für die horizontale Achse ist, und ein Vertikalachsen-Signal gültig gemacht wird, wenn der integrierte Zählwert für die vertikale Achse gleich oder größer als ein vorbestimmter Ansprechwert für die vertikale Achse ist; und
das Neutronensignal dann und nur dann ausgegeben wird, wenn sowohl das Horizontachsen-Signal als auch das Vertikalachsen-Signal gültig ist.

8. Neutronenbild-Erfassungsverfahren nach einem der Ansprüche 4 bis 6, wobei dann, wenn das Impulssignal aufgrund des Taktsignals abgeleitet wird, das mit dem gleichen Zeitintervall wie der Zeitbreite des von einem einzelnen Photon erzeugten Impulssignals erzeugt wird, und ein erzeugtes Impulssignal von einer Zählschaltung gezählt wird, eine Schaltung zum Hinzufügen einer vorbestimmten Anzahl an Impulssignalen entsprechend der Anzahl fortlaufender Impulssignale verwendet wird, sodass eine Neutroneneinfallsposition durch Kompensieren der Nicht-Linearität des Photon-Zählens bestimmt werden kann, wenn mehrere Photonen gleichzeitig gezählt werden, wenn das synchron zum verwendeten Taktsignal gewonnene Impulssignal fortlaufend ist.

9. Neutronenbild-Erfassungsverfahren nach Anspruch 5, wobei
als Neutronenwandler ein halbtransparenter Szintillator verwendet wird, der durch Mischen eines fluoreszierenden ZnS:Ag-Materials und ^{6}LiF oder $^{10}B_2O_3$ hergestellt ist und der, da er halbtransparent ist, die Eigenschaft aufweist, dass ein aufgrund eines einzelnen einfallenden Neutrons emittiertes Fluoreszenzlicht weit verteilt ist, und wobei
wenn mehrere Neutronen während einer bestimmten Zählzeit gleichzeitig an bestimmten Positionen des zweidimensionalen Neutronenbilddetektors einfallen, ein integrierter Zählwert einer Vertikalachsen-Zählwertverteilung und ein integrierter Zählwert einer Horizontalachsen-Zählwertverteilung gewonnen werden, und dann
entsprechenderweise eine Vertikalachsen-Einfallsposition und eine Horizontalachsen-Einfallsposition mehrerer gleichzeitig einfallender Neutronen getrennt durch Kombinieren eines größeren integrierten Zählwerts der Vertikalachse mit einem größeren integrierten Zählwert der Horizontalachse und Kombinieren eines kleineren integrierten Zählwerts der Vertikalachse mit einem kleineren integrierten Zählwert der Horizontalachse bestimmt werden.

10. Neutronenbild-Erfassungsverfahren nach einem der Ansprüche 4 bis 8, wobei
als Neutronenwandler ein halbtransparenter Szintillator verwendet wird, der durch Mischen eines fluoreszierenden ZnS:Ag-Materials und ^{6}LiF oder $^{10}B_2O_3$ hergestellt ist und der, da er halbtransparent ist, die Eigenschaft aufweist, dass das aufgrund eines einzelnen einfallenden Neutrons emittierte Fluoreszenzlicht weit verteilt ist, und wobei
bei Einfall eines Neutrons auf den Szintillator eine Zählwertverteilung entsprechenderweise auf einer vertikalen Achse und einer horizontalen Achse bezüglich einer einzelnen optischen Faser oder einer einzelnen Wellenlängen-verschiebenden Faser gewonnen wird;
aufgrund der gewonnenen Zählwertverteilung ein integrierter Zählwert für eine Horizontalachsen-Zählwertverteilung und ein integrierter Zählwert für eine Vertikalachsen-Zählwertverteilung gewonnen werden und dann die Gesamtsumme der Zählwerte als Summe des integrierten Zählwerts für die horizontale Achse und des integrierten Zählwerts für die vertikale Achse berechnet wird; und
aufgrund der Gesamtsumme der Zählwerte während einer vorbestimmten Zeitspanne ein Zählvorgang von einer Zählschaltung unterbrochen wird, sodass Mehrfachzählungen aufgrund von Nachleuchten im fluoreszierenden ZnS:Ag-Material entfernt werden können.

11. Neutronenbild-Erfassungsverfahren nach einem der Ansprüche 4 bis 10, wobei
das von einem einzelnen Photon erzeugte Impulssignal, das von einem Lichtdetektor entsprechend einer einzelnen Erfassungsposition ausgegeben wird, aufgrund des Taktsignals abgeleitet wird, das mit dem gleichen Zeitintervall wie der Zeitbreite des von einem einzelnen Photon erzeugten Impulssignals erzeugt wird, und das erzeugte Impulssignal als Synchronisationssignal betrachtet wird;
die Gesamtsumme der Photon-Zählwerte gewonnen wird, indem das Synchronisationssignal an der Einzelposition integriert wird, und gleichzeitig von dem Synchronisationssignal für die Einzelposition ein Positionszahlenwert entsprechend der Einzelposition erzeugt wird;
die Gesamtsumme eines Mittelpunkt-Berechnungswerts durch Integrieren der erzeugten Positionszahlenwerte gewonnen wird; und
die Medianposition durch Teilen der gewonnenen Gesamtsumme des Mittelpunkt-Berechnungswerts durch die Gesamtsumme der Photon-Berechnungswerte gewonnen wird.

Revendications

1. Procédé de détection d'image de neutrons pour recueillir une lumière fluorescente générée par un neutron incident en un intervalle de position désigné dans une géométrie unidimensionnelle et déterminer une position incidente du neutron en détectant la lumière fluorescente recueillie, dans lequel
la lumière fluorescente est détectée par un procédé de comptage de photons ;
dans lequel
un signal à impulsions généré par un photon individuel délivré en sortie est extrait ;
une distribution de valeurs de comptage est obtenue en termes de position incidente comme variable, sur un seul neutron incident, en comptant le signal à impulsions délivré en sortie ; et
une position incidente de neutron est déterminée en calculant un point médian sur la base de la distribution de valeurs de comptage obtenue,
caractérisé en ce que le signal à impulsions généré par un photon individuel délivré en sortie est extrait sur la base d'un signal d'horloge généré avec le même intervalle de temps que la largeur de temps du signal à impulsions généré par un photon unique.

2. Procédé de détection d'image de neutrons selon la revendication 1, comprenant en outre le recueil de la lumière fluorescente générée par un neutron incident en un intervalle de position désigné sur un axe vertical et un axe horizontal, respectivement, dans

une géométrie bidimensionnelle, dans lequel
une distribution de valeurs de comptage est obtenue sur l'axe vertical et l'axe horizontal, respectivement, en termes de position incidente comme variable ; et
la position incidente de neutron est déterminée sur l'axe vertical et l'axe horizontal, respectivement, en calculant un point médian sur l'axe vertical et l'axe horizontal, respectivement, sur la base des distributions de valeurs de comptage obtenues.

3. Procédé de détection d'image de neutrons selon la revendication 1, comprenant en outre le recueil de la lumière fluorescente depuis un scintillateur générant la lumière fluorescente sur un neutron incident en un intervalle de position désigné sur un axe vertical et un axe horizontal, respectivement, dans une géométrie bidimensionnelle et la détermination de la position incidente du neutron en détectant la lumière fluorescente recueillie ou en détectant la lumière fluorescente directement dans une géométrie bidimensionnelle, dans lequel
une distribution de valeurs de comptage bidimensionnelle est obtenue en termes de position incidente comme variable, sur un seul neutron incident, en comptant le signal à impulsions délivré en sortie, ou obtenue en détectant directement la lumière fluorescente ; et
la position incidente de neutron est déterminée sur l'axe vertical et l'axe horizontal, respectivement, sur la base des distributions de valeurs de comptage bidimensionnelles obtenues.

4. Procédé de détection d'image de neutrons selon la revendication 1, comprenant en outre le recueil de la lumière fluorescente depuis un scintillateur générant la lumière fluorescente sur un neutron incident, en utilisant des fibres optiques ou des fibres optiques à déplacement de longueur d'onde agencées en un intervalle de position désigné en parallèle dans une géométrie unidimensionnelle et la détermination de la position incidente du neutron en détectant la lumière fluorescente recueillie ou en détectant la lumière fluorescente avec sa longueur d'onde déplacée, dans lequel
la distribution de valeurs de comptage est obtenue en termes de position incidente par rapport à une fibre optique individuelle ou une fibre optique à déplacement de longueur d'onde individuelle comme variable, sur un seul neutron incident, en comptant le signal à impulsions délivré en sortie par un circuit de comptage ; et
la position incidente de neutron est déterminée en calculant le point médian sur la base de la distribution de valeurs de comptage obtenue.

5. Procédé de détection d'image de neutrons selon la revendication 1, comprenant en outre le recueil de la lumière fluorescente depuis un scintillateur générant la lumière fluorescente sur un neutron incident, en utilisant une fibre optique ou une fibre optique à déplacement de longueur d'onde agencée en un intervalle de position désigné sur un axe vertical et un axe horizontal, respectivement, en parallèle dans une géométrie bidimensionnelle, faisant d'une quantité de lumière fluorescente une valeur recueillie pour l'axe vertical et faisant de l'autre quantité de lumière fluorescente une valeur recueillie pour l'axe horizontal orthogonal à l'axe vertical de la fibre optique ou de la fibre optique à déplacement de longueur d'onde, et la détermination de la position incidente du neutron en détectant la lumière fluorescente recueillie par la fibre optique ou de la fibre optique à déplacement de longueur d'onde sur l'axe vertical et l'axe horizontal en utilisant un détecteur de lumière vertical et un détecteur de lumière horizontal, dans lequel
le signal à impulsions généré par un photon individuel délivré en sortie par le détecteur de lumière individuel est extrait sur la base du signal d'horloge généré avec le même intervalle de temps que la largeur de temps du signal à impulsions généré par un photon unique ;
la distribution de valeurs de comptage est obtenue sur l'axe vertical et l'axe horizontal, respectivement, en termes de position incidente par rapport à une fibre optique individuelle ou une fibre optique à déplacement de longueur d'onde individuelle comme variable, sur un seul neutron incident, en comptant le signal à impulsions délivré en sortie par un circuit de comptage ; et
la position incidente de neutron est déterminée sur l'axe vertical et l'axe horizontal, respectivement, en calculant le point médian sur l'axe vertical et l'axe horizontal, respectivement, sur la base de la distribution de valeurs de comptage obtenue.

6. Procédé de détection d'image de neutrons selon la revendication 1, comprenant en outre le recueil de la lumière fluorescente depuis un scintillateur générant la lumière fluorescente sur un neutron incident, en utilisant une fibre optique ou un guide de lumière agencé(e) en un intervalle de position désigné sur un axe vertical et un axe horizontal, respectivement, en parallèle dans une géométrie bidimensionnelle, et la détermination de la position incidente du neutron en détectant la lumière fluorescente recueillie par un détecteur de lumière agencé dans une géométrie bidimensionnelle ou en détectant la lumière fluorescente directement par un détecteur de lumière bidimensionnel, dans lequel
une distribution de valeurs de comptage bidimensionnelles est obtenue en termes de position incidente par rapport à une fibre optique individuelle ou une fibre optique à déplacement de longueur d'onde individuelle comme variable, sur un seul neutron incident, en comptant le signal à impulsions délivré en

sortie par un circuit de comptage, ou obtenue en détectant la lumière fluorescente directement par le détecteur de lumière bidimensionnel ; et
la position incidente de neutron est déterminée sur l'axe vertical et l'axe horizontal, respectivement, sur la base de la distribution de valeurs de comptage bidimensionnelles obtenue.

7. Procédé de détection d'image de neutrons selon l'une quelconque des revendications 4 à 6 dans lequel, pour permettre un changement d'un niveau de discrimination d'un signal neutronique :

lorsque le signal à impulsions est extrait sur la base du signal d'horloge généré avec le même intervalle de temps que la largeur de temps du signal à impulsions généré par un photon unique et que le signal à impulsions généré est compté, le signal à impulsions obtenu en synchronisme avec le signal d'horloge utilisé est compté lors d'un temps de comptage désigné par un circuit de comptage ;
une valeur de comptage intégrée pour une distribution de comptage d'axe horizontal et une valeur de comptage intégrée pour une distribution de comptage d'axe vertical sont obtenues ;
un signal d'axe horizontal est rendu valide si la valeur de comptage intégrée pour l'axe horizontal est égale ou supérieure à une valeur de discrimination prédéfinie pour l'axe horizontal, et un signal d'axe vertical est rendu valide si la valeur de comptage intégrée pour l'axe vertical est égale ou supérieure à une valeur de discrimination prédéfinie pour l'axe vertical ; et
le signal neutronique est délivré en sortie si et seulement si le signal d'axe horizontal et le signal d'axe vertical sont tous les deux valides.

8. Procédé de détection d'image de neutrons selon l'une quelconque des revendications 4 à 6, comprenant en outre l'utilisation d'un circuit pour additionner un nombre prédéterminé de signaux à impulsions en fonction du nombre de signaux à impulsions consécutifs de telle manière qu'une position incidente de neutron peut être déterminée en compensant la non linéarité du comptage de photons dans le cas d'un comptage de photons multiples simultanément si le signal à impulsions obtenu en synchronisme avec le signal d'horloge utilisé est consécutif, lorsque le signal à impulsions est extrait sur la base du signal d'horloge généré avec le même intervalle de temps que la largeur de temps du signal à impulsions généré par un photon unique, et qu'un signal à impulsions généré est compté par un circuit de comptage

9. Procédé de détection d'image de neutrons selon la revendication 5, dans lequel
un scintillateur semi-transparent fabriqué en mélangeant une matière fluorescente ZnS:Ag, et ^{6}LiF ou $^{10}B_2O3$ est utilisé comme un convertisseur de neutrons, qui a une caractéristique telle qu'une population de lumière fluorescente émise en réponse à un neutron incident unique se distribue largement du fait que le scintillateur est semi-transparent, en outre que, lorsqu'un couple de neutrons sont incidents simultanément dans des positions distinctes au niveau du détecteur d'image de neutrons bidimensionnel lors d'un temps de comptage prédéterminé, un nombre de comptages intégrés de distribution de nombres de comptage d'axe vertical et un nombre de comptages intégrés de distribution de nombres de comptage d'axe horizontal sont obtenus, et ensuite
une position incidente d'axe vertical et une position incidente d'axe horizontal, respectivement, d'un couple de neutrons incidents simultanément sont déterminées séparément en combinant un nombre de comptage intégré d'axe vertical plus grand avec un nombre de comptage intégré d'axe horizontal plus grand, et en combinant un nombre de comptage intégré d'axe vertical plus petit avec un nombre de comptage intégré d'axe horizontal plus petit.

10. Procédé de détection d'image de neutrons selon l'une quelconque des revendications 4 à 8, dans lequel
un scintillateur semi-transparent fabriqué en mélangeant une matière fluorescente ZnS:Ag, et ^{6}LiF ou $^{10}B_2O3$ est utilisé comme un convertisseur de neutrons, qui a une caractéristique telle qu'une population de lumière fluorescente émise en réponse à un neutron incident unique se distribue largement du fait que le scintillateur est semi-transparent, comprenant en outre qu'une distribution de valeurs de comptage sur un axe vertical et un axe horizontal, respectivement, est obtenue par rapport à une fibre optique individuelle ou une fibre à déplacement de longueur d'onde individuelle sur un neutron incident dans l'oscillateur ;
une valeur de comptage intégrée pour une distribution de comptage d'axe horizontal et une valeur de comptage intégrée pour une distribution de comptage d'axe vertical sont obtenues sur la base de la distribution de valeurs de comptage obtenue, et ensuite la somme totale de valeurs de comptage est calculée comme une somme de la valeur de comptage intégrée pour l'axe horizontal et la valeur de comptage intégrée pour l'axe vertical ; et
une opération de comptage par un circuit de comptage est suspendue sur une période de temps prédéterminée sur la base de la somme totale de valeurs de comptage de telle manière que des comptages multiples dus à une rémanence de la matière fluorescente ZnS:Ag peuvent être éliminés.

11. Procédé de détection d'image de neutrons selon l'une quelconque des revendications 4 à 10, dans lequel :

le procédé comprend en outre que le signal à impulsions généré par un photon individuel délivré en sortie d'un détecteur de lumière correspondant à une position de détection individuelle est extrait sur la base du signal d'horloge généré avec le même intervalle de temps que la largeur de temps du signal à impulsions généré par un photon unique, et le signal à impulsions généré est défini pour être un signal de synchronisation ;
la somme totale de valeurs de comptage de photons est obtenue en intégrant le signal de synchronisation à la position individuelle, et en même temps, une valeur de numéro de position correspondant à la position individuelle est générée par le signal de synchronisation pour la position individuelle ;
la somme totale d'une valeur de calcul de point milieu est obtenue en intégrant les valeurs de numéro de position générées ; et
la position médiane est obtenue en divisant la somme totale obtenue de la valeur de calcul de point milieu par la somme totale de valeurs de calcul de photons.

FIG. 1

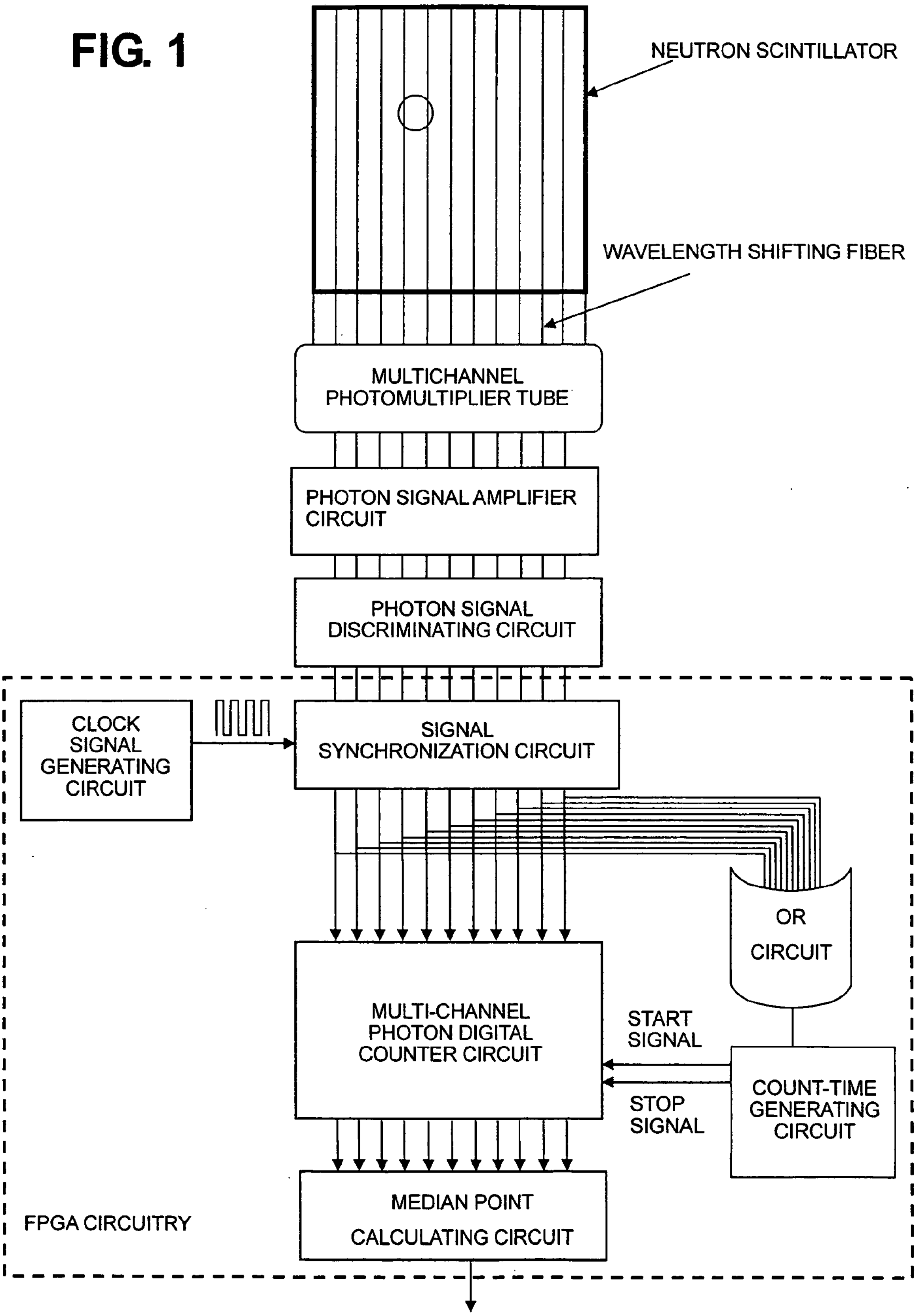

NEUTRON SCINTILLATOR
WAVELENGTH SHIFTING FIBER
MULTICHANNEL PHOTOMULTIPLIER TUBE
PHOTON SIGNAL AMPLIFIER CIRCUIT
PHOTON SIGNAL DISCRIMINATING CIRCUIT
CLOCK SIGNAL GENERATING CIRCUIT
SIGNAL SYNCHRONIZATION CIRCUIT
OR CIRCUIT
MULTI-CHANNEL PHOTON DIGITAL COUNTER CIRCUIT
START SIGNAL
STOP SIGNAL
COUNT-TIME GENERATING CIRCUIT
MEDIAN POINT CALCULATING CIRCUIT
FPGA CIRCUITRY
NEUTRON INCIDENT POSITION OUTPUT

FIG. 2A

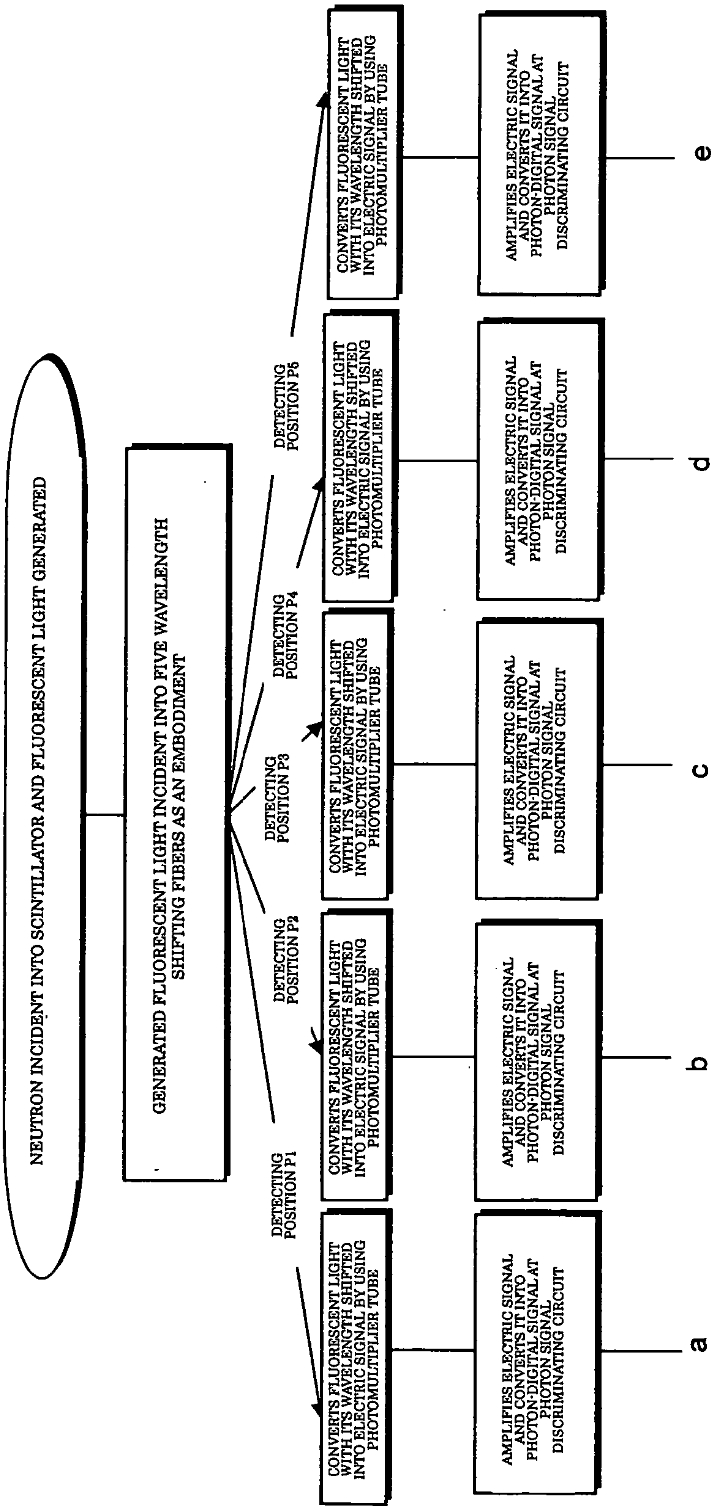

NEUTRON INCIDENT INTO SCINTILLATOR AND FLUORESCENT LIGHT GENERATED
GENERATED FLUORESCENT LIGHT INCIDENT INTO FIVE WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
DETECTING POSITION P1
DETECTING POSITION P2
DETECTING POSITION P3
DETECTING POSITION P4
DETECTING POSITION P5
CONVERTS FLUORESCENT LIGHT WITH ITS WAVELENGTH SHIFTED INTO ELECTRIC SIGNAL BY USING PHOTOMULTIPLIER TUBE
CONVERTS FLUORESCENT LIGHT WITH ITS WAVELENGTH SHIFTED INTO ELECTRIC SIGNAL BY USING PHOTOMULTIPLIER TUBE
CONVERTS FLUORESCENT LIGHT WITH ITS WAVELENGTH SHIFTED INTO ELECTRIC SIGNAL BY USING PHOTOMULTIPLIER TUBE
CONVERTS FLUORESCENT LIGHT WITH ITS WAVELENGTH SHIFTED INTO ELECTRIC SIGNAL BY USING PHOTOMULTIPLIER TUBE
CONVERTS FLUORESCENT LIGHT WITH ITS WAVELENGTH SHIFTED INTO ELECTRIC SIGNAL BY USING PHOTOMULTIPLIER TUBE
AMPLIFIES ELECTRIC SIGNAL AND CONVERTS IT INTO PHOTON-DIGITAL SIGNAL AT PHOTON SIGNAL DISCRIMINATING CIRCUIT
AMPLIFIES ELECTRIC SIGNAL AND CONVERTS IT INTO PHOTON-DIGITAL SIGNAL AT PHOTON SIGNAL DISCRIMINATING CIRCUIT
AMPLIFIES ELECTRIC SIGNAL AND CONVERTS IT INTO PHOTON-DIGITAL SIGNAL AT PHOTON SIGNAL DISCRIMINATING CIRCUIT
AMPLIFIES ELECTRIC SIGNAL AND CONVERTS IT INTO PHOTON-DIGITAL SIGNAL AT PHOTON SIGNAL DISCRIMINATING CIRCUIT
AMPLIFIES ELECTRIC SIGNAL AND CONVERTS IT INTO PHOTON-DIGITAL SIGNAL AT PHOTON SIGNAL DISCRIMINATING CIRCUIT
a
b
c
d
e

FIG. 2B

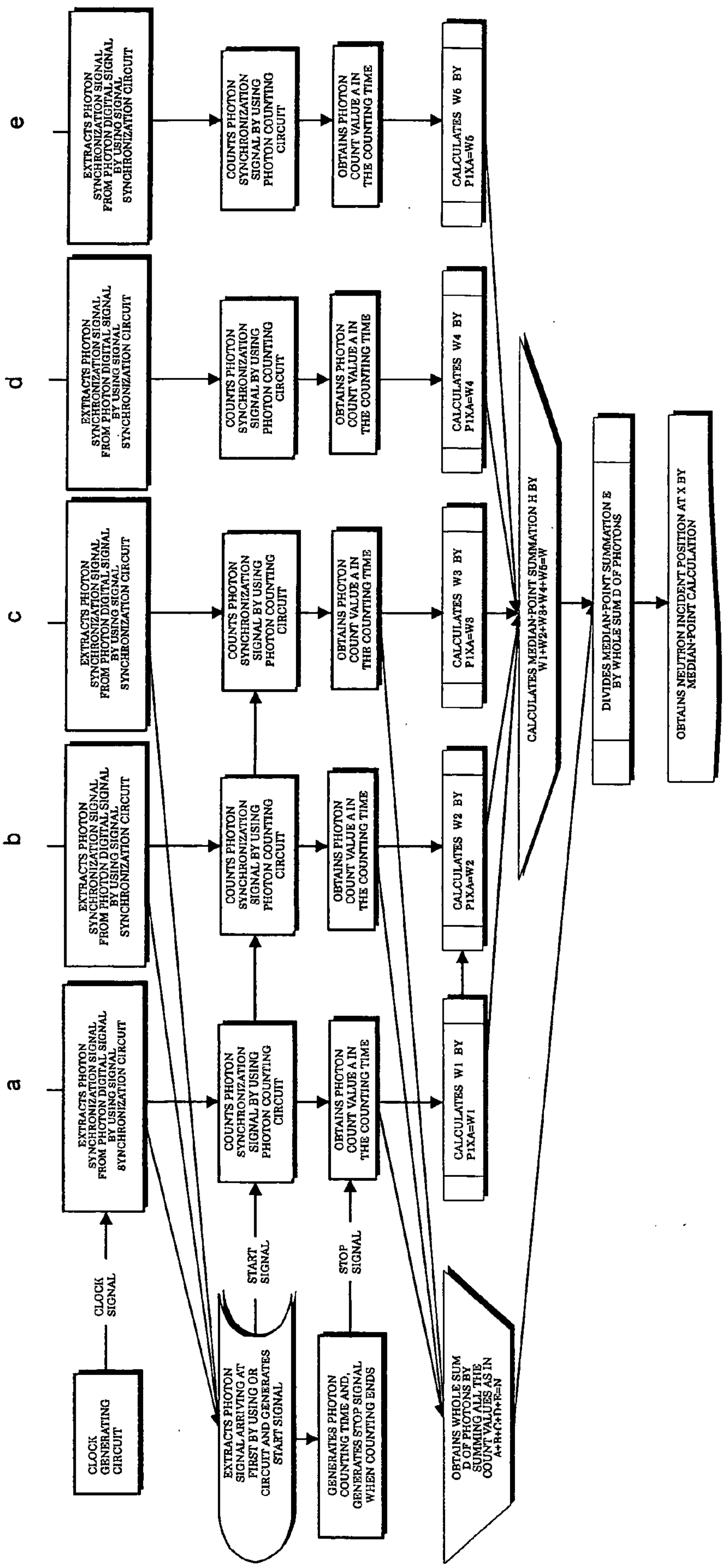

a
b
c
d
e
CLOCK GENERATING CIRCUIT
CLOCK SIGNAL
EXTRACTS PHOTON SYNCHRONIZATION SIGNAL FROM PHOTON DIGITAL SIGNAL BY USING SIGNAL SYNCHRONIZATION CIRCUIT
EXTRACTS PHOTON SIGNAL ARRIVING AT FIRST BY USING OR CIRCUIT AND GENERATES START SIGNAL
START SIGNAL
COUNTS PHOTON SYNCHRONIZATION SIGNAL BY USING PHOTON COUNTING CIRCUIT
GENERATES PHOTON COUNTING TIME AND, GENERATES STOP SIGNAL WHEN COUNTING ENDS
STOP SIGNAL
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
CALCULATES W1 BY P1XA=W1
CALCULATES W2 BY P1XA=W2
CALCULATES W3 BY P1XA=W3
CALCULATES W4 BY P1XA=W4
CALCULATES W5 BY P1XA=W5
OBTAINS WHOLE SUM D OF PHOTONS BY SUMMING ALL THE COUNT VALUES AS IN A+B+C+D+E=N
CALCULATES MEDIAN-POINT SUMMATION H BY W1+W2+W3+W4+W5=W
DIVIDES MEDIAN-POINT SUMMATION E BY WHOLE SUM D OF PHOTONS
OBTAINS NEUTRON INCIDENT POSITION AT X BY MEDIAN-POINT CALCULATION

FIG.3

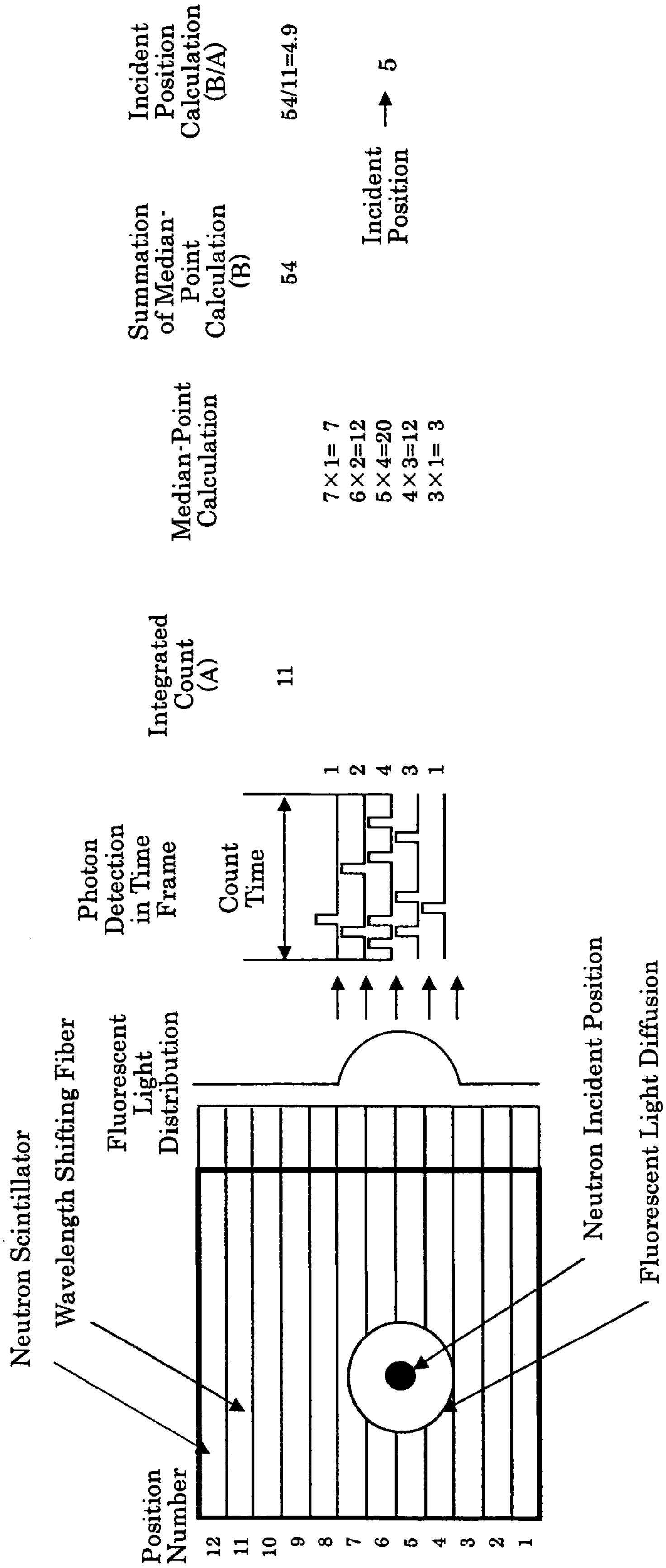
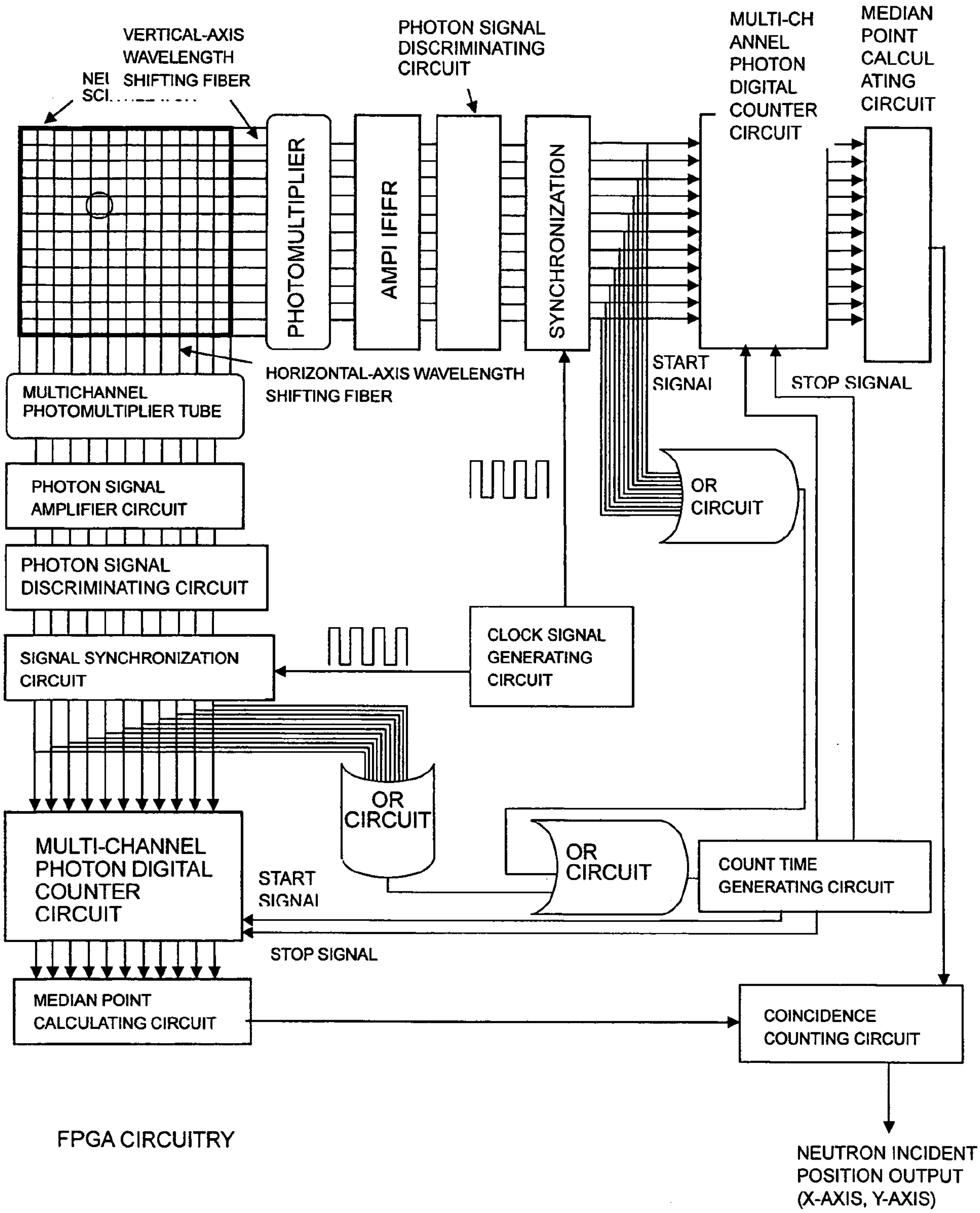

Position Number
12
11
10
9
8
7
6
5
4
3
2
1
Neutron Scintillator
Wavelength Shifting Fiber
Neutron Incident Position
Fluorescent Light Diffusion
Fluorescent Light Distribution
Photon Detection in Time Frame
Count Time
1
2
4
3
1
Integrated Count (A)
11
Median-Point Calculation
7×1= 7
6×2=12
5×4=20
4×3=12
3×1= 3
Summation of Median-Point Calculation (B)
54
Incident Position Calculation (B/A)
54/11=4.9
Incident Position → 5

FIG.4


VERTICAL-AXIS WAVELENGTH SHIFTING FIBER
NEI SCI
PHOTON SIGNAL DISCRIMINATING CIRCUIT
MULTI-CH ANNEL PHOTON DIGITAL COUNTER CIRCUIT
MEDIAN POINT CALCUL ATING CIRCUIT
PHOTOMULTIPLIER
AMPLIFIER
SYNCHRONIZATION
START SIGNAL
STOP SIGNAL
HORIZONTAL-AXIS WAVELENGTH SHIFTING FIBER
MULTICHANNEL PHOTOMULTIPLIER TUBE
PHOTON SIGNAL AMPLIFIER CIRCUIT
PHOTON SIGNAL DISCRIMINATING CIRCUIT
OR CIRCUIT
SIGNAL SYNCHRONIZATION CIRCUIT
CLOCK SIGNAL GENERATING CIRCUIT
OR CIRCUIT
MULTI-CHANNEL PHOTON DIGITAL COUNTER CIRCUIT
START SIGNAL
OR CIRCUIT
COUNT TIME GENERATING CIRCUIT
STOP SIGNAL
MEDIAN POINT CALCULATING CIRCUIT
COINCIDENCE COUNTING CIRCUIT
FPGA CIRCUITRY
NEUTRON INCIDENT POSITION OUTPUT (X-AXIS, Y-AXIS)

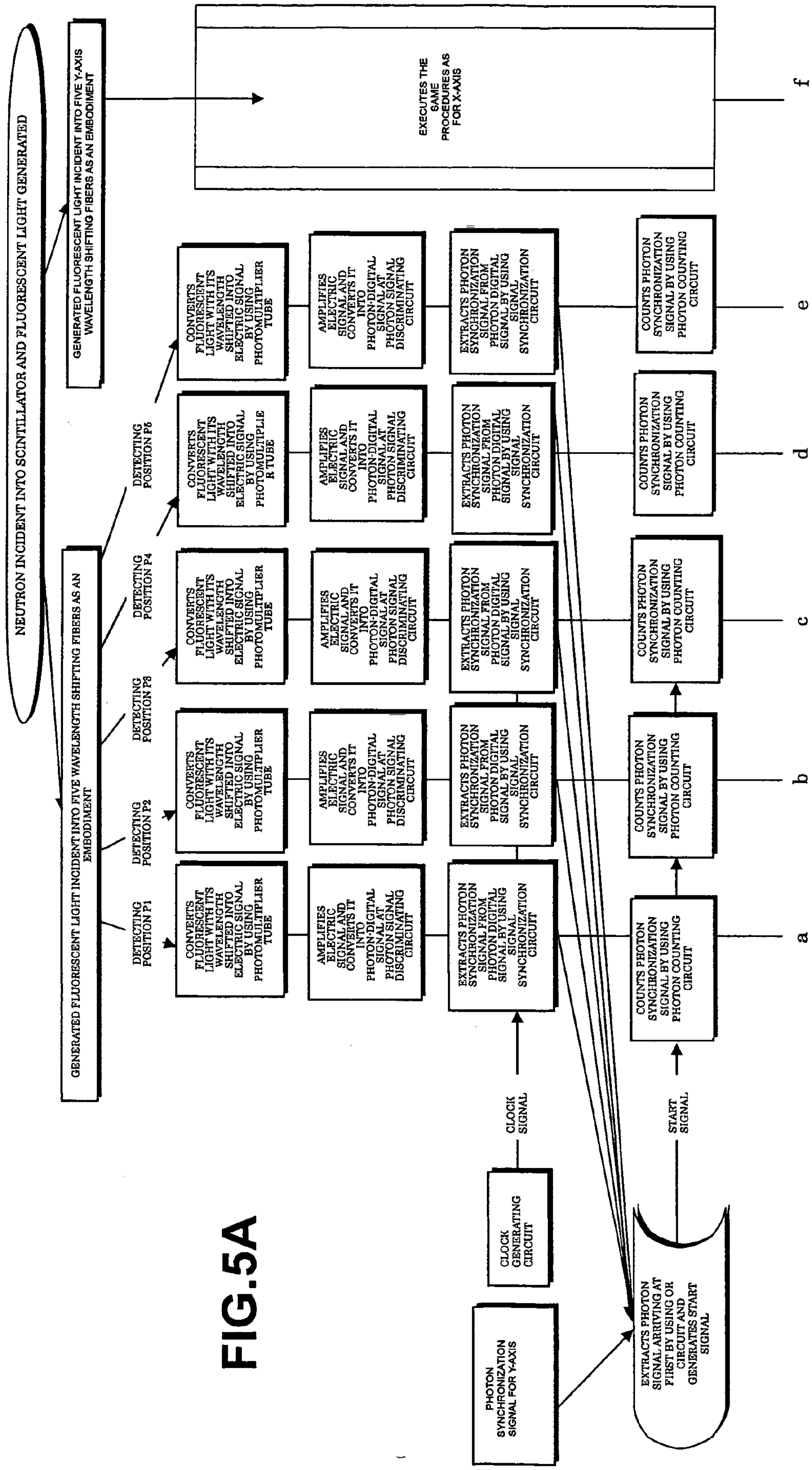

NEUTRON INCIDENT INTO SCINTILLATOR AND FLUORESCENT LIGHT GENERATED
GENERATED FLUORESCENT LIGHT INCIDENT INTO FIVE WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
GENERATED FLUORESCENT LIGHT INCIDENT INTO FIVE Y-AXIS WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
DETECTING POSITION P1
DETECTING POSITION P2
DETECTING POSITION P3
DETECTING POSITION P4
DETECTING POSITION P5
CONVERTS FLUORESCENT LIGHT WITH ITS WAVELENGTH SHIFTED INTO ELECTRIC SIGNAL BY USING PHOTOMULTIPLIER TUBE
AMPLIFIES ELECTRIC SIGNAL AND CONVERTS IT INTO PHOTON-DIGITAL SIGNAL AT PHOTON SIGNAL DISCRIMINATING CIRCUIT
EXTRACTS PHOTON SYNCHRONIZATION SIGNAL FROM PHOTON DIGITAL SIGNAL BY USING SIGNAL SYNCHRONIZATION CIRCUIT
COUNTS PHOTON SYNCHRONIZATION SIGNAL BY USING PHOTON COUNTING CIRCUIT
EXECUTES THE SAME PROCEDURES AS FOR X-AXIS
CLOCK GENERATING CIRCUIT
CLOCK SIGNAL
START SIGNAL
PHOTON SYNCHRONIZATION SIGNAL FOR Y-AXIS
EXTRACTS PHOTON SIGNAL ARRIVING AT FIRST BY USING OR CIRCUIT AND GENERATES START SIGNAL
a
b
c
d
e
f

FIG.5A

FIG.5B

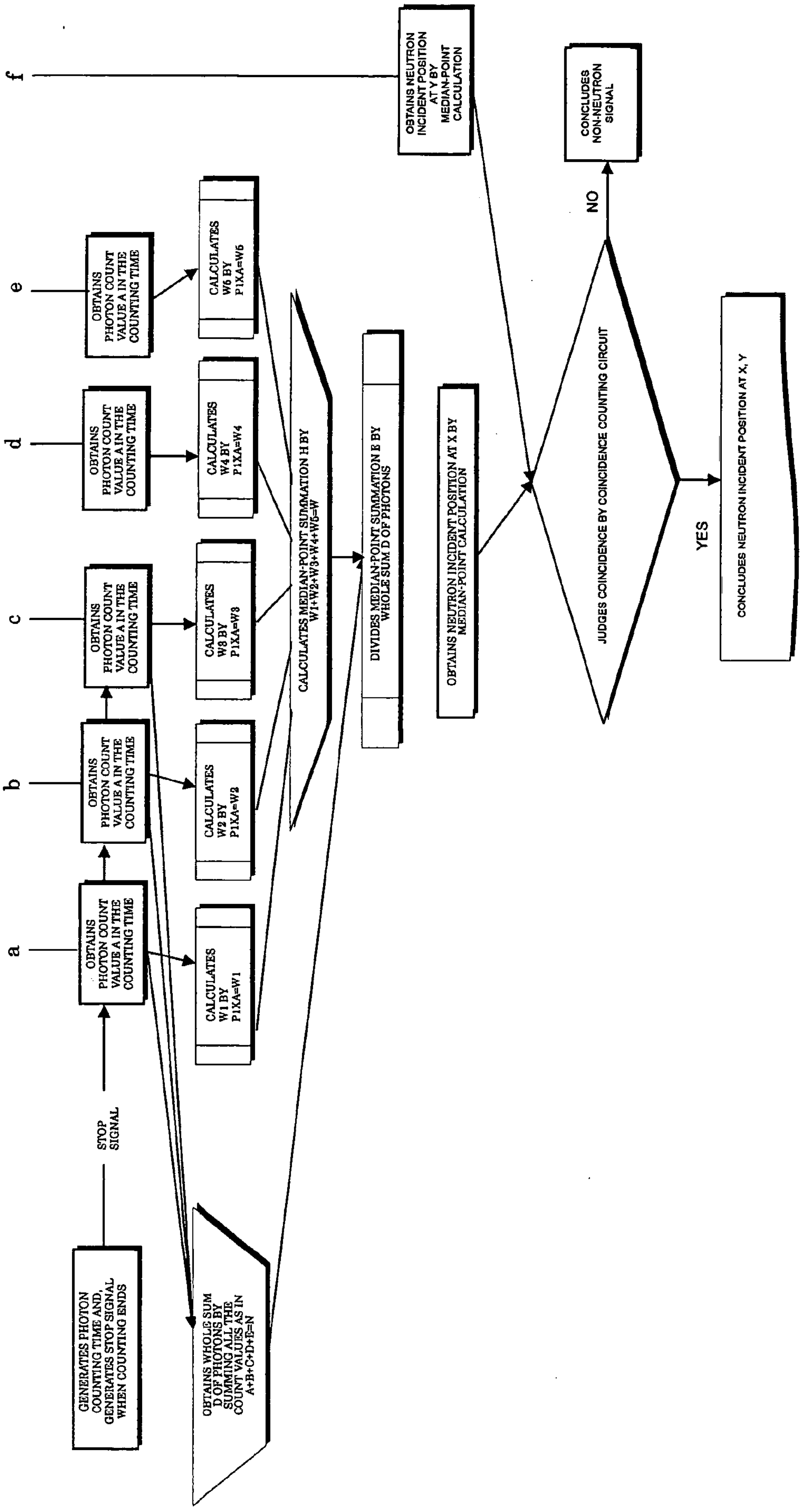

a
b
c
d
e
f
GENERATES PHOTON COUNTING TIME AND, GENERATES STOP SIGNAL WHEN COUNTING ENDS
STOP SIGNAL
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
CALCULATES W1 BY P1XA=W1
CALCULATES W2 BY P1XA=W2
CALCULATES W3 BY P1XA=W3
CALCULATES W4 BY P1XA=W4
CALCULATES W5 BY P1XA=W5
OBTAINS WHOLE SUM D OF PHOTONS BY SUMMING ALL THE COUNT VALUES AS IN A+B+C+D+E=N
CALCULATES MEDIAN-POINT SUMMATION H BY W1+W2+W3+W4+W5=W
DIVIDES MEDIAN-POINT SUMMATION E BY WHOLE SUM D OF PHOTONS
OBTAINS NEUTRON INCIDENT POSITION AT X BY MEDIAN-POINT CALCULATION
OBTAINS NEUTRON INCIDENT POSITION AT Y BY MEDIAN-POINT CALCULATION
JUDGES COINCIDENCE BY COINCIDENCE COUNTING CIRCUIT
NO
CONCLUDES NON-NEUTRON SIGNAL
YES
CONCLUDES NEUTRON INCIDENT POSITION AT X, Y

FIG. 6

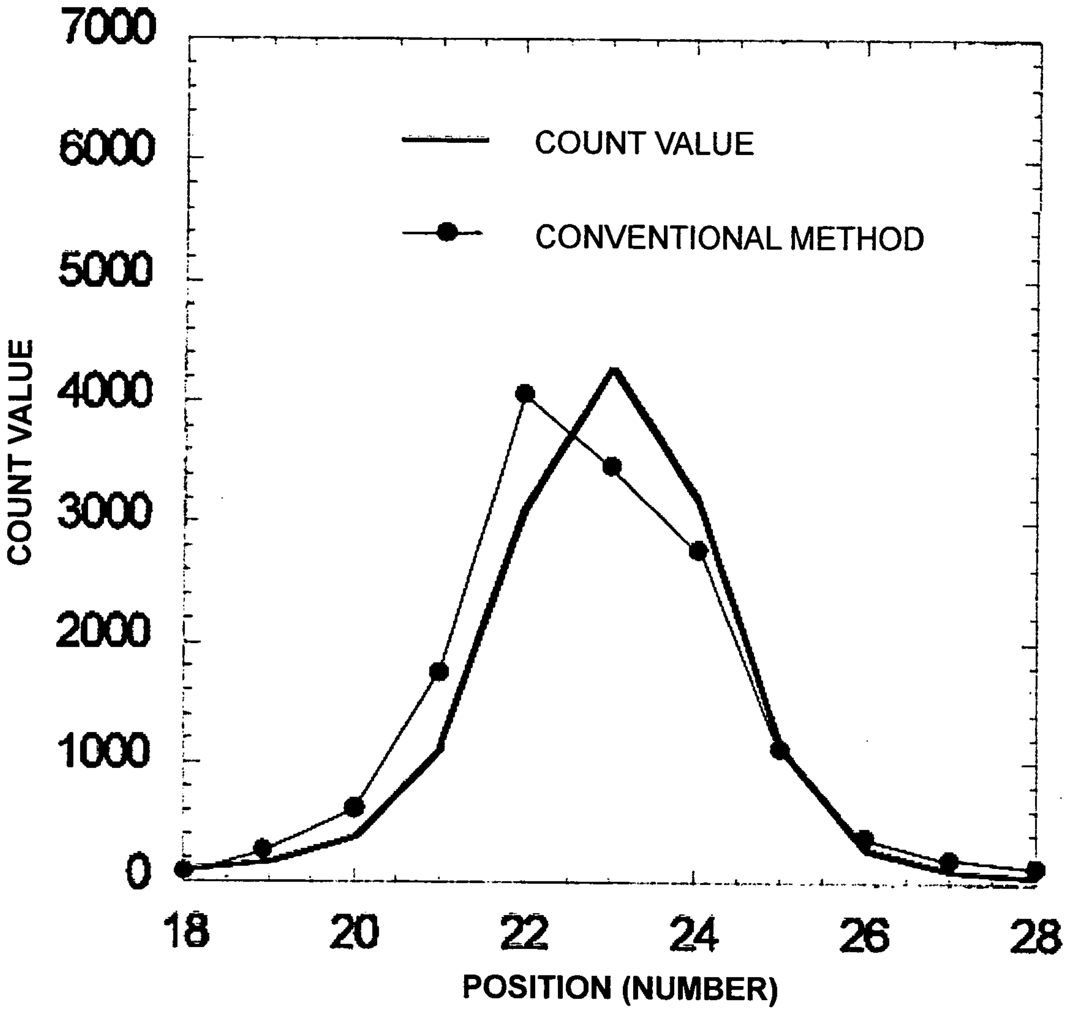

7000
6000
5000
4000
3000
2000
1000
0
COUNT VALUE
COUNT VALUE
CONVENTIONAL METHOD
18
20
22
24
26
28
POSITION (NUMBER)

FIG. 7

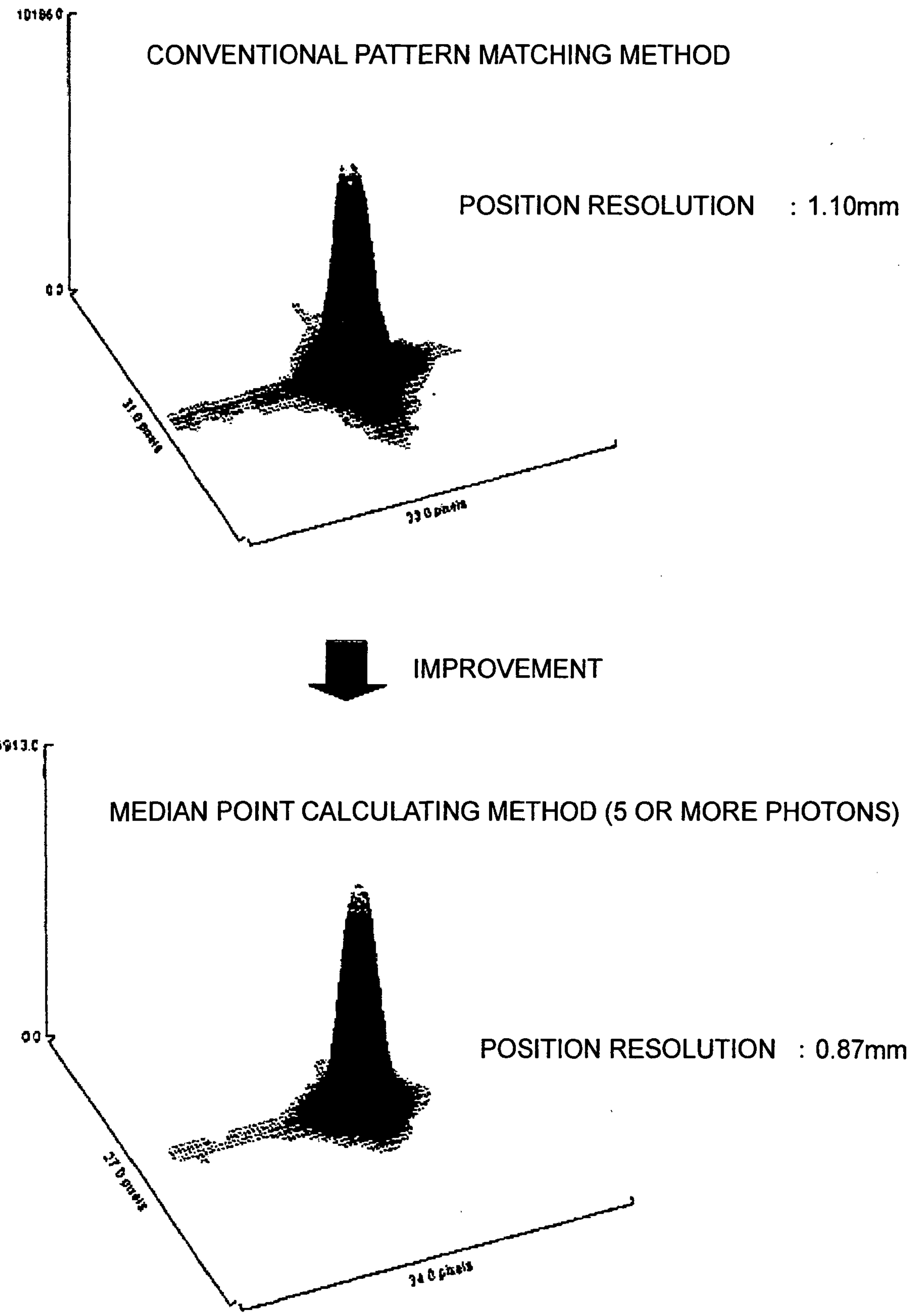

CONVENTIONAL PATTERN MATCHING METHOD
POSITION RESOLUTION : 1.10mm
IMPROVEMENT
MEDIAN POINT CALCULATING METHOD (5 OR MORE PHOTONS)
POSITION RESOLUTION : 0.87mm

FIG.8

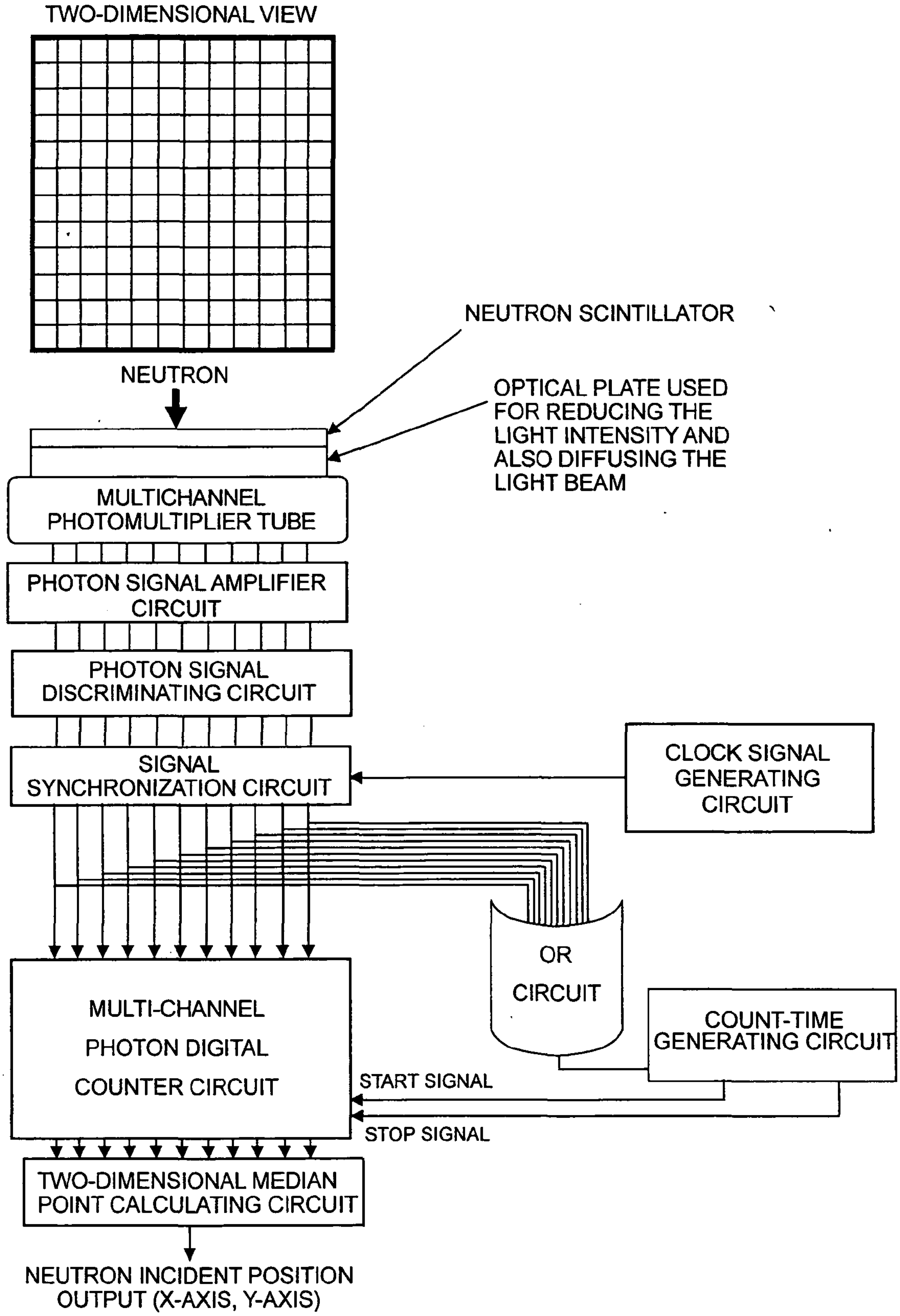

TWO-DIMENSIONAL VIEW
NEUTRON
NEUTRON SCINTILLATOR
OPTICAL PLATE USED FOR REDUCING THE LIGHT INTENSITY AND ALSO DIFFUSING THE LIGHT BEAM
MULTICHANNEL PHOTOMULTIPLIER TUBE
PHOTON SIGNAL AMPLIFIER CIRCUIT
PHOTON SIGNAL DISCRIMINATING CIRCUIT
SIGNAL SYNCHRONIZATION CIRCUIT
CLOCK SIGNAL GENERATING CIRCUIT
OR CIRCUIT
MULTI-CHANNEL PHOTON DIGITAL COUNTER CIRCUIT
COUNT-TIME GENERATING CIRCUIT
START SIGNAL
STOP SIGNAL
TWO-DIMENSIONAL MEDIAN POINT CALCULATING CIRCUIT
NEUTRON INCIDENT POSITION OUTPUT (X-AXIS, Y-AXIS)

FIG. 9A

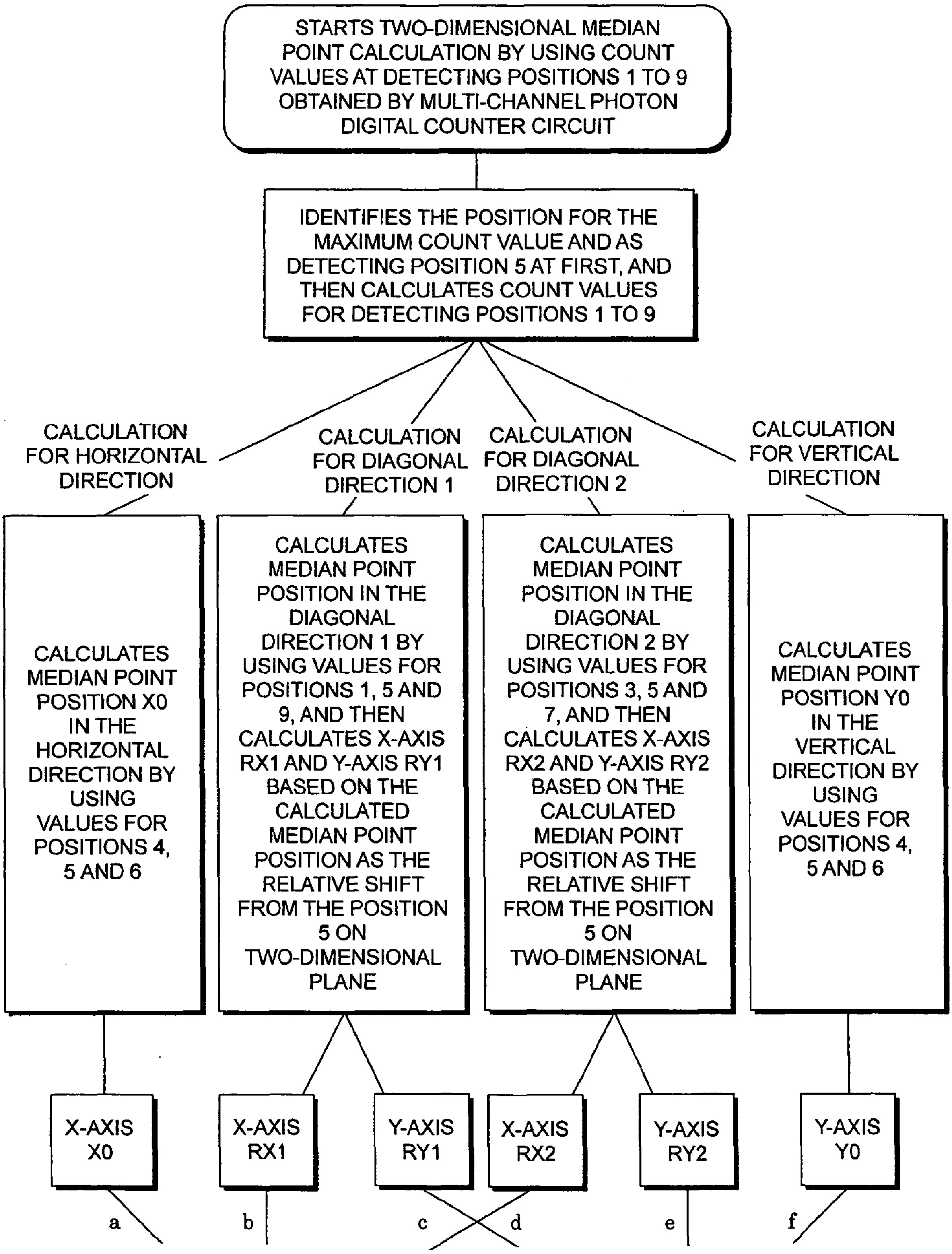

STARTS TWO-DIMENSIONAL MEDIAN POINT CALCULATION BY USING COUNT VALUES AT DETECTING POSITIONS 1 TO 9 OBTAINED BY MULTI-CHANNEL PHOTON DIGITAL COUNTER CIRCUIT
IDENTIFIES THE POSITION FOR THE MAXIMUM COUNT VALUE AND AS DETECTING POSITION 5 AT FIRST, AND THEN CALCULATES COUNT VALUES FOR DETECTING POSITIONS 1 TO 9
CALCULATION FOR HORIZONTAL DIRECTION
CALCULATION FOR DIAGONAL DIRECTION 1
CALCULATION FOR DIAGONAL DIRECTION 2
CALCULATION FOR VERTICAL DIRECTION
CALCULATES MEDIAN POINT POSITION X0 IN THE HORIZONTAL DIRECTION BY USING VALUES FOR POSITIONS 4, 5 AND 6
CALCULATES MEDIAN POINT POSITION IN THE DIAGONAL DIRECTION 1 BY USING VALUES FOR POSITIONS 1, 5 AND 9, AND THEN CALCULATES X-AXIS RX1 AND Y-AXIS RY1 BASED ON THE CALCULATED MEDIAN POINT POSITION AS THE RELATIVE SHIFT FROM THE POSITION 5 ON TWO-DIMENSIONAL PLANE
CALCULATES MEDIAN POINT POSITION IN THE DIAGONAL DIRECTION 2 BY USING VALUES FOR POSITIONS 3, 5 AND 7, AND THEN CALCULATES X-AXIS RX2 AND Y-AXIS RY2 BASED ON THE CALCULATED MEDIAN POINT POSITION AS THE RELATIVE SHIFT FROM THE POSITION 5 ON TWO-DIMENSIONAL PLANE
CALCULATES MEDIAN POINT POSITION Y0 IN THE VERTICAL DIRECTION BY USING VALUES FOR POSITIONS 4, 5 AND 6
X-AXIS X0
X-AXIS RX1
Y-AXIS RY1
X-AXIS RX2
Y-AXIS RY2
Y-AXIS Y0
a
b
c
d
e
f

FIG. 9B

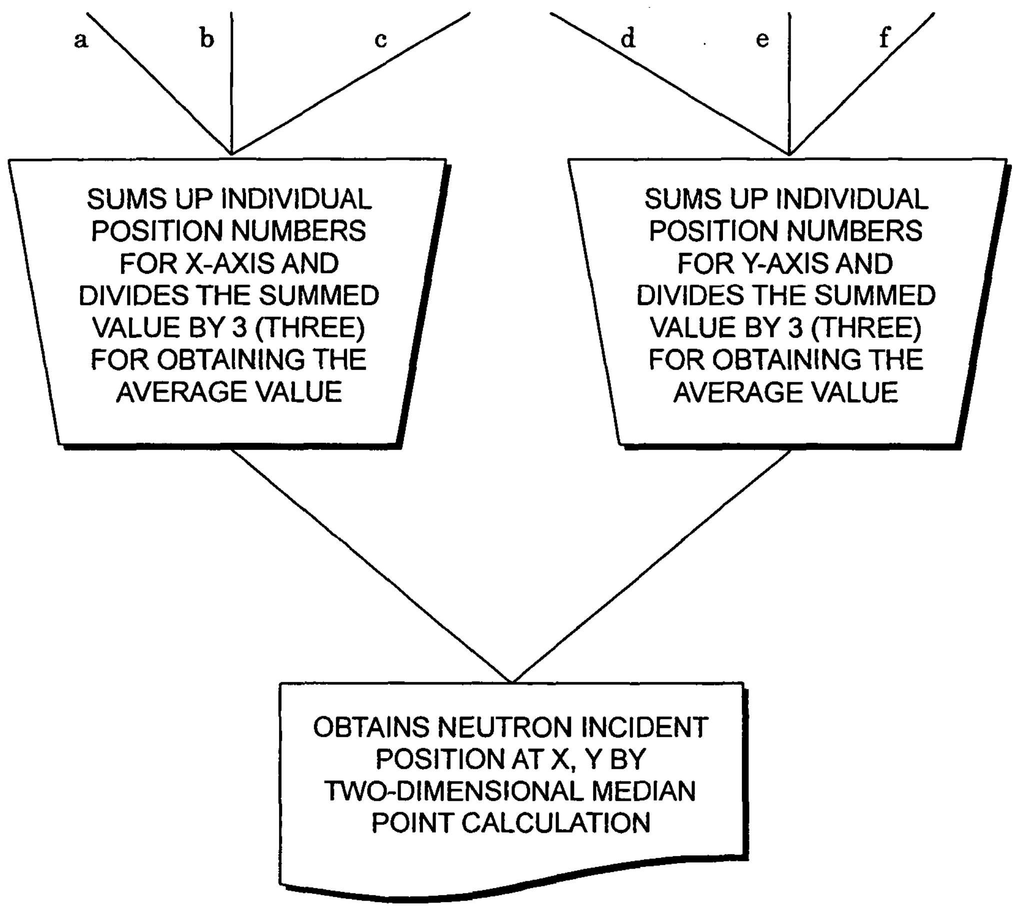

a
b
c
d
e
f
SUMS UP INDIVIDUAL POSITION NUMBERS FOR X-AXIS AND DIVIDES THE SUMMED VALUE BY 3 (THREE) FOR OBTAINING THE AVERAGE VALUE
SUMS UP INDIVIDUAL POSITION NUMBERS FOR Y-AXIS AND DIVIDES THE SUMMED VALUE BY 3 (THREE) FOR OBTAINING THE AVERAGE VALUE
OBTAINS NEUTRON INCIDENT POSITION AT X, Y BY TWO-DIMENSIONAL MEDIAN POINT CALCULATION

FIG. 10A

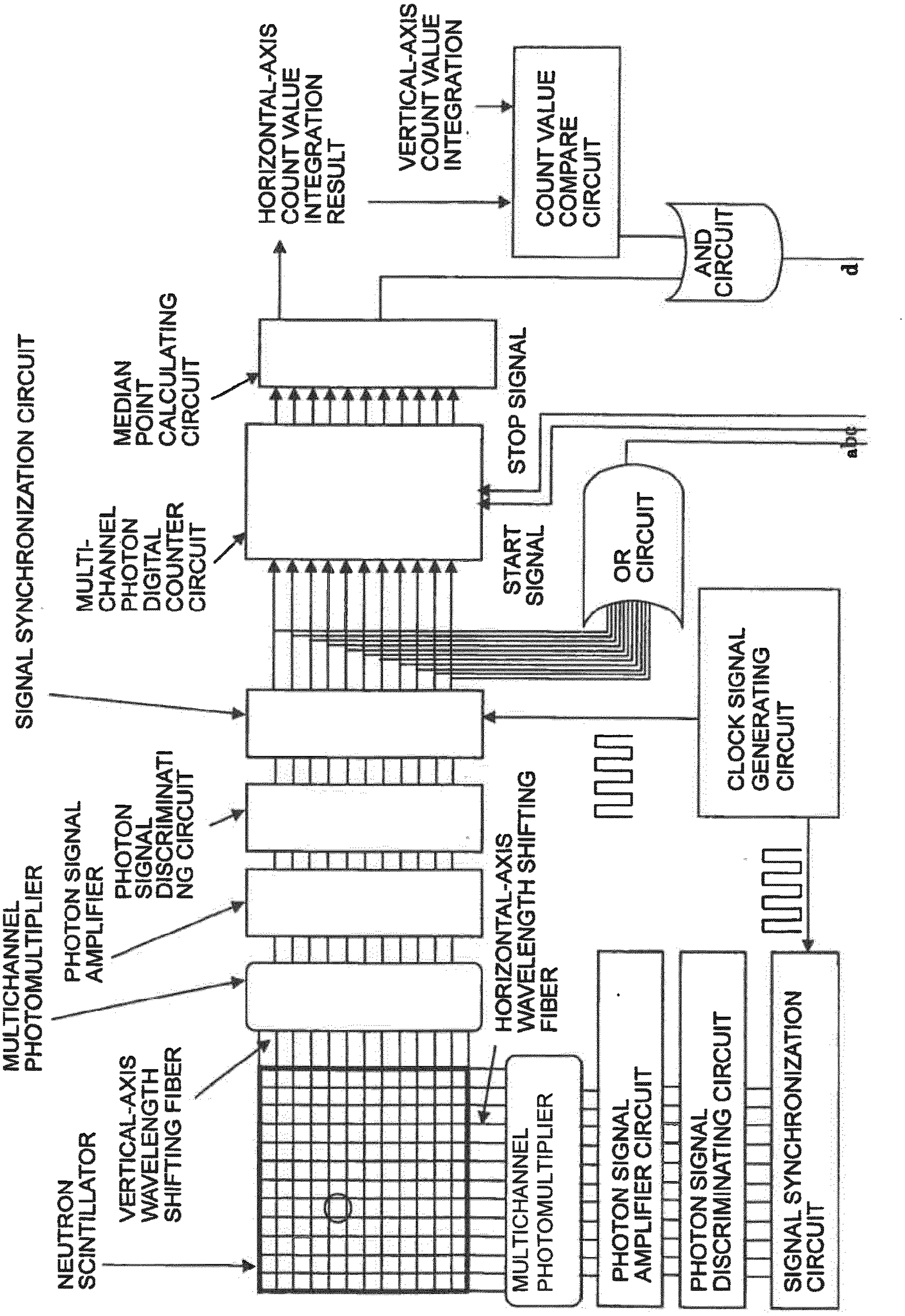

SIGNAL SYNCHRONIZATION CIRCUIT
NEUTRON SCINTILLATOR
VERTICAL-AXIS WAVELENGTH SHIFTING FIBER
MULTICHANNEL PHOTOMULTIPLIER
PHOTON SIGNAL AMPLIFIER
PHOTON SIGNAL DISCRIMINATING CIRCUIT
MULTI-CHANNEL PHOTON DIGITAL COUNTER CIRCUIT
MEDIAN POINT CALCULATING CIRCUIT
HORIZONTAL-AXIS COUNT VALUE INTEGRATION RESULT
VERTICAL-AXIS COUNT VALUE INTEGRATION
COUNT VALUE COMPARE CIRCUIT
AND CIRCUIT
d
STOP SIGNAL
START SIGNAL
OR CIRCUIT
abc
HORIZONTAL-AXIS WAVELENGTH SHIFTING FIBER
CLOCK SIGNAL GENERATING CIRCUIT
MULTICHANNEL PHOTOMULTIPLIER
PHOTON SIGNAL AMPLIFIER CIRCUIT
PHOTON SIGNAL DISCRIMINATING CIRCUIT
SIGNAL SYNCHRONIZATION CIRCUIT

FIG. 10B

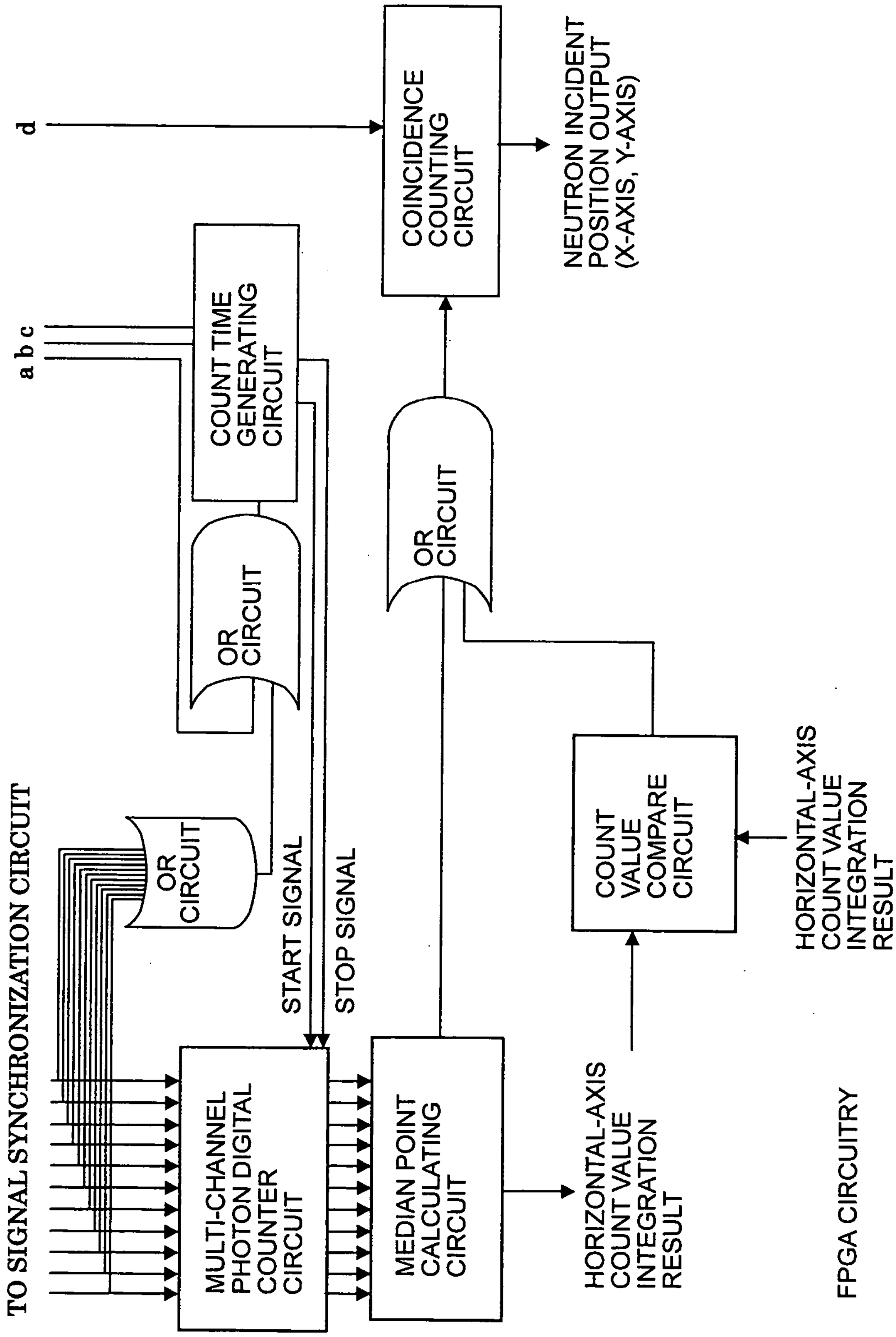
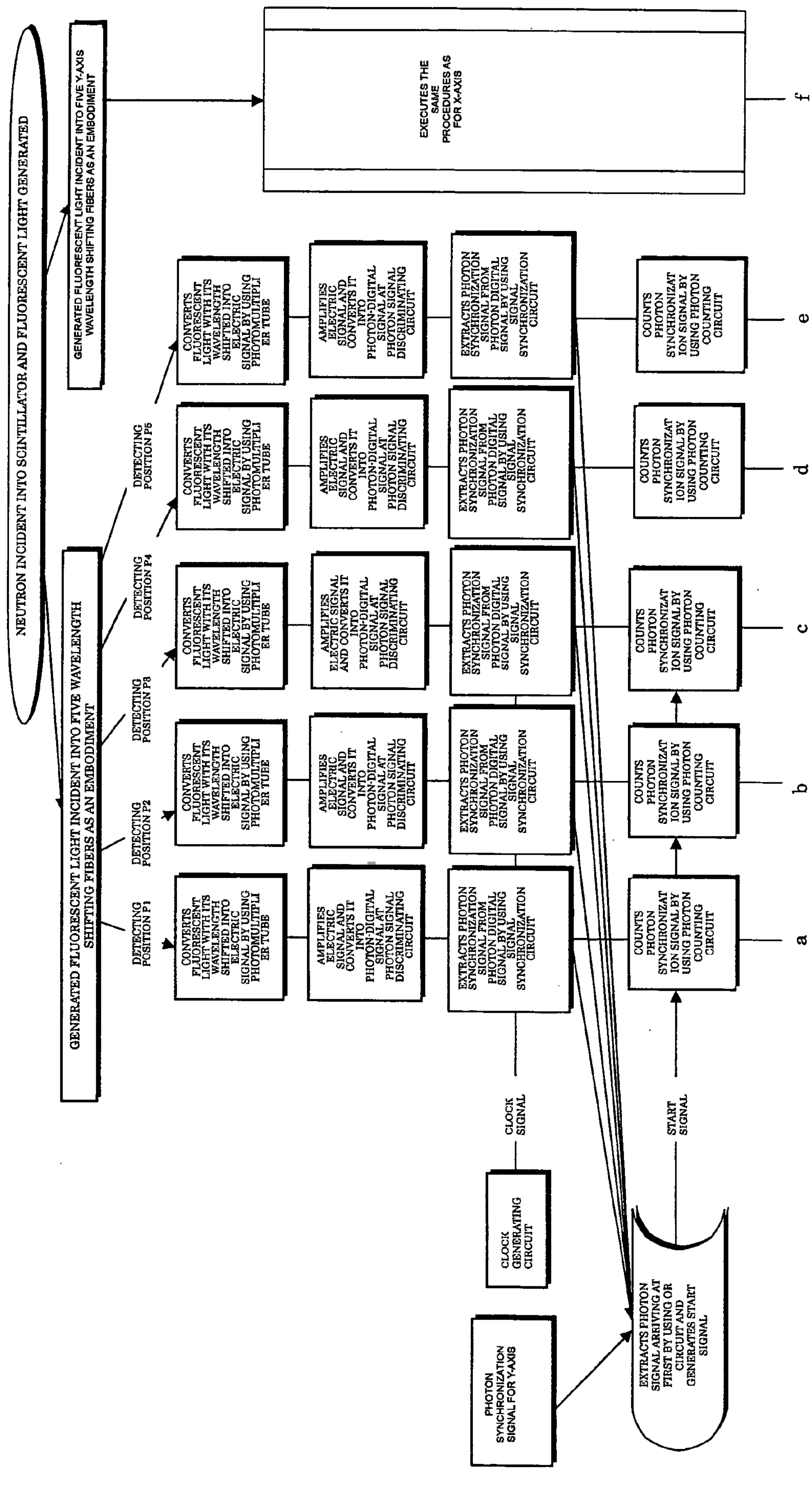

TO SIGNAL SYNCHRONIZATION CIRCUIT
OR CIRCUIT
OR CIRCUIT
OR CIRCUIT
a b c
d
COUNT TIME GENERATING CIRCUIT
COINCIDENCE COUNTING CIRCUIT
NEUTRON INCIDENT POSITION OUTPUT (X-AXIS, Y-AXIS)
START SIGNAL
STOP SIGNAL
MULTI-CHANNEL PHOTON DIGITAL COUNTER CIRCUIT
MEDIAN POINT CALCULATING CIRCUIT
HORIZONTAL-AXIS COUNT VALUE INTEGRATION RESULT
COUNT VALUE COMPARE CIRCUIT
HORIZONTAL-AXIS COUNT VALUE INTEGRATION RESULT
FPGA CIRCUITRY

FIG.11A


NEUTRON INCIDENT INTO SCINTILLATOR AND FLUORESCENT LIGHT GENERATED
GENERATED FLUORESCENT LIGHT INCIDENT INTO FIVE WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
GENERATED FLUORESCENT LIGHT INCIDENT INTO FIVE Y-AXIS WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
EXECUTES THE SAME PROCEDURES AS FOR X-AXIS
DETECTING POSITION P1
DETECTING POSITION P2
DETECTING POSITION P3
DETECTING POSITION P4
DETECTING POSITION P5
CONVERTS FLUORESCENT LIGHT WITH ITS WAVELENGTH SHIFTED INTO ELECTRIC SIGNAL BY USING PHOTOMULTIPLIER TUBE
AMPLIFIES ELECTRIC SIGNAL AND CONVERTS IT INTO PHOTON-DIGITAL SIGNAL AT PHOTON SIGNAL DISCRIMINATING CIRCUIT
EXTRACTS PHOTON SYNCHRONIZATION SIGNAL FROM PHOTON DIGITAL SIGNAL BY USING SIGNAL SYNCHRONIZATION CIRCUIT
COUNTS PHOTON SYNCHRONIZATION SIGNAL BY USING PHOTON COUNTING CIRCUIT
a
b
c
d
e
f
CLOCK SIGNAL
START SIGNAL
CLOCK GENERATING CIRCUIT
PHOTON SYNCHRONIZATION SIGNAL FOR Y-AXIS
EXTRACTS PHOTON SIGNAL ARRIVING AT FIRST BY USING OR CIRCUIT AND GENERATES START SIGNAL

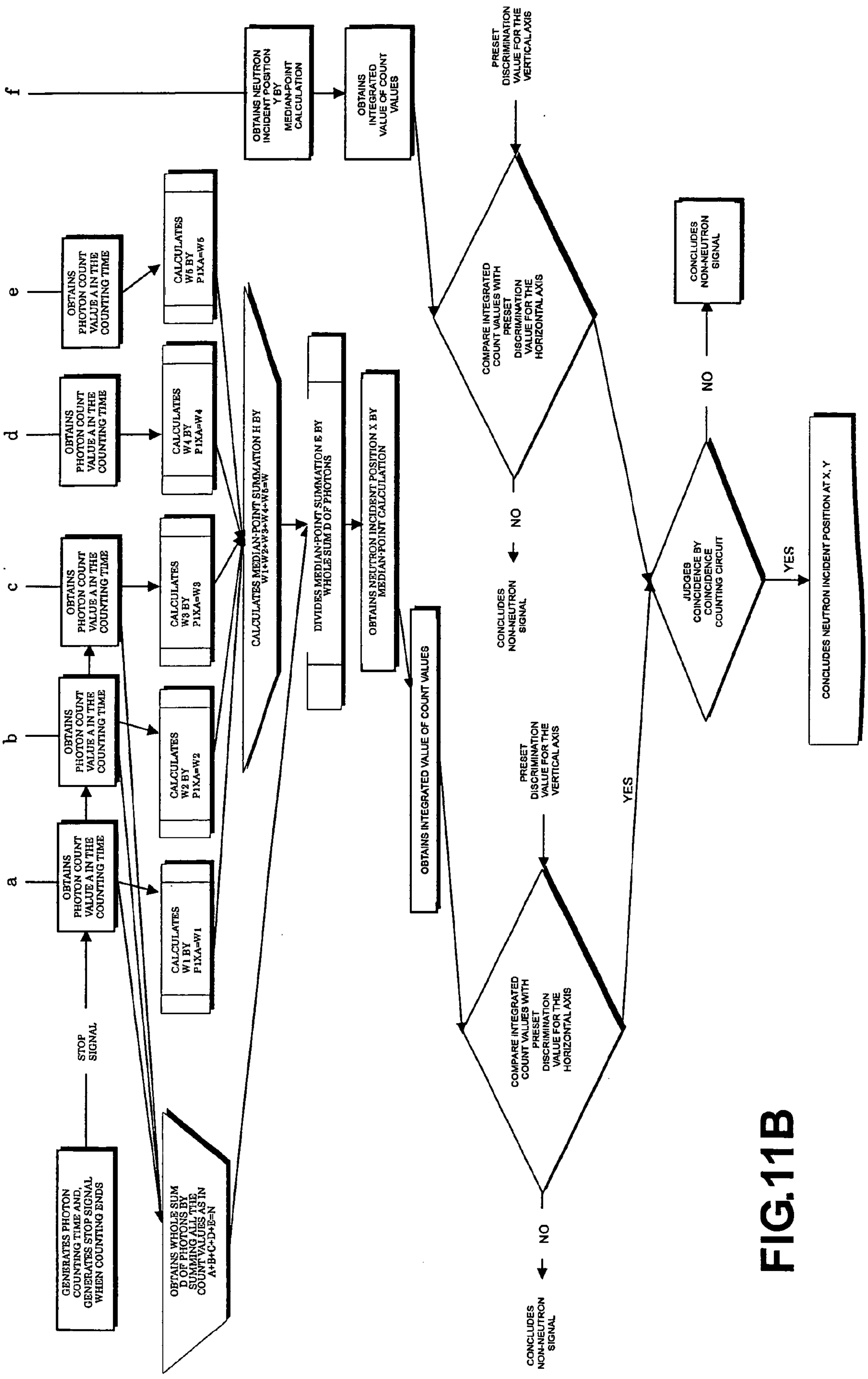

a
b
c
d
e
f
GENERATES PHOTON COUNTING TIME AND, GENERATES STOP SIGNAL WHEN COUNTING ENDS
STOP SIGNAL
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
CALCULATES W1 BY P1XA=W1
CALCULATES W2 BY P1XA=W2
CALCULATES W3 BY P1XA=W3
CALCULATES W4 BY P1XA=W4
CALCULATES W5 BY P1XA=W5
OBTAINS WHOLE SUM D OF PHOTONS BY SUMMING ALL THE COUNT VALUES AS IN A+B+C+D+E=N
CALCULATES MEDIAN-POINT SUMMATION H BY W1+W2+W3+W4+W5=W
DIVIDES MEDIAN-POINT SUMMATION E BY WHOLE SUM D OF PHOTONS
OBTAINS NEUTRON INCIDENT POSITION X BY MEDIAN-POINT CALCULATION
OBTAINS INTEGRATED VALUE OF COUNT VALUES
OBTAINS NEUTRON INCIDENT POSITION Y BY MEDIAN-POINT CALCULATION
OBTAINS INTEGRATED VALUE OF COUNT VALUES
PRESET DISCRIMINATION VALUE FOR THE VERTICAL AXIS
COMPARE INTEGRATED COUNT VALUES WITH PRESET DISCRIMINATION VALUE FOR THE HORIZONTAL AXIS
NO
CONCLUDES NON-NEUTRON SIGNAL
YES
PRESET DISCRIMINATION VALUE FOR THE VERTICAL AXIS
COMPARE INTEGRATED COUNT VALUES WITH PRESET DISCRIMINATION VALUE FOR THE HORIZONTAL AXIS
NO
CONCLUDES NON-NEUTRON SIGNAL
JUDGES COINCIDENCE BY COINCIDENCE COUNTING CIRCUIT
NO
CONCLUDES NON-NEUTRON SIGNAL
YES
CONCLUDES NEUTRON INCIDENT POSITION AT X, Y

FIG.11B

FIG. 12

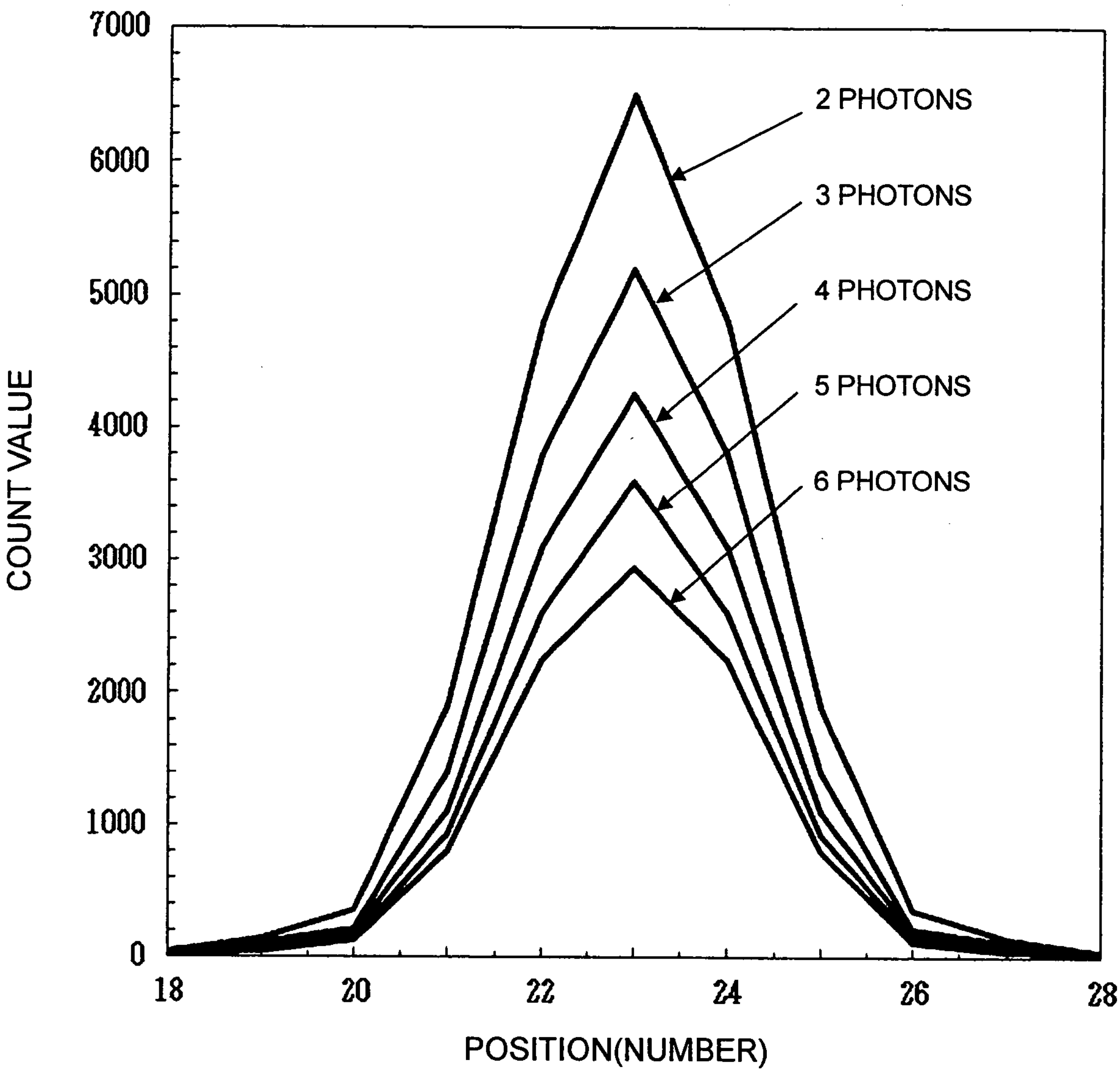

7000
6000
5000
4000
3000
2000
1000
0
COUNT VALUE
18
20
22
24
26
28
POSITION(NUMBER)
2 PHOTONS
3 PHOTONS
4 PHOTONS
5 PHOTONS
6 PHOTONS

FIG. 13

PROCESS MODE	PHOTON NUMBERS	POSITION RESOLUTION IN mm
MEDIAN POINT CALCULATION 0	2	1.04
MEDIAN POINT CALCULATION 1	3	0.97
MEDIAN POINT CALCULATION 2	4	0.92
MEDIAN POINT CALCULATION 3	5	0.87
MEDIAN POINT CALCULATION 4	6	0.84
MEDIAN POINT CALCULATION 5	7	0.81
PATTERN MATCHING METHOD	4	1.08

FIG. 14A

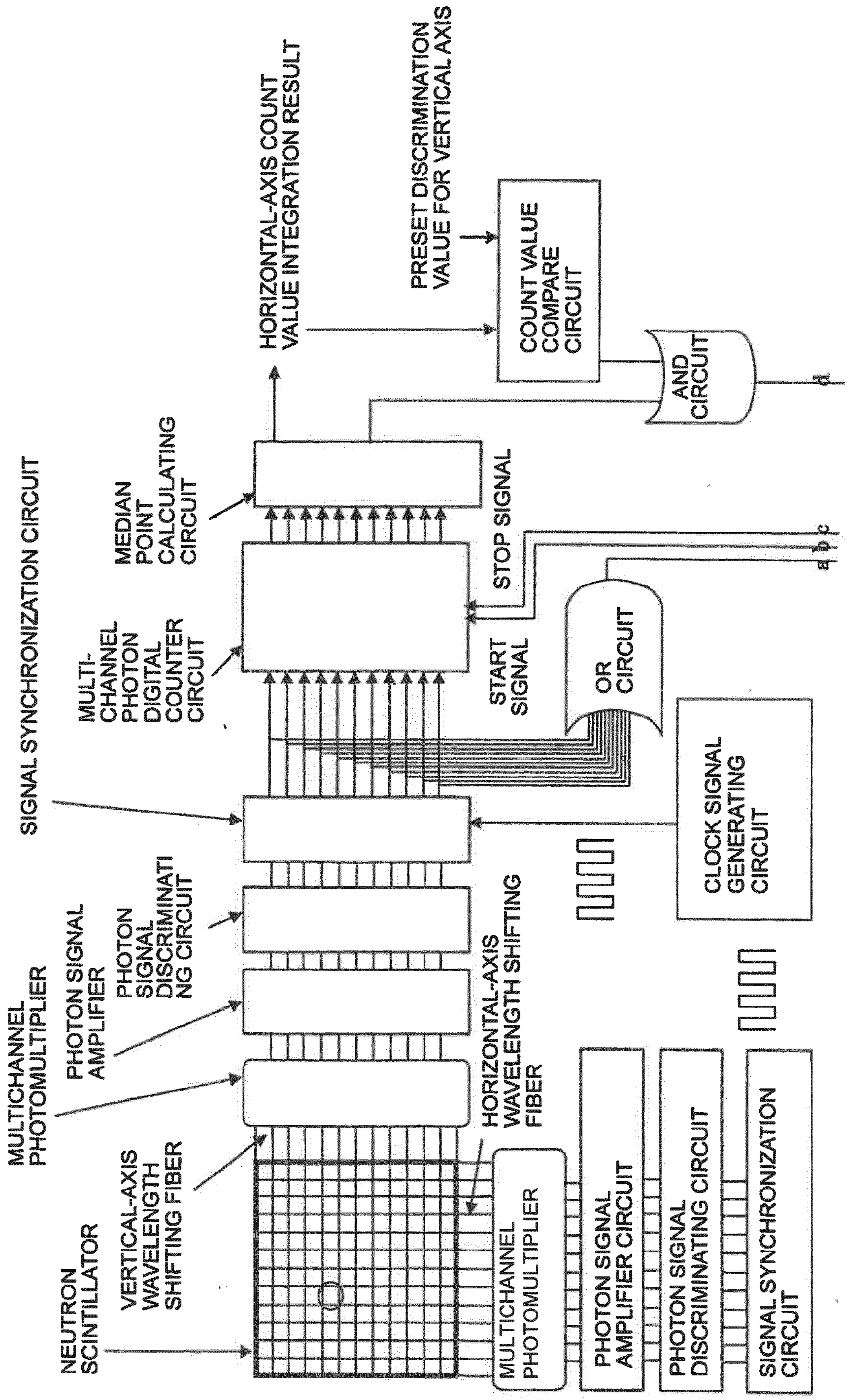

NEUTRON SCINTILLATOR
VERTICAL-AXIS WAVELENGTH SHIFTING FIBER
MULTICHANNEL PHOTOMULTIPLIER
PHOTON SIGNAL AMPLIFIER
PHOTON SIGNAL DISCRIMINATI NG CIRCUIT
SIGNAL SYNCHRONIZATION CIRCUIT
MULTI-CHANNEL PHOTON DIGITAL COUNTER CIRCUIT
MEDIAN POINT CALCULATING CIRCUIT
HORIZONTAL-AXIS COUNT VALUE INTEGRATION RESULT
PRESET DISCRIMINATION VALUE FOR VERTICAL AXIS
COUNT VALUE COMPARE CIRCUIT
AND CIRCUIT
d
STOP SIGNAL
START SIGNAL
OR CIRCUIT
a b c
CLOCK SIGNAL GENERATING CIRCUIT
HORIZONTAL-AXIS WAVELENGTH SHIFTING FIBER
MULTICHANNEL PHOTOMULTIPLIER
PHOTON SIGNAL AMPLIFIER CIRCUIT
PHOTON SIGNAL DISCRIMINATING CIRCUIT
SIGNAL SYNCHRONIZATION CIRCUIT

FIG. 14B

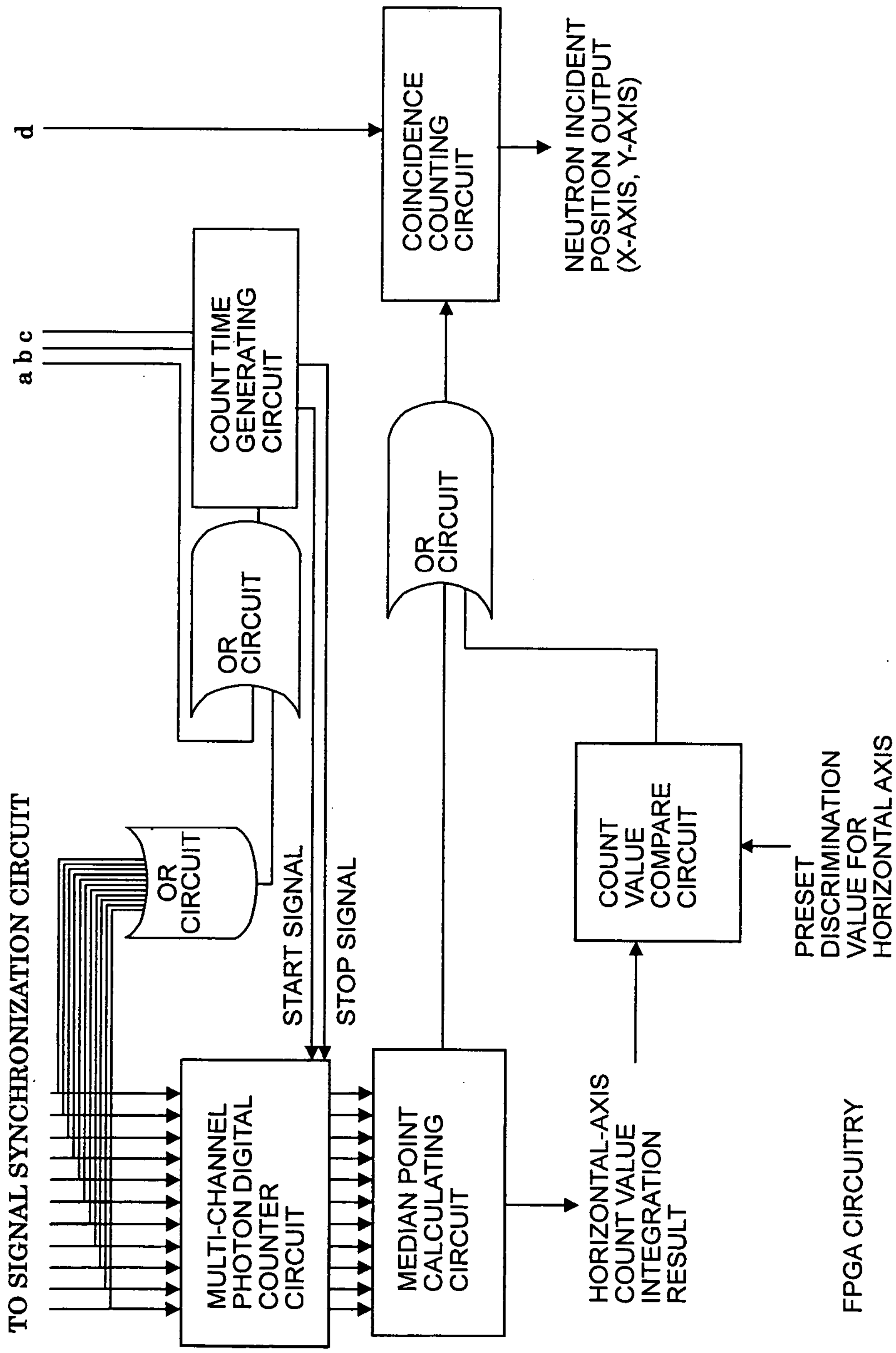

TO SIGNAL SYNCHRONIZATION CIRCUIT
OR CIRCUIT
OR CIRCUIT
OR CIRCUIT
COUNT TIME GENERATING CIRCUIT
a b c
d
COINCIDENCE COUNTING CIRCUIT
NEUTRON INCIDENT POSITION OUTPUT (X-AXIS, Y-AXIS)
START SIGNAL
STOP SIGNAL
MULTI-CHANNEL PHOTON DIGITAL COUNTER CIRCUIT
MEDIAN POINT CALCULATING CIRCUIT
HORIZONTAL-AXIS COUNT VALUE INTEGRATION RESULT
COUNT VALUE COMPARE CIRCUIT
PRESET DISCRIMINATION VALUE FOR HORIZONTAL AXIS
FPGA CIRCUITRY

FIG. 15A

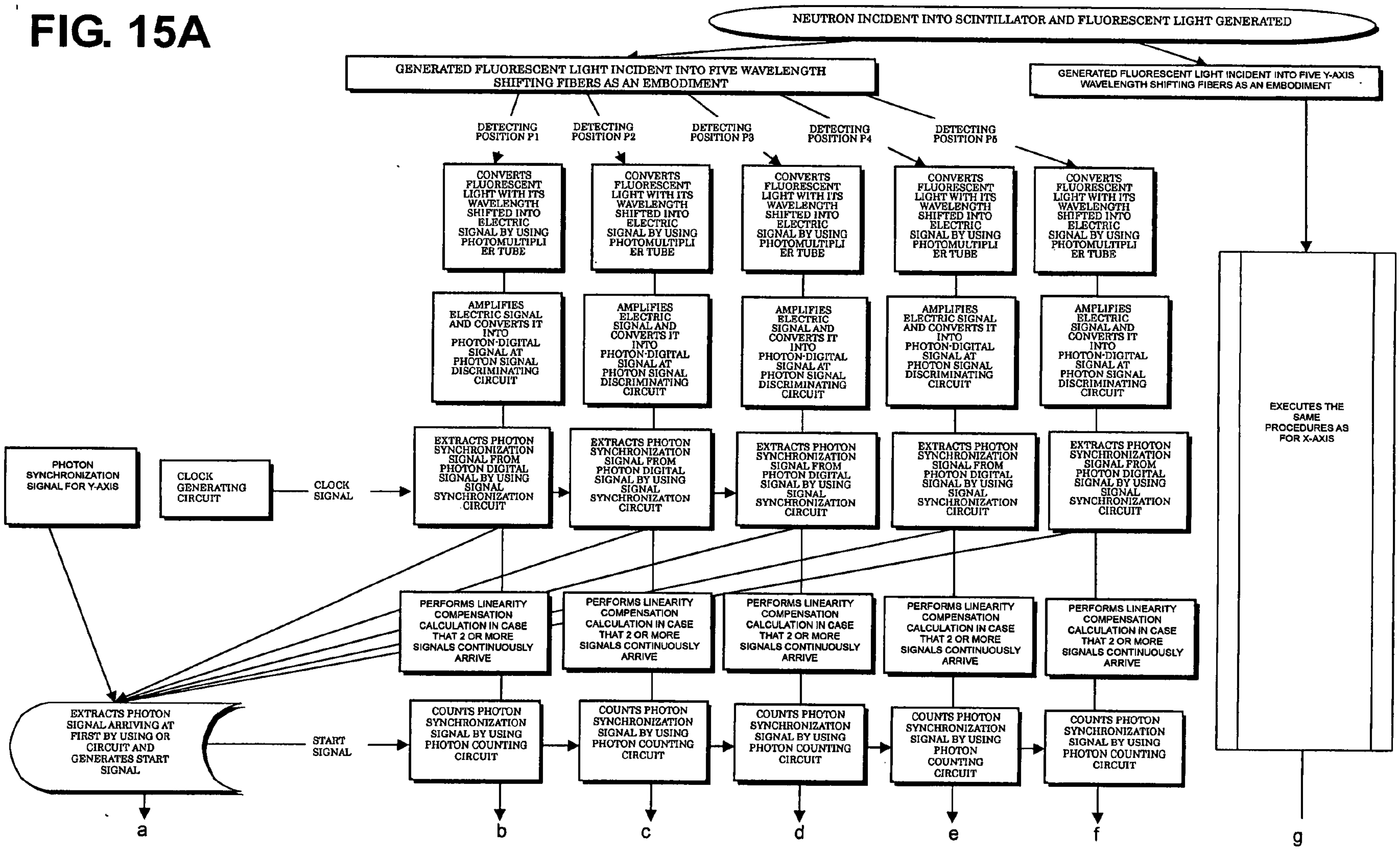

NEUTRON INCIDENT INTO SCINTILLATOR AND FLUORESCENT LIGHT GENERATED
GENERATED FLUORESCENT LIGHT INCIDENT INTO FIVE WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
GENERATED FLUORESCENT LIGHT INCIDENT INTO FIVE Y-AXIS WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
DETECTING POSITION P1
DETECTING POSITION P2
DETECTING POSITION P3
DETECTING POSITION P4
DETECTING POSITION P5
CONVERTS FLUORESCENT LIGHT WITH ITS WAVELENGTH SHIFTED INTO ELECTRIC SIGNAL BY USING PHOTOMULTIPLI ER TUBE
AMPLIFIES ELECTRIC SIGNAL AND CONVERTS IT INTO PHOTON-DIGITAL SIGNAL AT PHOTON SIGNAL DISCRIMINATING CIRCUIT
EXTRACTS PHOTON SYNCHRONIZATION SIGNAL FROM PHOTON DIGITAL SIGNAL BY USING SIGNAL SYNCHRONIZATION CIRCUIT
PERFORMS LINEARITY COMPENSATION CALCULATION IN CASE THAT 2 OR MORE SIGNALS CONTINUOUSLY ARRIVE
COUNTS PHOTON SYNCHRONIZATION SIGNAL BY USING PHOTON COUNTING CIRCUIT
EXECUTES THE SAME PROCEDURES AS FOR X-AXIS
PHOTON SYNCHRONIZATION SIGNAL FOR Y-AXIS
CLOCK GENERATING CIRCUIT
CLOCK SIGNAL
EXTRACTS PHOTON SIGNAL ARRIVING AT FIRST BY USING OR CIRCUIT AND GENERATES START SIGNAL
START SIGNAL
a
b
c
d
e
f
g

FIG. 15B

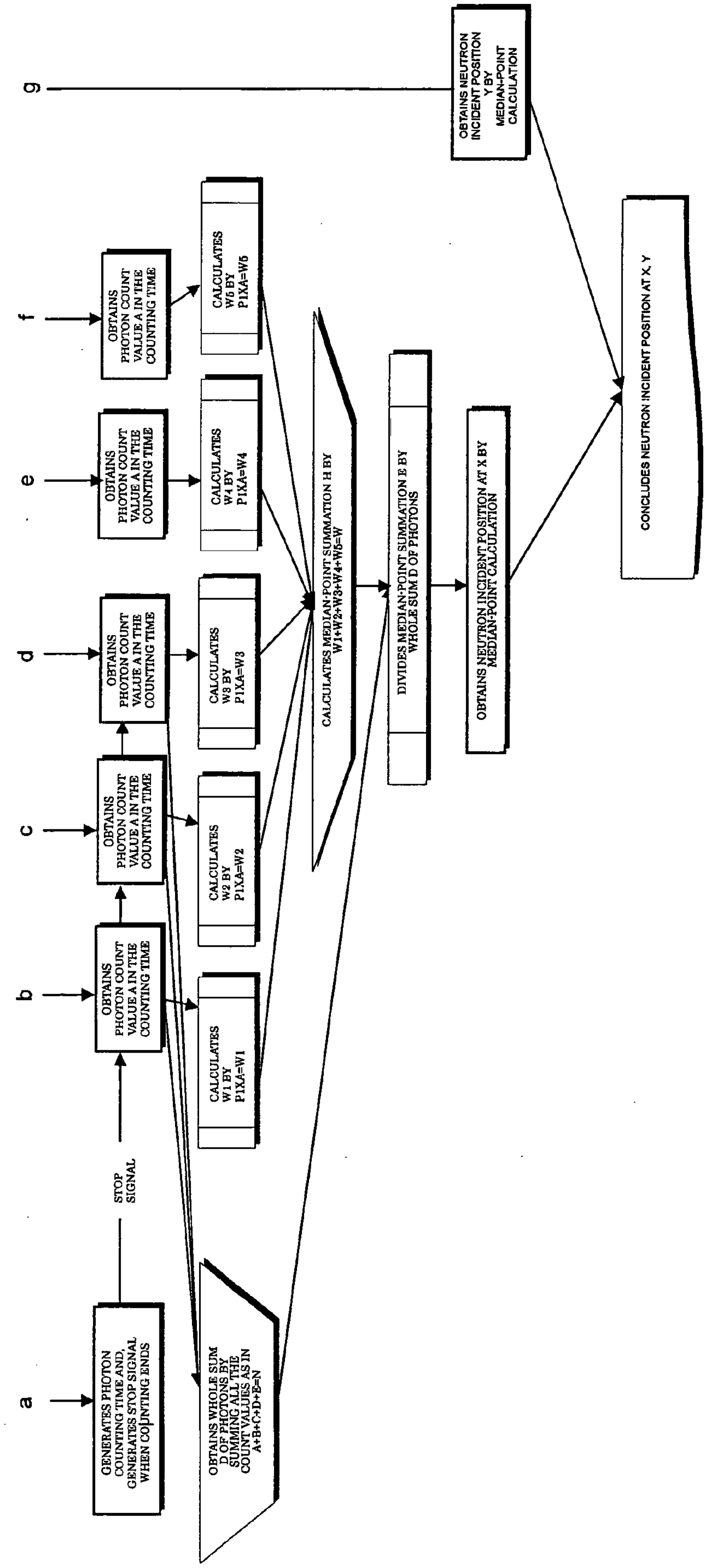

a
b
c
d
e
f
g
GENERATES PHOTON COUNTING TIME AND, GENERATES STOP SIGNAL WHEN COUNTING ENDS
STOP SIGNAL
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
CALCULATES W1 BY P1XA=W1
CALCULATES W2 BY P1XA=W2
CALCULATES W3 BY P1XA=W3
CALCULATES W4 BY P1XA=W4
CALCULATES W5 BY P1XA=W5
OBTAINS WHOLE SUM D OF PHOTONS BY SUMMING ALL THE COUNT VALUES AS IN A+B+C+D+E=N
CALCULATES MEDIAN-POINT SUMMATION H BY W1+W2+W3+W4+W5=W
DIVIDES MEDIAN-POINT SUMMATION E BY WHOLE SUM D OF PHOTONS
OBTAINS NEUTRON INCIDENT POSITION AT X BY MEDIAN-POINT CALCULATION
OBTAINS NEUTRON INCIDENT POSITION Y BY MEDIAN-POINT CALCULATION
CONCLUDES NEUTRON INCIDENT POSITION AT X, Y

FIG. 16

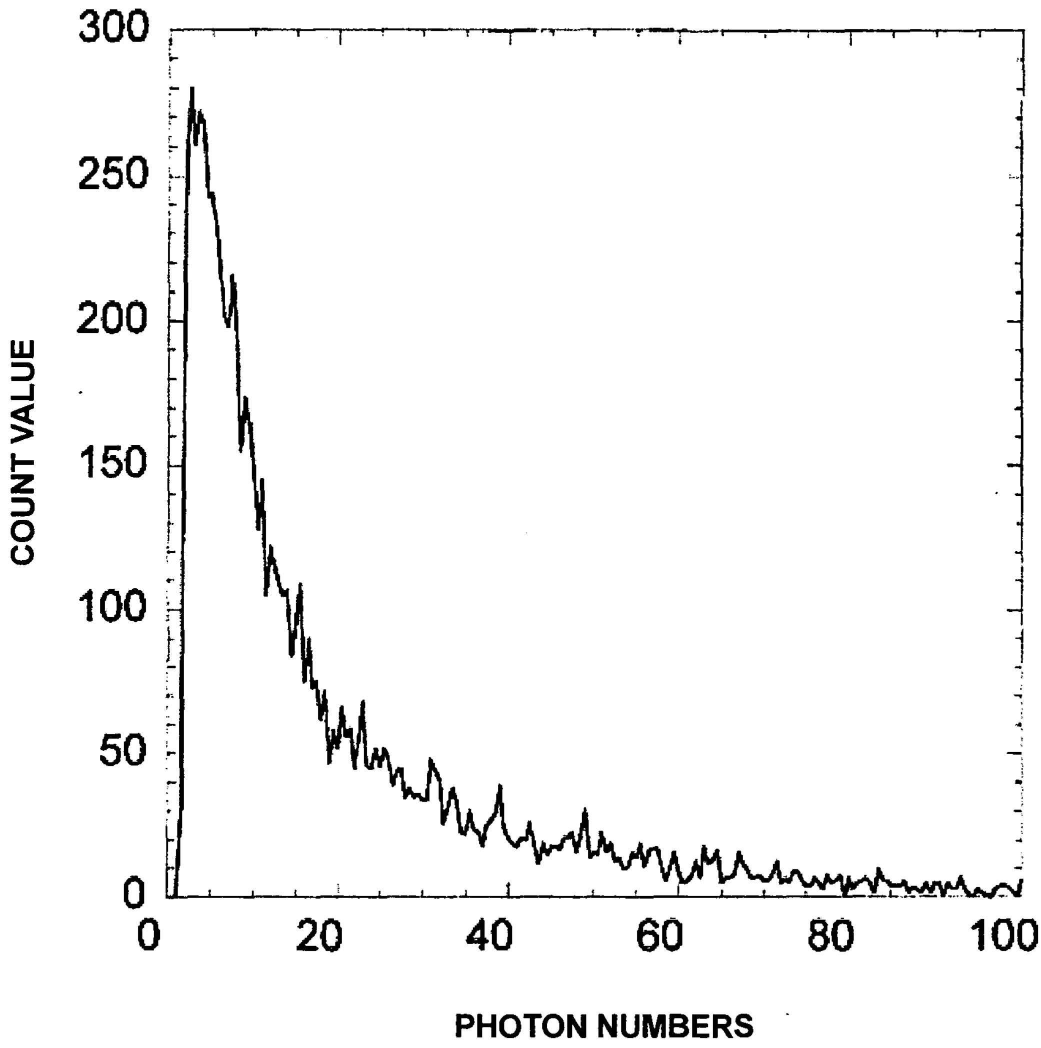

300
250
200
150
100
50
0
COUNT VALUE
0
20
40
60
80
100
PHOTON NUMBERS

FIG.17

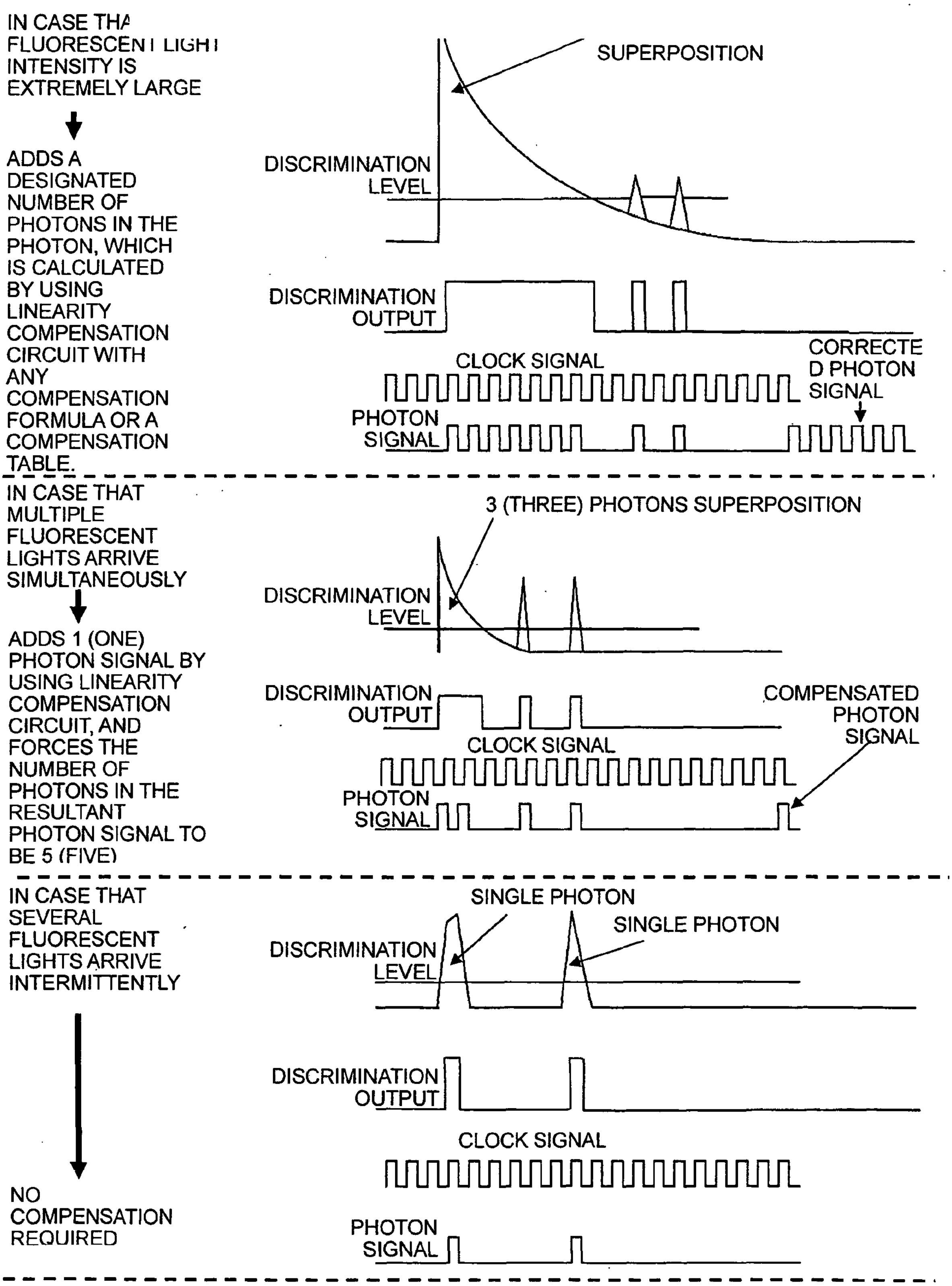

IN CASE THAT FLUORESCENT LIGHT INTENSITY IS EXTREMELY LARGE
ADDS A DESIGNATED NUMBER OF PHOTONS IN THE PHOTON, WHICH IS CALCULATED BY USING LINEARITY COMPENSATION CIRCUIT WITH ANY COMPENSATION FORMULA OR A COMPENSATION TABLE.
SUPERPOSITION
DISCRIMINATION LEVEL
DISCRIMINATION OUTPUT
CLOCK SIGNAL
CORRECTED PHOTON SIGNAL
PHOTON SIGNAL
IN CASE THAT MULTIPLE FLUORESCENT LIGHTS ARRIVE SIMULTANEOUSLY
ADDS 1 (ONE) PHOTON SIGNAL BY USING LINEARITY COMPENSATION CIRCUIT, AND FORCES THE NUMBER OF PHOTONS IN THE RESULTANT PHOTON SIGNAL TO BE 5 (FIVE)
3 (THREE) PHOTONS SUPERPOSITION
DISCRIMINATION LEVEL
DISCRIMINATION OUTPUT
COMPENSATED PHOTON SIGNAL
CLOCK SIGNAL
PHOTON SIGNAL
IN CASE THAT SEVERAL FLUORESCENT LIGHTS ARRIVE INTERMITTENTLY
NO COMPENSATION REQUIRED
SINGLE PHOTON
SINGLE PHOTON
DISCRIMINATION LEVEL
DISCRIMINATION OUTPUT
CLOCK SIGNAL
PHOTON SIGNAL

FIG. 18

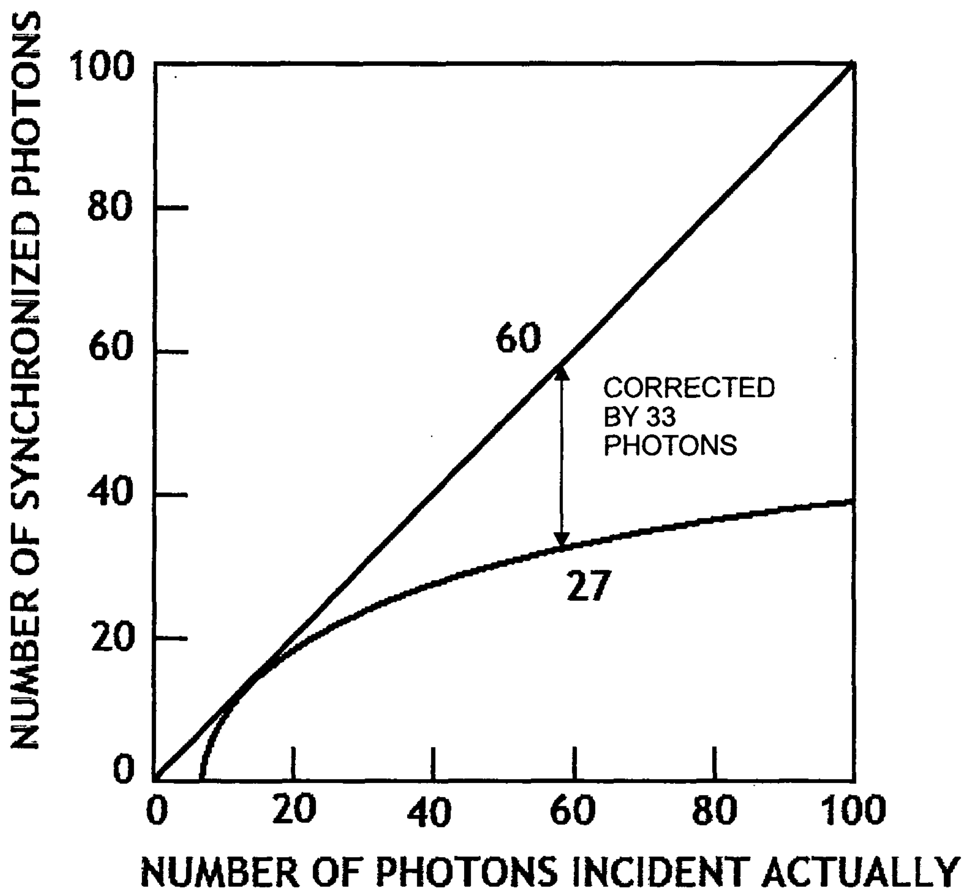
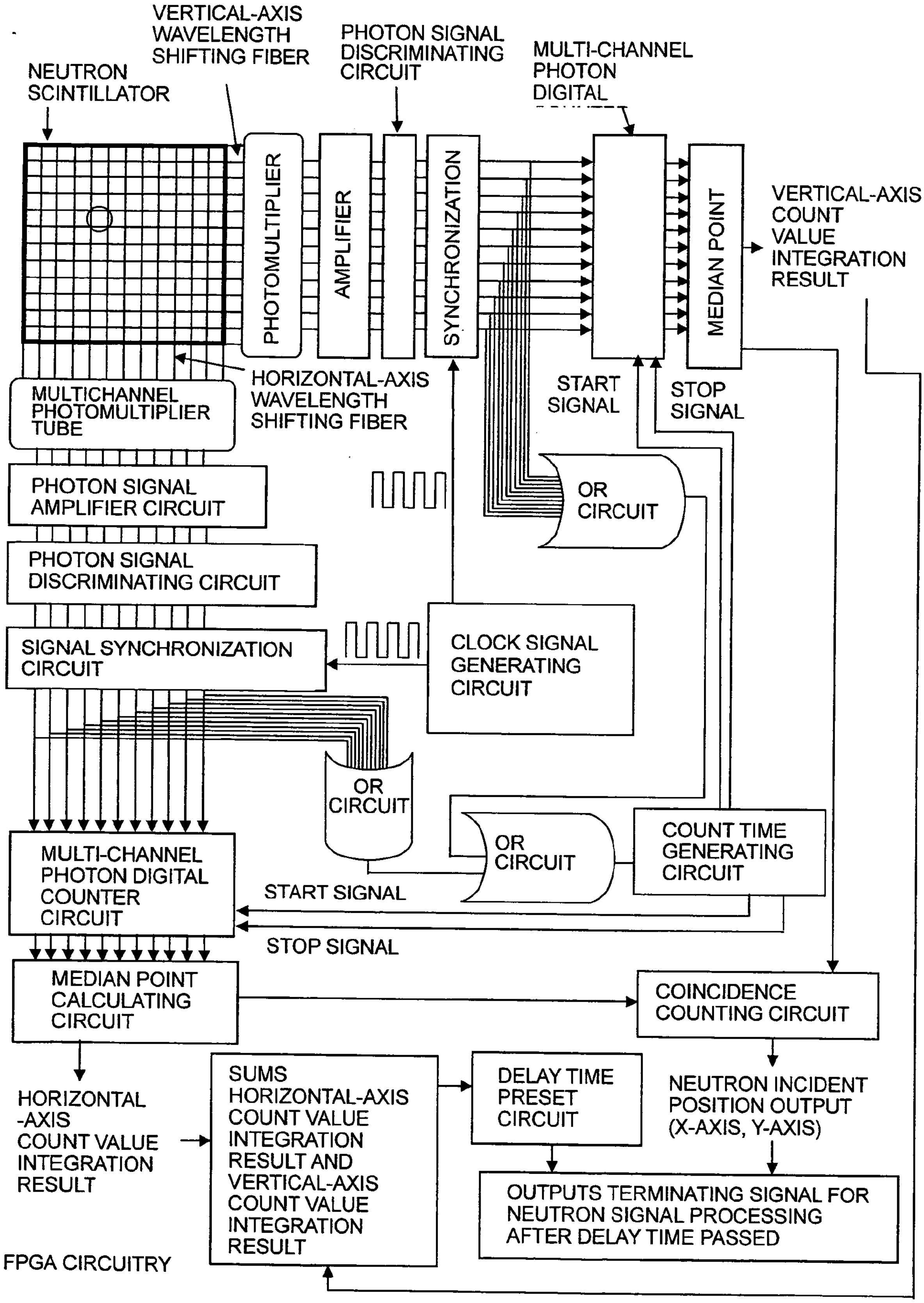

NUMBER OF SYNCHRONIZED PHOTONS
100
80
60
40
20
0
0
20
40
60
80
100
NUMBER OF PHOTONS INCIDENT ACTUALLY
60
CORRECTED BY 33 PHOTONS
27

FIG. 19



VERTICAL-AXIS WAVELENGTH SHIFTING FIBER
NEUTRON SCINTILLATOR
PHOTON SIGNAL DISCRIMINATING CIRCUIT
MULTI-CHANNEL PHOTON DIGITAL
PHOTOMULTIPLIER
AMPLIFIER
SYNCHRONIZATION
MEDIAN POINT
VERTICAL-AXIS COUNT VALUE INTEGRATION RESULT
HORIZONTAL-AXIS WAVELENGTH SHIFTING FIBER
MULTICHANNEL PHOTOMULTIPLIER TUBE
START SIGNAL
STOP SIGNAL
PHOTON SIGNAL AMPLIFIER CIRCUIT
OR CIRCUIT
PHOTON SIGNAL DISCRIMINATING CIRCUIT
SIGNAL SYNCHRONIZATION CIRCUIT
CLOCK SIGNAL GENERATING CIRCUIT
OR CIRCUIT
OR CIRCUIT
COUNT TIME GENERATING CIRCUIT
MULTI-CHANNEL PHOTON DIGITAL COUNTER CIRCUIT
START SIGNAL
STOP SIGNAL
MEDIAN POINT CALCULATING CIRCUIT
COINCIDENCE COUNTING CIRCUIT
HORIZONTAL -AXIS COUNT VALUE INTEGRATION RESULT
SUMS HORIZONTAL-AXIS COUNT VALUE INTEGRATION RESULT AND VERTICAL-AXIS COUNT VALUE INTEGRATION RESULT
DELAY TIME PRESET CIRCUIT
NEUTRON INCIDENT POSITION OUTPUT (X-AXIS, Y-AXIS)
OUTPUTS TERMINATING SIGNAL FOR NEUTRON SIGNAL PROCESSING AFTER DELAY TIME PASSED
FPGA CIRCUITRY

FIG. 20A

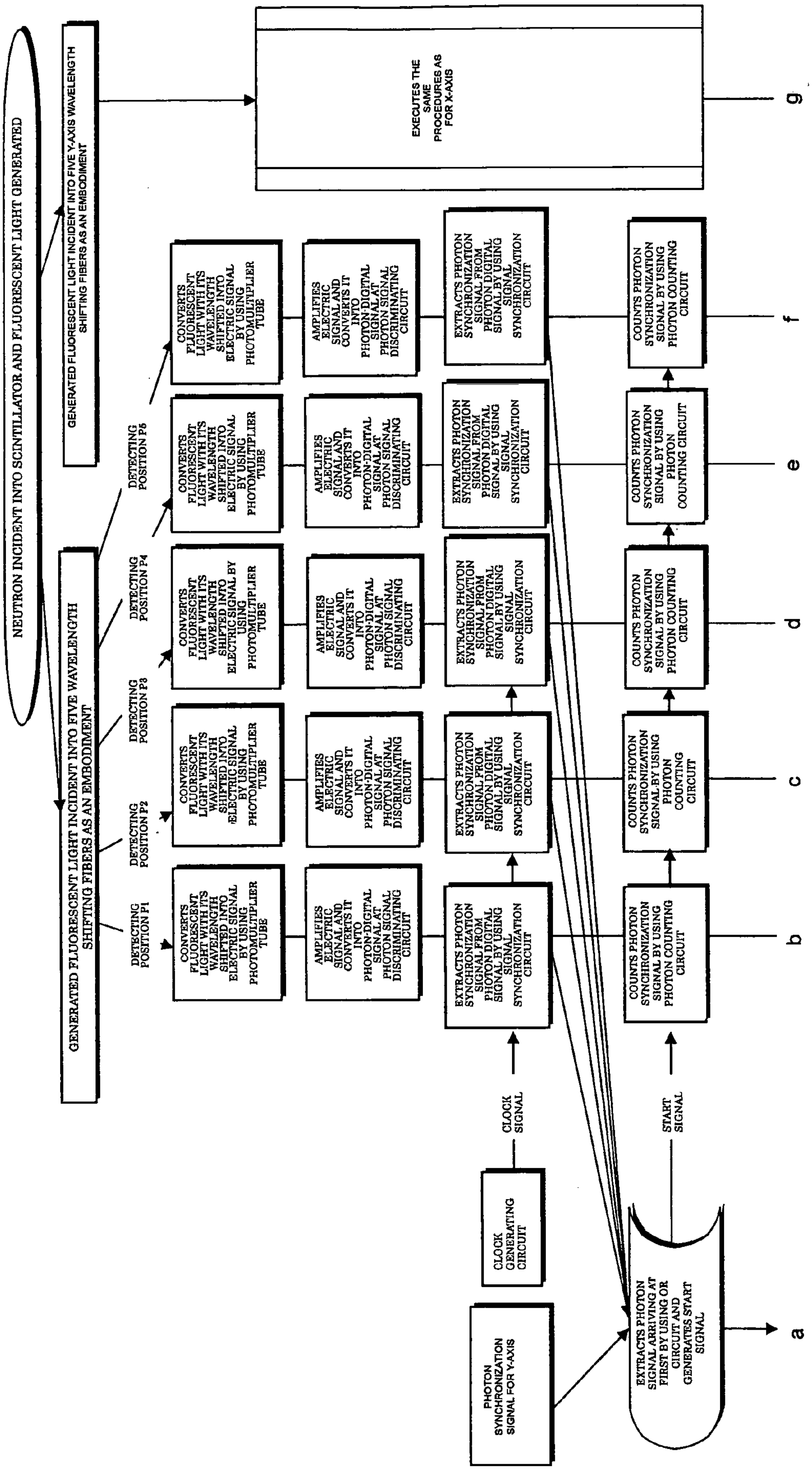

NEUTRON INCIDENT INTO SCINTILLATOR AND FLUORESCENT LIGHT GENERATED
GENERATED FLUORESCENT LIGHT INCIDENT INTO FIVE WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
GENERATED FLUORESCENT LIGHT INCIDENT INTO FIVE Y-AXIS WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
EXECUTES THE SAME PROCEDURES AS FOR X-AXIS
DETECTING POSITION P1
DETECTING POSITION P2
DETECTING POSITION P3
DETECTING POSITION P4
DETECTING POSITION P5
CONVERTS FLUORESCENT LIGHT WITH ITS WAVELENGTH SHIFTED INTO ELECTRIC SIGNAL BY USING PHOTOMULTIPLIER TUBE
AMPLIFIES ELECTRIC SIGNAL AND CONVERTS IT INTO PHOTON-DIGITAL SIGNAL AT PHOTON SIGNAL DISCRIMINATING CIRCUIT
EXTRACTS PHOTON SYNCHRONIZATION SIGNAL FROM PHOTON DIGITAL SIGNAL BY USING SIGNAL SYNCHRONIZATION CIRCUIT
COUNTS PHOTON SYNCHRONIZATION SIGNAL BY USING PHOTON COUNTING CIRCUIT
CLOCK GENERATING CIRCUIT
CLOCK SIGNAL
START SIGNAL
PHOTON SYNCHRONIZATION SIGNAL FOR Y-AXIS
EXTRACTS PHOTON SIGNAL ARRIVING AT FIRST BY USING OR CIRCUIT AND GENERATES START SIGNAL
a
b
c
d
e
f
g

FIG. 20B

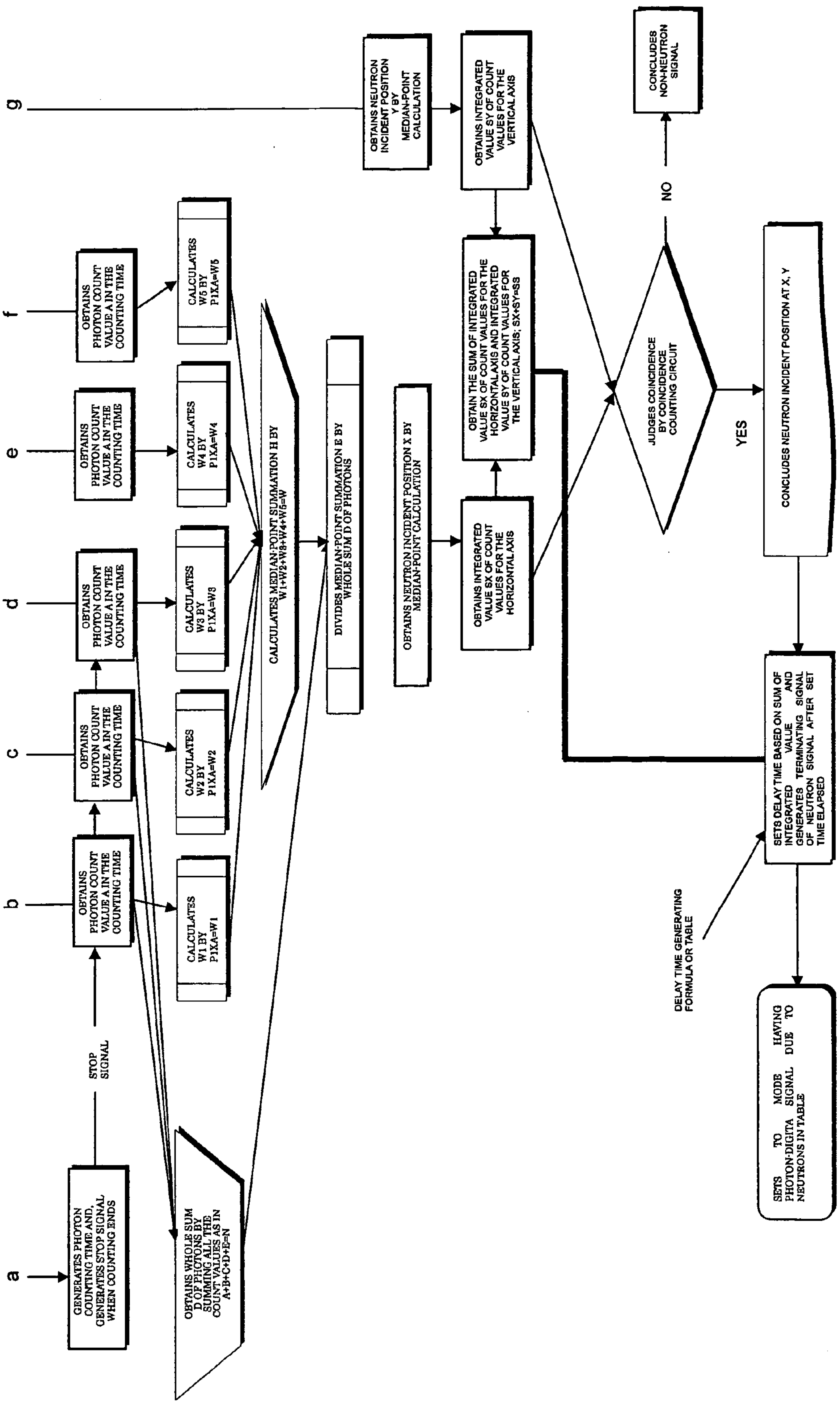

a
b
c
d
e
f
g
GENERATES PHOTON COUNTING TIME AND, GENERATES STOP SIGNAL WHEN COUNTING ENDS
STOP SIGNAL
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS PHOTON COUNT VALUE A IN THE COUNTING TIME
OBTAINS WHOLE SUM D OF PHOTONS BY SUMMING ALL THE COUNT VALUES AS IN A+B+C+D+E=N
CALCULATES W1 BY P1XA=W1
CALCULATES W2 BY P1XA=W2
CALCULATES W3 BY P1XA=W3
CALCULATES W4 BY P1XA=W4
CALCULATES W5 BY P1XA=W5
CALCULATES MEDIAN-POINT SUMMATION H BY W1+W2+W3+W4+W5=W
DIVIDES MEDIAN-POINT SUMMATION E BY WHOLE SUM D OF PHOTONS
OBTAINS NEUTRON INCIDENT POSITION X BY MEDIAN-POINT CALCULATION
OBTAINS NEUTRON INCIDENT POSITION Y BY MEDIAN-POINT CALCULATION
OBTAINS INTEGRATED VALUE SX OF COUNT VALUES FOR THE HORIZONTAL AXIS
OBTAIN THE SUM OF INTEGRATED VALUE SX OF COUNT VALUES FOR THE HORIZONTAL AXIS AND INTEGRATED VALUE SY OF COUNT VALUES FOR THE VERTICAL AXIS; SX+SY=SS
OBTAINS INTEGRATED VALUE SY OF COUNT VALUES FOR THE VERTICAL AXIS
JUDGES COINCIDENCE BY COINCIDENCE COUNTING CIRCUIT
NO
CONCLUDES NON-NEUTRON SIGNAL
YES
CONCLUDES NEUTRON INCIDENT POSITION AT X, Y
DELAY TIME GENERATING FORMULA OR TABLE
SETS DELAY TIME BASED ON SUM OF INTEGRATED VALUE AND GENERATES TERMINATING SIGNAL OF NEUTRON SIGNAL AFTER SET TIME ELAPSED
SETS TO MODE HAVING PHOTON-DIGITA SIGNAL DUE TO NEUTRONS IN TABLE

FIG. 21

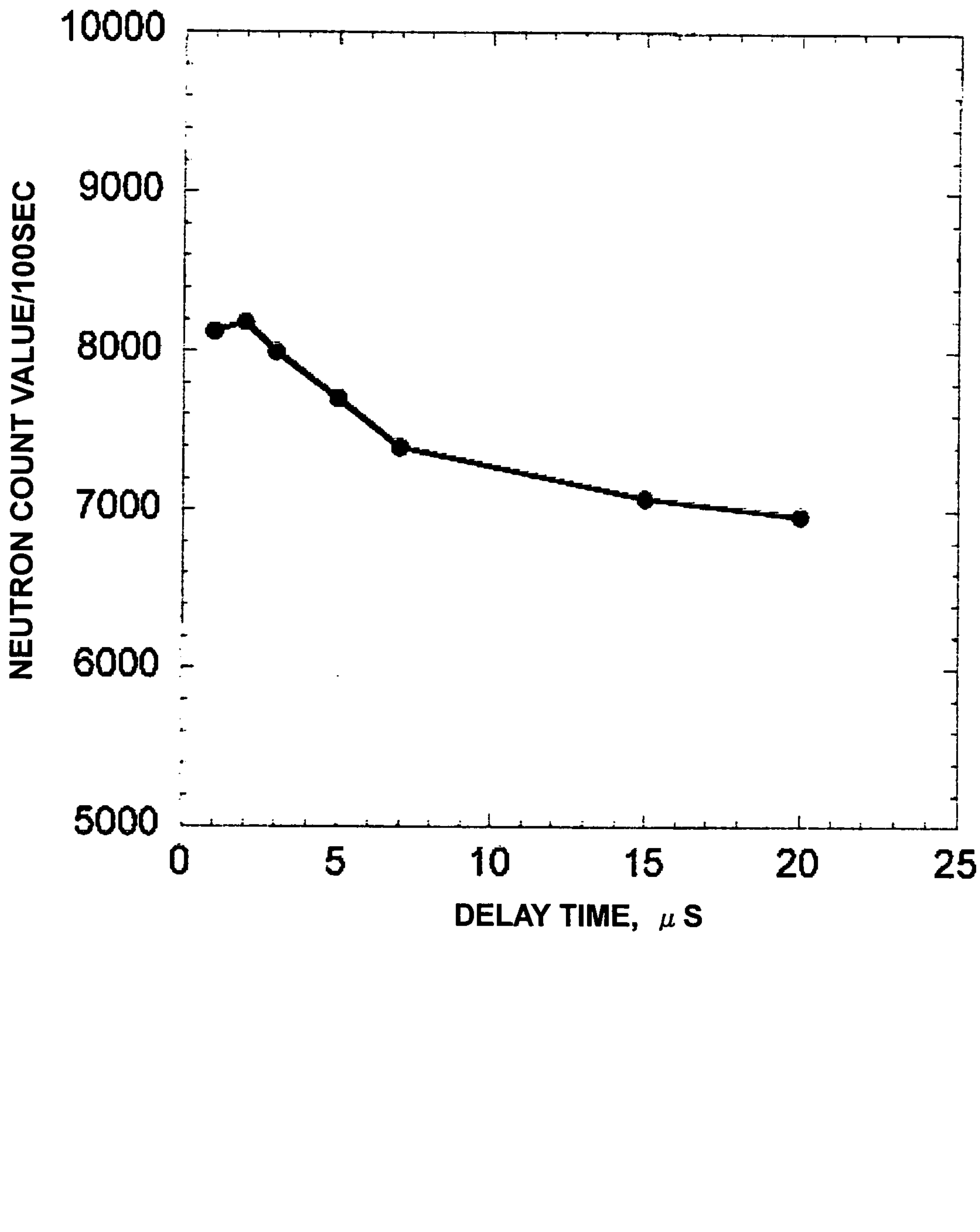

10000
9000
8000
7000
6000
5000
NEUTRON COUNT VALUE/100SEC
0
5
10
15
20
25
DELAY TIME, μS

FIG. 22

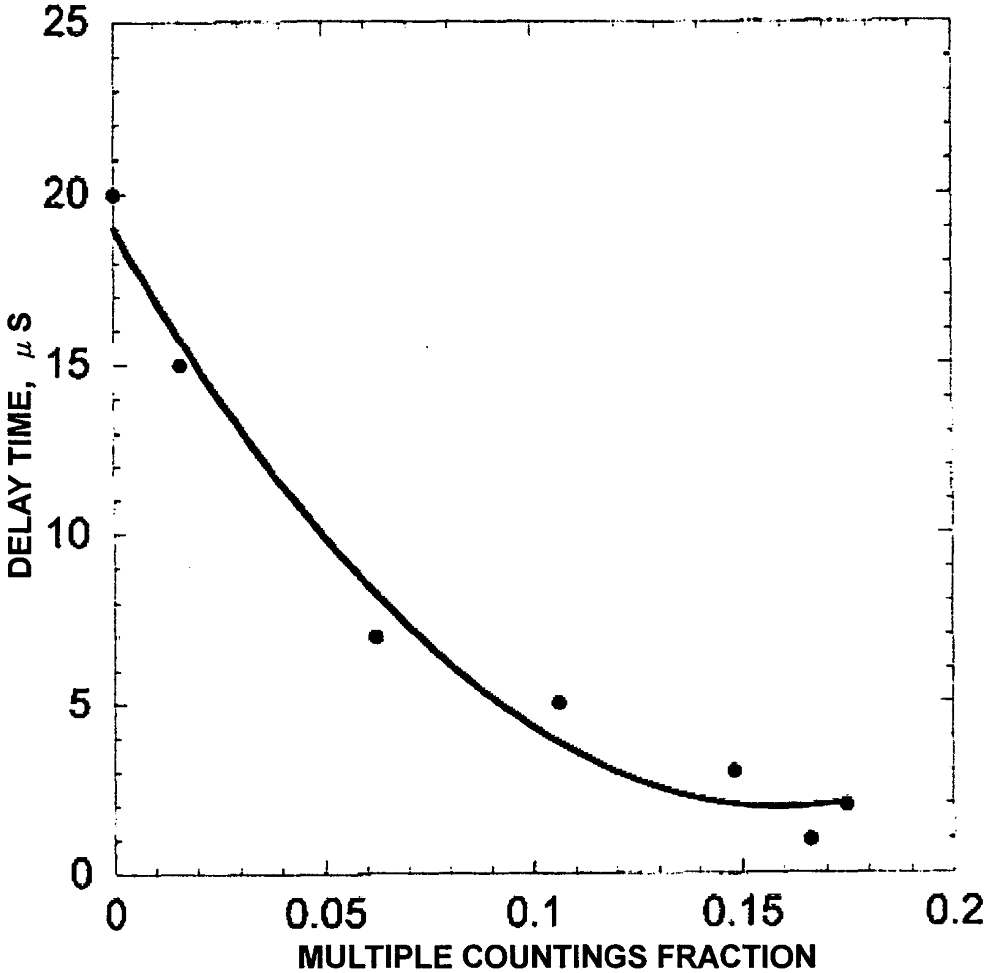

25
20
15
10
5
0
DELAY TIME, μS
0
0.05
0.1
0.15
0.2
MULTIPLE COUNTINGS FRACTION

FIG. 23

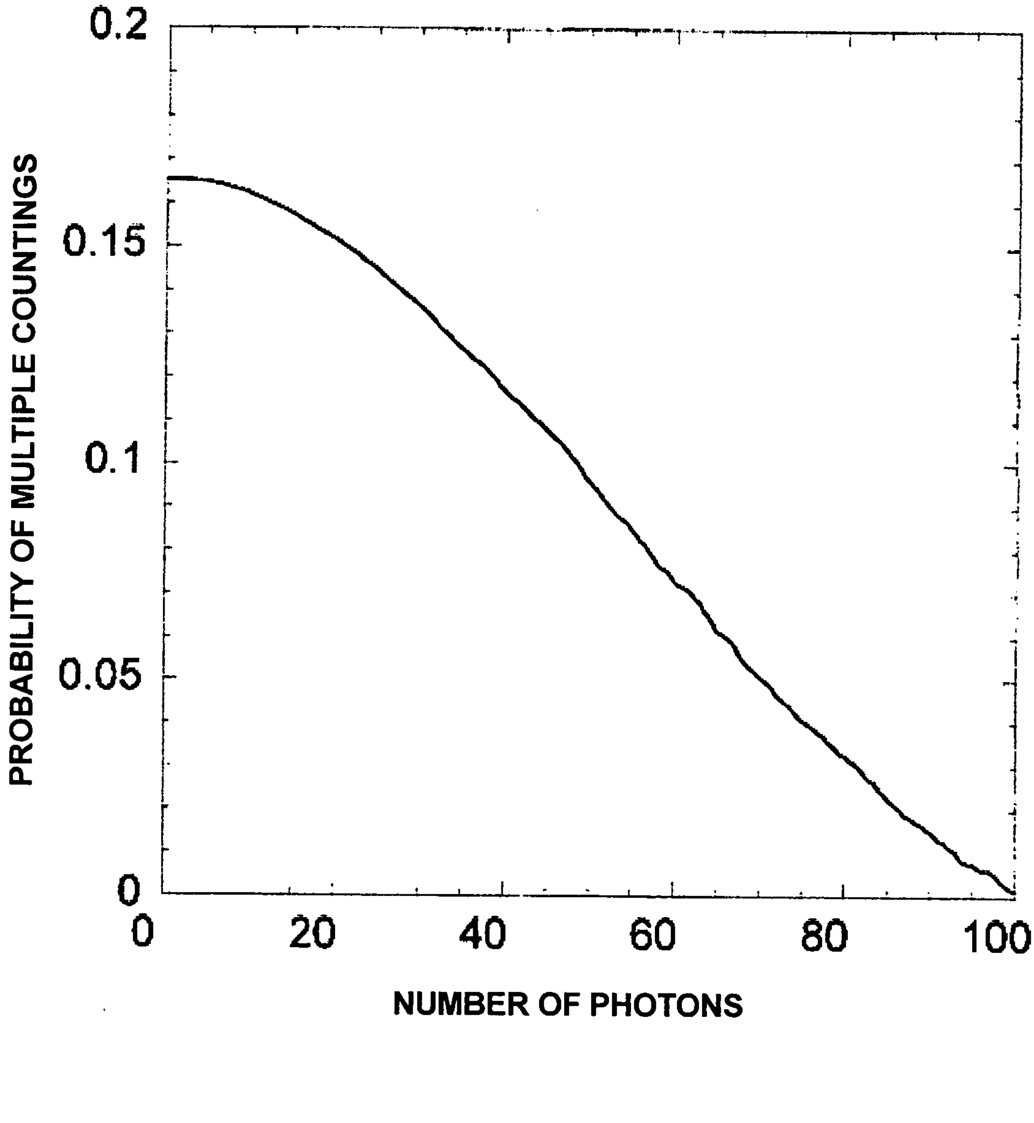

PROBABILITY OF MULTIPLE COUNTINGS
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
NUMBER OF PHOTONS

FIG. 24

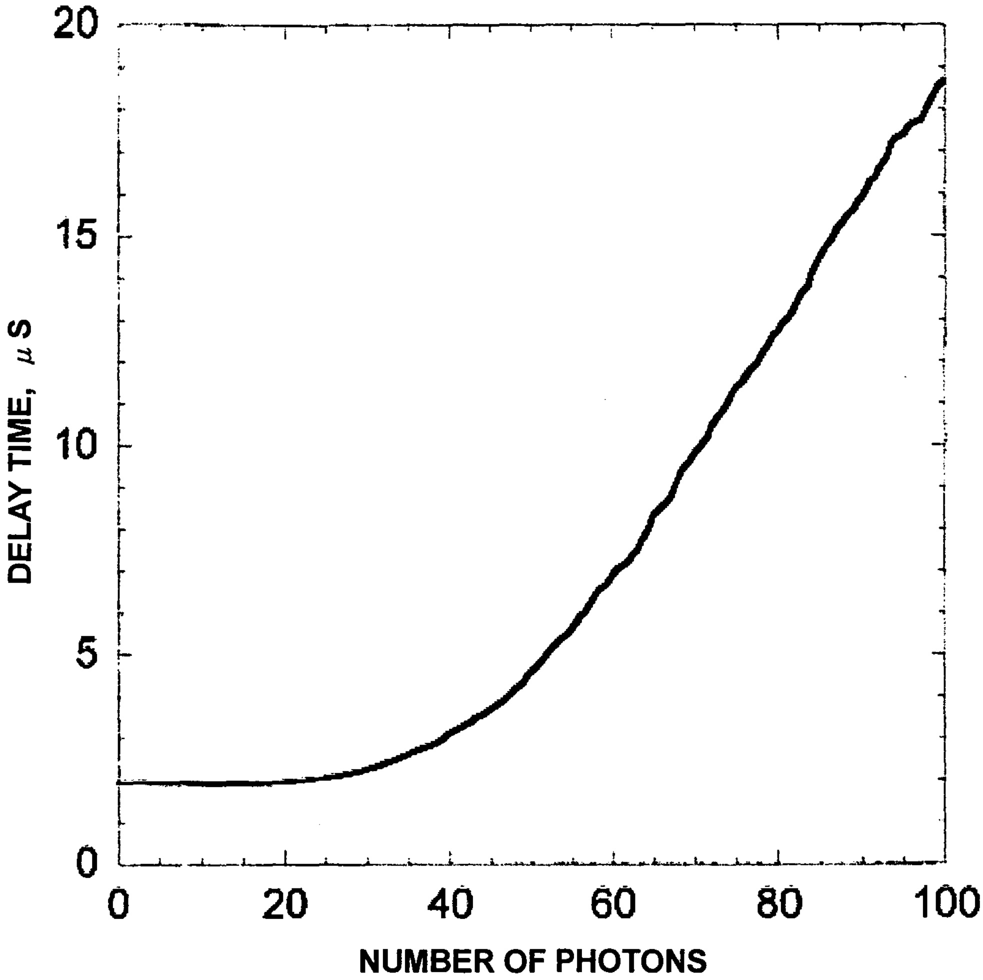


FIG. 25

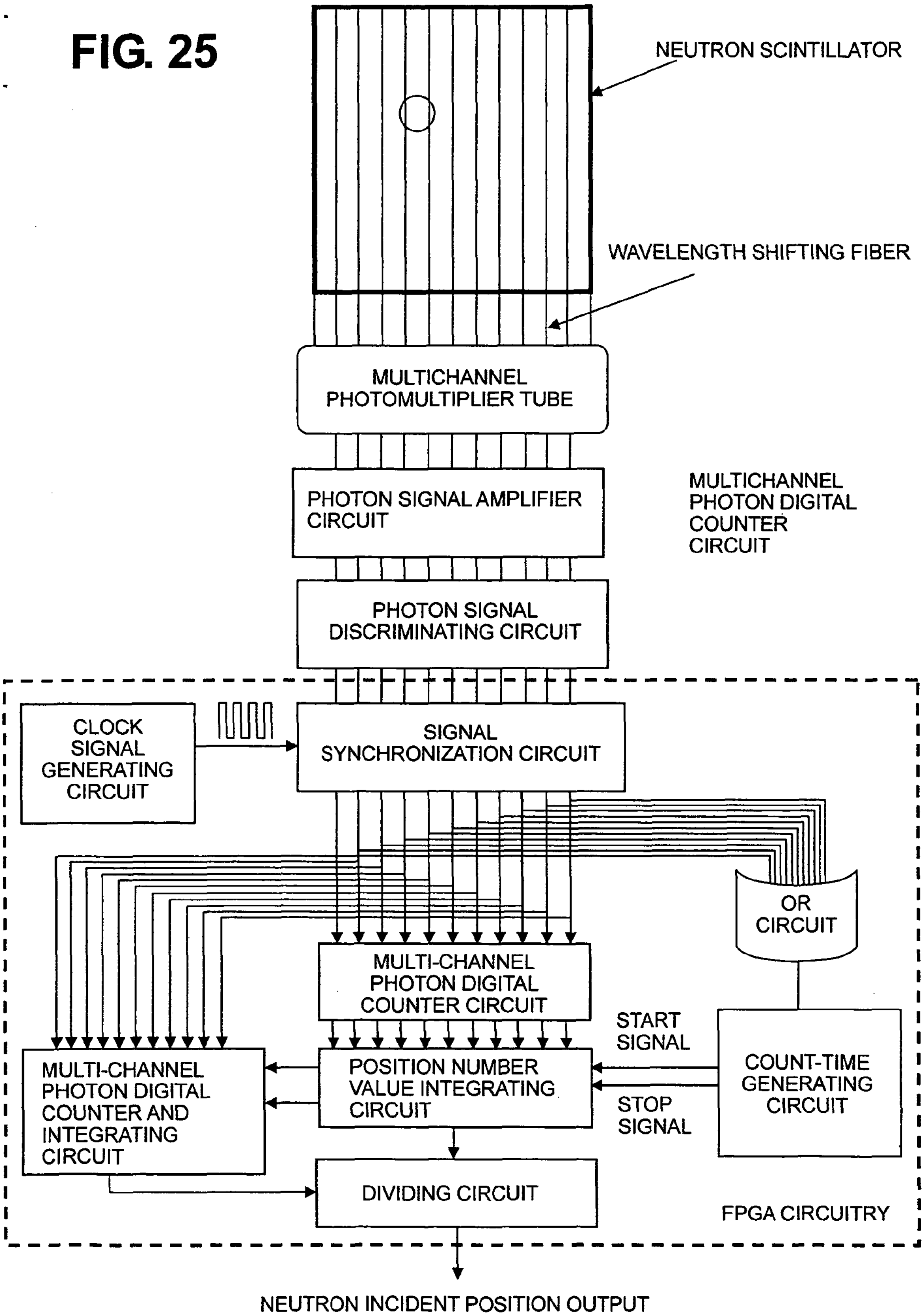

NEUTRON SCINTILLATOR
WAVELENGTH SHIFTING FIBER
MULTICHANNEL PHOTOMULTIPLIER TUBE
PHOTON SIGNAL AMPLIFIER CIRCUIT
MULTICHANNEL PHOTON DIGITAL COUNTER CIRCUIT
PHOTON SIGNAL DISCRIMINATING CIRCUIT
CLOCK SIGNAL GENERATING CIRCUIT
SIGNAL SYNCHRONIZATION CIRCUIT
OR CIRCUIT
MULTI-CHANNEL PHOTON DIGITAL COUNTER CIRCUIT
START SIGNAL
MULTI-CHANNEL PHOTON DIGITAL COUNTER AND INTEGRATING CIRCUIT
POSITION NUMBER VALUE INTEGRATING CIRCUIT
COUNT-TIME GENERATING CIRCUIT
STOP SIGNAL
DIVIDING CIRCUIT
FPGA CIRCUITRY
NEUTRON INCIDENT POSITION OUTPUT

FIG. 26

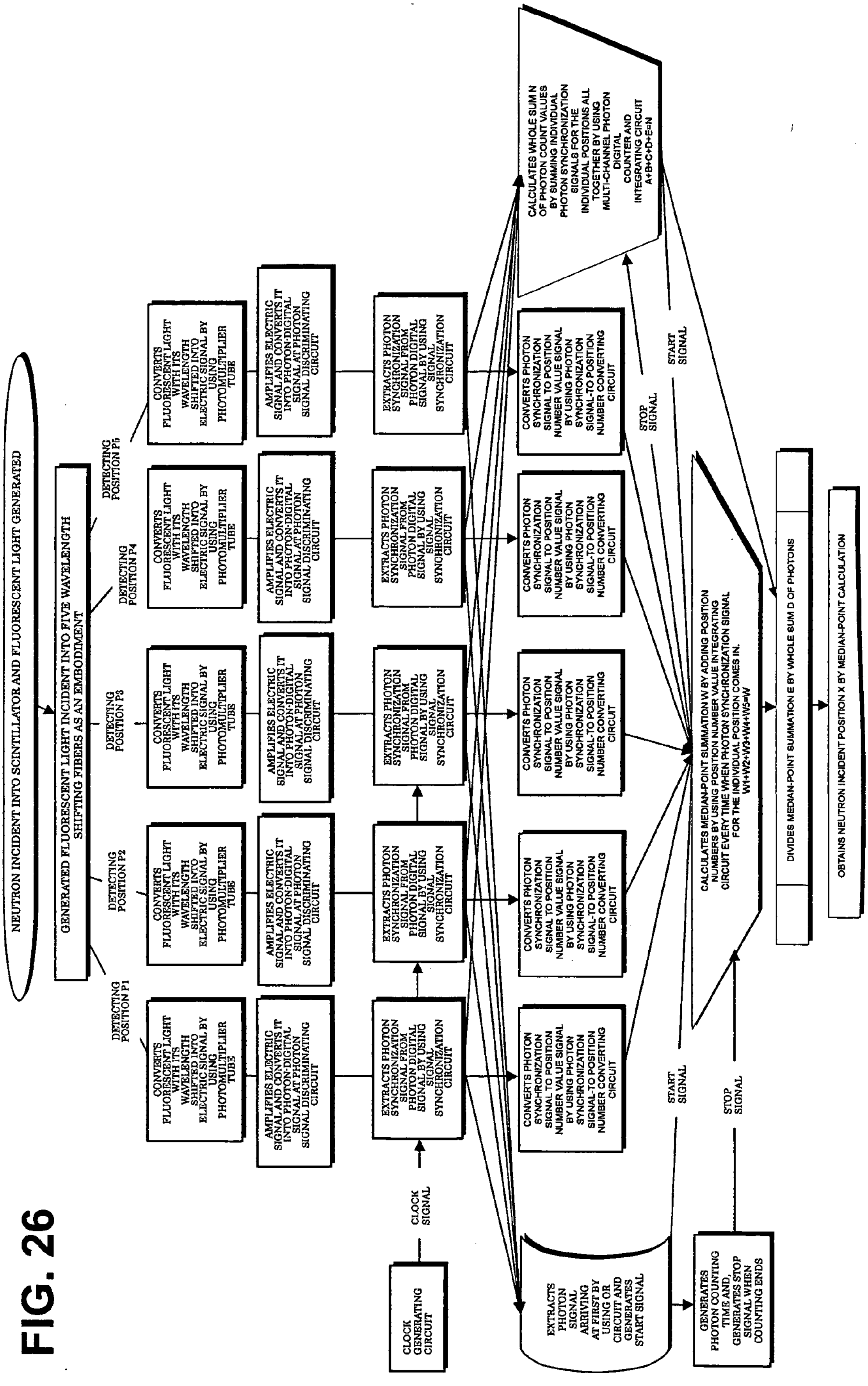

NEUTRON INCIDENT INTO SCINTILLATOR AND FLUORESCENT LIGHT GENERATED
GENERATED FLUORESCENT LIGHT INCIDENT INTO FIVE WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
DETECTING POSITION P1
DETECTING POSITION P2
DETECTING POSITION P3
DETECTING POSITION P4
DETECTING POSITION P5
CONVERTS FLUORESCENT LIGHT WITH ITS WAVELENGTH SHIFTED INTO ELECTRIC SIGNAL BY USING PHOTOMULTIPLIER TUBE
AMPLIFIES ELECTRIC SIGNAL AND CONVERTS IT INTO PHOTON-DIGITAL SIGNAL AT PHOTON SIGNAL DISCRIMINATING CIRCUIT
EXTRACTS PHOTON SYNCHRONIZATION SIGNAL FROM PHOTON DIGITAL SIGNAL BY USING SIGNAL SYNCHRONIZATION CIRCUIT
CONVERTS PHOTON SYNCHRONIZATION SIGNAL TO POSITION NUMBER VALUE SIGNAL BY USING PHOTON SYNCHRONIZATION SIGNAL-TO POSITION NUMBER CONVERTING CIRCUIT
CLOCK GENERATING CIRCUIT
CLOCK SIGNAL
EXTRACTS PHOTON SIGNAL ARRIVING AT FIRST BY USING OR CIRCUIT AND GENERATES START SIGNAL
GENERATES PHOTON COUNTING TIME AND, GENERATES STOP SIGNAL WHEN COUNTING ENDS
START SIGNAL
STOP SIGNAL
CALCULATES MEDIAN-POINT SUMMATION W BY ADDING POSITION NUMBERS BY USING POSITION NUMBER VALUE INTEGRATING CIRCUIT EVERY TIME WHEN PHOTON SYNCHRONIZATION SIGNAL FOR THE INDIVIDUAL POSITION COMES IN. W1+W2+W3+W4+W5=W
CALCULATES WHOLE SUM N OF PHOTON COUNT VALUES BY SUMMING INDIVIDUAL PHOTON SYNCHRONIZATION SIGNALS FOR THE INDIVIDUAL POSITIONS ALL TOGETHER BY USING MULTI-CHANNEL PHOTON DIGITAL COUNTER AND INTEGRATING CIRCUIT A+B+C+D+E=N
DIVIDES MEDIAN-POINT SUMMATION E BY WHOLE SUM D OF PHOTONS
OBTAINS NEUTRON INCIDENT POSITION X BY MEDIAN-POINT CALCULATION

FIG. 27

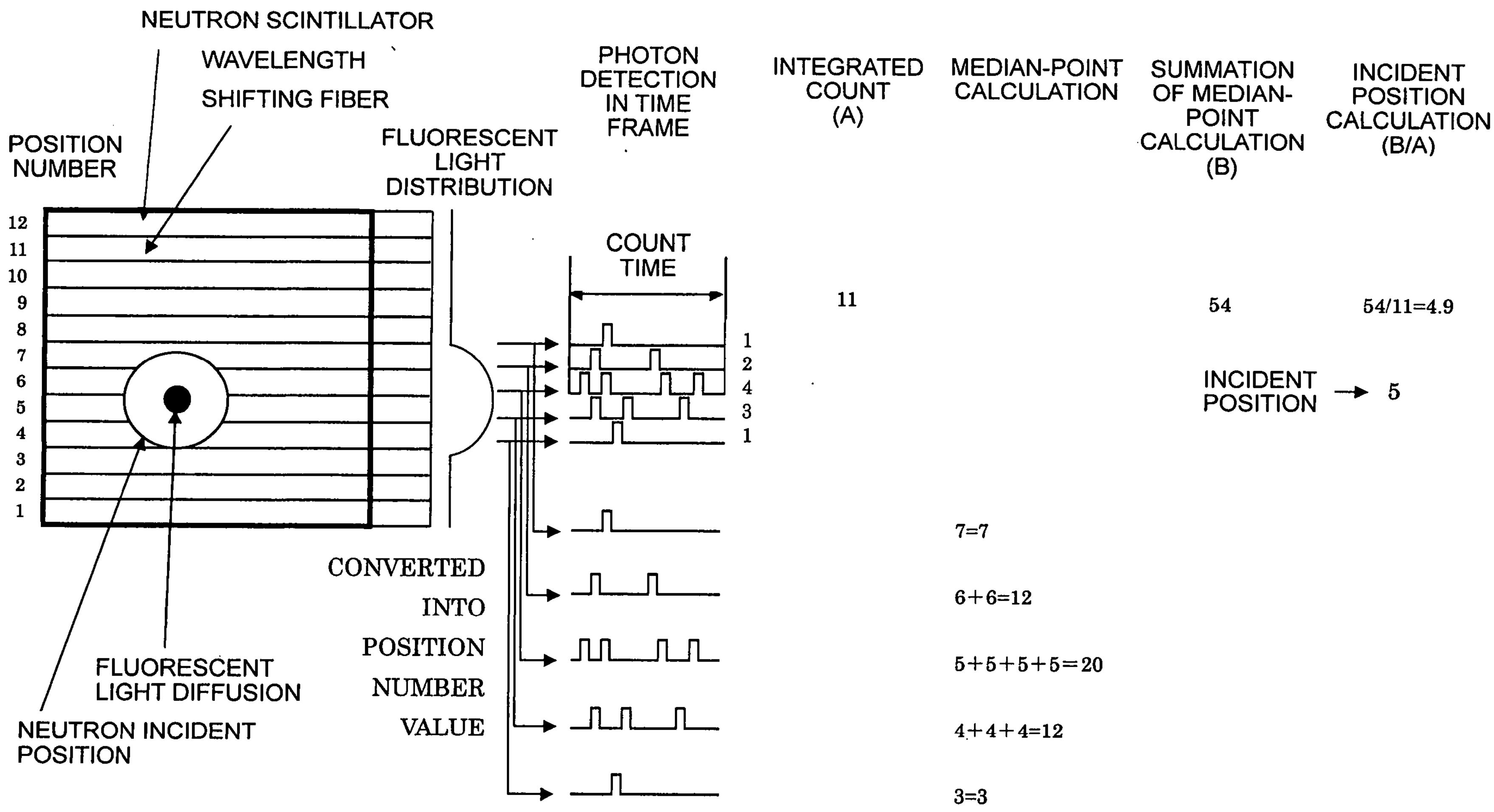

NEUTRON SCINTILLATOR
WAVELENGTH SHIFTING FIBER
POSITION NUMBER
12
11
10
9
8
7
6
5
4
3
2
1
FLUORESCENT LIGHT DISTRIBUTION
FLUORESCENT LIGHT DIFFUSION
NEUTRON INCIDENT POSITION
CONVERTED INTO POSITION NUMBER VALUE
PHOTON DETECTION IN TIME FRAME
COUNT TIME
1
2
4
3
1
INTEGRATED COUNT (A)
11
MEDIAN-POINT CALCULATION
7=7
6+6=12
5+5+5+5=20
4+4+4=12
3=3
SUMMATION OF MEDIAN-POINT CALCULATION (B)
54
INCIDENT POSITION CALCULATION (B/A)
54/11=4.9
INCIDENT POSITION
5

FIG. 28

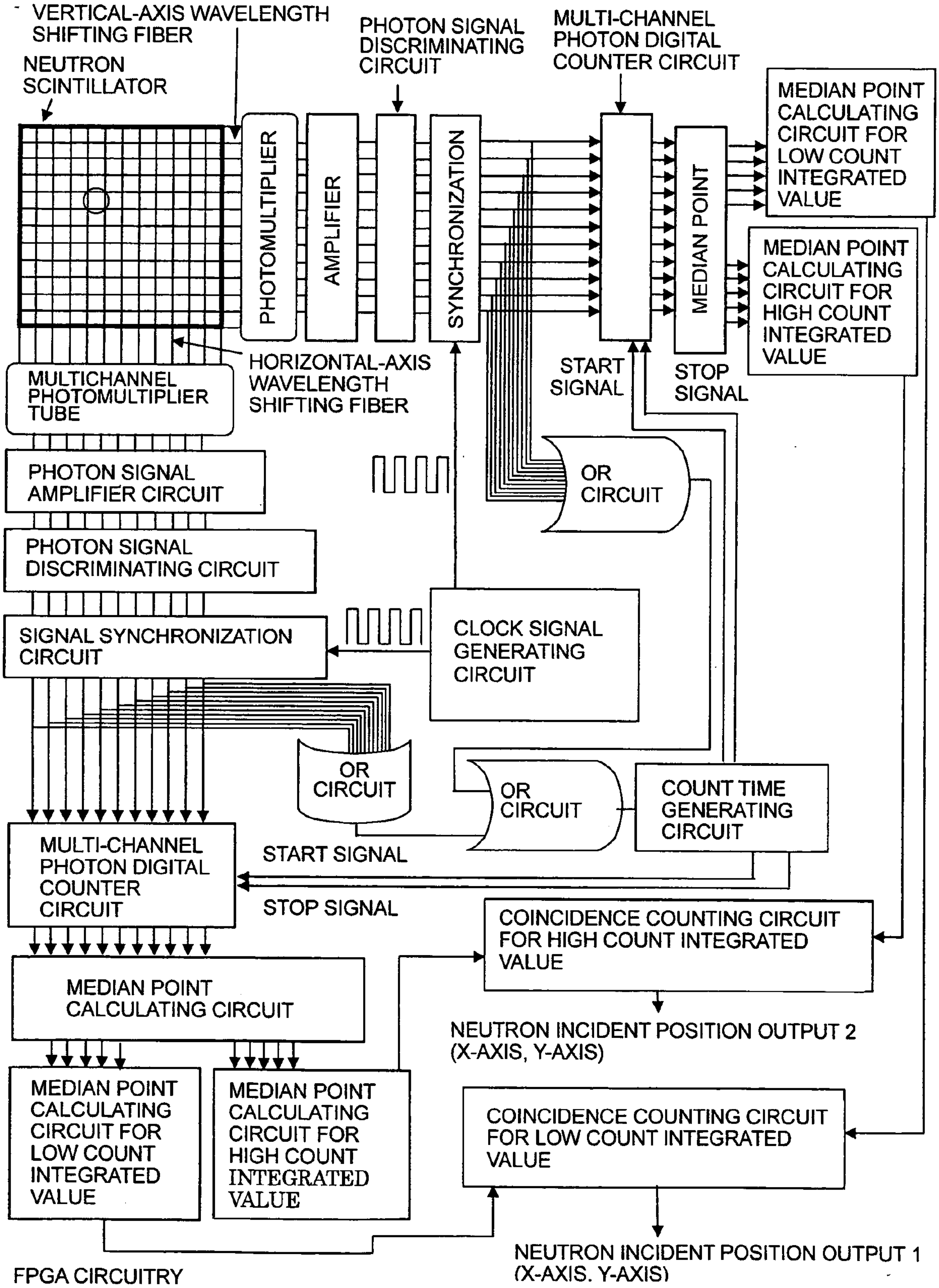

VERTICAL-AXIS WAVELENGTH SHIFTING FIBER
NEUTRON SCINTILLATOR
PHOTON SIGNAL DISCRIMINATING CIRCUIT
MULTI-CHANNEL PHOTON DIGITAL COUNTER CIRCUIT
MEDIAN POINT CALCULATING CIRCUIT FOR LOW COUNT INTEGRATED VALUE
PHOTOMULTIPLIER
AMPLIFIER
SYNCHRONIZATION
MEDIAN POINT
MEDIAN POINT CALCULATING CIRCUIT FOR HIGH COUNT INTEGRATED VALUE
HORIZONTAL-AXIS WAVELENGTH SHIFTING FIBER
MULTICHANNEL PHOTOMULTIPLIER TUBE
START SIGNAL
STOP SIGNAL
PHOTON SIGNAL AMPLIFIER CIRCUIT
OR CIRCUIT
PHOTON SIGNAL DISCRIMINATING CIRCUIT
SIGNAL SYNCHRONIZATION CIRCUIT
CLOCK SIGNAL GENERATING CIRCUIT
OR CIRCUIT
OR CIRCUIT
COUNT TIME GENERATING CIRCUIT
MULTI-CHANNEL PHOTON DIGITAL COUNTER CIRCUIT
START SIGNAL
STOP SIGNAL
COINCIDENCE COUNTING CIRCUIT FOR HIGH COUNT INTEGRATED VALUE
MEDIAN POINT CALCULATING CIRCUIT
NEUTRON INCIDENT POSITION OUTPUT 2 (X-AXIS, Y-AXIS)
MEDIAN POINT CALCULATING CIRCUIT FOR LOW COUNT INTEGRATED VALUE
MEDIAN POINT CALCULATING CIRCUIT FOR HIGH COUNT INTEGRATED VALUE
COINCIDENCE COUNTING CIRCUIT FOR LOW COUNT INTEGRATED VALUE
NEUTRON INCIDENT POSITION OUTPUT 1 (X-AXIS. Y-AXIS)
FPGA CIRCUITRY

FIG. 29A

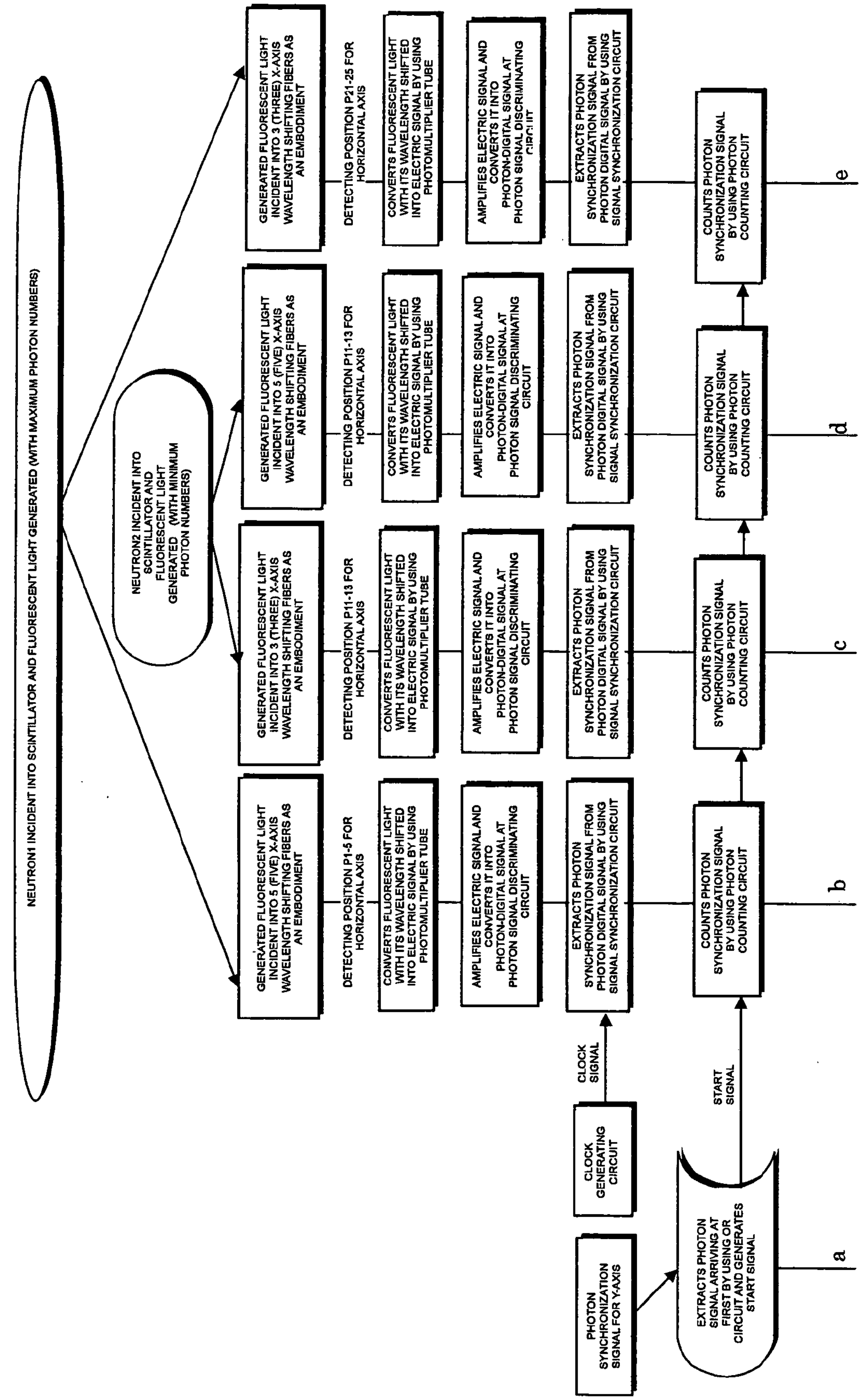
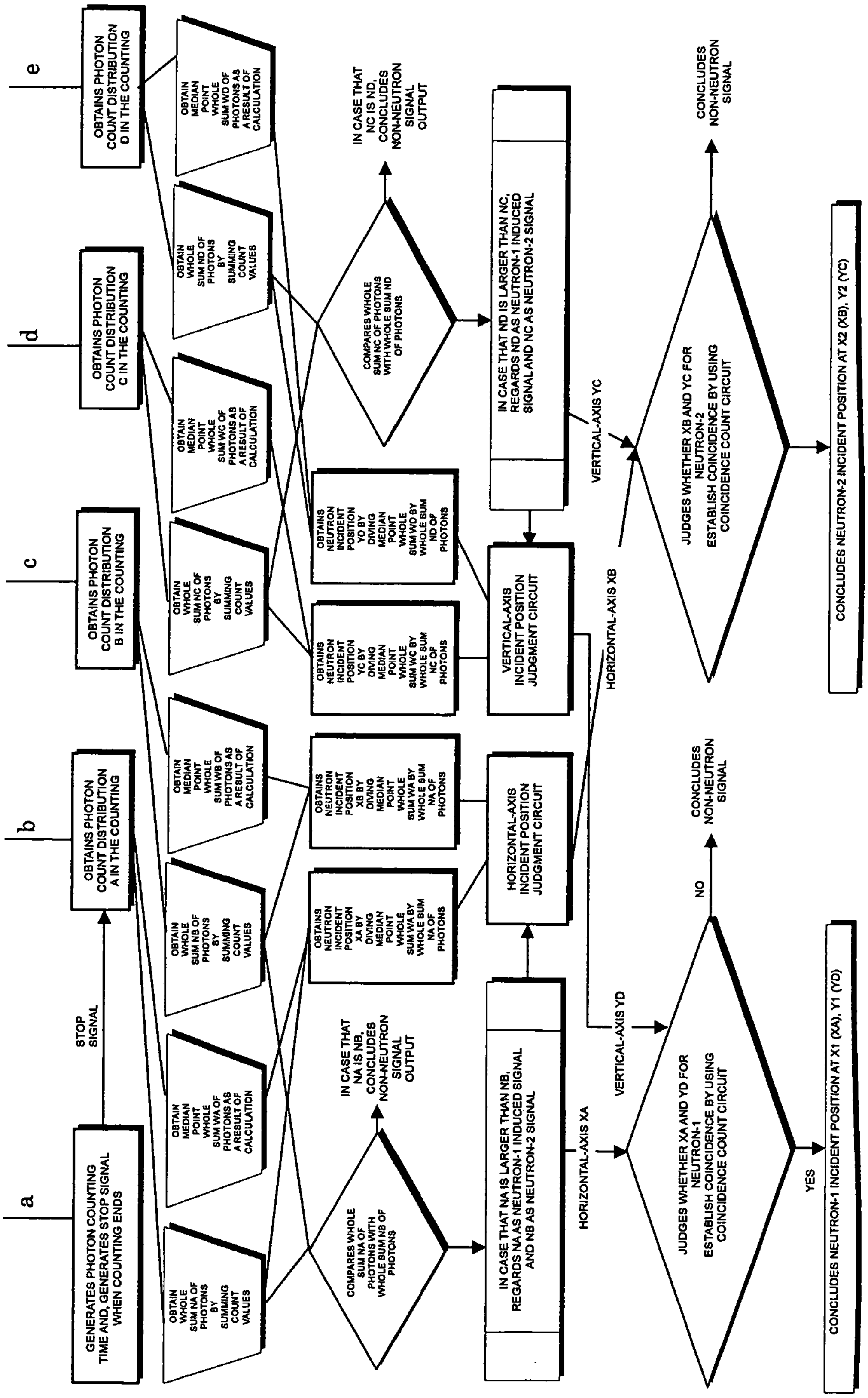

NEUTRON1 INCIDENT INTO SCINTILLATOR AND FLUORESCENT LIGHT GENERATED (WITH MAXIMUM PHOTON NUMBERS)
NEUTRON2 INCIDENT INTO SCINTILLATOR AND FLUORESCENT LIGHT GENERATED (WITH MINIMUM PHOTON NUMBERS)
GENERATED FLUORESCENT LIGHT INCIDENT INTO 5 (FIVE) X-AXIS WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
GENERATED FLUORESCENT LIGHT INCIDENT INTO 3 (THREE) X-AXIS WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
GENERATED FLUORESCENT LIGHT INCIDENT INTO 5 (FIVE) X-AXIS WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
GENERATED FLUORESCENT LIGHT INCIDENT INTO 3 (THREE) X-AXIS WAVELENGTH SHIFTING FIBERS AS AN EMBODIMENT
DETECTING POSITION P1-5 FOR HORIZONTAL AXIS
DETECTING POSITION P11-13 FOR HORIZONTAL AXIS
DETECTING POSITION P11-13 FOR HORIZONTAL AXIS
DETECTING POSITION P21-25 FOR HORIZONTAL AXIS
CONVERTS FLUORESCENT LIGHT WITH ITS WAVELENGTH SHIFTED INTO ELECTRIC SIGNAL BY USING PHOTOMULTIPLIER TUBE
AMPLIFIES ELECTRIC SIGNAL AND CONVERTS IT INTO PHOTON-DIGITAL SIGNAL AT PHOTON SIGNAL DISCRIMINATING CIRCUIT
EXTRACTS PHOTON SYNCHRONIZATION SIGNAL FROM PHOTON DIGITAL SIGNAL BY USING SIGNAL SYNCHRONIZATION CIRCUIT
COUNTS PHOTON SYNCHRONIZATION SIGNAL BY USING PHOTON COUNTING CIRCUIT
CLOCK SIGNAL
CLOCK GENERATING CIRCUIT
START SIGNAL
PHOTON SYNCHRONIZATION SIGNAL FOR Y-AXIS
EXTRACTS PHOTON SIGNAL ARRIVING AT FIRST BY USING OR CIRCUIT AND GENERATES START SIGNAL
a
b
c
d
e

FIG. 29B


a
b
c
d
e
GENERATES PHOTON COUNTING TIME AND, GENERATES STOP SIGNAL WHEN COUNTING ENDS
STOP SIGNAL
OBTAINS PHOTON COUNT DISTRIBUTION A IN THE COUNTING
OBTAINS PHOTON COUNT DISTRIBUTION B IN THE COUNTING
OBTAINS PHOTON COUNT DISTRIBUTION C IN THE COUNTING
OBTAINS PHOTON COUNT DISTRIBUTION D IN THE COUNTING
IN CASE THAT NA IS NB, CONCLUDES NON-NEUTRON SIGNAL OUTPUT
IN CASE THAT NC IS ND, CONCLUDES NON-NEUTRON SIGNAL OUTPUT
IN CASE THAT NA IS LARGER THAN NB, REGARDS NA AS NEUTRON-1 INDUCED SIGNAL AND NB AS NEUTRON-2 SIGNAL
IN CASE THAT ND IS LARGER THAN NC, REGARDS ND AS NEUTRON-1 INDUCED SIGNAL AND NC AS NEUTRON-2 SIGNAL
HORIZONTAL-AXIS INCIDENT POSITION JUDGMENT CIRCUIT
VERTICAL-AXIS INCIDENT POSITION JUDGMENT CIRCUIT
HORIZONTAL-AXIS XA
VERTICAL-AXIS YD
HORIZONTAL-AXIS XB
VERTICAL-AXIS YC
JUDGES WHETHER XA AND YD FOR NEUTRON-1 ESTABLISH COINCIDENCE BY USING COINCIDENCE COUNT CIRCUIT
JUDGES WHETHER XB AND YC FOR NEUTRON-2 ESTABLISH COINCIDENCE BY USING COINCIDENCE COUNT CIRCUIT
NO
YES
CONCLUDES NON-NEUTRON SIGNAL
CONCLUDES NON-NEUTRON SIGNAL
CONCLUDES NEUTRON-1 INCIDENT POSITION AT X1 (XA), Y1 (YD)
CONCLUDES NEUTRON-2 INCIDENT POSITION AT X2 (XB), Y2 (YC)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2000187007 A **[0004]**
- JP 2002071816 A **[0004]**
- JP 2009008695 A **[0004]**
- US 20070096028 A1 **[0006]**

Non-patent literature cited in the description

- *Nucl. Instr. and Meth.,* 1999, vol. A439, 311-320 **[0005]**
- *Nucl. Instr. and Meth.,* 2004, vol. A529, 254-259 **[0006]**
- *Nucl. Instr. and Meth.,* 2009, vol. A600, 217-219 **[0006]**