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(54) EMISSION TOMOGRAPHY SYSTEM

(72) Phelps, Michael E.;
Hoffman, Edward J.;
Williams, Charles W.;
Burgiss, Samuel G.,
U.S.A.

(73) Granted to Ortec Incorporated
U.S.A.

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ABSTRACT OF THE DISCLOSURE

A data acquisition system for incorporation in a positron emission tomograph system to allow the removal of random coincidence events on a true "line-of-response" basis with substantially "dead-timeless" operation. The positron emission tomograph provides sectional images on the human body following the administration of radiopharmaceuticals labeled with positron emitting radionuclides.

BACKGROUND OF THE INVENTION

This invention relates in general to positron emission tomography and more particularly to a data acquisition system which allows a highly accurate determination of the number of background signals due to random coincidences and provides for the subraction of this background from the total number of detected coincidences either on a substantially instantaneous basis or on a delayed basis. Input circuits are provided to allow for substantially "dead-timeless" operation.

Computerized positron emission tomography is a method of providing visual images along a plane or planes taken through the interior of a patient's body. In this method, positron emitting radionuclides are administered to the patient. The positron emitting nuclides, such as for example Carbon-11, Nitrogen-13, Oxygen-15, Fluorine-18, and Gallium-68, emit positrons which travel only a few millimeters before they interact with the matter of the patient's body in a process called positron annihilation. In this process the positron interacts with an electron and their mass is converted into the energy of two photons, emitted at substantially 180° with respect to one another, each of the photons having an energy of approximately 511 Kev. A positron annihilation is detected by determining the time coincidence of two photons sensed at detectors oriented 180° apart. By constructing an array of a number of detectors surrounding the area to be examined and detecting coincidences between photons sensed at pairs of these detectors located on either end of straight line paths, the patterns of location of the positron emitting radionuclides can be constructed by a computer.

A number of systems utilizing this technology have been developed in the art. Some of these systems employ detectors arranged to determine positron interactions only on a single tomographic plane, while others utilize arrays of detectors positioned on multiple planes. Most usually, a reconstruction of the positron annihilation positions is carried out by means of a programmed computer responding to the number of photons detected in coincidence at straight-line separated detectors over a period of time. Such tomographic diagnostic systems are described in the following references.

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In order to improve the accuracy of the measurements, it is necessary to determine as accurately as possible the number of accidental coincidences that occur between straight-line separated detectors. For any given resolution period, which has been set as the coincidence resolving time, there will occur a number of photon coincidences due only to random distribution of photons and not to true events, where true events are defined as positron annihilation for which both ~~electrons~~ photons are detected by the detection array. One method of determining this random background has been to shift the system in and out of coincidence and thereby measure the number of total and random coincidences occurring and thereafter subtract the background so determined from the total of coincidence counts recorded. Utilizing this method of background determination, a considerable period of time, which otherwise would be available for measurement of the true events is utilized in determining the background. The more this time is increased, the more accurate is the background determination, but the time available for "source count" is decreased with either a requirement for increased radiation intensity or an acceptance of decreased accuracy. If, on the other hand, the background measurement time is decreased with a consequent inaccuracy in determination of this component, then the difference between the total counts and the background count becomes an inaccurate number. But, it is this difference which is representative of the true events being measured. Various attempts have been made to "sandwich" measurements such that background counts are first determined, then total counts, then background counts in a technique which also compensates for time variation in the background counts. Nonetheless, the time spent measuring the background necessarily is time not spent measuring the source and hence decreases the accuracy below that which could be achievable for the total time of measurement.

Also, since the measurements are not made simultaneously, errors such as patient movement may further distort the data.

Another approach has been to determine the coincidences occurring outside the field of view of the positron emission system, but surrounding the detectors which define that field of view, while simultaneously measuring all coincidences within the field of view. By simultaneously measuring coincidences occurring in this outer field, and utilizing these as the background measurement, the background counts are determined at the same time that the total source plus background measurement is being made within the positron field of view. The resultant background count is supplied to a memory, as is the total count, where they are subsequently provided to a suitably programmed computer for subtraction. This system, while enjoying the advantage of making efficient utilization of the measuring period, undergoes the disadvantage that the background determination is made outside the field of view and to the extent that there is a spatial variation in photon background, this results in lack of accuracy in the measurement. It may be particularly significant, in that there may be photon background related specifically to the radiation in the field of view.

SUMMARY OF THE INVENTION

Broadly speaking, in the present invention, a positron emission tomographic system is provided, in which the random photon coincidence background is determined for the lines of sight along which the positron annihilations are located. The circuitry is arranged so that this background may be subtracted substantially simulataneouly from the total photon coincidence measurement, or may be stored in a temporary memory for latter subtraction. In this system, an appropriate coincidence resolution time, for example, 12.5 nanoseconds, is selected and coincidences of photons detected at 180° opposed detectors within this time resolution are recorded as the overall coincidence count. It is recognized that this count includes both photons which are in time coincidence because they are produced as a result of a positron annihilation and photons which occur randomly, and therefore are accidentally in time coincidence with one another. Thus, this total count includes a source (true events) count plus a background (random coincidences) count.

In this invention, the background count is determined by measuring photons detected at these same sets of photon detectors and employing the same coincidence resolution period, where the signals from one set of detectors are passed through a delay longer in time than this resolution period. The coincidences thus determined cannot be true events since they are not simultaneous. Thus, these delayed coincidences are a suitable measure of the random coincidence level produced by photons within the lines of sight measurement field.

The background signal derived as described above can either be directly subtracted from the source plus background count as the measurement is going on by utilizing an up-down counter arrangement, or this subtraction can be carried out after the measurement is completed by storing both the source plus background counts and the background counts themselves in memory for later computation. In this system the counts acquired in the manner described above are provided to a programmed computer for reconstruction of the image of the area from which the positrons were emitted and for presentation of the image in conventional fashion for computer assisted tomographic displays.

One problem encountered with system design in computer assisted emission tomographic equipment of this type lies in the loss of signals due to dead time in the circuitry. Since the positron emissions are produced as a result of radioactive decay, they are characterized by a random distribution in time and for any given strength of the radionuclide, the minimum separation time between detected events is system dependent and may be much shorter than the average separation time between these same events. In order not to lose source counts, then, because of their occurring in a dead time, the data acquisition circuitry must have a high speed resolution time matching these minimum separations. In the system described herein, this problem is overcome by the use of a fast FIFO buffer in which the input data acquisition time resolution is characterized by a short resolution to allow for detection of very closely spaced events, while the output data transfer time is fixed by the memory transfer rate. Thus the circuitry to which these signals are transferred may be characterized by much lower resolution time without loss of data due to dead time for high burst rates.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Fig. 1 is an illustration generally in diagrammatic form of a data acquisition system in accordance with the principles of this invention;

Fig. 2 is an illustration in block diagrammatic form of the discriminator/coincidence portions of the system illustrated in Fig. 1;

Fig. 3 is a block diagram of the input processor portion of the system illustrated in Fig. 1; and

Fig. 4 is an illustration in more detail of a block diagram of portions of the processor illustrated in Fig. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The overall configuration of an emission computerized tomographic system employing annihilation coincidence detection is illustrated in Fig. 1. The overall system includes generally, three subsystems, a detector subsystem 25, a data acquisition subsystem 26, and a computer subsystem 27. In this invention the emphasis is on the data acquisition subsystem 26 and its specific interaction with the detector subsystem 25. As previously indicated the purpose of the system illustrated in Fig. 1 is to determine the location and intensity of positron emitting radionuclides within a patient's body. The basis for this determination is the detection of photons emitted simultaneously at 180^{o} to each other as a result of positron annihilation.

In Fig. 1, which is only one of the configurations to which this patent applies, the field of view of the detection system for detecting the presence of positrons by means of their annihilation is indicated by the circular outline 30. Surrounding the field of view 30 is an array of photon detectors (PMT) arranged in banks A through F. Each bank includes eleven detectors, typically NaI(Tl). The output from each of these detectors responds to a photon incident upon its sensing area by producing a flash of light which is converted into an electrical signal. The signals from the detectors are transmitted to the data acquisition subsystem 26, which serves to time discriminate each event in each one of the detectors and to determine the coincidence relationship of the detected events in opposing banks. This provides to the computer not only a quantitative measure of the number of coincidences between each pair of detectors in the array but also and at the same time the number of those coincidences which are due to random events. The computer can then determine for each pair of detectors what the true coincidence count rate due to positron annihilations is. Alternatively, this function can be performed within the data acquisition subsystem 26, providing the net or true count to the computer in substantially real time. In both arrangements, the computer performs the functions of reconstructing the image in the field of view of the detectors in a conventional fashion for such systems.

THE DETECTOR SUBSYSTEM 25

As above described, for this system, there are 66 NaI (Tl) detectors located in banks of eleven detectors per bank. Each of the detectors is mounted in an individual lead shield designed to protect it from radiation originating outside of the field of view. The field of view is generally indicated at 30 in Fig. 1. A suitable distance between opposing banks in this detector array is 100 cm. Under these circumstances, the field of view 30 would be a circular area having a diameter of approximately 50 cm. Each of the detectors is individually shielded in a lead block. A lead shadow shield which may be placed in front of each bank of detectors has individual rectangular holes to allow each detector a clear line of sight to all of the detectors in the opposing bank only. The entire array of detectors is placed between two lead discs of generally annular shape with an inner diameter of 60 cm and an outer diameter extending beyond the sensitive portions of the individual detectors. Typically each of these lead discs may be 1.5 inches thick. In one suitable configuration, the NaI(Tl) detectors have a diameter of 3.8 cm and a length of 7.5 cm. With holes in the shadow shields of 2.3 or 1.5 cm width by 3.8 cm in axial direction, an average detector pair resolution of about 1.1 and 0.8 cm full width half maximum respectively is obtained in the plane. With this configuration, there are 121 180^{o} lines of sight for each pair of banks, or 363 lines of sight overall. As above mentioned, in order to determine occurrence of a positron annihilation, coincidences must be detected between the simultaneously emitted photons which are 180^{o} with respect to one another. In the system described, it is necessary to determine coincidence of detected photons occurring at any one of the 363 paired detectors.

While a specific hexagonal planar array of detectors has been described, it should be understood that there are many other suitable geometries to which these claims apply, both in a single plane and in multiple planes. The basic requirement is that the field of view is defined by a plurality of detectors pairs separated by 180^{o}.

DATA ACQUISITION SUBSYSTEM

The data acquisition subsystem receives signals from each of the individual detectors and processes them to provide, as an output to the computer, a quantitative measure of the number of coincidences between each pair of detectors in the detector array, where the determination of coincidences is the simultaneous occurrence of detected signals within a specifically set coincidence resolution time. This system is also arranged to determine those coincidences which are attributable to true events and coincidences which are due to random photons occurring accidentally within the time resolution period set for determining coincidences. In one mode of operation, these accidental, or random, coincidences are immediately subtracted from the total number of coincidences to provide a measure of the true positron annihilation coincidences and it is only these latter signals for each pair of detectors which are transmitted to the computer.

In the data acquisition system illustrated in Fig. 1, the complete circuitry is illustrated only for the detector banks A and D. It will be understood that similar complete circuitry is provided for banks C and F, as one pair, and banks B and E as another pair. This circuitry, which is not shown, has its output illustrated in Fig. 1 as a twenty-four channel output from banks B and E and a twenty-four channel output from banks C and F.

As illustrated in the block diagram of the circuitry for the banks A and D, an eleven channel discriminator 40 provides eleven output data signals to input processor 45 and simultaneously provides an OR output line, which carries a signal, whenever any one of the eleven detectors in bank A has a signal on it, to coincidence circuits 47 and 49. Similarly, the output from each of the detectors in bank D is provided as an eleven signal input to a second eleven channel discriminator 42 which, in turn, provides an eleven channel output data signal to input processor 45 and an OR signal, indicating whenever any one of the eleven detectors in bank D has a signal on it, as the second input to coincidence circuit 49 and also through a time delay to the second input terminal of coincidence circuit 47. As indicated in Fig. 1, the output from the coincidence circuit 47 is provided as a random strobe signal to input processor 45, while the output from coincidence circuit 49 is provided as a total strobe signal to input processor 45.

Thus, for the pair of banks A and D there are eleven signals from the bank A discriminator 40, eleven signals from the bank D discriminator 42, one from the random strobe output of coincidence circuit 47, and one from the total strobe output of coincidence circuit 49. There are, then, a total of twenty-four signals for the bank pair A and D. Similarly, bank pair B and E and bank pair C and F each provide twenty-four signals to the input processor 45.

The overall operation of this sytem is one in which each photon detected at any one of the individual photomultipliers in any of the banks A through F results in an output signal which is amplified and sent to the eleven channel discriminator associated with the bank in which the photomultiplier is located. At the discriminator this analog signal undergoes energy discrimination to discriminate, for example, against photons of energy less than 100 Kev, and is converted to a logic pulse. These logic pulses are then provided directly to the input proccessor 45. Thus, the input processor 45 has eleven discrete data lines entering it from the discriminator circuit 40, a signal on any one of these lines being indicative of a photon detected at the corresponding detector. Each of the eleven channel discriminators also provides an OR output when any one of the photomultipliers in the bank is receiving a signal. OR outputs from opposing banks, such as for example banks A and D are fed to a coincidence circuit (coincidence circuit 49 in Fig. 1) which provides a TOTAL STROBE output signal whenever it receives OR signals from the two opposing banks within the coincidence time period. This time period is typically set to have a coincidence time period of 12.5 nanoseconds.

The OR gate from the eleven channel discriminator 42 for bank D is also coupled to a second conincidence circuit 47 through a time delay circuit 50, the other input to that same coincidence circuit 47 being provided directly from the output of the eleven channel discriminator 40 on the opposing bank A of detectors. Typically the length of this delay might be 40 nano-seconds.

Coincidence circuit 47 determines time coincidence between the signals from discriminator circuit 40, indicating detection of a photon in one of the sensors in bank A and the delayed OR signal from discriminator 42 indicating the detection of a signal from one of the photomultipliers in bank D, a time delay previously. This coincidence cannot be attributable to positron annihilation pulses, since there occur simultaneously in real time. These delayed coincidences provide a suitable measure of random coincidences between photons in the field of view 30 of the detector array. Thus, the output signal from coincidence circuit 47 represents the accidental or random coincidence back-ground rate, while that from the non-delayed coincidence circuit 49 represents the total or, true annihilation photon coincidences plus the random coincidences.

In Fig. 2, there is illustrated a further definition in block diagrammatic form of the discriminator coincidence circuit arrangement. Each of the eleven outputs from the detector bank is fed through its preamplifier 60 to a constant fraction discri-minator 62. The constant fraction discriminator has a threshold which is capable of adjustment over a wide voltage range, e.g., from 2.5 millivolts to 300 millivolts, to allow for variations in photomultiplier gain. The discriminator is characterized by an amplitude-dependent time walk of approximately ± 250 picoseconds over a dynamic range of 100:1. In this measurement system, however, the dynamic range is only 5:1, that is, from 100 Kev to 511 Kev.

The output pulses from the constant fraction discriminator 62 are provided directly along eleven data input lines to the input processor 45 and are also provided to OR gate 64. The output from OR gate 64 is provided as one input to AND gate 66 and is also provided as an input to a second AND gate 68. These AND gates form the coincidence circuits illustrated in Fig. 1. The output from AND gate 68 is designated as the TOTAL STROBE (TOTAL STRB) output, while the output from AND gate 66 is the RANDOM STROBE (RND STRB) output. The second input to AND gate 68 is provided from another preamplifier discriminator OR gate channel, just as is shown in Fig. 2, but where the signals are generated from the opposing bank of photomultiplier detectors. The second input to AND gate 66, however, is the output from that second channel OR gate supplied through a time delay circuit.

As discussed above in connection with Fig. 1, the outputs of the discriminator coincidence circuits are applied to an input processor 45. The inputs to the input processor 45 include, then, eleven data channels corresponding to the eleven detectors in each bank and, for each pair of opposing banks of detectors, a rondom strobe signal representing coincidences between photons detected in one bank and delayed signals from photons detected in the opposite bank. Additionally, a total strobe signal representing the total coincidence, without delay, occurring between photons detected in one bank in coincidence with photons detected in the opposite bank is provided.

In addition to the above signals the input processor 45 receives routing/gating signals to control its operation.

In Fig. 3 there is illustrated in block diagram form the input processor configuration. The processor unit includes a temporary store circuit 70 which is the direct recipient of the input signals described above. The output signals from the temporary store circuit 70 are provided to encoder circuit 72, which, in turn, provides an output to the memory and data processor assembly 74 and thence through interface and control unit 76 to the computer 80 in the computer subsystem 27. The principal function of the input processor 45 is to accumulate for each one of three hundred and sixty-three line-of-sight paths passing through the field of view 30, a count corresponding to total coincidences occurring for each path, and a count corresponding to the number of random conincidences occurring for each path. In one mode of operation, the input processor promptly determines the difference between these counts for each one of these lines of sight and provides it to the computer system 27. Alternatively, in another mode, the input processor may provide both values, that is the total coincidence value and random coincidence value to the computer for subsequent computation.

The temporary store circuit 70 performs the function of buffering the input data. While it has a coincidence burst rate capability of 8 Mhz, the data from this temporary store is transferred through the encoder 72 to the memory 74 at a transfer rate of 700 Khz. Thus, the temporary store facility provides for dead-timeless operation in that events very closely spaced in time may be received into the temporary store, becasue of its

8 Mhz, coincidence burst rate, yet the transfer rate into the mass memory 74 can occur at 700 Khz, which is far in excess of the typical analysis rate of 20 Khz.

Fig. 4 is an illustration in greater detail of the input processor circuitry. The eleven input signals from bank A and the eleven from bank D are provided to the AD bank pair latch circuit 90. Similarly, the eleven input signals from banks B and E are provided to a second bank pair latch circuit 92, while those from banks C and F are provided to a third bank pair latch 94. Each of the strobe signals, both total and random, from the coincidence circuits are provided to a strobe latch and input timing circuit 98.

The strobe latch and input timing circuit 98 provides a separate pair of output connections to each of the bank pair latches 90, 92, and 94. In response to a strobe input, either random or total, from the coincidence circuits associated with a particular bank pair, this strobe timing and control circuit provides, first a clock pulse to the associated bank pair latch and thereafter an enable pulse. A typical value for the width of the clock pulse is 150 nanoseconds. The strobe timing and control circuit 98 also provides separate output signals to the FIRST IN-FIRST OUT (FIFO) register 100, indicating whether the input strobe was a random strobe or a normal total strobe and indicating from which bank pair the strobe originated.

The outputs from the bank pair latches 90, 92 and 94 are provided on two eleven channel output lines, one eleven channel output line carrying the data signal indicative of a photon of sufficient energy being detected at any one of the detectors in the banks A, B and C. The channel on which the signal occurs is, of course, indicative of the position of the particular detector in the bank. Thus, a signal on the number one channel of this output would indicate that a photon was detected in the first detector position in any one of the banks A, B or C. Similarly, a second eleven channel output is provided carrying signals from the opposing banks D, E and F. These two eleven channel outputs are provided as inputs to the FIFO register 100, along with the strobe identification signals form the strobe latch and timing circuit 98.

In operation, signals from the individual detector bank discriminators are carried to the input of the bank pair latches but are not entered into the latch unless a strobe signal occurs. Upon occurrence of a strobe signal at the input to the strobe latch and timing circuit ~~100,~~ 98, the appropriate clock pulse output is actuated and this signal serves to enter the data signal into the bank pair latch. At the conclusion of this clock pulse an enable signal is produced from the strobe latch and input timing circuit 98 to transfer the data signal from the bank pair latch into the FIFO register 100. Since the strobe latch and timing circuit 98 simulataneously provide output signals to the FIFO register 100 indicative of the type of strobe and the bank pair from which it originated, the multiple bit signal in the FIFO is indicative of the bank pair location of the two detectors that sensed the photons producing the coincidence, the detector position and whether the coincidence was a random one or a total one.

It should be noted that with this system it is possible to have more than two data lines actuated at the same time at the input to a bank pair latch so that it is not possible, in that situation, to identify which straight line path was involved in a coincidence. In the incidence a signal is provided to the memory circuit 104 indicative of multiple coincidence.

The FIFO register 100 is a typical FIFO register having at least twenty-eight bit positions and is sixteen registers long in the clocking direction. As above indicated, the bank pair latches operate with a clocking pulse of 150 nanoseconds corresponding to a burst rate acceptance of approximately 8 Mhz., and the signals from these bank pair latches are entered into the FIFO register at approximately this frequency. The register is arranged, however, to clear data from the shift register to encoder 102 at a much lower output clocking rate, for example, 700 Khz. Since the storage capacity of the FIFO register 100 is sufficient to realize the average separation rate between events this is a sufficiently high transfer output rate, even though the input rate to the shift register must be able to resolve events occurring with the minimum separation, due to the random nature of the radio-nuclide decay.

The twenty-eight bit output from the FIFO register 98 is coupled to encoder unit 102, which encodes these input bits into a twelve-bit address signal to the memory 104.

As above mentioned, there are one hundred and twenty-one lines of sight in each pair of detector banks, requiring one hundred and twenty-one separate addresses in memory. A seven bit binary code, then can encompass all of these addresses with seven addresses left over. Since, in the illustrated embodiment, there are three pairs of detector banks, a two bit code can identify which pair of banks the lines of sight are in, with one bit left over. This bit can be used to indicate whether the detected coincidence was a random strobe or a total strobe. The additional bits from the encoder 102 can then be used for routing control and instructions.

On such control instruction determines the mode in which the overall system is operating. There are three basic modes. In one mode the memory accumulates only total strobes as a measure of the count. In a second mode the total strobes are accumulated in memory and the random strobes are also accumulated in memory, subject to their difference being computed at a later time. In a third mode, total coincidences are inserted into memory as an algebraically positive signal, while random coincidence are inserted as an algebraically negative signal, so that the accumulated counts represents the algebraic sum of total strobes and random strobes. In this latter mode, the memory has in it, at any given time, virtually immediately, the net count representative of the positron coincidences. The signals passing from memory to the encoders may also control various housekeeping functions of the system, such as clearing and restarting, and an unload clock signal controlling the speed at which the FIFO register 98 is read out into the encoder 102.

While a specific configuration for circuit operation of this embodiment employing a generally hexagonal array of three pairs of detector banks has been described, it will be understood that the invention may take various suitable forms, not only in terms of the geometry of detector array, in single or multiple planes, but also in terms of the specific configurations of circuitry employed to achieve these results.

The invention is then intended to be limited only by the spirit and scope of the appended claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In a tomography scanning system having,

a source of positron radiation directing positrons into an area to be scanned,

a plurality of pairs of detectors for detecting photons emitted during positron annihilation within said area, said detectors being arranged in a generally annular array surrounding said area,

a first coincidence circuit having first and second input connections and at least one output connection, said first coincidence circuit being arranged to provide a signal on said output connection whenever signals are present at said first and second input connections in time coincidence with one another, said plurality of pairs of detectors being coupled to said first coincidence circuit input connections, such that a first group of detectors is coupled to said first input and a second group of detectors positioned generally opposite said first group is coupled to said second input connection, a pair of detectors including one detector from each group, where the detectors defining a pair are connected by a line of sight within said area, the plurality of said pairs defining a field of view, the improvement comprising,

a second coincidence circuit having first and second input connections and an output connection, said second coincidence circuit being arranged to provide a signal on said output connection whenever signals on said first and second input connections are in time coincidence with one another, said plurality of detectors being coupled to said first input connection of said second coincidence circuit,

time delay means, said time delay means being coupled between said plurality of detectors and said second input connection of said second coincidence circuit, and

Claim 1 continued....

means for determining for each pair of detectors the difference between the number of signals appearing at the output of said second coincidence circuit from the number of signals appearing at the output of said first coincidence circuit and providing said difference as an indication of the number of positrons annihilated in the line of sight between detectors forming that pair, the differences for all of said pairs defining the pattern of positron annihilation within said field of view.

2. A tomography scanning system in accordance with claim 1 wherein said plurality of detectors are arranged in an array of banks of detectors, each bank having an opposite parallel bank paired with it and wherein, in said first coincidence circuit, time coincidences are determined between signals from detectors in paired banks, and wherein in said second coincidence circuit said first input receives signals from detectors in one bank, while said second input receives delayed signals from detectors in the paired bank, and further including means for providing to said difference determination means an identification of which detectors in said banks generated the signals for each time coincidence.

3. In a tomography scanning system having,

a source of positron radiation within an area to be scanned directing positrons into an area to be scanned,

a plurality of pairs of photon detectors disposed around the periphery of said area, a pair of detectors being defined as two detectors connected by a straight line of sight path, within said area, said detectors providing output signals in response to photons impinging upon them,

first coincidence means for providing output signals indicative of the number of time coincidences between photons

Claim 3 continued...

sensed at each of said pairs of detectors, the improvement comprising,

second coincidence means for providing output signals indicative of the number of coincidences between photons sensed at each of said pairs of detectors with a fixed time separation between the time said photons are sensed at one detector of said pair and the other detector of said pair,

encoder means,

coupling means for coupling said detector output signals and said first and second coincidence means output signals to said encoder, said encoder providing output signals indicative of the location of detectors providing the signals resulting in said coincidence means signal and which of said coincidence means produced said signal, and

means for determining for each pair of detectors the difference between the number of signals appearing at the output of said second coincidence circuit from the number of signals appearing at the output of said first coincidence circuit and providing said difference as an indication of the number of positrons annihilated in the line of sight between detectors forming that pair, the differences for all of said pairs defining the pattern of positron annihilation within said field of view.

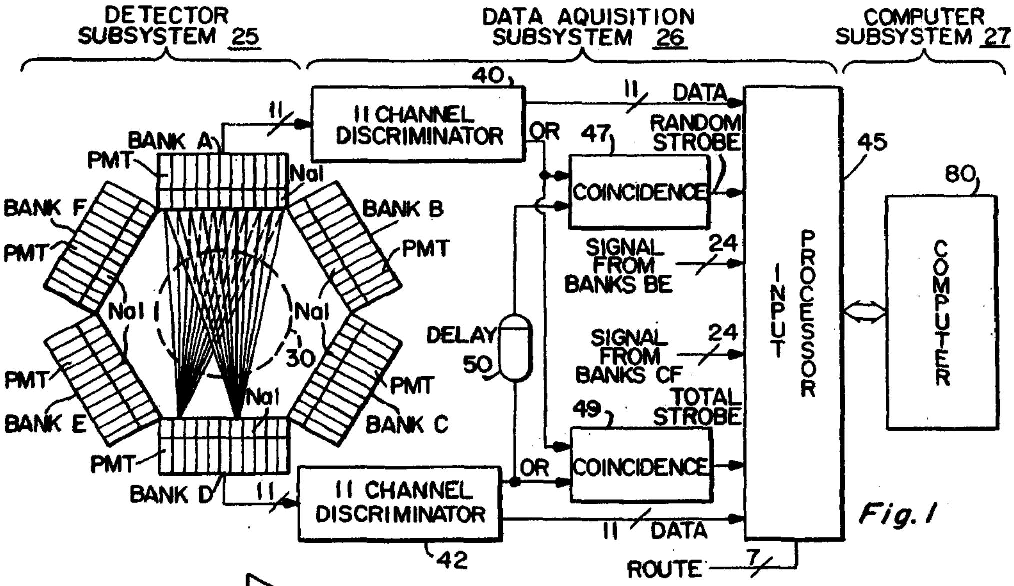

Fig. 1

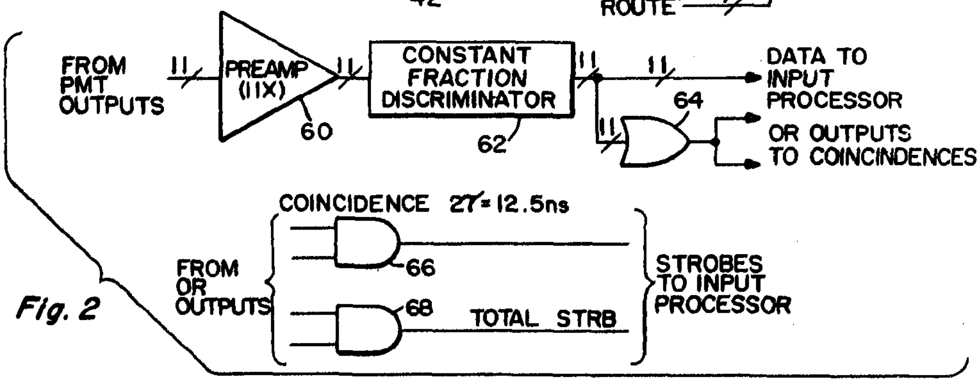

Fig. 2

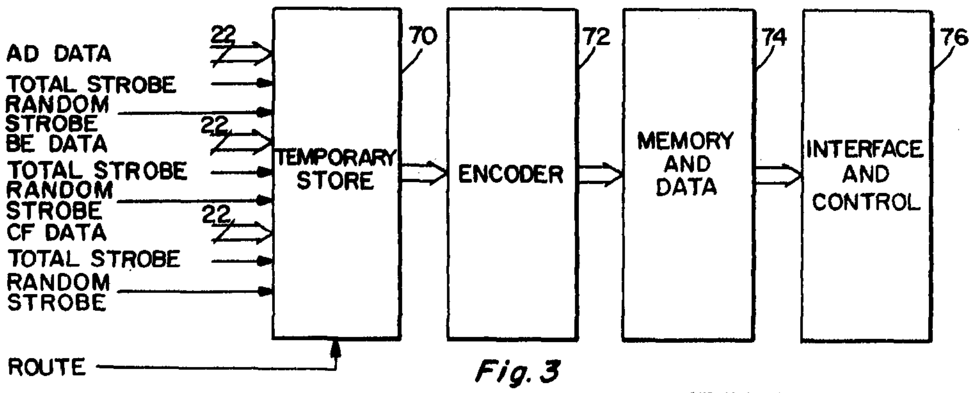

Fig. 3

MICHAEL E. PHELPS
EDWARD J. HOFFMAN
CHARLES W. WILLIAMS
SAMUEL G. BURGISS
Inventors

George H. Riches and Associates
Attorney

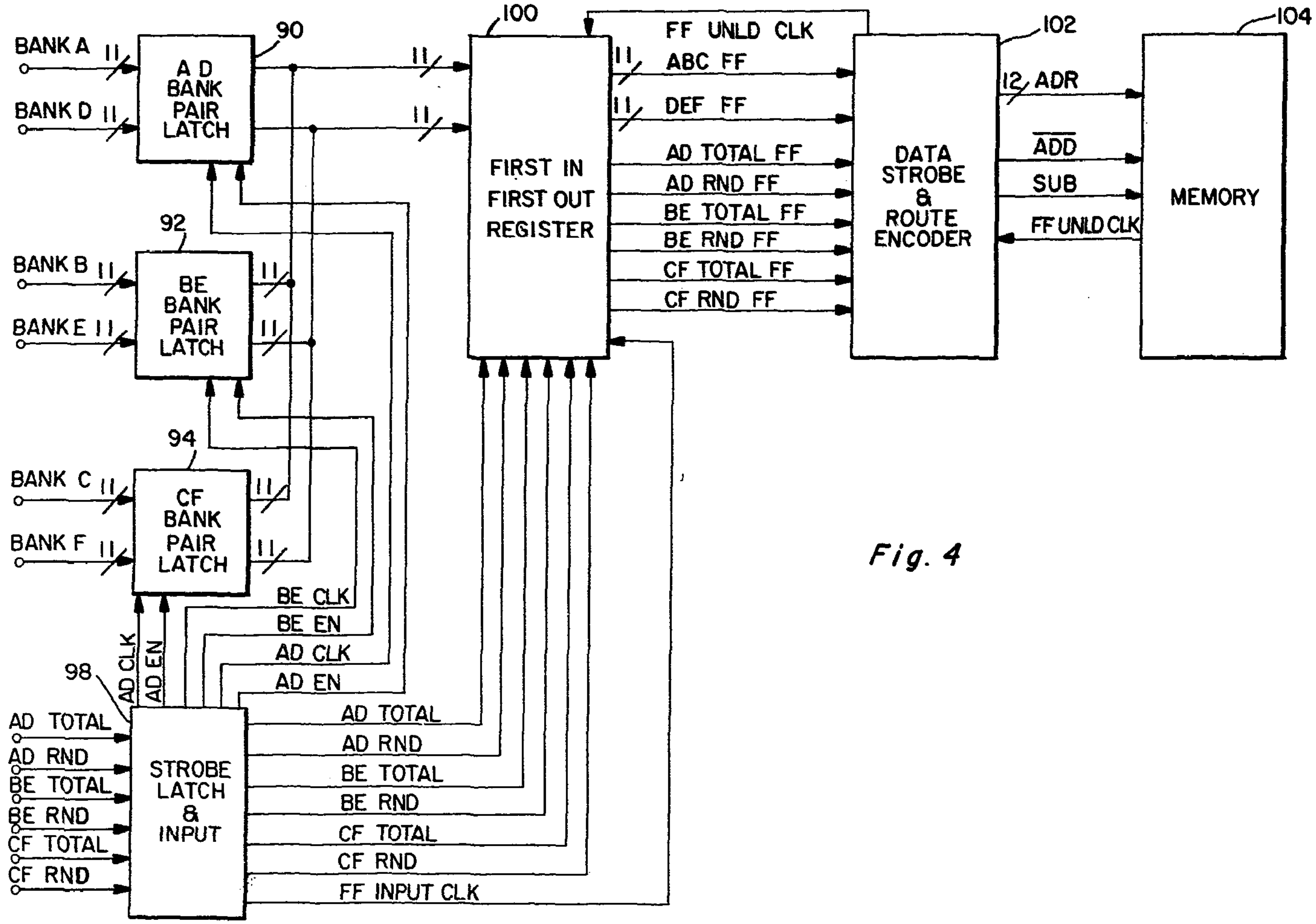

Fig. 4

MICHAEL E. PHELPS
EDWARD J. HOFFMAN
CHARLES W. WILLIAMS
SAMUEL G. BURGISS
Inventors

Attorney.

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7-7