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

(11) Publication number: **0 157 417**
A2

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: **85104007.1**

(22) Date of filing: **02.04.85**

(51) Int. Cl.⁴: **A 61 B 6/00**

(30) Priority: **03.04.84 JP 66259/84**

(43) Date of publication of application: **09.10.85**
Bulletin 85/41

(84) Designated Contracting States: **DE NL**

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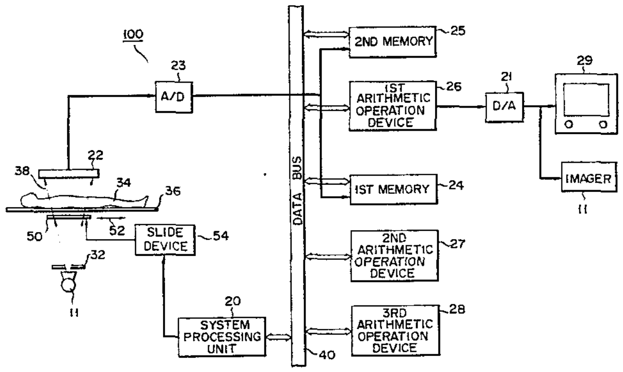
(54) **X-ray diagnostic apparatus for eliminating scattered x-ray components.**

(57) In an X-ray diagnostic apparatus (100), it is very desirable to mittigate the adverse effect of the scattered X-ray components. When the X-ray shield member (50) is positioned in the X-ray projection area (38) during the first X-ray projection period, the first X-ray transmission image data is obtained. From this X-ray transmission image data, the scattered X-ray component data is calculated in the interpolation method of a SINC function. When the X-ray shield member (50) is removed from the X-ray projection area (38) during the second X-ray projection period, the second X-ray transmission image data is obtained that includes not only the primary X-ray components (Ip(x, y) but also the scattered X-ray components (Isc(x, y). The desirable X-ray transmission image data is obtained by subtracting the first image data from the second image data.



ACTORUM AG

X-ray diagnostic apparatus for eliminating scattered X-ray components

This invention generally relates to an X-ray diagnostic apparatus in which a transmitted X-ray image of an object under examination, e.g., a patient, is available for diagnostic purposes, and more particularly, to an X-ray diagnostic apparatus by which visible X-ray images of the object can be obtained, based only upon primary X-rays, without any adverse influences caused by the scattered X-rays.

Generally, in the X-ray diagnostic apparatus set forth in the preamble, X-rays incident on an X-ray detector through the object under examination such as a patient contain not only primary X-rays but also X-rays which have been scattered by the object. The scattered X-rays constitute one of the major causes of deteriorated contrast and resolution in the transmitted X-ray image. This makes it necessary to eliminate the scattered X-ray components from the transmitted X-ray image data as provided by the X-ray detector.

One of the approaches to eliminate the scattered X-ray components is to use a so-called "Buckey Blade" or an elimination grid for the scattered X-rays (referred to as a "grid"). This approach newly involves a problem in that there is a limit in the scattered X-ray elimination, because the grid *per se* produces the scattered X-rays incident thereupon.

The elimination of the scattered X-rays is very significant in the field of the X-ray diagnosis for the reasons that it improves an X-ray image quality, such as contrast and resolution, and thus allows a logarithm conversion of primary X-rays image data, thereby obtaining an accurate attenuation quantity of X-rays caused by the object when the X-rays pass through the object. Many studies have been made on the scattered X-rays, aiming at their effective elimination. The complicated phenomena of the scattered X-rays impede or almost reject a theoretical approach to this theme. This is the present stage of technology in this field.

For the above background reasons, an object of the present invention is to provide, by introducing a novel technical idea, an X-ray diagnostic apparatus which can effectively eliminate the scattered X-ray image components from the transmitted X-ray image components as obtained by the X-ray detector.

The object of the present invention may be accomplished by providing an X-ray diagnostic apparatus comprising:

an X-ray source for successively generating X-rays;

a detector for detecting an X-ray image of an object under examination by projecting the X-rays from the X-ray source toward the object, and for converting the detected image into X-ray transmission signals;

an analogue-to-digital converter for converting the X-ray transmission signals into corresponding digital transmission data;

an X-ray shield member having a plurality of X-ray shields, for partially blocking the penetration of the X-rays over an X-ray projection area defined by projecting the X-rays from the X-ray source to the X-ray detection means through the object;

a first memory for temporarily storing at least first X-ray transmission data acquired during a first X-ray projection period under the condition that the X-ray shield member is inserted into the X-ray projection area;

a second memory for temporarily storing at least second transmission data acquired during a second X-ray projection period under the condition that the X-ray shield member is removed from the X-ray projection area;

a first arithmetic operation device for performing a first subtraction between the first X-ray transmission data and the second X-ray transmission data so as to obtain first scattered X-ray intensity data of portions within the X-ray projection area which are shielded by the X-ray shields, and for performing a second subtraction between second scattered X-ray intensity data and the second X-ray transmission data so as to obtain third X-ray transmission data free from the scattered X-ray components; and

a second arithmetic operation device for performing data interpolation by a SINC function to the first scattered X-ray intensity data so as to obtain the second scattered X-ray intensity data over the entire X-ray projection area.

This and other objects and features of the present invention may be best understood by reference to the specification and the accompanying drawings, in which;

Fig. 1 is an illustration for explaining an occurrence of scattered X-rays when an X-ray is projected toward an object under examination;

Fig. 2 shows a graphic representation on an X-ray intensity vs., a detection position on an X-ray detector;

Figs. 3A, 3B and 3C graphically illustrate a spatial distribution of the scattered X-rays' intensity;

Fig. 4 shows a schematic block diagram of an X-ray diagnostic apparatus according to one preferred embodiment of the present invention;

Fig. 5 schematically shows a front view of an X-ray shield member;

Figs. 6A, 6B and 6C graphically illustrate operations of the bilevel quantization;

Fig. 7 shows a block diagram of the third arithmetic operation device of Fig. 4;

Fig. 8 is a flow chart of the entire operation of the apparatus shown in Fig. 4;

Figs. 9 and 10 schematically illustrates the scattered X-ray intensity data with respect to the X-ray shield member and the detector;

Fig. 11 shows a practical circuit of the third arithmetic operation device; and

Fig. 12 shows a timing chart of the signals of the circuit shown in Fig. 11.

A detailed description of the invention, as given in this specification, is organized in accordance with the following index which is presented for the convenience of the reader.

1). PRINCIPLE BACKGROUND OF INVENTION

First, a description is made of a phenomenon of the scattered X-ray.

It is assumed that X-rays incident on the object under examination such as a patient are generally classified into primary X-rays which directly transmit through the object and enter into an X-ray detector, and X-rays absorbed or scattered by the object through interactions of the X-rays with atoms constituting the object. Those scattered ones are called "scattered X-rays". In the energy range of medical X-rays (radiated under 50 KVp to 120 KVp of the X-ray tube voltage), some causes for the scattered X-rays are known, for example, photoelectric effects, Compton effects, Thomson effects, and the like. These phenomena cooperate to cause the scattered X-rays to have adverse effects on the transmitted X-ray image (will be described later). In general, because the scattered X-rays incident on the X-ray detector experience multi-scattering within the object, it is very difficult to exactly grasp an intensity and a spatial spread of an incident X-ray beam. This phenomenon is explained as follows.

Fig. 1 schematically illustrates how an X-ray radiated from an X-ray source 11 such as an X-ray tube, is scattered within an object, under examination and reaches an X-ray detector 13, while depicting a spatial spread with respect to the detecting positions of the X-ray detector. Fig. 2 illustrates an X-ray intensity distribution over the detecting positions of the X-ray detector 13. As seen from Fig. 2, a narrow spread, or spatial distribution of a sharp peak (as indicated by character K), located substantially at the center of the distribution curve, is caused by an inherent matter of the diagnosis system, for example, an X-ray focal spot and a wide spread (as indicated by character L) is caused by the scattered X-rays.

In Fig. 3, a spatial distribution of the scattered X-rays is graphically shown. In Fig. 3A, a narrow X-ray beam is projected toward a body 14. In Fig. 3B, spatial distributions of the respective scattered X-rays are graphically shown. In Fig. 3C, an actual spatial distribution of the scattered X-rays is graphically shown, that is obtained by summing these spatial distributions. The characters "-a" and "a" define an area projected by the X-rays (referred to as an "X-ray projection area") on the detecting positions of the X-ray detector 13. The symbol "Isc(x)" denotes an intensity of the scattered X-rays in the X-direction. For convenience and clarity of illumination, these drawings are illustrated in one dimension.

A total X-ray intensity distribution Im(x, y) incident on the detector 13 is the sum of the primary X-ray intensity distribution Ip(x, y) and the scattered X-rays intensity distribution Isc(x, y) and is given by:

$$Im(x, y) = Ip(x, y) + Isc(x, y) \quad ..... (1).$$

where (x, y) indicates coordinates for representing positions on the X-ray detector 13.

As previously described, since the spatial distributions of the scattered X-ray components Isc(x, y) gradually vary over the X-ray projection area, it is practically possible to relatively, precisely estimate the scattered X-ray component Isc(x, y) over the X-ray projection area by employing a plurality of the scattered X-ray component data.

The basic of the present invention can be realized based upon the above-described recognition.

In accordance with the basic idea of the present invention, the X-rays are successively projected toward the object under examination in such a way that an X-ray shield member is interposed between the X-ray source and the X-ray detector within the X-ray projection area.

The X-ray projection area is defined by projecting the X-ray from the X-ray source to the X-ray detector through the object. Under such a condition, first transmitted X-ray image data obtained by the detector may contain theoretically the scattered X-ray components of the shielded portions only, because the primary X-ray components have been shielded by the X-ray shield member before reaching the X-ray detector. Second transmitted X-ray image data is acquired under the condition that the X-ray shield member is removed from the X-ray projection area. Accordingly, the second X-ray image data contains not only the scattered X-ray components but also the primary X-ray components. As a result, subtracting the first X-ray image data from the second one enables desirable image data to be calculated in accordance with the above equation 1. This desirable image data involves only the primary X-ray components.

2). ARRANGEMENT OF THE APPARATUS

Referring to Fig. 4, a description is made of an X-ray diagnostic apparatus 100 according to the preferred embodiment, in which the above basic idea has been employed.

An X-ray source 30 generates X-rays that are projected through a collimeter 32 toward a patient 34 under examination. The patient 32 lies down on a couch 36. The X-ray projection area of the X-ray source 30 which is defined by the collimeter 32 is denoted by reference numeral 38, that is defined by projecting the X-ray from the X-ray source 30 to the X-ray detector 22 through the patient 34.

An X-ray shield member 50 is provided under the couch 36. In other words, it is positioned in front of the patient 34 along the X-ray transmission path. This shield member 50 is designed to be slidable in parallel to the patient 34 or the couch 36. The slide operation into the X-ray projection area 38 will be described later. A slide direction is indicated by an arrow 52.

A system processing unit 20 is provided with the X-ray diagnostic apparatus 100. A slide device 54 allows to mechanically slide the X-ray shield member 50 along the slide direction 52 under the control of the system processing unit 20. An X-ray detector 22 such as an image intensifier is positioned behind the patient 34 along the X-ray transmission path within the X-ray projection area 38. Outputs of the detector 22 are fed to an analogue-to-digital converter (A/D converter) 23. To the A/D converter 23, first, second memories 24 and 25 are connected. The first memory 24 is mainly communicated with a first arithmetic operation device 26 and the second memory 25 is communicated with a second arithmetic operation device 27.

A third arithmetic operation device 28 is communicated with the first memory 25 via the data bus 40. The output of the first arithmetic operation device 26 communicated with the second arithmetic operation device 27 is connected via a digital-to-analogue converter 21 to a TV monitor 29 and also an imager 30 which optically records the X-ray images on X-ray films. The first and second memories 24, 25 and the first to third arithmetic operation device 26 to 28 and the other circuit elements are controlled via a control line (not shown) by the system processing unit 20.

3). X-RAY SHIELD MEMBER

Fig. 5 shows a front view of the X-ray shield member 50. The X-ray shield member 50 is fabricated by a plurality of X-ray shield materials such as lead pieces 56 and a thin plate-like material such as a synthetic resin film 58. These lead pieces 56 are positioned with equidistance relationship in a matrix in the resin film 58. Each lead pieces 56 has a size of 2mm x 2mm, for example.

While the X-ray shield member 50 is positioned in the X-ray projection area 38 defined by projecting the

X-ray from the X-ray source 11 via the collimeter 50 to the X-ray detector 22 through the object 34, the intensity distribution of the transmitted X-ray image signal is obtained by projecting the X-ray toward the object 34, that is shown by a graphic representation of Fig. 10. This intensity distribution Isc represents one which is taken along the lines A-A' on the surface of the X-ray detector 22. As seen from the distribution curve, the intensity levels of those positions where the lead pieces 56 are positioned (indicated by numerical references 1, 2, 3, 4, and 5) steeply drop. Consequently, these intensity levels indicate the intensity of the scattered X-ray components Isc, because the primary X-ray components are substantially completely blocked by those lead pieces 56.

Fig. 9 is an enlarged drawing for illustrating the relationship between the X-ray shield member 50 and the peripheral components.

It should be noted that the arrangement of the X-ray source 11 and the detector 22 shown in Fig. 7, is reversed, compared with the arrangement shown in Fig. 4, but there is no technical difference between them.

4). OPERATION OF THE APPARUTUS

Operations of the X-ray diagnostic apparatus (100) will now be described with reference to Figs. 4 to 7.

Referring back to Fig. 4, the X-ray source 30 is energized to project the first X-ray toward the patient 34 while the X-ray shield member 50 is slid along the longitudinal axis (not shown in detail) of the couch 36 and positioned within the X-ray projection area 38 by means of the slide device 54. The slide device 54 is electronically controlled by the system control unit 20. The X-ray transmitted through the patient 34 is incident, as the X-ray image upon the X-ray detector 22. The X-ray image is converted into an analogue X-ray transmission image signal. Thereafter, it is converted by the A/D converter 23 into corresponding digital transmission data (will be referred to as "X-ray shielded data"). The digital transmission data is temporarily stored as the X-ray shielded data in the first memory 24.

From the digital X-ray shielded data stored in the first memory 24, the amount of the scattered X-ray components of the shielded portions by the lead pieces 56 can be calculated by the first arithmetic operation device 26 in a given calculation method (will be described later). The resultant data is stored in the first memory 24, that represents the intensity distribution of scattered X-ray components.

Thereafter, another X-ray projection is excuted after the X-ray shield member 50 has been completely removed from the X-ray projection area 38 by driving the slide device 54. Similarly, X-ray transmission data is acquired and temporarily stored as second X-ray transmission data (will be referred to as "X-ray original image data") in the second memory 25. Thereafter, both the first transmission data (X-ray shielded data) stored in the first memory 24 and the second X-ray transmission data (X-ray original image data Im(x, y)) stored in the second memory 25 are fed to the first arithmetic operation device 26. The functions of this device 26 are as follows.

First, the X-ray shielded data that has been stored in the first memory 24 is substracted from the X-ray original image data, thereby obtaining "scattered X-ray intensity data" of the portions within the X-ray projection area 38 which are shielded by the lead pieces 56. Second, another subtraction is carried out between the X-ray original image data and the intensity data of the scattered X-rays (will be described later).

The above-described X-ray intensity data derived from the first arithmetic operation device 26 is transferred to the second arithmetic operation device 27 via the data bus 40. In the second arithmetic operation device 26, the X-ray intensity data is bilevel-quantized in such a way that for example, a certain intensity level is converted into a digital "1" level (corresponding to the portion that is shielded by the lead piece 56), and an intensity level higher than the threshold level is converted into a digital "0" level (corresponding to the portions that are not shielded, or substantially not shielded by the lead piece 56).

5). BILEVEL QUANTIZATION

The bilevel quantization will now be described in more detail.

Fig. 6 shows an enlarged signal waveform of the X-ray intensity data in relation to the position of the lead piece 56. The X-ray intensity data of the portion which is not shielded by the lead piece 56 has a higher level than the threshold level is converted into the digital "0" level signal. The X-ray intensity data of the portion which is shielded by the lead piece 56 has a lower level than the threshold level is converted into the digital "1" level signal. This level conversion is called "the bilevel quantization". This bilevel quantization is carried out in the second arithmetic operation device 27. As seen from Fig. 6B, in general, the waveform of the X-ray intensity signal is distorted and stretched. It is therefore necessary to distinguish the desirable signal belonging to the X-ray shielded portion (i.e., the scattered X-ray signal) from the signal belonging to the other portion (i.e., the primary X-ray signal and a part of the scattered X-ray signal). As a result, the 1-level signal contains only the scattered X-ray components caused by the corresponding lead piece 56 in the X-ray shield member 50. (see Fig. 6C).

6). CALCULATION OF SCATTERED X-RAY

The resultant bileveled data of the second arithmetic operation device 27 is fed via the data bus 40 to the system processing unit 20. In this unit 20, central addresses and distances between the adjoining central addresses having the above 1-level signal with respect to the entire memory region of the first memory 24, and average valves of the X-ray shielded data of the X-ray shielded region are obtained by utilizing the X-ray shielded data which has been stored in the first memory 24. The average valves of the X-ray shielded region are so-called "scattered X-ray data". It is apparent that this system processing unit 20 also performs the sequence control of the entire system 100.

Thus, the scattered X-ray data of the system processing unit 20 is transferred via the data bus 40 to the third arithmetic operation device 28 in combination with the data relating to the portion which is shielded by the lead piece 56, i.e., the central addresses and the distances for the X-ray shielded portions. In the third arithmetic operation device 28, an interpolation operation is effected by way of a SINC function (a sampling function) by receiving the data of the central addresses and the distances derived from the system processing unit 20 and also addresses of the respective pixels of the memories. As a result, the desirable scattered X-ray intensity data Isc(x, y) (see formula (1)), over the entire X-ray projection area 38 can be calculated in the third arithmetic operation device 28.

The scattered X-ray intensity data Isc(x, y) over the entire X-ray projection area 38 is sent via the data bus 40 to the first arithmetic operation device 26. In the first arithmetic operation device 26, the X-ray original image data Im(x, y) which has been previously stored in the second memory 25 is subtracted from the scattered X-ray intensity data Isc(x, y), so that the primary X-ray data Ip(x, y) can be obtained therein. In other words, formula (1) is calculated in the first arithmetic operation device 28.

Thereafter, the primary X-ray data Ip(x, y) is A/D-converted into the corresponding analogue signal in the D/A converter 21. The converted primary X-ray signal is fed to the TV monitor 29 and also the imager 30 for displaying and recording the X-ray transmission image of the object 34 having no adverse effects of the scattered X-ray components.

7). FUNCTIONS OF ARITHMETIC OPERATION DEVICES

The functions of the major circuit components will now be summarized.

The first arithmetic operation device 26 performs that the first subtraction is executed between the X-ray shielded data stored in the first memory 24 and the X-ray original image data Im(x, y) stored in the second memory 25, thereby deriving the X-ray intensity data of the portions within the X-ray projection area which are shielded by the lead pieces 56 (i.e., the intensity data for the scattered X-ray of the shielded portion), and the second subtraction is effected between the above-described X-ray original image data and the intensity data of the scattered X-ray Isc(x, y) over the entire projection area which is derived from the third arithmetic operation device 28, thereby obtaining X-ray transmission data from which adverse effects by the scattered X-rays have been eliminated.

The second arithmetic operation device 27 performs the bilevel quantization to the intensity data (digital signal) for the scattered X-rays of the shielded portions, thereby discriminating the scattered X-ray intensity data of the shielded portions from the X-ray intensity data of the non-shielded portions.

The system processing unit 20 processes the bileveled intensity data and also the X-ray shielded data to obtain central addresses of the respective shielded portions with respect to the memory region of the first memory means 24 and also addresses indicating distances between the adjoining central addresses thereof, and the average value of the scattered X-ray data for the shielded portions.

The third arithmetic operation device 28 performs the data interpolation by the SINC function on the average value of the scattered X-ray data for the shielded portions by utilizing the central addresses, distances and addresses for the respective pixels, thereby obtaining the scattered X-ray intensity data Isc(x, y) over the entire X-ray projection area 38.

8). DETAILED OPERATION OF 3RD ARITHMETIC OPERATION DEVICE

A description will now be made of the operations of the third arithmetic operation device 28 in more detail.

As previously described, the major function of this device 28 is to execute the interpolation of the scattered data based upon the sampling function, i.e., a SINC function.

This is represented by the following equation;

$$S(x, y) = \sum_{n_1=-\infty}^{\infty} \sum_{n_2=-\infty}^{\infty} S(n_1X, n_2Y) \cdot \frac{\sin [\frac{2\pi}{X}(x-n_1X)/2]}{\frac{2\pi}{X}(x-n_1X)/2} \cdot \frac{\sin [\frac{2\pi}{Y}(y-n_2Y)/2]}{\frac{2\pi}{Y}(y-n_2Y)/2} \quad \ldots (2)$$

Where S(x, y) denotes the addresses (x, y) of the memory, $S(n_1X, n_2Y)$ indicates the addresses (n_1X, n_2Y) of the portion in the memory, which is shielded by the lead piece 56, X represents the distance between the adjoining lead pieces 56 with respect to the memory in the horizontal direction, and Y represents the distance between the adjoining lead pieces 56 with respect to the memory in the vertical direction. Equation 1 implies that the intensity of the scattered X-ray at a certain memory address can be given by the function of the type of (sin Z)/Z (so-called "sampling function"), and also the intensity of the scattered X-ray which has been acquired in the equidistance relation. That is to say, the scattered X-ray intensity S(x, y) at a certain memory address (in the first memory 24) is represented by the equidistantly-acquired intensity data;

$$\sum_{n_1=-\infty}^{\infty} \sum_{n_2=-\infty}^{\infty} S(n_1X,\ n_2Y)$$

multiplied by the SINC function;

$$\frac{\sin\ [\frac{2\pi}{X}(x-n_1X)/2]}{\frac{2\pi}{X}(x-n_1X)/2} \cdot \frac{\sin\ [\frac{2\pi}{Y}(y-n_2Y)/2]}{\frac{2\pi}{Y}(y-n_2Y)/2} \cdot$$

It is understood from the foregoing that the scattered X-ray intensity data for the intermediate portions surrounded by the shielded portions can be directly calculated from the above SINC function method. However, such an interpolation calculation cannot be directly applied to the remaining pixels located outside the corner portions, e.g., the portions corresponding to the lead pieces 1 and 5 shown in Fig. 9. Accordingly, the interpolation data for these outside portions may be substituted by those for the corner portions. As a result, the entire intensity amounts of the scattered X-rays can be calculated for the storage region of the first memory 24 (512 × 512 pixel numbers), whereby the desired spatial distribution of the scattered X-ray intensity Isc(x, y) over the entire projection area 38 can be obtained.

9). INTERNAL CIRCUIT DIAGRAM OF 3RD ARITHMETIC OPERATION DEVICE

A detailed description will now be made of the internal circuit diagram of the third arithmetic operation device 28 by which the data interpolation by the sampling function is performed.

Fig. 7 shows a block diagram of the fundamental circuit of the third arithmetic operation device 28. As an input of the device 28, there is provided a register unit 70. The register unit 70 is constructed by seven registers 70A to 70G. These registers 70A to 70G temporarily hold the X-ray shielded data, the intensity data of the scattered X-ray, and the address data of the respective pixels in the memory region of the first memory 24 (see Fig. 4). These data are fed from the other circuit elements via the external data bus 40. For example, the address data for the X direction xADD is fed from the system processing unit 20 via the data bus 40 to the second register 70B.

A subtracter 72 is connected to the first and second registers 70A and 70B, which temporarily store the data n_1X and xADD, respectively. The subtracter 72 subtacts two sets of these data to obtain $(x-n_1X)$. Similarly, since the subtracter 72 is connected to the third and fourth register 70C and 70D, another subtraction is carried out between the data n_2Y and yADD to obtain $(y-n_2Y)$. The data yADD denotes the address in the Y direction. A first multiplier 7 is connected, on one hand, to the output of the subtracter 72 and, on the other hand, to the fifth and sixth register 70E and 70F. First, this register 7 multiplies the subtracted data $(x-n_1X)$ by $\frac{1}{X}$ which is held in the fifth register 70E, thereby obtaining:

$$\frac{1}{X} \cdot (x-n_1X) \qquad \text{.....} \ (3)$$

Second, it multiplies the subtracted data $(y-n_2Y)$ by $\frac{1}{Y}$ which is temporarily stored in the sixth register 70F, thereby obtaining:

$$\frac{1}{Y} \cdot (y-n_2Y) \qquad \text{.....} \ (4)$$

A first Read Only Memory (ROM) 76 as a conversion table is connected to the first multiplier 74. When one multiplied result $(\frac{1}{X} \cdot (x-n_1X))$ is input from the multiplier 74 to the first ROM, the following value is derived therefrom by means of the conversion table:

$$\frac{\sin\,[\frac{2\pi}{X}(x-n_1X)/2]}{\frac{2\pi}{X}(x-n_1X)/2} \qquad \text{.....} \ (5)$$

When the other multiplied result ($\frac{1}{Y} \cdot (y-n_2Y)$) is input from the multiplier 74 to the first ROM, the following value is output therefrom by means of the conversion table:

$$\frac{\sin\left[\frac{2\pi}{Y}(y-n_2Y)/2\right]}{\frac{2\pi}{Y}(y-n_2Y)/2} \quad \text{.....}\ (6)$$

X-register 77 and Y-register 79 connected parallel thereto are connected to the output of the first ROM 76 so as to hold the converted values denoted by the equations (5) and (6), respectively.

A second multiplier 80 is connected to the X-register 77 and Y-register 79 so as to multiply the above-mentioned two values by each other. Thereafter, the resultant value of the second multiplier 80 is again multiplied in a third multiplier 82 by the data S(n1X, n2Y) which is held in the seventh register 70G, thereby obtaining:

$$S(n_1X,\ n_2Y)\frac{\sin\left[\frac{2\pi}{X}(x-n_1X)/2\right]}{\frac{2\pi}{X}(x-n_1X)/2} \cdot \frac{\sin\left[\frac{2\pi}{Y}(y-n_2Y)/2\right]}{\frac{2\pi}{Y}(y-n_2Y)/2} \quad \text{.....}\ (7)$$

An adder 84 is connected to the output of the third multiplier 82 so as to add the finally-multiplied value as indicated in the above value (7) to the X-ray shield data which has been stored in the first memory 24. The resultant value of this adder 84 is then stored in the first memory 24.

10). ENTIRE OPERATION OF EMBODIMENT

The entire operation of the X-ray diagnostic apparatus 100 will now be summarized with reference to the relevant figures and the flow chart of Fig. 8.

After the X-ray shield member 50 is inserted into the X-ray projection area 38, the first X-ray is projected toward the object 34 to acquire the X-ray shield data by the detector 22 and A/D converter 23 (step 1). That is, the first X-ray generated from the

X-ray source 11 is transmitted through the X-ray shield member 50 and object 34 and received by the detector 22. The detected signal is converted into the digital X-ray shield data that implies the X-ray intensity of the scattered X-rays relating to the X-ray shielded portions (corresponding to the lead pieces 56). This X-ray shield data is temporarily stored in the first memory 24.

A further detailed explanation will now be given to the X-ray shield data. As shown in Fig. 9, while the X-ray shield member 50 is positioned in the X-ray projection area 38, the X-ray is projected toward the object 34. The X-ray intensity distribution of the X-ray shield data is represented in Fig. 10. This distribution data is taken along the line A-A' of Fig. 9. As easily seen from the X-ray intensity data of Fig. 10, the respective values as indicated by 1 to 5 remarkably drop. These portions correspond to those which are shielded by the lead pieces 56. Accordingly, these intensity values are the scattered X-ray data Isc of the shieled portions, because the primary X-rays have been cut by the lead pieces 56.

It should be noted that the X-ray shield data include not only the above intensity values of the scattered X-rays but also those of the primary X-rays.

After the acquisition of the X-ray shield data is accomplished, the X-ray shield member 50 is removed away along the arrow 52 from the X-ray projection area 38 by the slide device 54. Then the second X-ray projection is carried out to acquire the X-ray original image data (step 2). The X-ray original image data is temporarily stored in the second memory 25.

In step 3, a first digital subtraction is performed between the X-ray shield data stored in the first memory 24 and the X-ray original data stored in the second memory 25. This digital subtraction is carried out in the first arithmetic operation device 26. As a result, only the X-ray intensity values of the scattered X-rays can be obtained because, as previously described in step (1), the values on the primary X-rays (the portions not shielded by the lead pieces 56) are subtracted from the X-ray shield data.

In step 4, the first subtracted values ($x-n_1X$, $y-n_2Y$) are bilevel-quantized in the second arithmetic operation device 27. Since the bilevel quantization has been explained with reference to Fig. 6, no further explanation is made here. By the bilevel quantization, for instance, the portions having a given intensity value of the scattered X-rays are denoted by 1-level signal, and the remaining portions are indicated by 0-level signal, so that the 1-level portions correspond to the portions which are shielded by the lead pieces 56.

The bilevel-quantized data obtained in step 4 is fed via the data bus 40 to the system processing unit 20 so as to obtain the desirable address data on the X-ray shielded portions and also the entire intensity data of the scattered X-ray Isc(x, y) in step 5. The system processing unit 20 processes the bilevel-quantized data (Fig. 6C) to obtain the central addresses of the portions which are shielded by the lead pieces 56, and also the distances between the adjoining the central addresses with respect to the memory region of the first memory 24. This unit 20 also processes to obtain the intensity data of the scattered X-ray in the above-mentioned portions based upon the X-ray shield data which has been stored in the first memory 24.

Both the address data and the intensity data of the scattered X-ray with respect to the portions which are shielded by the lead pieces 56 (in step 5) are input via the data bus 40 to the third arithmetic operation device 28 to be used in the data interpolation by the sampling function, i.e., the SINC function (step 6).

As previously described in 8) DETAILED OPERATION OF 3RD ARITHMETIC OPERATION DEVICE, such a data interpolation by the SINC function is accomplished performing equation (2). That is to say, the calculation is excuted for the entire addresses (x, y) of the memory region (the first memory 24), so that the interpolated value for one set of the scattered X-ray data $S(n_1X, n_2Y)$ can be calculated. Such an arithmetic operation of equation (2) is repeated for all of the scattered X-ray data, with a result that the interpolated intensity data for the respective pixels Isc(x, y) is finally stored in the first memory 24.

In the next step 7, a second digital subtraction is performed between the X-ray original image data acquired in step 2 and the interpolated intensity data of the scattered X-ray Isc(x, y) acquired in step 6. In other words, the first arithmetic operation device 26 subtracts the interpolated intensity data of the scattered X-ray Isc(x, y) over the entire projection area from the X-ray original image data Im(x, y) so as to obtain the desirable image data containing only the primary X-ray components Ip(x, y) (see equation (1)).

In the final step 8, the desirable X-ray image data having only the primary X-ray components Ip(x, y) is D/A-converted by the D/A converter 21 into the analogue X-ray image signal which is supplied either to the TV monitor 29 to be displayed, or to the imager to be recorded.

In connection with the third arithmetic operation device 28, it is also possible to utilize as independent data the intensity data of the scattered X-ray over the entire projection area Isc(x, y). In this case, this intensity data is derived from the first memory 24 through the data bus 40, which can store at least the intensity data having 1 TV frame capacity.

11). PRACTICAL CIRCUIT OF 3RD ARITHMETIC OPERATION DEVICE

Fig. 11 shows a block diagram of the practical circuit of the third arithmetic operation device 28. A description of this practical circuit will now be made with reference to Fig. 7.

The registers 70A to 70G of Fig. 7 correspond to latch circuits 90A to 90G of Fig. 11. An adder 92 is employed as the subtracter 72 to add $(x-n_1X)$ to $(y-n_2Y)$. It should be noted that in practice the subtraction is effected by this adder 92.

The first multiplier 74, ROM 76, second multiplier 80 and third multiplier 82 are identical to those in Fig. 7. A latch circuit (X) 94 and latch circuit (Y) 96 correspond to the X-register 77 and Y-register 79. Another latch circuit 98 is connected to the output of the third multiplier 82, thereby deriving the output signal L-OUT therefrom.

The circuit elements employed are all commercially available and listed in the following table.

TABLE

LATCH 90A to 90G, LATCH(X)(Y), LATCH 98	---SN74LS374N	----TI
ADDER92	---74F283	---Fairchild
1st & 3rd MULTIPLIER 74	---Am29516	---AMD
ROM 76	---MB7142	---Fujitsu
2nd MULTIPLIER 80	---MPY-8HJ	---TRW

A description will now be made of a timing chart shown in Fig. 12.

A signal HD has the horizontal (X direction) scanning period (63.5 μS) with respect to the memory region. A signal $\overline{\text{SCAT H}}$ is a signal to obtain the scattered X-ray signal X is the X direction, and a signal $\overline{\text{SCAT V}}$ is a signal to obtain the scattered X-ray signal Y in the Y direction. A signal VADR is an address signal in the Y direction. A REFERENCE CKC is a reference clock signal having a period of 100 ns.

The respective output signals of the first multiplier 74 (MPY(A)) and of the second multiplier 82

(MPY(B)) are represented under a given timing in Fig. 12. A signal L-OUT is an output signal of the final latch circuit 98. This output signal L-OUT has a delay of 400 ns.

In accordance with the present invention various advantage can be realized.

The X-ray image data containing only the primary X-ray components can be obtained by subtracting the interpolated intensity data of the scattered X-rays from the X-ray original image data which is taken without using the X-ray shield member. The scattered X-ray intensity data is interpolated by utilizing the sampling function.

As a result, it is possible to provide the X-ray diagnostic apparatus by which the X-ray images of the X-ray scanned object can be displayed, whose contrast and sharpness are remarkably improved. It can also contribute to the quantative analysis on the medical image data.

While the present invention has been described using a specific embodiment, it should be understood that further modifications and changes can be made without departing from the scope of the present invention.

For example, in the previous embodiment as shown in Fig. 4, the second arithmetic operation device 27 was employed to perform the bilevel quantization to the intensity data of the scattered X-ray for the portions which are not shielded by the lead pieces 56. However, it is possible to omit the second arithmetic operation device 27.

Further, it is not necessary to obtain the average value of the scattered X-ray data for the shielded portions in the system processing unit 20. That is to say, in the previous embodiments the central addresses of the bilevel-quantized data (1-level signal) were utilized as the data indicating the shielded portions.

However, it is not absolutely necessary to employ such central addresses, but to utilize the other addresses.

It is also possible to construct a single operation unit to combining all of the arithmetic operations of the first to third devices 26, 27 and 28. Also a single memory can be realized instead of the first and second memories 24 and 25.

Claims:

1. An X-ray diagnostic apparatus (100) characterized by comprising:

an X-ray source (11) for successively generating X-rays;

means (22) for detecting an X-ray image of an object (34) under examination by projecting the X-rays from the X-ray source (11) toward the object (34), and for converting the detected image into X-ray transmission signals;

an analogue-to-digital converter (23) for converting the X-ray transmission signals into corresponding digital transmission data;

an X-ray shield member (50) having a plurality of X-ray shields (56), for partially blocking the transmission of the X-rays over an X-ray projection area (38) defined by projecting the X-rays from the X-ray source (11) to the X-ray detection means (22) through the object (34);

first memory means (24) for temporarily storing at least first X-ray transmission data acquired during a first X-ray projection period under the condition that the X-ray shield member (50) is inserted into the X-ray projection area (38);

second memory means (25) for temporarily storing at least second transmission data (Im(x, y)) acquired during a second X-ray projection period under the condition that the X-ray shield member (50) is removed away from the X-ray projection area (38);

first arithmetic operation means (26) for performing a first subtraction between the first X-ray transmission data and the second X-ray transmission data so as to obtain first scattered X-ray intensity data of portions within the X-ray projection area (38) which are shielded by the X-ray shields (56), and for performing a second subtraction between second scattered X-ray intensity data (Isc(x, y)) and the second X-ray transmission data (Im(x, y)) so as to obtain third X-ray transmission data (Ip(x, y)) free from the scattered X-ray components; and

second arithmetic operation means (28) for performing data interpolation by a SINC function to the first scattered X-ray intensity data so as to obtain the second scattered X-ray intensity data (Isc(x, y)) over the entire X-ray projection area (38).

2. An apparatus (100) as claimed in Claim 1, characterized by further comprising third arithmetic operation means (27) coupled to the first arithmetic operation means (26) for performing bilevel quantization to the first scattered X-ray intensity data of the shielded portions so as to obtain bileveled intensity data one of which represents effective intensity data of the scattered X-ray components of the shielded portions.

3. An apparatus as claimed in Claim 2, characterized by further comprising system processing means (20) coupled to the third arithmetic operation means (27) for at least processing the bileveled intensity data derived from the third arithmetic operation means (27) and the first X-ray transmission data stored in the first memory means (24) so as to obtain memory data for the shielded portions and average values of the scattered X-ray intensity data, whereby the second arithmetic operation executes the data interpolation by the SINC function on the average values of the scattered X-ray intensity data based upon the memory data for the shielded portions so as to obtain the second scattered X-ray intensity data (Isc(x, y)) over the entire X-ray projection area (38).

4. An apparatus (100) as claimed in Claim 3, characterized in that the memory data for the shielded portions contains central addresses of the respective shielded portions with respect to the first memory

means (24) and also addresses indicating distances between the adjoining central addresses thereof.

5. An apparatus (100) as claimed in Claim 1, characterized in that the X-ray shield member (50) is constructed by a synthetic resin film (58) and the X-ray shields which are lead pieces (56) equidistantly arranged in a matrix form.

6. An apparatus (100) as claimed in Claim 5, characterized in that each of said lead pieces (56) is a square having 2 × 2 millimeters.

7. An apparatus (100) as claimed in Claim 1, characterized in that the interrupted insertion of the X-ray shield member (50) into the X-ray projection area (38) is effected by a mechanical slide device (54) along a longitudinal axis of a couch (36) on which the object (34) under examination lies down.

8. An apparatus (100) as claimed in Claim 1, characterized in that the X-ray shield member (50) is positioned adjacent to the X-ray source (11) within the X-ray projection area (38).

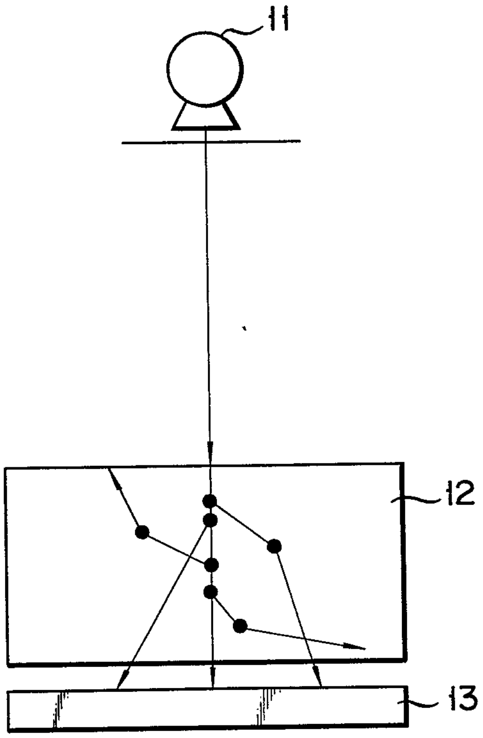
9. An apparatus (100) as claimed in Claim 1, characterized in that all the first, second and third arithmetic operation means (26:28:27) are united into a single arithmetic operation device.

10. An apparatus (100) as claimed in Claim 1, characterized in that all the first, second and third arithmetic operation means (26:28:27) are united into a single arithmetic operation device, and both the first and second memory means (24:25) are merged into a single memory device.

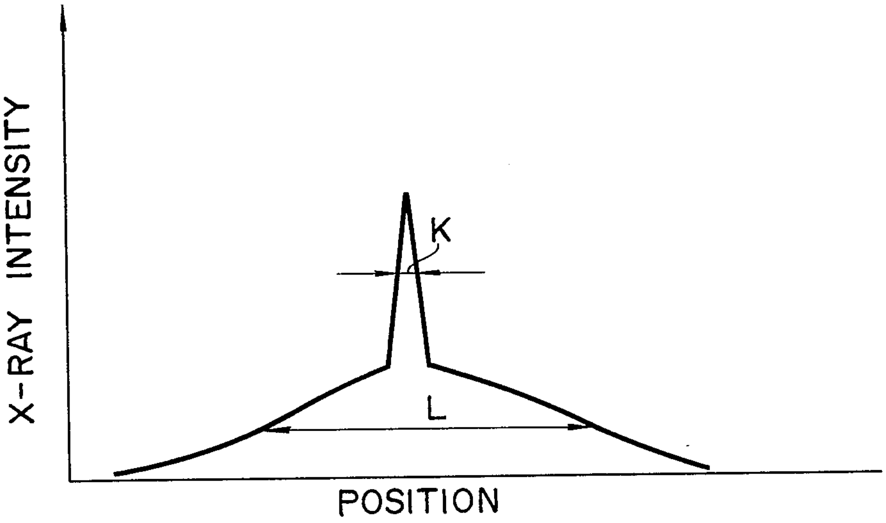
11. An apparatus (100) as claimed in Claim 1, characterized in that the first arithmetic operation of the first arithmetic operation means (26) to obtain the data representing the intensity distribution of scattered X-ray components of the shielded portions is effected prior over the second arithmetic operation so as to subtract the data (Isc(x, y)) representing the

intensity distribution of scattered X-ray components over the entire projection area (38) from the second transmission data (Im(x, y)).

F I G. 1



F I G. 2



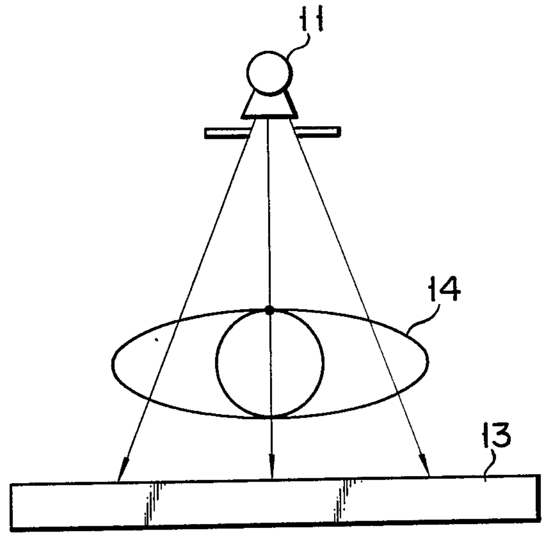


FIG. 3A

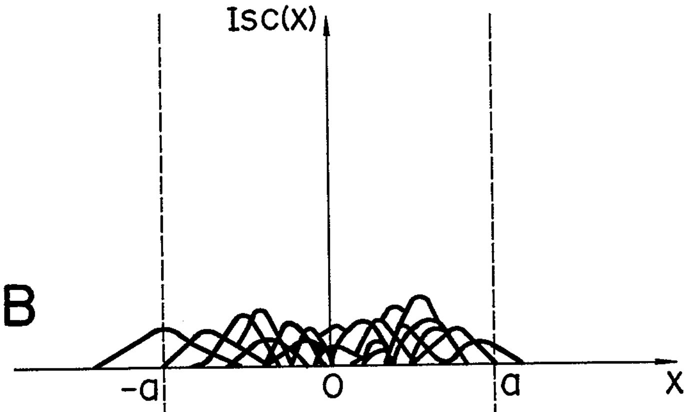


FIG. 3B

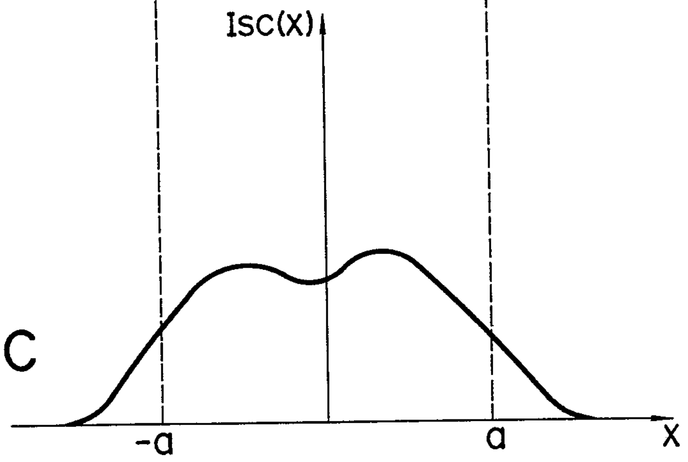


FIG. 3C

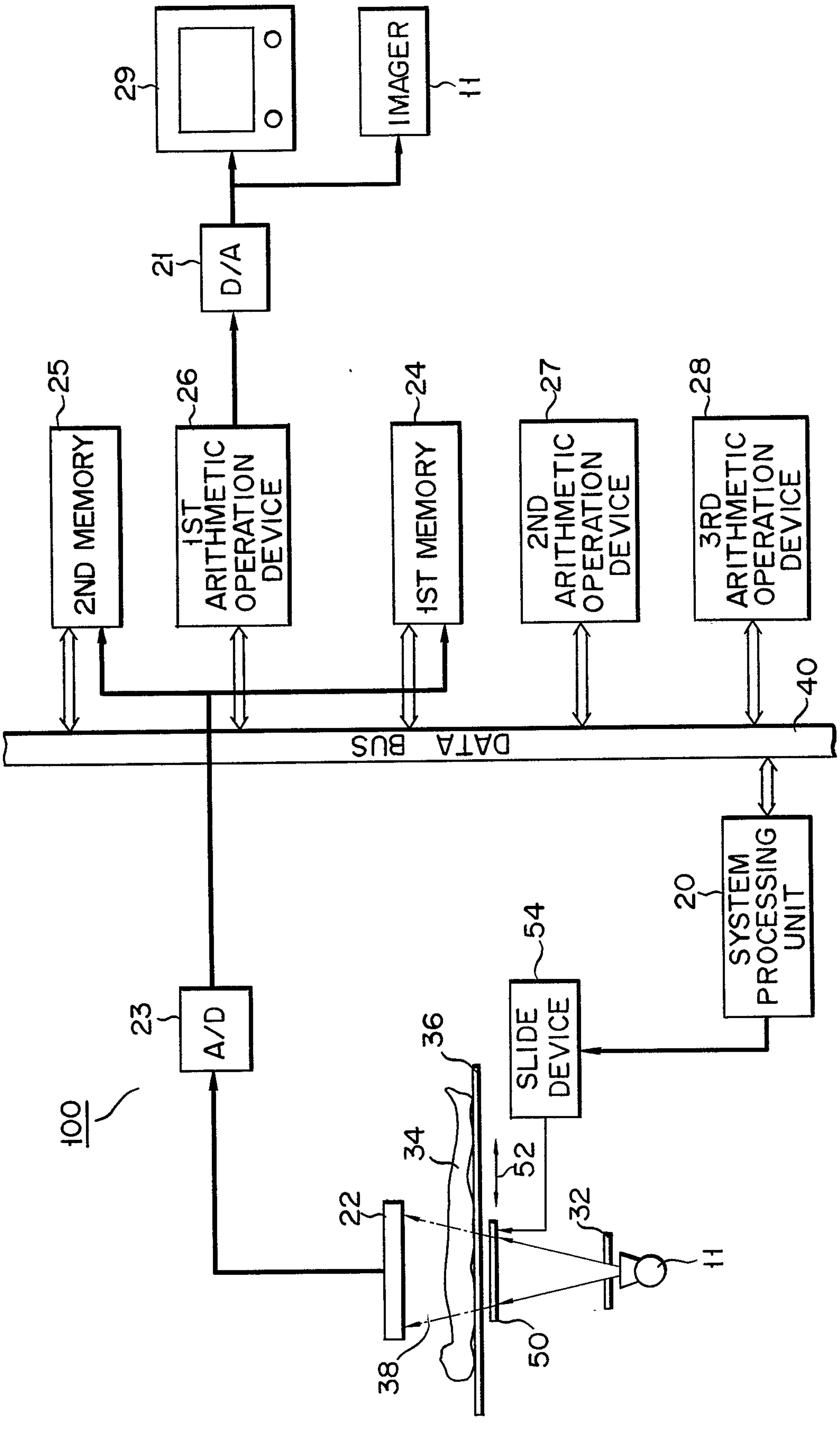

100
23
A/D
36
SLIDE DEVICE
54
34
52
22
32
11
38
50
50
20
SYSTEM PROCESSING UNIT
DATA BUS
40
2ND MEMORY
25
1ST ARITHMETIC OPERATION DEVICE
26
1ST MEMORY
24
2ND ARITHMETIC OPERATION DEVICE
27
3RD ARITHMETIC OPERATION DEVICE
28
D/A
21
29
IMAGER
11

FIG. 4

FIG. 5

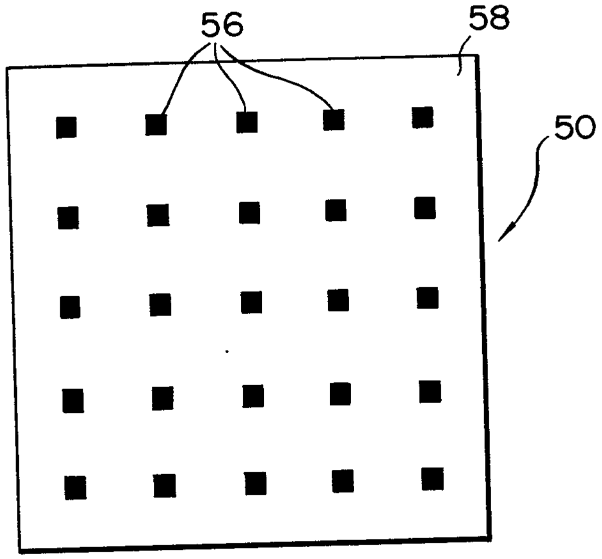


FIG. 6A

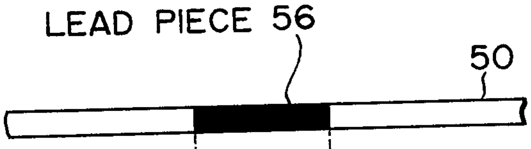


FIG. 6B

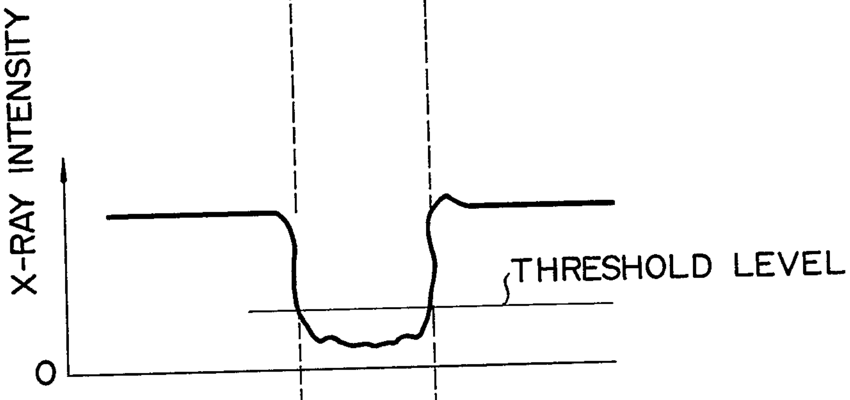


FIG. 6C

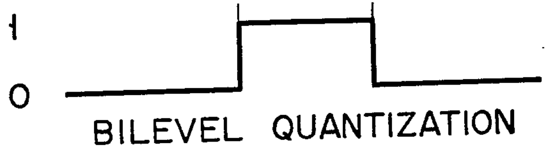
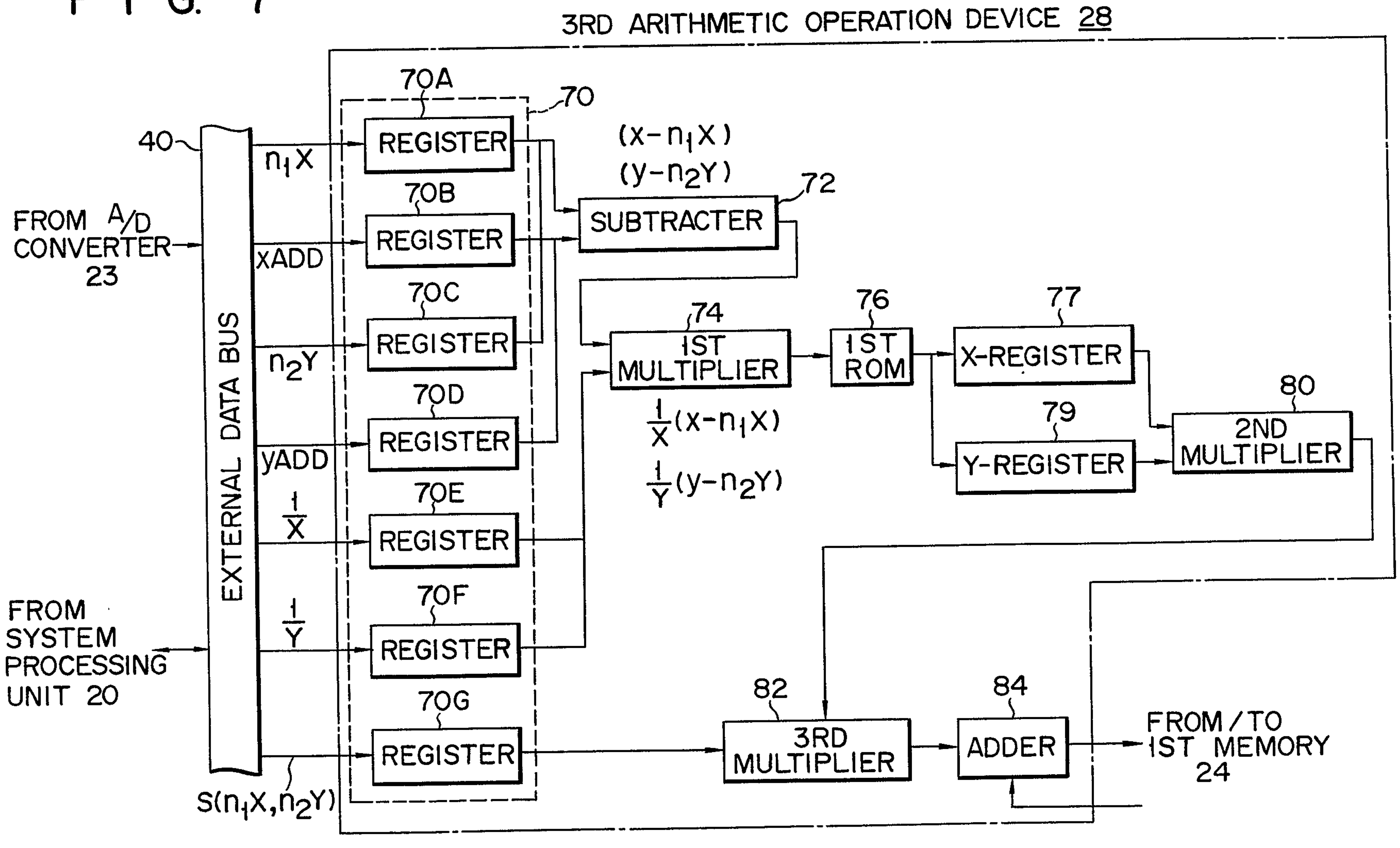


FIG. 7


3RD ARITHMETIC OPERATION DEVICE 28
40
FROM A/D CONVERTER 23
FROM SYSTEM PROCESSING UNIT 20
EXTERNAL DATA BUS
n_1X
xADD
n_2Y
yADD
$\frac{1}{X}$
$\frac{1}{Y}$
$S(n_1X, n_2Y)$
70
70A
REGISTER
70B
REGISTER
70C
REGISTER
70D
REGISTER
70E
REGISTER
70F
REGISTER
70G
REGISTER
$(x-n_1X)$
$(y-n_2Y)$
72
SUBTRACTER
74
1ST MULTIPLIER
$\frac{1}{X}(x-n_1X)$
$\frac{1}{Y}(y-n_2Y)$
76
1ST ROM
77
X-REGISTER
79
Y-REGISTER
80
2ND MULTIPLIER
82
3RD MULTIPLIER
84
ADDER
FROM/TO 1ST MEMORY 24

F I G. 8

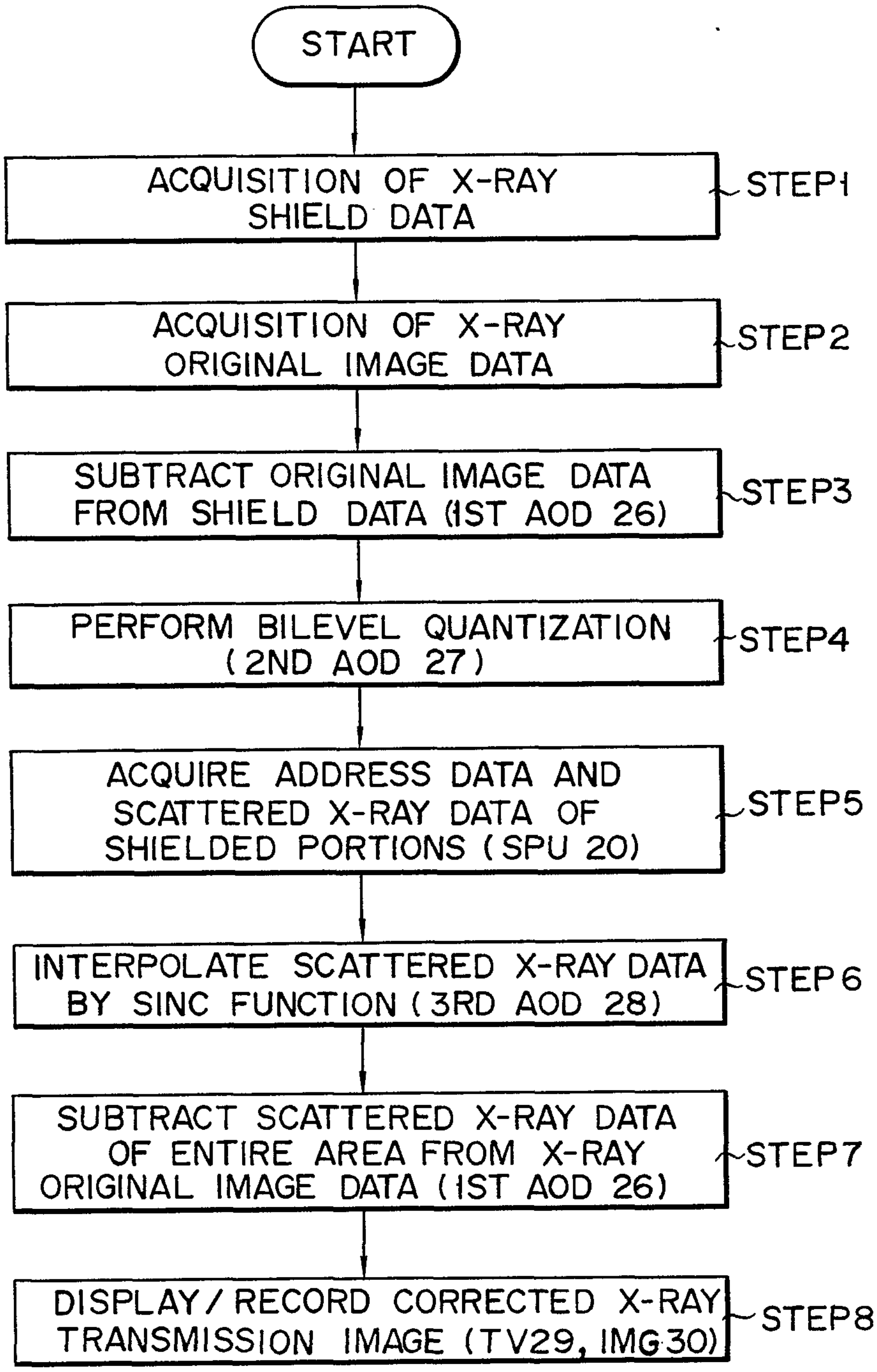

START
ACQUISITION OF X-RAY SHIELD DATA
STEP1
ACQUISITION OF X-RAY ORIGINAL IMAGE DATA
STEP2
SUBTRACT ORIGINAL IMAGE DATA FROM SHIELD DATA (1ST AOD 26)
STEP3
PERFORM BILEVEL QUANTIZATION (2ND AOD 27)
STEP4
ACQUIRE ADDRESS DATA AND SCATTERED X-RAY DATA OF SHIELDED PORTIONS (SPU 20)
STEP5
INTERPOLATE SCATTERED X-RAY DATA BY SINC FUNCTION (3RD AOD 28)
STEP6
SUBTRACT SCATTERED X-RAY DATA OF ENTIRE AREA FROM X-RAY ORIGINAL IMAGE DATA (1ST AOD 26)
STEP7
DISPLAY/RECORD CORRECTED X-RAY TRANSMISSION IMAGE (TV29, IMG30)
STEP8

FIG. 9

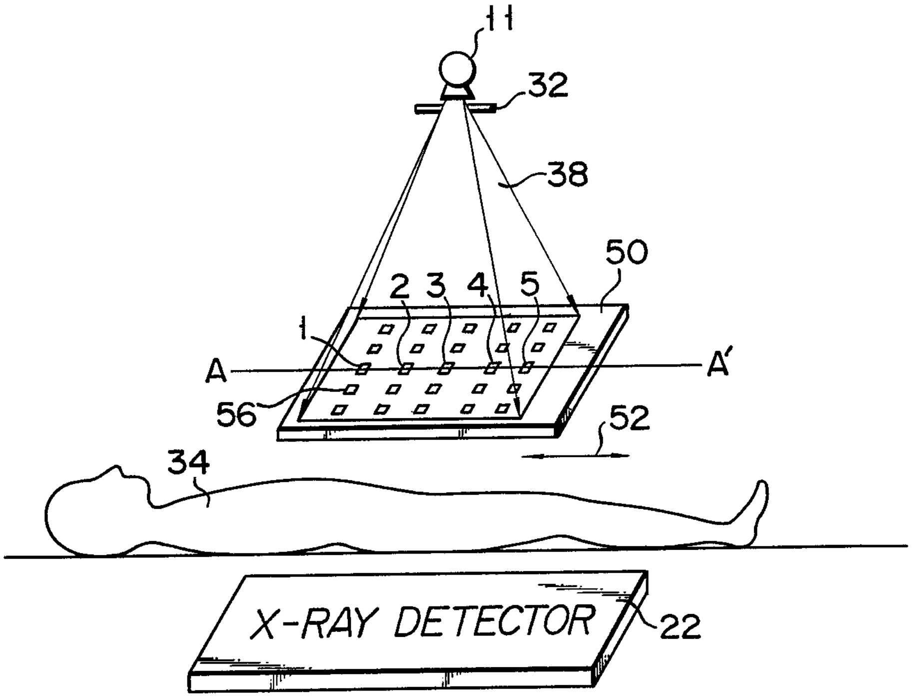

11
32
38
50
2 3 4 5
1
A
A′
56
52
34
X-RAY DETECTOR
22

FIG. 10

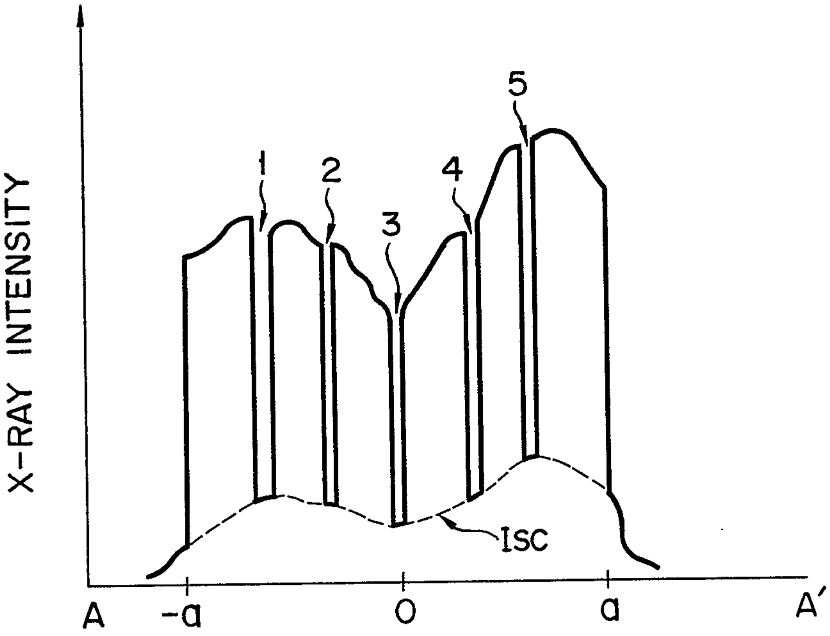

X-RAY INTENSITY
1
2
3
4
5
ISC
A
-a
0
a
A′

FIG. 11

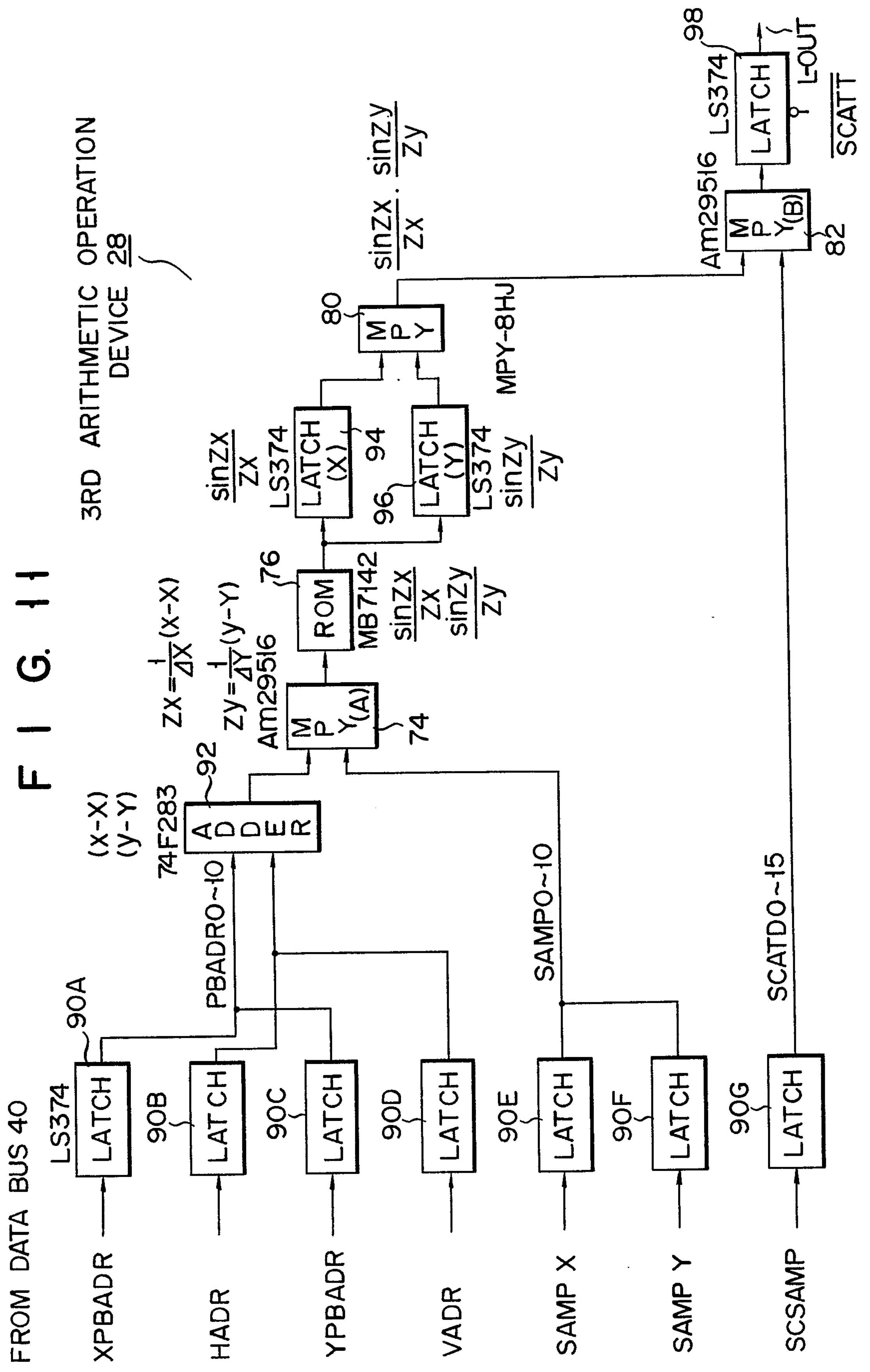
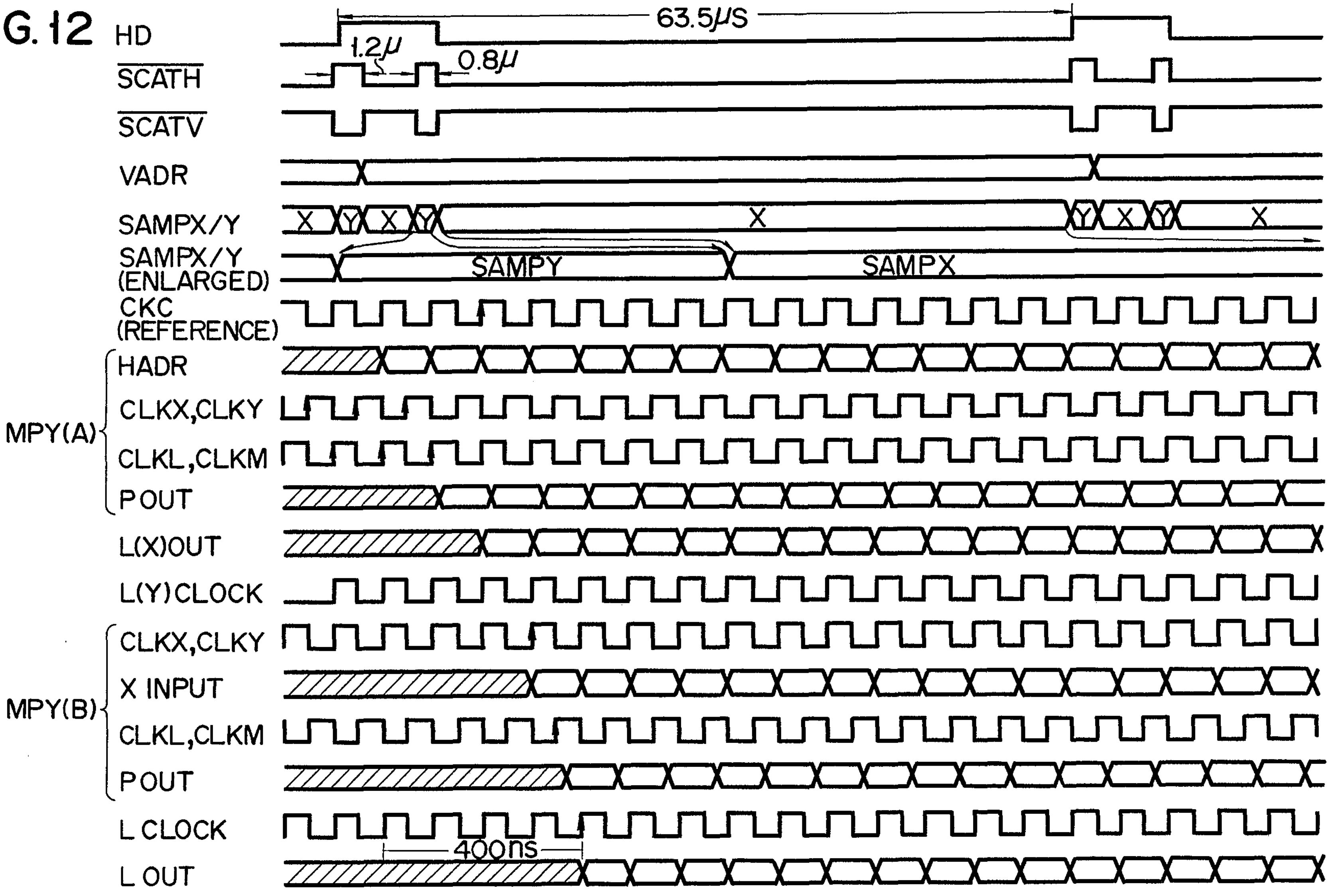

3RD ARITHMETIC OPERATION DEVICE 28
FROM DATA BUS 40
XPBADR
HADR
YPBADR
VADR
SAMP X
SAMP Y
SCSAMP
LS374
LATCH
90A
90B
90C
90D
90E
90F
90G
PBADR0~10
SAMP0~10
SCATD0~15
(x-X)
(y-Y)
74F283
ADDER
92
$Zx = \frac{1}{\Delta X}(x-X)$
$Zy = \frac{1}{\Delta Y}(y-Y)$
Am29516
MPY(A)
74
ROM
76
MB7142
$\frac{\sin Zx}{Zx}$
$\frac{\sin Zy}{Zy}$
LATCH (X)
94
LATCH (Y)
96
MPY
80
MPY-8HJ
$\frac{\sin Zx}{Zx} \cdot \frac{\sin Zy}{Zy}$
MPY(B)
82
98
L-OUT
$\overline{SCATT}$

FIG.12


HD
63.5μS
1.2μ
0.8μ
SCATH
SCATV
VADR
SAMPX/Y
X
Y
X
Y
X
Y
X
Y
X
SAMPX/Y (ENLARGED)
SAMPY
SAMPX
CKC (REFERENCE)
MPY(A)
HADR
CLKX,CLKY
CLKL,CLKM
POUT
L(X)OUT
L(Y)CLOCK
MPY(B)
CLKX,CLKY
X INPUT
CLKL,CLKM
POUT
L CLOCK
400ns
L OUT