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(71) Applicant: KONINKLIJKE PHILIPS ELECTRON-
ICS N.V. [NL/NL]; Groenewoudseweg 1, NL-5621 BA
Eindhoven (NL).

(72) Inventors: JAGO, James, R.; Prof. Holstlaan 6, NL-5656
AA Eindhoven (NL). OLSSON, Lars, J.; Prof. Holstlaan
6, NL-5656 AA Eindhoven (NL). ENTREKIN, Robert,
R.; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).

(74) Agent: LOTTIN, Claudine; Internationaal Octrooibureau
B.V., Prof Holstlaan 6, NL-5656 AA Eindhoven (NL).

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(54) Title: ULTRASONIC DIAGNOSTIC SYSTEMS WITH SPATIAL COMPOUNDED PANORAMIC IMAGING

(57) Abstract: A method and apparatus are described which produce spatially compounded panoramic ultrasonic images by elec-
tronically steering beams in a plurality of different look directions as a transducer is moved in relation to a panoramic image field.
The received echo information is compounded, then aligned and combined with previously acquired echo information to form a
spatially compounded panoramic image. Alternatively, the received echo information may be aligned with previously acquired echo
information, then combined to produce spatial compounding and a panoramic image in one process.

Ultrasonic diagnostic systems with spatial compounded panoramic imaging

This invention relates to ultrasonic diagnostic imaging systems and, in particular, to ultrasonic diagnostic imaging systems which produce spatially compounded panoramic images.

A method of processing and displaying ultrasonic images which is presently
5   commercially available is known as extended field of view or panoramic imaging. In a basic realtime imaging mode, an ultrasonic transducer produces realtime images of the area of the body immediately in front of the transducer aperture. When the transducer is moved to another location on the body, the images will be of the area in front of the transducer aperture at the new location. That is, as the transducer is moved along the body, the ultrasound system
10   will continuously produce an image of the area currently in front of the transducer aperture at any given moment. Panoramic imaging produces a composite image covering all of the areas which were in front of the transducer aperture including its starting and ending locations and every location in between. Panoramic imaging was initially performed over twenty years ago by B-arm ultrasound scanners, which would send and receive scanlines as the transducer was
15   moved. The spatial location of each scanline was tracked by position sensors in the B-arm and the scanlines then assembled to form a continuous image under the path of travel of the transducer. In today's commercial systems the transducer used is an array transducer which continuously scans and acquires image frames. The need for the B-arm is obviated by correlating successive image frames on the basis of their common (overlapping) image
20   content. When the array transducer is moved in a path such that successive image frames are overlapping and are co-planar there is generally sufficient correlation to align the image frames to each other. The aligned image frames are assembled together to form a continuous

recognizes that the image alignment process could be used in other image improvement

procedures such as compounding. In U.S. Pat. 5,566,674 this extension is made by acquiring

images of the same anatomy in the body from different transducer positions as demonstrated

in fig. 1 of that patent. The images are aligned, then compounded to form a new image with

5   reduced shadowing and speckle.

It is desirable to have an imaging technique which combines all of the

favorable attributes of the above systems, that is, a panoramic image in which shadowing and

speckle are reduced by compounding. The technique suggested by the '004 and '674 patents,

acquiring images from different transducer positions, has numerous drawbacks, however.

10   Many paths along which a transducer is moved for panoramic imaging are substantially

linear, such as the leg when imaging the saphenous veins. While points in the image may be

interrogated by different scanlines of the image frame from frame to frame, the apertures of

the two scanlines are usually highly correlated and produce little if any compounding effect

because the scanlines in the overlapping image areas are substantially parallel. In other areas

15   of the body such as the abdomen, the torso is generally too large with too much attenuation to

be able to view the same anatomy from both sides of the body. Thus the diversity in views of

the anatomy needed for compounding often cannot be obtained by simply moving the

transducer. Even if they can, the transducer displacement required to acquire them, the

distortion caused by tissue deformation from the transducer, and the possibility that the two

20   views will not be co-planar and hence not correlated all increase the likelihood that the

panoramic imaging registration algorithm will fail. It is desirable to be able to produce

spatially compounded panoramic images without these drawbacks.

In accordance with the principles of the present invention, spatially

compounded panoramic ultrasound images are produced by acquiring images as an array

25   transducer is translated in relation to an area to be scanned. As the transducer is moved

scanlines are electronically steered in a plurality of look directions relative to the transducer.

The electronically steered scanlines are combined to form spatially compounded images

which are aligned and combined to form a spatially compounded panoramic image. In one

embodiment spatially compounded images are initially formed, then aligned and combined to

30   form the panoramic image. In another embodiment component image frames of different

look directions are aligned and then combined to form the spatially compounded panoramic

image in one combining step, which reduces blurring from the transducer motion. In the first

approach, the spatially compounded images may be produced at the rate of once for each full

3

sequence of look directions, once for each new look direction, or after a partial new sequence of look directions have been scanned.

In the drawings:

Figure 1 illustrates the scanning of a spatially compounded panoramic image in accordance with the principles of the present invention;

Figure 2 illustrates in block diagram form an ultrasonic diagnostic imaging system constructed in accordance with the principles of the present invention;

Figure 3 illustrates in block diagram form a preferred implementation of the spatial compounding processor of Figure 2;

Figures 4a and 4b illustrate three overlapping elemental images which form a panoramic image; and

Figure 5 depicts the organization of a panoramic image history buffer;

Figures 6a-6c illustrate how successive elemental images are entered into the history buffer of Figure 5;

Figures 7a-7d illustrate different techniques for acquiring and combining component frames from different look directions to form spatially compounded panoramic images in accordance with the principles of the present invention;

Figure 8 illustrates a process for compounding and registering component frames acquired as shown in Figure 7c;

Figure 9 illustrates a process for registering and combining component frames directly into a spatially compounded panoramic image;

Figure 10 illustrates a process for acquiring component frames of differing look directions which reduces the maximum steering angle difference between successive component frames;

Figure 11 illustrates a spatially compounded panoramic imaging process in which partially compounded images are used; and

Figure 12 illustrates a sequence of frames in which the registration algorithm only operates on frames of the same steering direction.

Figure 1 illustrates panoramic scanning in accordance with the present invention. A scanhead 10 is moved along the surface 94 of the body to produce a panoramic image of the tissue and vessels 92,94,96 beneath the path of travel of the scanhead. Generally an ultrasonic couplant (not shown) is applied between the scanhead and the skin surface to facilitate sliding the scanhead and the passage of ultrasound between the scanhead and the body. The scanhead includes an array transducer 12 and the scanhead is moved generally in

line with the image plane of the transducer as indicated at 14 so that successive images will have some common image content. As the scanhead is translated the array transducer is operated to transmit and receive ultrasonic beams which are electronically steered in a plurality of look directions. Figure 1 illustrates three beam steering directions by the

5   scanlines indicated at A, B, and C. The scanlines at A are steered to the left, the scanlines at B are steered to the right, and the scanlines at C are steered straight ahead from the array transducer. While this example only shows three steering directions for clarity of illustration, in a constructed embodiment up to nine different steering directions are used. Figure 1 illustrates the use of a steered linear array transducer, but a steered phased array transducer or

10   steered curved array transducer as shown in U.S. patent [application serial number 09/577,021] may also be used. The beam steering angles differ sufficiently so that points in the body which are interrogated by multiple beams are viewed at look directions differing sufficiently to give the improved image quality of spatial compounding when echoes from the point are combined. Transmission and reception of the differently steered beams may be

15   interleaved in any order, but in a preferred embodiment component image frames of scanlines of the same steering direction are acquired in succession, as discussed below. As the scanhead is moved in the direction 14 shown in the drawing, the tissue and vessels beneath the scanhead are interrogated by overlapping scanlines of multiple look directions as shown at the right portion 90 of the drawing. Echoes from common points are combined to produce

20   spatial compounding, and the scanlines beneath the path of travel of the scanhead are assembled in one image to produce a spatially compounded panoramic image.

An advantage of this scanning technique is that the tissue of interest is rapidly electronically scanned from multiple predetermined look directions so that the spatial compounding effect is reliably obtained. It will be appreciated that moving a linear array

25   transducer without beam steering along a flat surface of the body, such as down the leg, will produce no spatial compounding effect as the points in the image will always be viewed from the same look direction. If the surface of the body along which the transducer is move is curved or irregular, some spatial compounding may occur, but the effect can be extremely variable as it will be a function of the irregularity of the path of travel and the distance over

30   which the transducer is moved, and many areas of the image may exhibit no spatial compounding effect at all. Even the use of a curved array without beam steering can only produce a spatial compounding effect, if any, which is strongly a function of the distance moved by the transducer. Electronic beam steering can eliminate much of this variability, reliably producing a more uniform spatial compounding effect along the entire panoramic

image. A further advantage is that the compounding of echoes from rapidly electronically steered look directions need not rely upon the accurate registration of component frames during panoramic image formation, which is often the limiting factor in using averaging for panoramic image combining because of the blurring caused by elemental image mis-registration.

Referring to Figure 2, an ultrasonic diagnostic imaging system constructed in accordance with the principles of the present invention is shown. A scanhead 10 including an array transducer 12 transmits beams at different angles over an image field denoted by the dashed rectangle and parallelograms. Three groups of scanlines are indicated in the drawing, labeled A, B, and C with each group being steered at a different angle relative to the scanhead. The transmission of the beams is controlled by a transmitter 14 which controls the phasing and time of actuation of each of the elements of the array transducer so as to transmit each beam from a predetermined origin along the array and at a predetermined angle. The echoes returned from along each scanline are received by the elements of the array, digitized by analog to digital conversion, and coupled to a digital beamformer 16. The digital beamformer delays and sums the echoes from the array elements to form a sequence of focused, coherent digital echo samples along each scanline. The transmitter 14 and beamformer 16 are operated under control of a system controller 18, which in turn is responsive to the settings of controls on a user interface 20 operated by the user of the ultrasound system. The system controller controls the transmitter to transmit the desired number of scanline groups at the desired angles, transmit energies and frequencies. The system controller also controls the digital beamformer to properly delay and combine the received echo signals for the apertures and image depths used.

The scanline echo signals are filtered by a programmable digital filter 22, which defines the band of frequencies of interest. When imaging harmonic contrast agents or performing tissue harmonic imaging the passband of the filter 22 is set to pass harmonics of the transmit band. The filtered signals are then detected by a detector 24. In a preferred embodiment the filter and detector include multiple filters and detectors so that the received signals may be separated into multiple passbands, individually detected and recombined to reduce image speckle by frequency compounding. For B mode imaging the detector 24 will perform amplitude detection of the echo signal envelope. For Doppler imaging ensembles of echoes are detected and assembled for each point in the image and are Doppler processed to estimate the Doppler shift or Doppler power intensity.

In accordance with the principles of the present invention the digital echo signals are processed by spatial compounding in a processor 30. The digital echo signals are initially pre-processed by a preprocessor 32. The pre-processor 32 can preweight the signal samples if desired with a weighting factor. The samples can be preweighted with a weighting

5   factor that is a function of the number of component frames used to form a particular compound image. The pre-processor can also weight edge lines that are at the edge of one overlapping image so as to smooth the transitions where the number of samples or images which are compounded changes. The pre-processed signal samples may then undergo a resampling in a resampler 34. The resampler 34 can spatially realign the estimates of one

10   component frame or to the pixels of the display space. This may be desirable when there is motion between image frames, there is motion within an image, or there is scanhead motion during image acquisition. However, in many of the embodiments described below, this realignment is bypassed and is performed by the panoramic image processor when elemental images are aligned to form the panoramic image.

15   After resampling the image frames are compounded by a combiner 36. Combining may comprise summation, averaging, peak detection, or other combinational means. The samples being combined may also be weighted prior to combining in this step of the process. Finally, post-processing is performed by a post-processor 38. The post-processor normalizes the combined values to a display range of values. Post-processing can be most

20   easily implemented by look-up tables and can simultaneously perform compression and mapping of the range of compounded values to a range of values suitable for display of the compounded image.

The compounding process may be performed in estimate data space or in display pixel space. The compound images may be stored in memory (not shown) in either

25   estimate or display pixel form. If stored in estimate form the images may be scan converted by scan converter 40 when replayed from the memory for display. The scan converter and memory may also be used to render three dimensional presentations of the spatially compounded images as described in U.S. Patents 5,485,842 and 5,860,924. Following scan conversion the spatially compounded images are processed for display by a video processor

30   44 and displayed on an image display 50.

In accordance with the principles of the present invention the spatially compounded image data is used to form a panoramic image. The image data is coupled to an EFOV image processor 70. The EFOV image processor, which may operate with either estimate data (pre-scan converted) images or display data (scan converted pixel data) images,

receives each newly acquired image during the panoramic mode of operation and computes
the displacement and rotation between the new image and a previously acquired elemental
image of the panoramic image, as more fully described below. The EFOV image processor
stores the new image in registration with the previously acquired elemental images in an

5   extended image memory 72 as described below. Each time the panoramic image is extended
by the addition of new image data, the EFOV image data stored in the extended image
memory 72 is extracted from the memory and combined by a combiner 74 to form a new
panoramic image, which is coupled to the video processor 44 for viewing on the display 50.

        Figure 3 illustrates a preferred implementation of the spatial compounding

10   processor 30 of Figure 2. The processor 30 is preferably implemented by a general purpose
microprocessor or CPU, or one or more digital signal processors 60 which process the image
data in various ways. The processor 60 can weight the received image data and can resample
the image data to spatially align pixels from component frame to component frame, for
instance. The processor 60 directs the processed image frames to a plurality of frame

15   memories 62 which buffer the individual image frames. The number of image frames capable
of being stored by the frame memories 62 is preferably at least equal to the maximum
number of image frames to be compounded such as sixteen frames. Preferably the processor
is responsive to control parameters including image display depth, depth of region of greatest
compounding, clinical application, compound display rate, mode of operation, scanhead

20   motion and acquisition rate for determining the number of images to compound at a given
instant in time. The processor selects component frames stored in the frame memories 62 for
assembly as a compound image in accumulator memory 64. Various embodiments of the
accumulator memory which subtract the oldest component frame when adding a new
component frame, or which accumulate different compound images simultaneously, are

25   described in U.S. patent [application serial number 09/335,159], the contents of which are
incorporated herein by reference. The compounded image formed in the accumulator
memory 64 is weighted or mapped by a normalization circuit 66, then compressed to the
desired number of display bits and, if desired, remapped by a lookup table (LUT) 68. The
fully processed compounded image is then transmitted to the scan converter for formatting

30   and display as an elemental image of a panoramic image.

        The EFOV image processor 70 receives elemental images from the spatial
compounding processor 30 such as the sequence of partially overlapping elemental images
A', B', and C' shown in Figure 4a. The processor 70 computes the displacement from one
elemental image to the next on the basis of their overlapping (common) image areas. The

registration algorithms for computing this displacement are well known, including block

matching, correlation, normalized correlation, sum of absolute or squared differences,

gradient descent or mutual information techniques. Alternatively sensors of the motion or

displacement of the scanhead can be used to sense the registration parameters, including

5   Doppler sensing. When the displacement necessary to align (register) a new elemental image

to a previous elemental image in a panoramic image is known, the new elemental image can

be combined with the others to produce an extended image. The overlapping regions of the

elemental images are combined by techniques such as averaging, median filtering, peak

detection, or other linear, non-linear or adaptive processes. One way to do this is to employ a

10   buffer memory as the extended image memory 72 in which a single panoramic image formed

from previously acquired elemental images is stored. The new elemental image is then added

to the panoramic image in the buffer, generally through some form of weighting or

averaging, to produce a new panoramic image for display. Once the new elemental image has

been added to the panoramic image it can no longer be separately identified, as it is blended

15   into and becomes an integral part of the panoramic image. In a preferred embodiment of the

present invention, a history buffer is used for the extended image memory 72, in which the

pixels of the individual elemental images continue to be separately distinguishable. Figure 5

depicts the organization of a preferred history buffer 130. The x,y coordinates of the history

buffer 130 shown on the top surface 132 correspond to the maximum sight area of a

20   displayed panoramic image. The column depth z of the history buffer is the maximum

number of pixels of different elemental images which can be stored and combined to form

each pixel of the panoramic image. In the illustrated embodiment the history buffer is shown

to be six pixels deep as shown by delineations 132. In a constructed embodiment the history

buffer may be eight to sixteen pixels deep.

25   Referring back to Figure 4a, three exemplary elemental images A', B', and C'

are shown which are acquired as the initial elemental images for a panoramic image. Image

A' is the first to be acquired as the scanhead moves from left to right to acquire images A',

B', and C' in succession. Image A' is therefore entered first into the history buffer 130 and is

aligned to the left edge of the buffer as shown in Figure 5. If the scanhead were moving from

30   right to left, the first image A' would be aligned at the right side of the buffer so that the

panoramic image could be extended from right to left instead of from left to right as depicted

in this example. When the image A' is entered into the history buffer, it completely fills the

pixel storage areas (depth z) beneath its x,y coordinates with image A' pixel values as shown

in Figure 6a. Figures 6a-6c depict the history buffer cross-section in a plane 140 between

arrows 7-7 in Figure 5. The remaining pixel storage areas of the history buffer continue to be set to invalid values at this time.

Image B' is next acquired and aligned with image A' as described above. Image B' is stored in the history buffer in its aligned position in x,y coordinates with respect to image A'. Where image B' overlays image A', the image A' pixels are "pushed down" by one pixel depth so that the upper pixel is occupied by pixel B' and the remaining are still occupied by image A' pixel values, as shown in Figure 6b. In areas where image B' does not overlay image A', the full pixel depth is filled with image B' pixel values.

When image C' is acquired and aligned with image B' the push down process is repeated as shown in Figure 6c. In the columns indicated by arrow 142 where all three images overlap, the top pixel is from image C', the next pixel down is from pixel B', and the remaining pixel depth is filled with image A' pixels. In image areas where only images B' and C' overlap, the top pixel in the column is an image C' pixel, and those below are image B' pixels.

This process continues as additional elemental images are acquired to extend the panoramic image. The finite depth of the history buffer, six pixels in this example, limits the number of images which can overlap at any pixel location to the most recent six overlapping images. Older image pixels at the location are "pushed out" of the bottom of the buffer which, in the z direction, operates as a FIFO (first in, first out) buffer. This is unlike the above-described technique of simply recursively adding a new elemental image to a panoramic image, where an unlimited number of overlapping images are blended together. The finite limit of the history buffer provides a benefit of reduced image blurring as compared to the technique of simply recursively blending a panoramic image, since very old images in the history buffer overlay are removed by the FIFO push-down process. This is not possible where elemental images are blended into the panoramic image and are no longer separately distinguishable, unless each elemental image is stored and its position tracked for subsequent subtraction from the panoramic image. In addition the history buffer readily permits the scanning direction to be reversed during a scan. Another benefit is that the algorithm for combining elemental images into a panoramic image can be changed and different algorithms applied to the same extended image set.

Each time a new elemental image is added to the history buffer the combining algorithm is applied to the pixel data by combiner 74 to form a pixel of a panoramic image from each column of pixels in the history buffer. It is seen that the initial filling of an entire column with pixels of the first image acquired at an x,y coordinate effects a weighting of the

pixel data in favor of the initial image. If such weighting is not desired, the columns in the history buffer could only be filled one pixel depth at a time, or by another desired depth weighting. The combining algorithm may effect a summing of the pixel data at each column, an averaging or median filtering process, or some other linear or nonlinear filtering function

5   (FIR, IIR, static, conditional, or adaptive) automatically or adaptively selected or chosen by the user. The panoramic image for elemental images A', B', and C' would appear as shown by outline 120 in Figure 4b. In a preferred embodiment the area of the most recently acquired image, all or some (e.g., the leading edge) of the area currently beneath the transducer aperture, is displayed as a live, realtime image, which assists the user when moving the

10   scanhead along a selected path of anatomy. The previously acquired portion of the panoramic image is generally displayed as a static image, although it can also be displayed in motion when acquired and displayed in a synchronized manner as with the assistance of a heart gate (ECG signal).

        Figures 7a-7d illustrate different techniques for combining component frames

15   from different look directions to form spatially compounded panoramic images. Figure 7a illustrates an acquisition sequence of five component frames acquired from different steering directions. The first component frame A is acquired with the scanlines all steered in a look direction $\angle 1$, the second component frame B is acquired with the scanlines all steered in a look direction $\angle 2$, the third component frame C is acquired with the scanlines all steered in a

20   look direction $\angle 3$, the fourth component frame D is acquired with the scanlines all steered in a look direction $\angle 4$, and the fifth component frame E is acquired with the scanlines all steered in a look direction $\angle 5$. The sequence then repeats with another component frame A steered in a look direction $\angle 1'$, another component frame B steered in a look direction $\angle 2'$, another component frame C steered in a look direction $\angle 3'$, and so on. One way to spatially

25   compound this acquisition sequence is to wait until a complete new sequence of five component frames is acquired and then combine them, as shown in Figure 7b. Component frames A-E are combined to form one spatially compounded image 150 which is a combination of look directions $\angle 1$-$\angle 5$. After a new sequence of component frames A-E is acquired they are combined to form a second spatially compounded image (not shown) which

30   is a new combination of look directions $\angle 1'$-$\angle 5'$. An advantage of this technique is that each spatially compounded image which is used as an elemental image for a panoramic image is formed from entirely different image data. A disadvantage of this technique is that the frame rate at which a new elemental image is added to the panoramic image is limited in proportion

to the number of component frames of a spatially compounded image and the time required
to acquire them, which can give a discontinuous appearance to the buildup of the panoramic
image.

Figure 7c illustrates a second compounding technique which provides
5   elemental images for the panoramic image at a more rapid rate. In this sequence spatially
compounded image 162 combines the first five acquired component frame of look directions
∠1-∠5. When another component frame is acquired a second spatially compounded image
164 is formed of look directions ∠2-∠1'. Spatially compounded image 166 is formed of look
directions ∠3-∠2', and spatially compounded image 168 is formed of look directions ∠4-
10   ∠3'. Spatially compounded elemental images for panoramic imaging are thus produced at the
component frame acquisition rate, with each elemental image including four- fifths of the
image data as the preceding elemental image. The buildup of the panoramic image will
appear much smoother and more continuous as elemental images are added to the panoramic
image at a rapid rate. This compounding technique may be carried out by the methods and
15   apparatus described in the aforementioned U.S. patent [application serial number
09/335,159], including an image accumulator memory from which the oldest component
frame is subtracted and the new component frame added, or by the use of multiple image
accumulator memories which simultaneously produce compounded images of different sets
of component frames.

20   The technique of Figure 7c is used in the spatially compounded panoramic
imaging process diagrammed in Figure 8. The component frames representing a complete
acquisition sequence (one set of all angles A-E in this example) are first combined before
registration into a compounded image by the Compound process. This assumes that the
scanhead movement during this sequence is negligible, otherwise the compound image will
25   be blurred. In this example no component-frame-to-component-frame registration is
performed by the compound image processor. This Compound process is repeated for every
sequence of steered frames, ideally at the acquisition frame rate by for example an
accumulator method described above. The sequence of compounded images formed as the
scanhead is moved are then processed by the registration algorithm "Register" of the EFOV
30   image processor 70 to generate a single panoramic image of compounded data. This approach
has the advantage that the artifact reduction resulting from the spatial compounding should
help the registration algorithm to be very robust. Also, the real-time component at the leading
edge of the panoramic image already represents a compounded image without the need for
further processing.

Figure 7d illustrates a compounding technique which is intermediate the techniques of Figures 7b and 7c. This technique produces spatially compounded elemental images for panoramic imaging at a faster rate than Figure 7b, reducing the discontinuous buildup appearance of that technique, but at a lesser rate than Figure 7c, which reduces

5   computational complexity. In Figure 7d a spatially compounded image 172 is formed of look directions $\angle 1$-$\angle 5$. The next spatially compounded image 174 is formed after a plurality of new look directions are acquired and is formed of look directions $\angle 4$-$\angle 3$'. Each spatially compounded image contains some of the same image data as the preceding spatially compounded image, and includes a plurality of new look directions (in this example, three)

10   so that the panoramic image process is not processing a large amount of redundant image data. The interval at which new spatially compounded images are produced in the technique of Figure 7d is user variable; for instance, if the number of look directions is nine, the user might elect to have new spatially compounded images produced every four or five component frames. If the number of look directions is only three, the user may prefer to

15   produce a spatially compounded image every three frames, the technique of Figure 7b.

Figure 9 illustrates a spatially compounded panoramic imaging process in which steered component frames A-E can be input directly into the registration algorithm "Register" before they are combined, thus generating a panoramic image with significant spatial compounding even when scanning along a flat surface. In this process a single

20   registration step registers component frames of different look directions directly into a panoramic image to produce the panoramic image and spatial compounding simultaneously. Note that the panoramic image itself is generated by continually registering each new component frame with the previous set of registered component frames, traceable back to the first frame A of the acquisition. Conversely, the real-time component of the panoramic image

25   would be continuously updated by registering the N previous frames (where N is the number of unique steering angles) with the most recent frame.

One potential disadvantage of this method is that most algorithms for determining the frame-frame registration become less reliable when there is a large difference in view angle between the frames. This is mainly because of the influence of ultrasound

30   image artifacts, such as anisotropy, which can cause echoes and shadows from some targets to appear in different locations or at different intensities in images obtained from different angles. For the sequence shown in Figure 9, the difference in view angle between frames is small except for the transitions between the end of one complete set of angles (frame E) and the beginning of the next (frame A'). An alternative acquisition sequence is shown in Figure

13

10, which maintains a more uniform (and lesser maximum) angle difference between all frames at the expense of a higher minimum angle difference. Other angle sequences will have different advantages and disadvantages in registration robustness and beam steering programming.

5   Figure 11 illustrates a spatially compounded panoramic imaging process that is a compromise between the processes shown in Figures 9 and 10 above. This process compounds a sub-set of steered component frames (three of the five, in this example) to produce a first partially compounded image (e.g., A,C,E), followed by compounding of the remaining set of steered frames (e.g., B,C,D) to produce a second partially compounded

10   image. In the illustrated steering sequence, a non-steered frame C is acquired for every sub-sequence to ensure that the real-time (i.e., most recent image data) component of the panoramic image always includes non-steered data. This process would be repeated continuously, with the partially compounded images (A,C,E and B,C,D) being input sequentially into the registration algorithm Register. This approach would allow some

15   reduction of image artifacts and hence improvement in the robustness of the registration, while not incurring as much motion blurring during rapid scanhead movement as for the process of Figure 8.

In an embodiment of the present invention it is desirable to register component frames for spatial compounding and elemental images of a panoramic image as accurately as

20   possible. This ability is made more difficult when component frames exhibiting different steering directions are being registered because, as mentioned above, a target can return different echoes when interrogated from different angles, which puts great demand on the registration algorithm. Figure 12 illustrates a technique which addresses this problem by registering only component frames of a common steering direction. Figure 12 illustrates a

25   sequence of component frames A, B, C, etc. which are acquired as the transducer is moved along the body. Each component frame is acquired after translation of the transducer and its image to a new location. It may be seen that the translation between frames A and D is a combination of the translations from frame A to frame B to frame C to frame D. This may be expressed mathematically as

30   $$A \rightarrow D = A \rightarrow B + B \rightarrow C + C \rightarrow D$$

The translations between other frames of a common look direction may similarly be expressed as

$$B \rightarrow E = B \rightarrow C + C \rightarrow D + D \rightarrow E$$

$$C \rightarrow F = C \rightarrow D + D \rightarrow E + E \rightarrow F$$

$$D{\rightarrow}G = D{\rightarrow}E + E{\rightarrow}F + F{\rightarrow}G$$

and so on. The translation between the frames on the left side of each equation are computed by the registration algorithm of the panoramic image processor, as each pair of frames is acquired at the same look direction, easing the demands put on the registration algorithm.

5   The translation between succesively acquired frames is then computed from the simultaneous equations. For example, the translations $C{\rightarrow}F$ and $D{\rightarrow}G$ are computed by the registration algorithm. The translation between successively acquired frames $F{\rightarrow}G$ is calculated from

$$D{\rightarrow}G - C{\rightarrow}F = D{\rightarrow}E + E{\rightarrow}F + F{\rightarrow}G - C{\rightarrow}D - D{\rightarrow}E - E{\rightarrow}F$$

$$D{\rightarrow}G - C{\rightarrow}F = F{\rightarrow}G - C{\rightarrow}D$$

10      $$F{\rightarrow}G = C{\rightarrow}D + D{\rightarrow}G - C{\rightarrow}F$$

With $D{\rightarrow}G$ and $C{\rightarrow}F$ being determined by the registration algorithm and $C{\rightarrow}D$ being determined from a previous equation, the translation from frame F to frame G can be determined from the last equation. Thus, the registration algorithm is only called upon to determine the translation between commonly steered frames, with the frame-to-frame

15   displacement between successively acquired frames of differing steering directions determined from the simultaneous equations.

In order to start the above process, the translation between two pairs of successively acquired frames must be known, $A{\rightarrow}B$ and $B{\rightarrow}C$. Once these interframe displacements are known, the others can all be determined by registering frames of common

20   look directions and use of the simultaneous equations. Thus, at the outset of the process, the registration algorithm can be called upon to determine the translation between frames of different look directions, in this example, from A to B and from B to C. A variation of this which eases the task of the registration algorithm is for the user to pause momentarily before beginning to move the transducer in order to allow the transducer to acquire at least one full

25   sequence of frames of the different look directions while the transducer is at rest. The frame to frame translations between these frames will thus be zero, and consequently the initial equations will have some frame to frame translation values of zero. Once the transducer begins to move, the nonzero values will be determined by measuring the translation between frames of the same steering direction and the process will proceed as described above.

30   As a third alternative, these translations may be approximated by starting with three precursor frames A', B' and C' as shown in Figure 12, which are acquired at the same look direction. The translations from A' to B' and from B' to C' are determined by the registration algorithm using these commonly steered frames, then used as the translations

from A to B and from B to C. Given a substantially constant rate of transducer motion and high frame acquisition rate, the use of the translations between the precursor frames for those of the first frames in the sequence will be substantially accurate. The use of a sequence of commonly steered frames may be repeated during the acquisition process to estimate

5   accumulated translation errors or make adjustments to the registration process as desired.

One skilled in the art will recognize that the foregoing discussion illustrates frame to frame translation computations simply with plus and minus signs, but that in a constructed embodiment in which frame to frame motion includes translation and rotation, the acutal computations may involve more complex matrix operations.

10   The technique of Figure 12 is most accurate when only a few look directions are used for compounding, that is, when the sequence of component frames is relatively short. In the example of Figure 12, the sequence of component frames is only three frames in duration. This is because the technique relies upon the capability of aligning commonly steered frames between which there may be substantial transducer translation and hence little

15   common image content with which to register the two frames, putting the registration algorithm to a demanding task. Hence it may be desirable to activate this technique adaptively when the number of differently steered component frames is small, and to change to a different technique, such as simply trying to register successive frames, when the number of differently steered frames is high, e.g., eight or nine frames.

20   The frames which are registered in the foregoing examples may be entire image frames, or partial image frames, or image frames of reduced resolution or line density, or may be reference scanlines transmitted between displayed image frames for registration purposes as described in U.S. patent [application serial number 09/335,060].

The final choice of which method to use in a particular case will depend on the

25   speed of movement of the probe (and/or target), which could be clinical application dependent, and the inherent robustness of the chosen panoramic image registration algorithm to angle dependent artifacts. In general, the accuracy required to register component frames for spatial compounding is more demanding than the registration required to form a panoramic image from elemental images. Thus, when the probe is being moved slowly, it is

30   usually preferable to spatially compound before panoramic image registration. When the probe is being moved quickly, which can produce a blurred spatially compounded image, it is usually preferable to send component frames directly to the panoramic image registration process and let the panoramic registration algorithm reduce blurring to the best of its capability. In a preferred embodiment this choice is made adaptively by detecting the degree

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of scanhead motion as described in U.S. patent [application serial number 09/335,158] and automatically adjusting the spatial compounding and/or panoramic registration processes in response thereto. The panoramic imaging registration and combining algorithms may also be varied adaptively in response to the degree of scanhead motion, as may the variables of

5   spatial compounding as described in U.S. patent [application serial number 09/335,058].

Panoramic images can be formed using all ultrasound imaging modes, including fundamental and harmonic modes, power motion mode, Doppler, and grayscale, and 2D and 3D imaging modes. Spatial compounding, likewise, can operate in all of these modes. Thus, spatially compounded harmonic images of the present invention can be formed

10   in all of the ultrasound imaging modes.

CLAIMS:

1.   A method of producing a spatially compounded ultrasonic panoramic image comprising:

        transmitting a plurality of electronically steered beams in a plurality of directions from an array transducer aperture as the transducer aperture is moved in relation to

5   an extended image field so as to interrogate points in the extended image field from multiple look directions;

        receiving echoes in response to the transmitting;

        locationally organizing the received echoes; and

        combining locationally aligned echoes to produce a panoramic, spatially compounded

10   ultrasonic image which is larger than the transducer aperture.

2.   The method of Claim 1, wherein combining comprises:

        combining echoes from points in the image field which have been interrogated from multiple look directions to produce a spatially compounded image; and

15   combining the spatially compounded image with a previously acquired spatially compounded image to produce a panoramic, spatially compounded ultrasonic image which is larger than the transducer aperture.

3.   The method of one of Claims 1 or 2, for producing a spatially compounded

20   ultrasonic panoramic image comprising:

        receiving, from a translating transducer aperture, sequences of component image frames, different component image frames of a sequence exhibiting scanlines electronically steered in different look directions;

        combining a plurality of the component image frames to produce an elemental

25   spatially compounded image; and

        combining the elemental spatially compounded image with a previously acquired elemental spatially compounded image to produce a spatially compounded ultrasonic panoramic image.

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4.   The method of Claim 3, wherein the first-named combining comprises combining a plurality of component image frames on a spatially aligned basis.

5.   The method of Claim 3, wherein aligning utilizes one of block matching,
normalized correlation, correlation, sum of absolute differences, sum of squared differences, gradient descent, mutual information processing, Doppler sensing, or position or motion sensors.

6.   The method of one of Claims 1 or 2, for producing a spatially compounded
ultrasonic panoramic image comprising:
            receiving, from a translating transducer aperture, sequences of component
image frames, different component image frames of a sequence exhibiting scanlines electronically steered in different look directions;
            registering component image frames which exhibit a common look direction;
registering component image frames which exhibit different look directions through use of
the registered component image frames which exhibit a common look direction; and
            combining the registered component image frames to produce a spatially
compounded ultrasonic panoramic image.

7.   The method of one of Claims 1 or 2, for determining the translation between
successive image frames of repetitive sequences of image frames, each sequence including a plurality of image frames which exhibit different look directions comprising:
            acquiring a plurality of the sequences of image frames;
            registering an image frame of one of the sequences with an image frame of
another of the sequences which exhibits the same look direction by comparing the information content of the two frames to determine a registration value; and
            determining the translation between successive image frames of different look
directions by a calculation utilizing the registration value.

8.   An ultrasonic imaging system which produces a spatially compounded
panoramic image comprising:
            an array transducer;

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        a transmit controller, coupled to the array transducer, and operable to cause the array transducer to transmit beams electronically steered in a plurality of look directions as the array transducer is translated with respect to an image field;

        a beamformer, coupled to the array transducer, which produces coherent echo signals in response to beams transmitted in a plurality of look directions;

        a registration processor which aligns echo signals received from common points in an image field; and

        a combiner which combines aligned echo signals to produce spatially compounded panoramic image data.

9.   The ultrasonic imaging system of Claim 8, further comprising:

        a spatial compounding processor, responsive to the echo signals produced by the beamformer, which produces spatially compounded echo signals;

        wherein the registration processor and the combiner operate upon spatially compounded echo signals.

10.   The ultrasonic imaging system of Claim 8, wherein the transmit controller is operable to cause the array transducer to transmit beams for component images, wherein different component images exhibit beams steered in different look directions.

11.   The ultrasonic imaging system of Claim 8, wherein the spatial compounding processor includes a plurality of image memories which simultaneously assemble component images for different spatially compounded images.
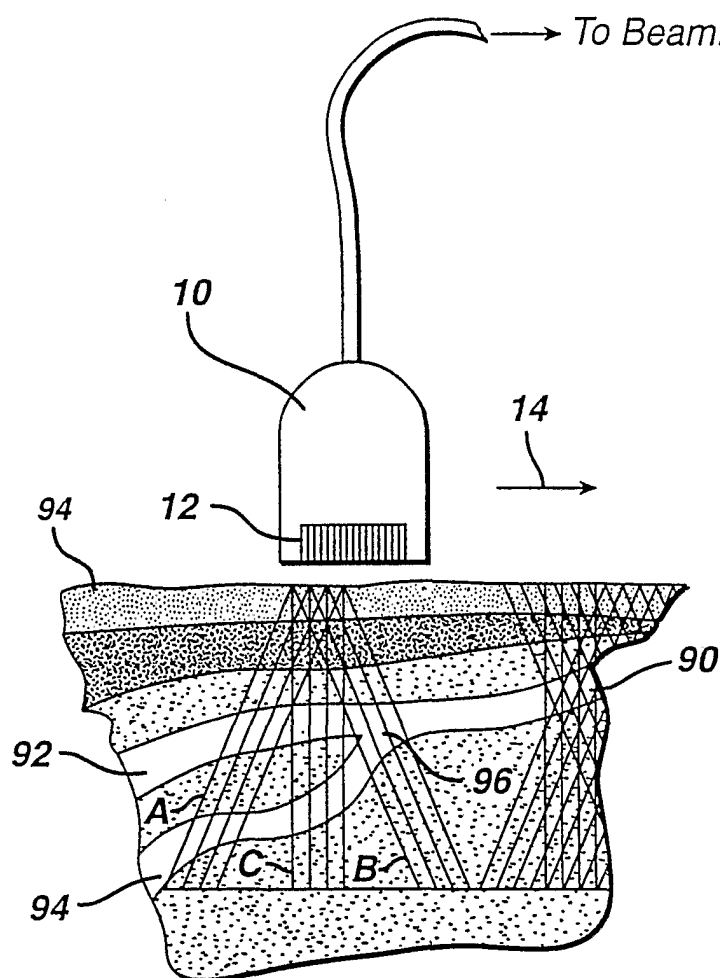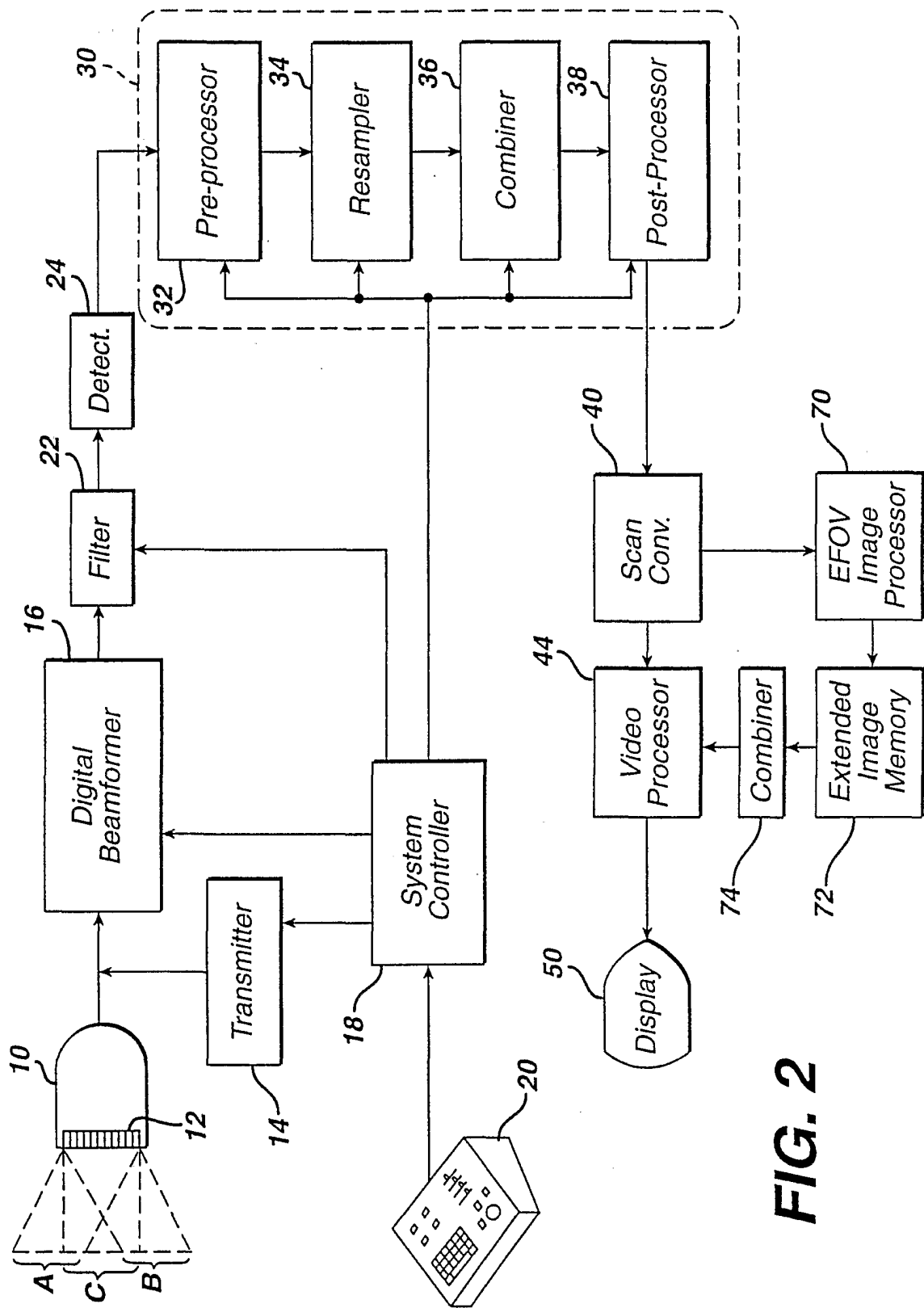
FIG. 1

FIG. 2
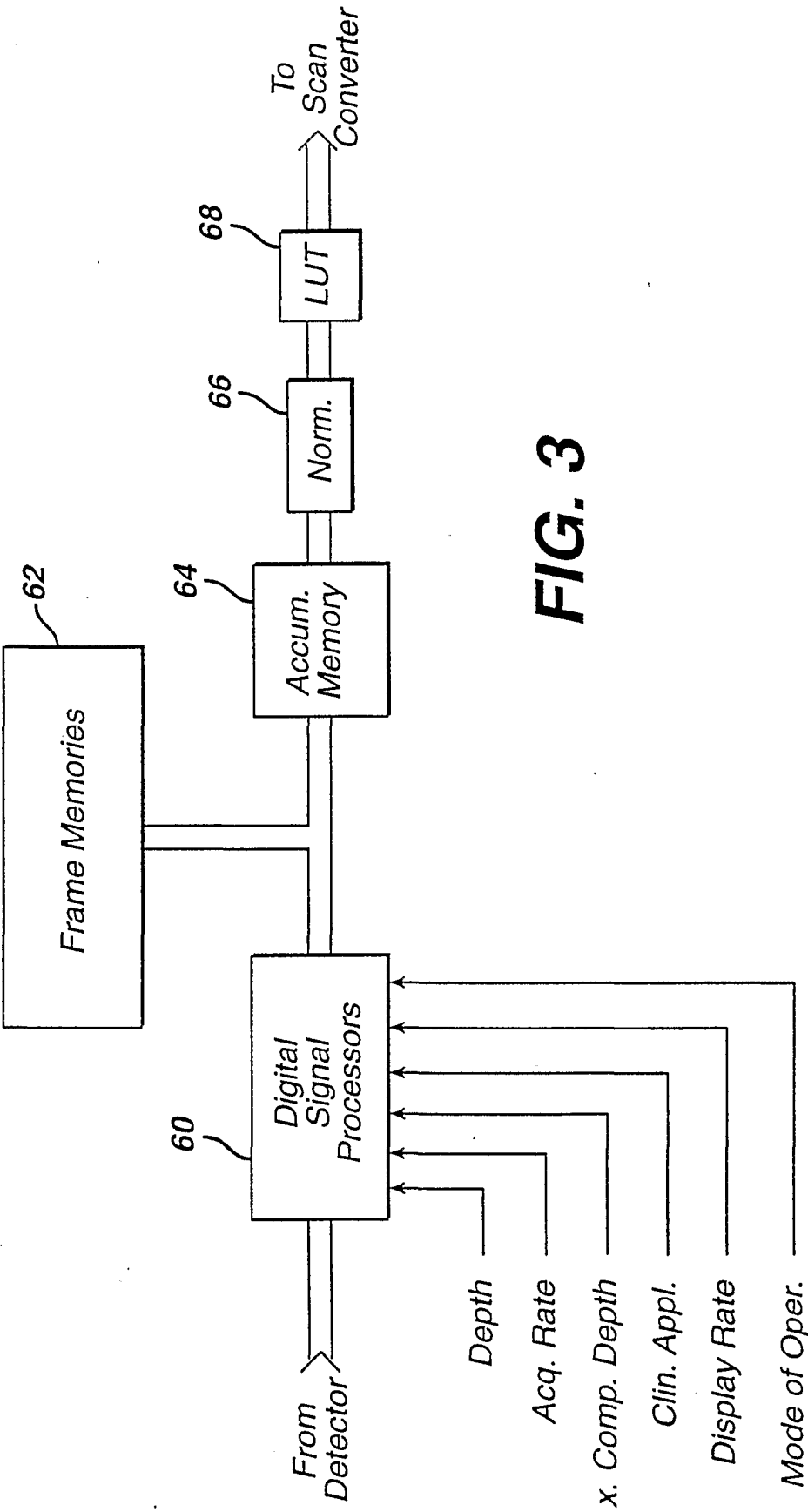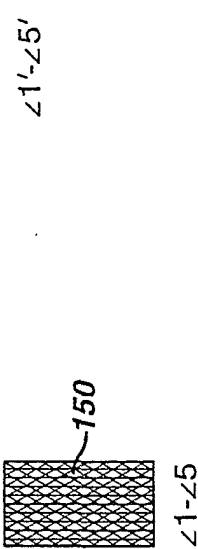
FIG. 3

FIG. 4a
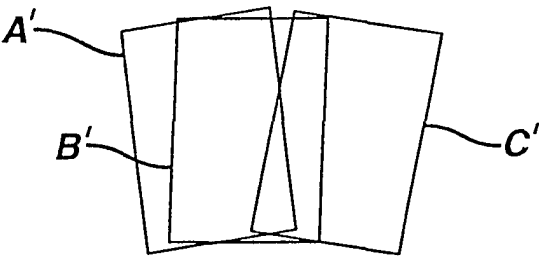
FIG. 4b
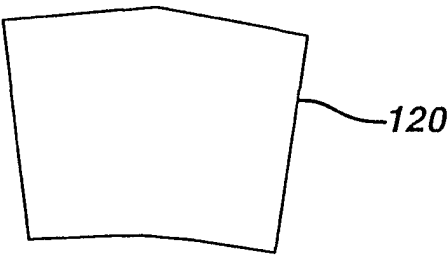
FIG. 5
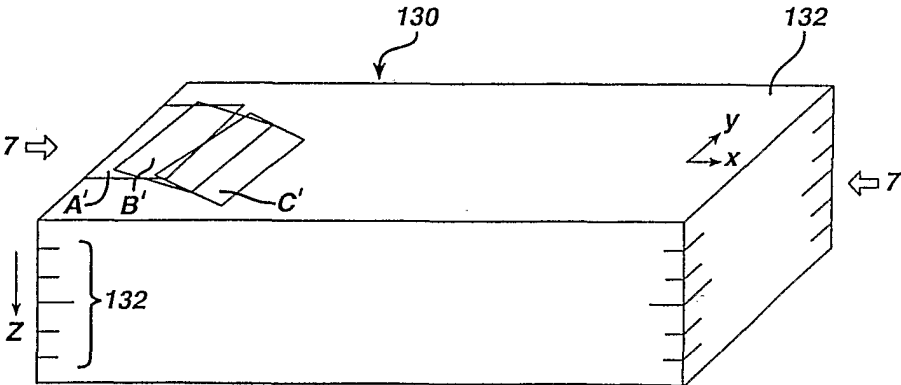
FIG. 6a
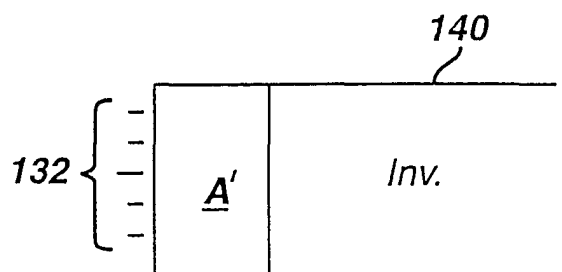
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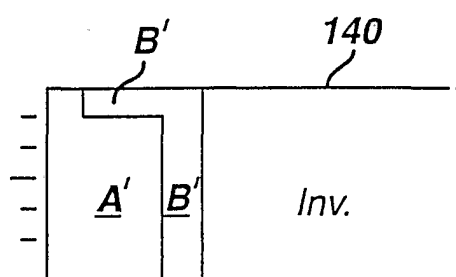
FIG. 6c
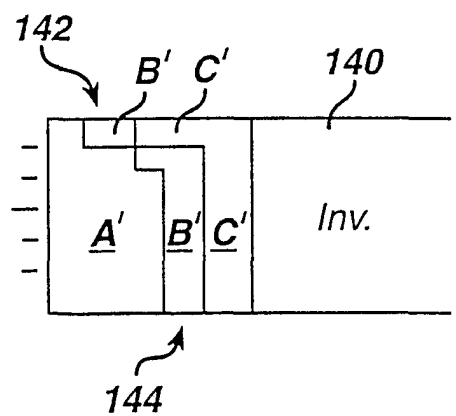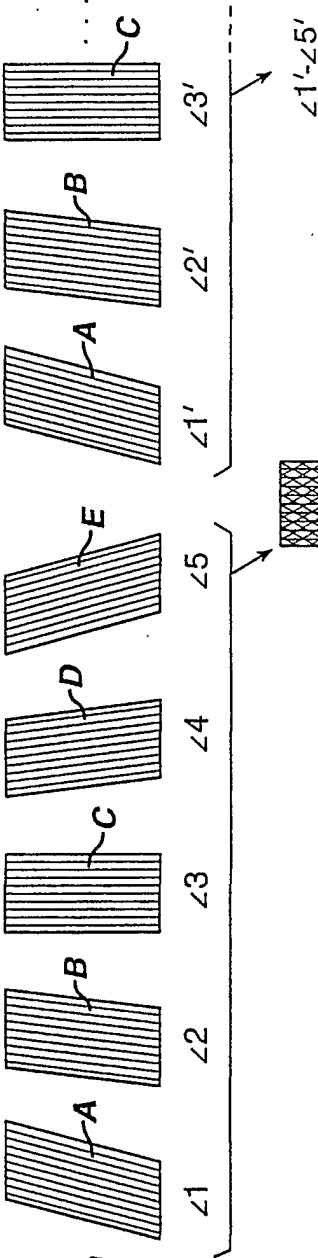
FIG. 7a

FIG. 7b
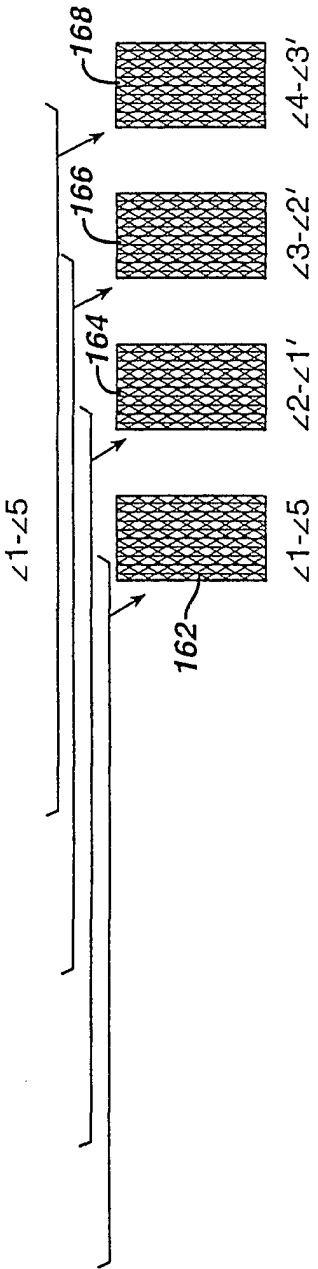
FIG. 7c
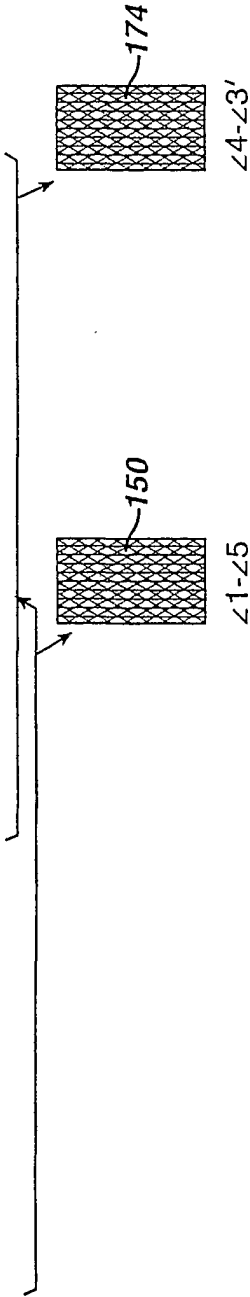
FIG. 7d

FIG. 8
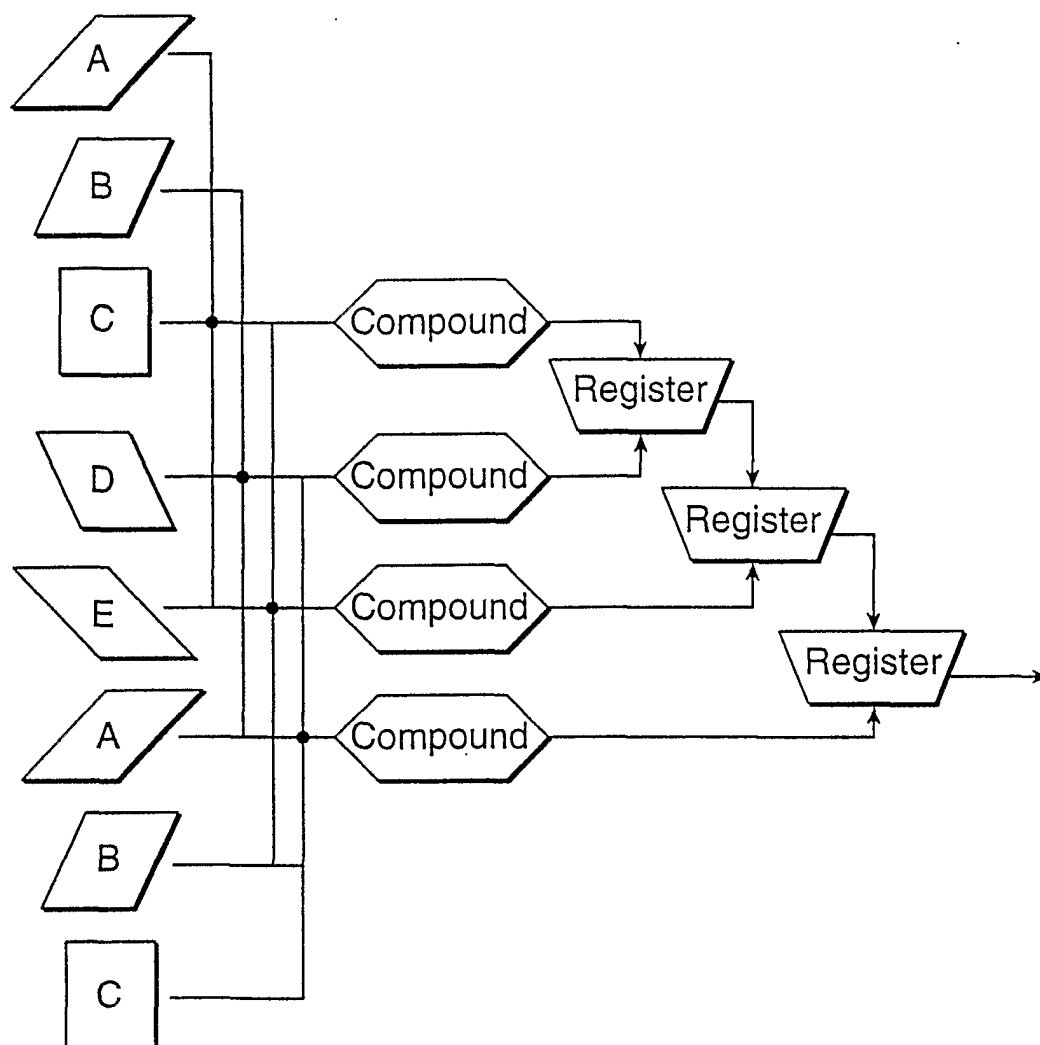
FIG. 9
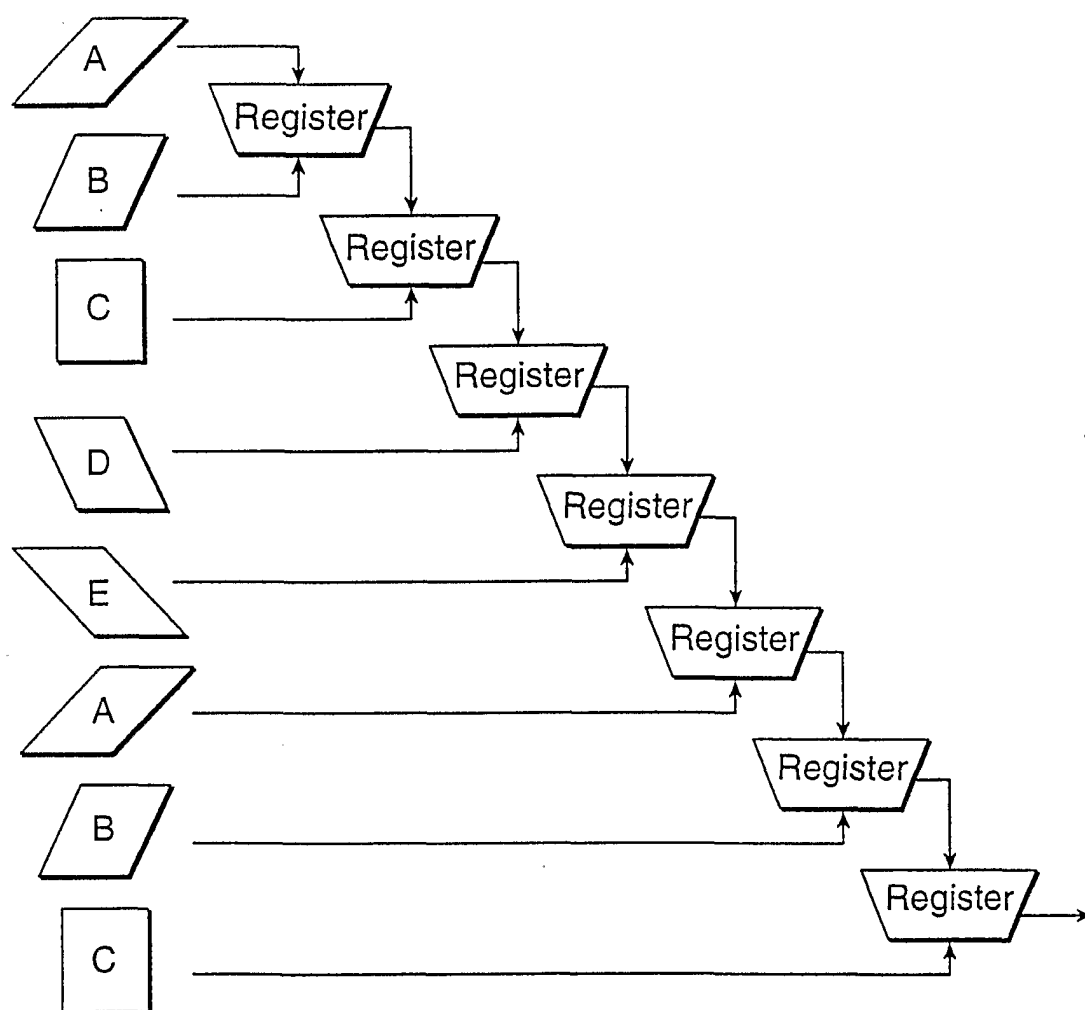
FIG. 10
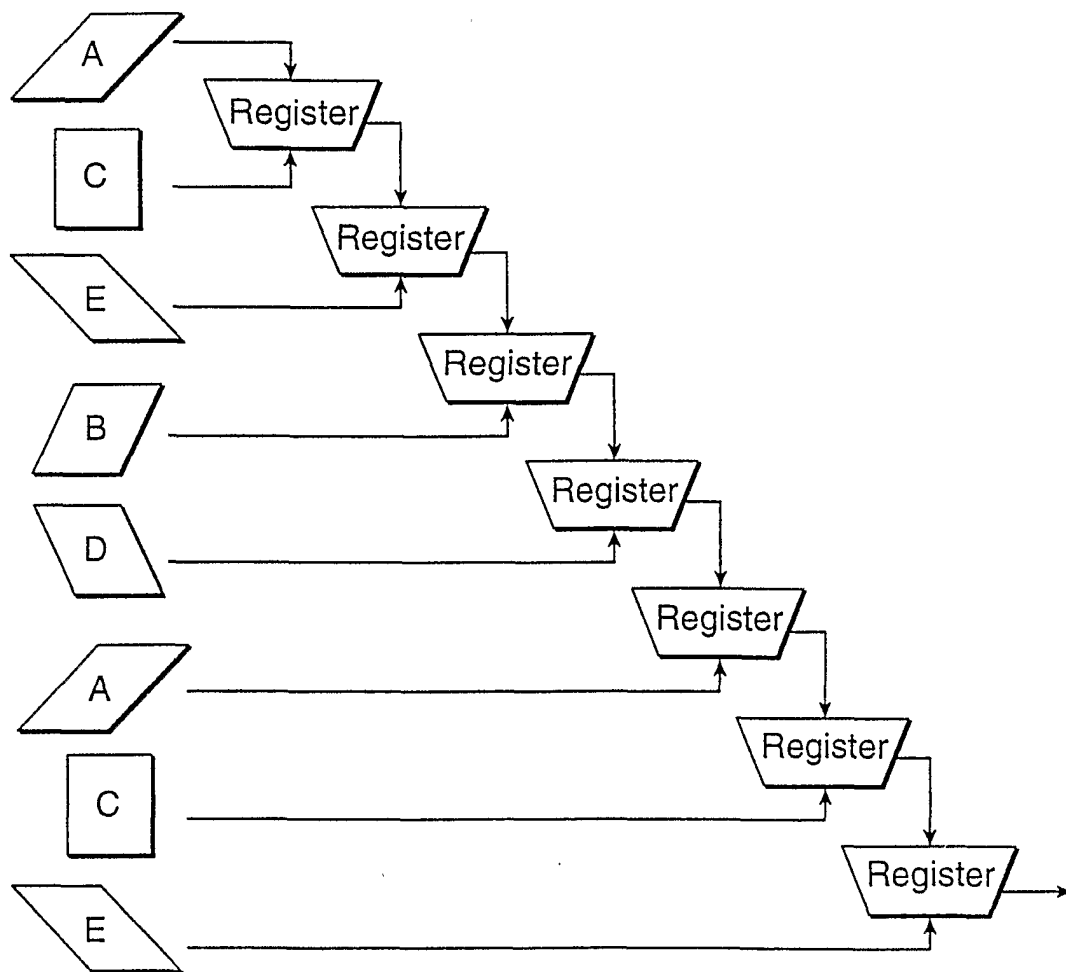
FIG. 11
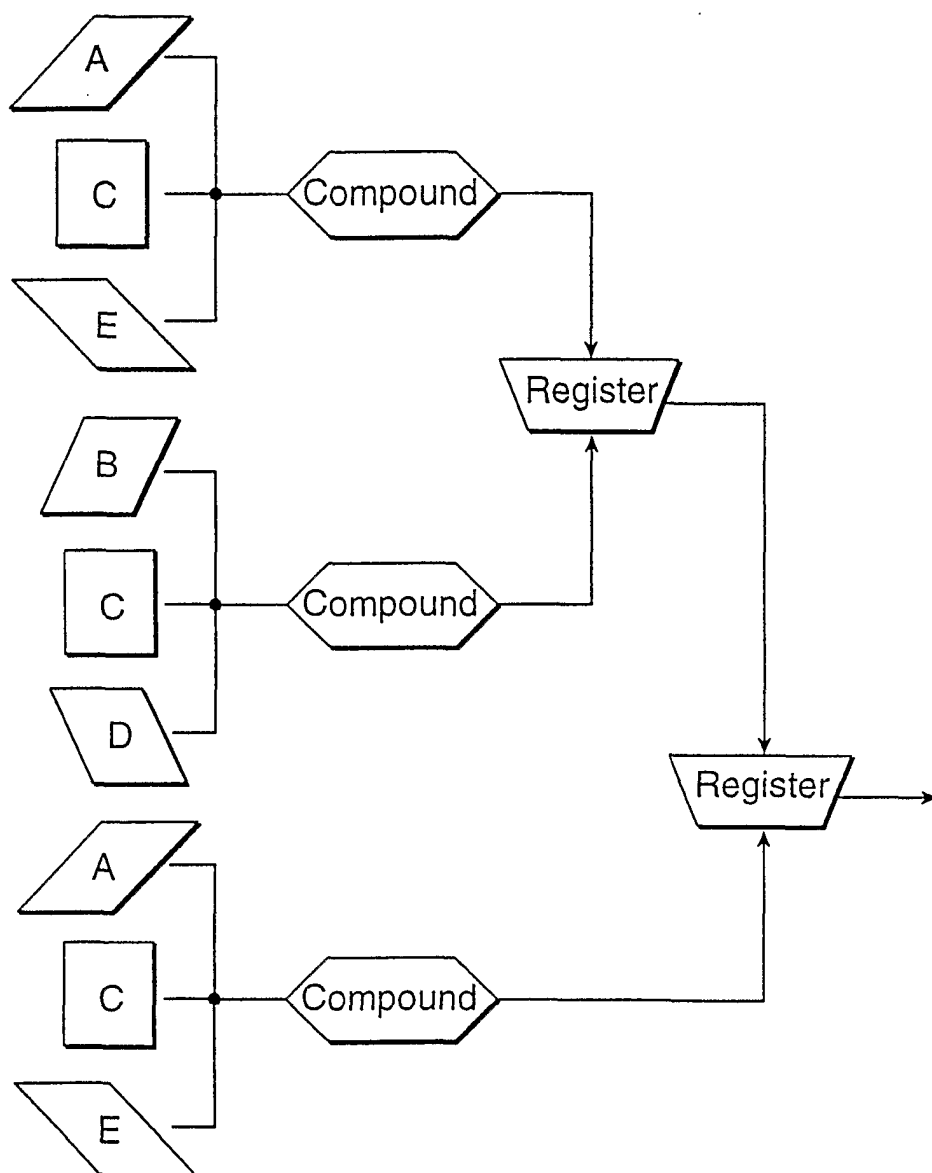
FIG. 12
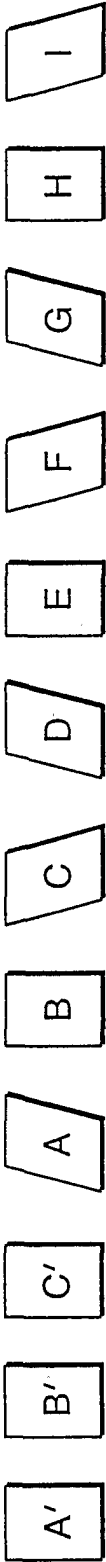
专利名称(译)	具有空间复合全景成像的超声诊断系统		
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[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦电子N.V.		
当前申请(专利权)人(译)	皇家飞利浦电子N.V.		
[标]发明人	JAGO JAMES R OLSSON LARS J ENTREKIN ROBERT R		
发明人	JAGO, JAMES, R. OLSSON, LARS, J. ENTREKIN, ROBERT, R.		
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摘要(译)

描述了一种方法和设备，当换能器相对于全景图像场移动时，该方法和设备通过在多个不同的观察方向上电子控制光束来产生空间复合的全景超声图像。接收的回波信息被复合，然后对准并与先前获取的回波信息组合以形成空间复合的全景图像。或者，接收的回波信息可以与先前获取的回波信息对准，然后组合以在一个过程中产生空间复合和全景图像。