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(54) Imaging systems

(57) An imaging system for examining an area comprises: a transducer for generating and transmitting pulses into the examined area and for receiving echoes reflected from a target in said area, the transducer further having means for developing a first set of signals in response to return time and magnitude of the echoes; means for translating the transducer along a scanning path in the vicinity of the examined area and for developing and recording a second set of signals in response to the position of said transducer along the scanning path; means on the transducer for producing a beam of energy having an angle sufficiently large to impinge on such a target from substantially all positions of the transducer along the scanning path; means for displaying multi-grey level images on a display surface, the images having length and width dimensions corresponding to length and width dimensions of targets in the examined area, and including a storage surface; and means for processing the first and

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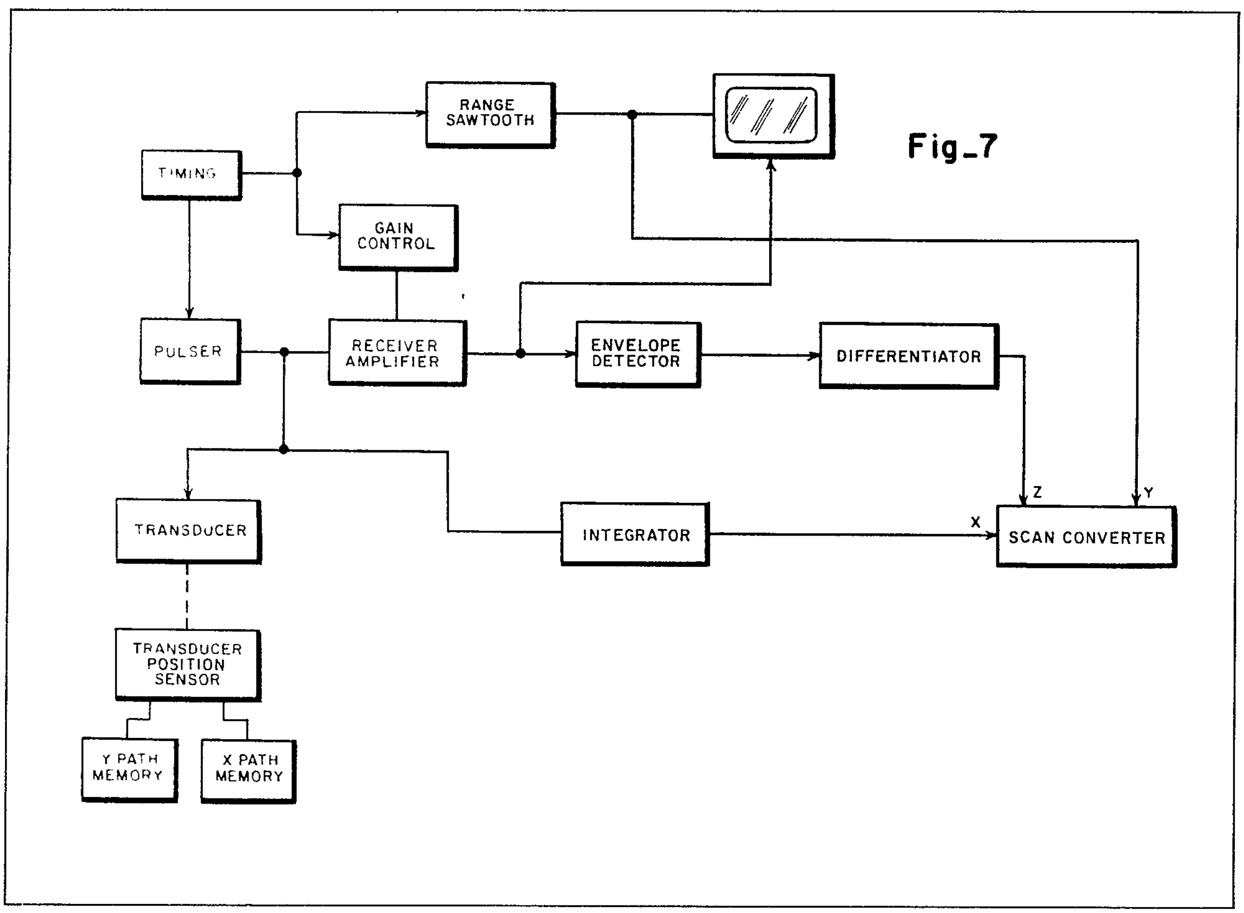

Fig_7

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second set of signals and applying the processed signals to the displaying means. The processing means comprises: an envelope detector for detecting an envelope of the first set of signals; a differentiator for differentiating the envelope; means for recording and storing said differentiated envelope in a scan converter; and means responsive to the recorded and stored information for generating and image on an image scan converter which comprises the displaying means.

Fig_1A

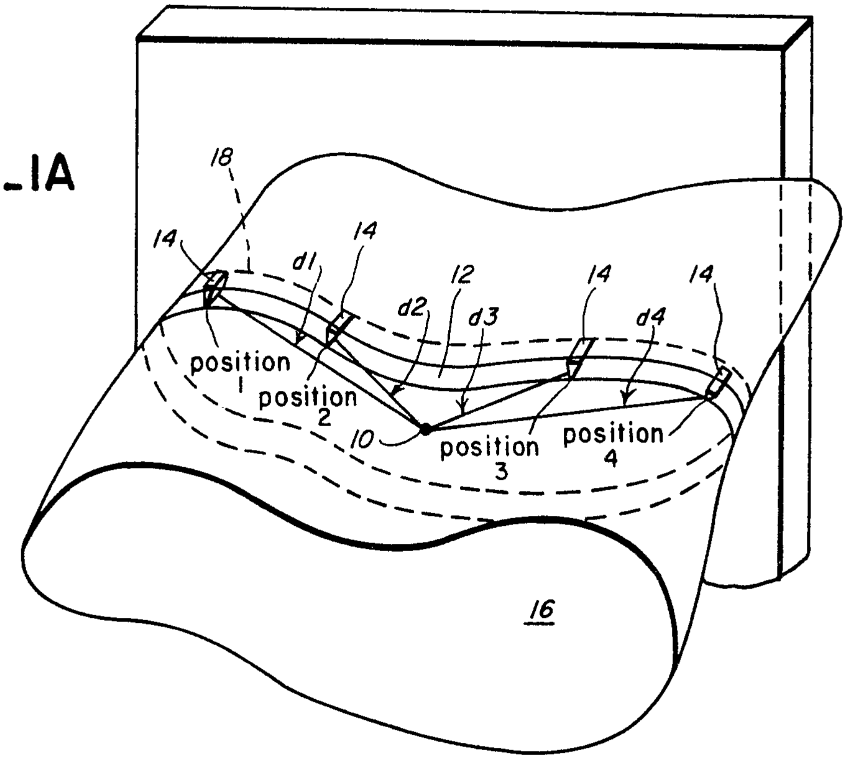


Fig_1B

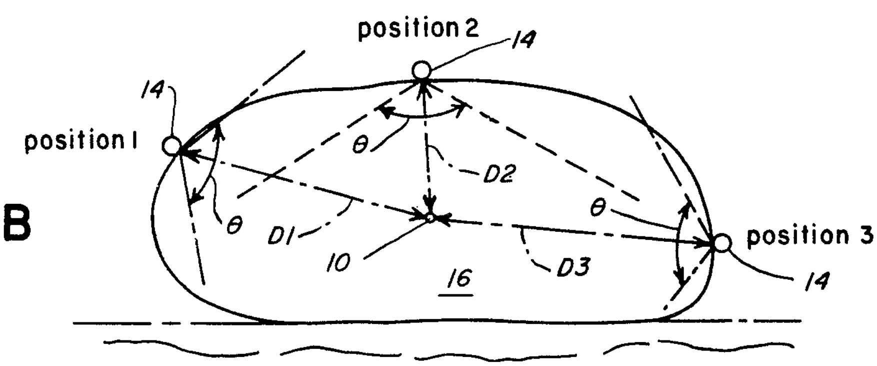


Fig_6

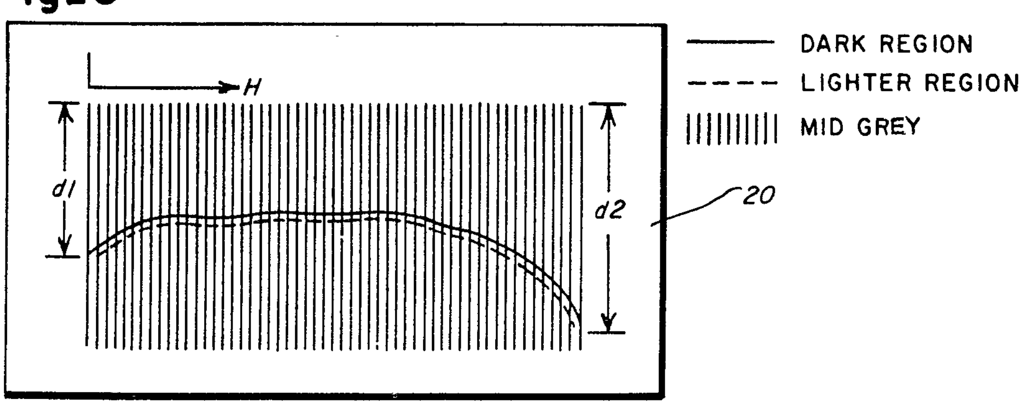
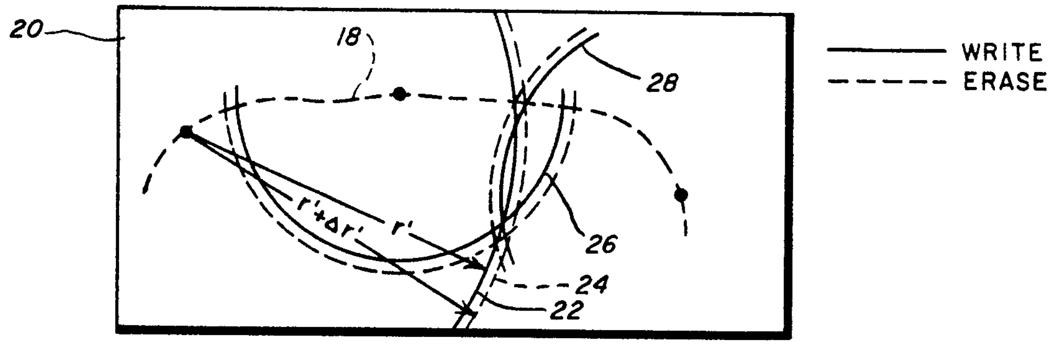


Fig_2



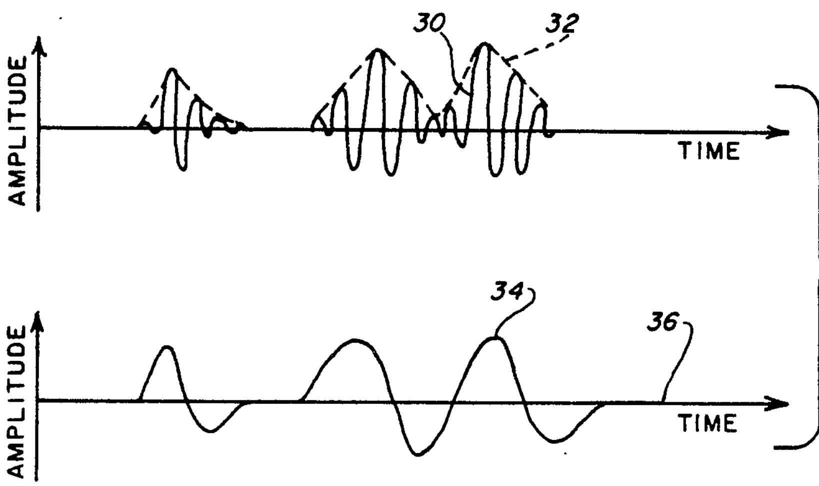


Fig_3

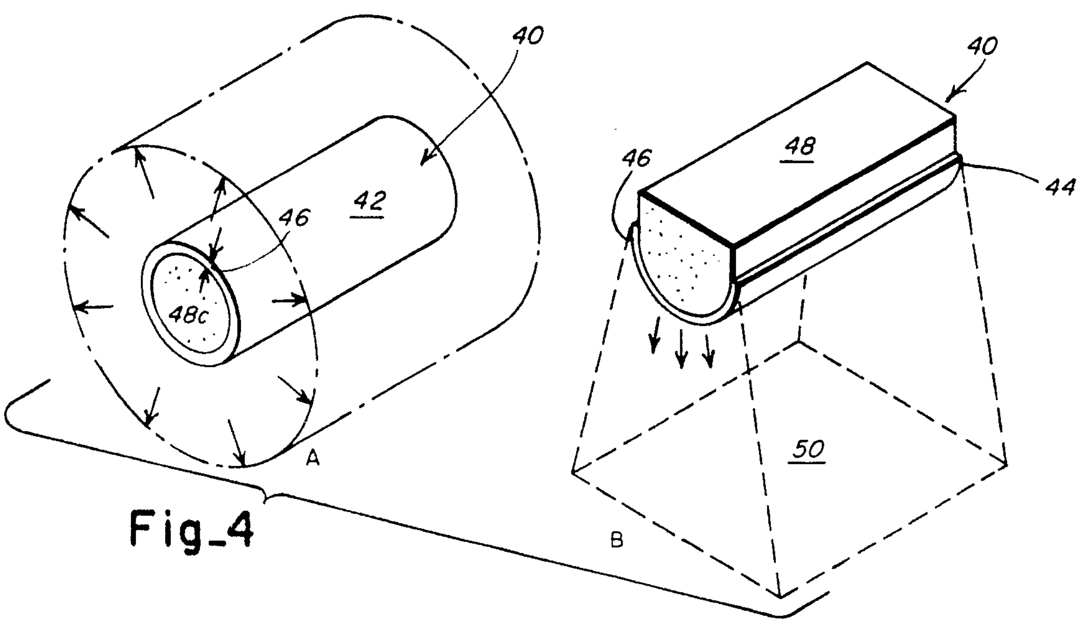


Fig_4

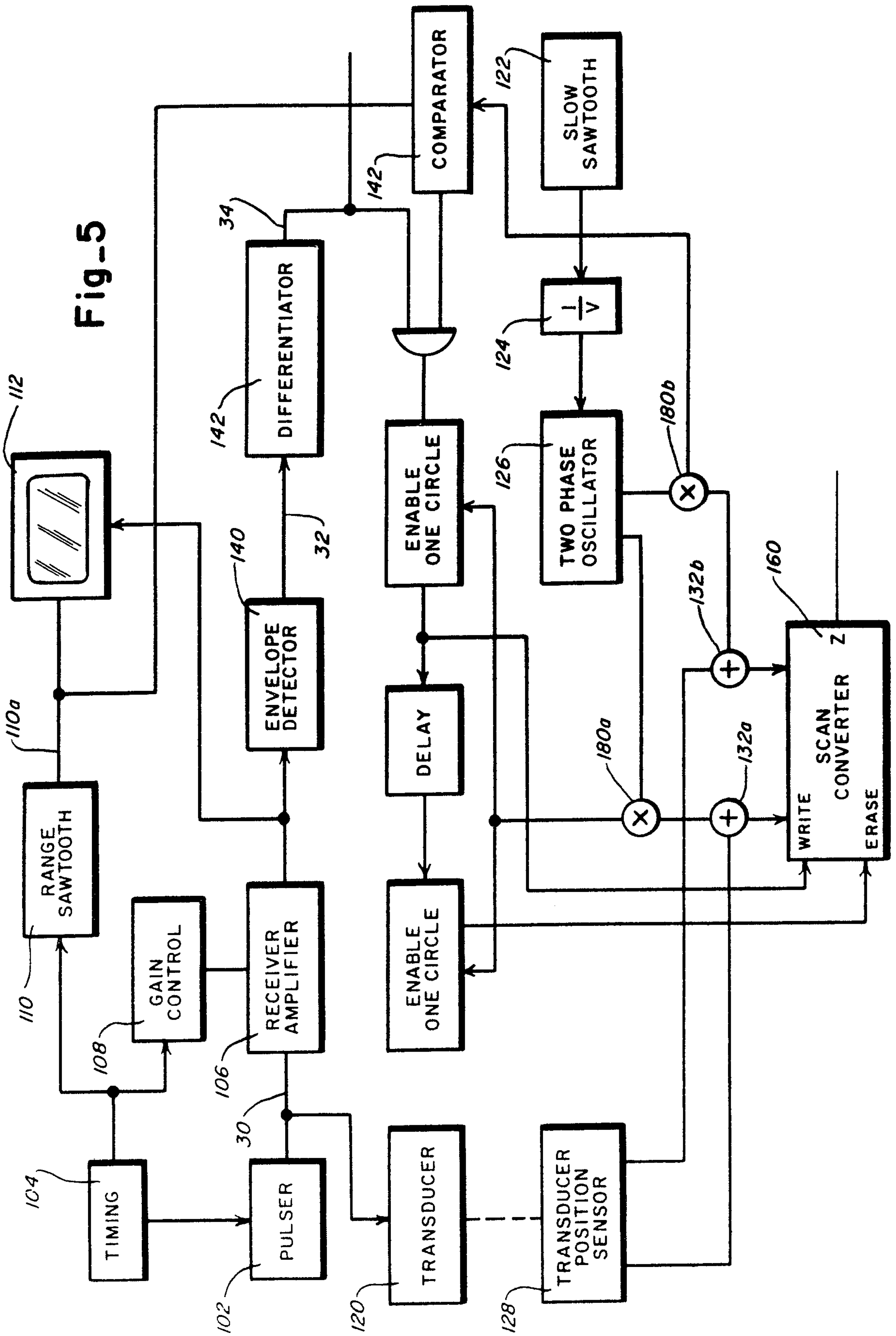

TIMING
PULSER
TRANSDUCER
TRANSDUCER POSITION SENSOR
GAIN CONTROL
RECEIVER AMPLIFIER
RANGE SAWTOOTH
ENVELOPE DETECTOR
DIFFERENTIATOR
COMPARATOR
SLOW SAWTOOTH
1/V
TWO PHASE OSCILLATOR
ENABLE ONE CIRCLE
DELAY
ENABLE ONE CIRCLE
SCAN CONVERTER
WRITE
ERASE
Z
104
102
120
128
108
106
30
110
110a
112
140
32
142
34
142
122
124
126
180b
180a
132b
132a
160

Fig_5

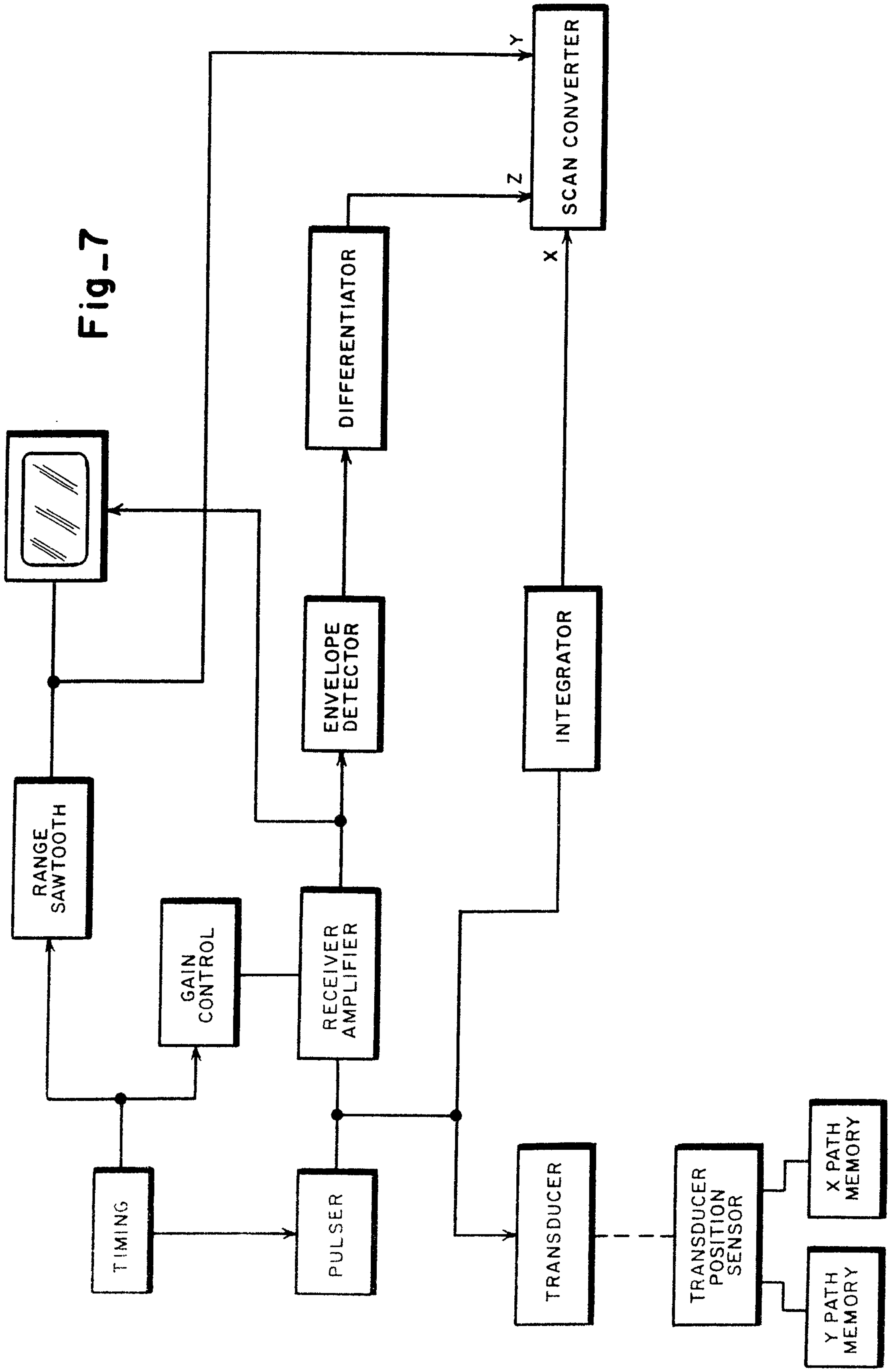
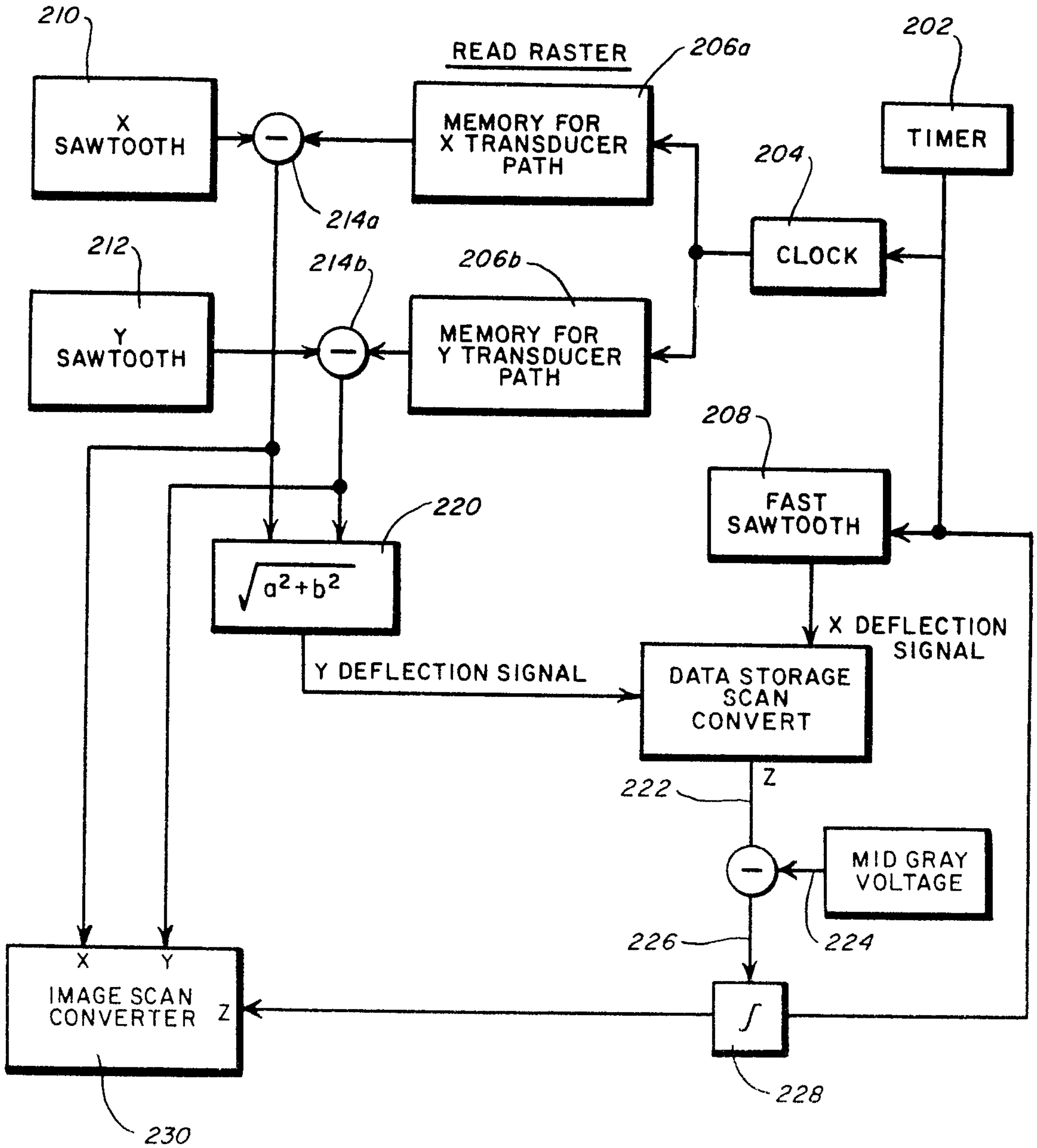

TIMING
PULSER
RANGE SAWTOOTH
GAIN CONTROL
RECEIVER AMPLIFIER
ENVELOPE DETECTOR
DIFFERENTIATOR
INTEGRATOR
SCAN CONVERTER
X
Y
Z
TRANSDUCER
TRANSDUCER POSITION SENSOR
X PATH MEMORY
Y PATH MEMORY

Fig_7

Fig_8


210
X SAWTOOTH
214a
READ RASTER
206a
MEMORY FOR X TRANSDUCER PATH
202
TIMER
204
CLOCK
212
Y SAWTOOTH
214b
206b
MEMORY FOR Y TRANSDUCER PATH
208
FAST SAWTOOTH
220
$\sqrt{a^2+b^2}$
X DEFLECTION SIGNAL
Y DEFLECTION SIGNAL
DATA STORAGE SCAN CONVERT
Z
222
MID GRAY VOLTAGE
224
226
X
Y
IMAGE SCAN CONVERTER
Z
$\int$
228
230

SPECIFICATION

Imaging systems

The present invention relates to imaging systems, such as ultrasonic imaging systems.

Imaging systems are known using a transducer to convert an electrical signal into an ultrasonic signal. This signal propagates into the object to be imaged. Irregularities and discontinuities in the object cause the ultrasonic signal to be reflected back to the transducer which converts the ultrasonic signal back into electrical signals. These signals are processed to form the image. Such systems can be used to form a B-scan image which is an image in a plane through an object where the intensity of the B-scan image at any point in the image is related to the intensity of the corresponding reflected ultrasonic signal for the corresponding part of the object plane.

In conventional B-scan imaging, a narrow beam is directed into the object to be imaged. The transducer is mechanically constrained to keep the centre of the beam in a plane. The signal is generally a short pulse although any signal with wide bandwidth can be used. A straight line raster is created on the imaging surface. It starts at the scaled position of the transducer at the same time as the transducer is pulsed. The raster proceeds in the scaled direction of the beam at a rate corresponding to one-half the scaled velocity of sound in the object being imaged. The echoes that are received by the transducer are used to intensify the raster and make a permanent mark on the B-scan image.

It is well-known that the range resolution of ultrasound or radar is determined by the bandwidth of the signal, and the lateral resolution is determined by the size of the aperture of the transmitting and receiving antennas or transducers.

At the same lateral position, two objects can be resolved if they differ in range by ΔR where

$$(1) \quad \Delta R = \frac{V}{2B}$$

where V = velocity of propagation
B = bandwidth of the signal

Two objects at the same range can be resolved if they are laterally separated by S where

$$(2) \quad S = \frac{1.22\, VX}{Af}$$

where X = distance from transducer to objects
f = frequency of signal
A = aperture or diameter of transducer or antenna
V = velocity of propagation

S cannot be smaller than ΔR so if Equation (2) yields S smaller than ΔR the lateral resolution is ΔR - that is the lateral and range resolution are the same.

According to an embodiment of our co-pending Patent Application No. 7939202 (Serial No. 2039042) a circular raster is generated that starts at the scaled position of a transducer at the same time as a pulse is generated and transmitted into the area to be scanned. As the pulse expands radially, the circular raster expands at a rate equal to one-half the scaled velocity of sound. If a short pulse is used, the echoes received are envelope detected. The envelope is differentiated. A writing surface is prepared by starting at mid grey. When the derivative is positive, the raster beam writes a circular arc. When it is negative the raster erases a circular arc. This process forms the image.

In many practical instances, the raster cannot be created fast enough because of the finite bandwidth of the deflection circuits. In this case, the return echoes must be memorised in either an analogue or digital memory register and clocked into the write/erase electronics at a rate commensurate with the maximum rate that the raster can be generated.

According to the present invention there is provided an imaging system for examining an area, comprising:

transducer means for generating and transmitting pulses into the examined area and for receiving echoes reflected from a target in said area, said transducer means further having means for developing a first set of signals in response to return time and magnitude of the echoes;

means for translating said transducer means along a scanning path in the vicinity of the examined area and for developing and recording a second set of signals in response to the position of said transducer means along the scanning path;

means on said transducer means for producing a beam of energy having an angle sufficiently large to impinge on such a target from substantially all positions of the transducer means along the scanning path;

means for displaying multi-grey level images on a display surface, the images having length and width dimensions corresponding to length and width dimensions of targets in the examined area, and including a storage surface; and

means for processing said first and second set of signals and applying the processed signals to said displaying means, wherein said processing means comprises:

means for detecting an envelope of the first set of signals;

means for differentiating said envelope;

means for recording and storing said differentiated envelope in storage means; and

means responsive to the recorded and stored information for generating an image on an image scan converter which comprises the displaying means.

In an embodiment of the invention, in a first step, the differentiated envelope is recorded in storage means. The storage means may be a scan converter, in which case the horizontal raster position is proportional to the number of pulses transmitted from the beginning of the scan. The vertical raster starts at the same time as the pulse is transmitted and slews vertically, generally at a constant rate.

At each pulse, the horizontal and vertical co-ordinates of the centre of the transducer are converted to digital co-ordinates and memorised in a digital memory.

A raster is created to read the data in the following way.

The grey level of the image at Cartesian co-ordinates (x,y) in the scaled image plane is determined by integrating the output of the read raster that scans across the data. The read raster travels horizontally across the data at a constant rate. The vertical position of the read raster at a position corresponding to the n^{th} pulse after the start of data collection is

$$(3)\quad V_n = \sqrt{(x-x_n)^2 + (y-y_n)^2}$$

where x_n and y_n are the (x,y) co-ordinates of the transducer at the n^{th} pulse.

The *x* and *y* co-ordinates of the image are varied in TV format. The integrated signal modulates the intensity of the image surface to form the image.

For a better understanding of the present invention and to show how the same may be carried into effect reference will now be made to the accompanying drawings in which:

Figure 1A is an isometric illustration of a body to be scanned;

Figure 1B is an elevated view of the image plane in Figure 1A;

Figure 2 is a diagrammatic representation of data written on a storage surface;

Figure 3 is a graphic illustration of the electrical waveforms representing incoming reflection pulse data;

Figure 4 shows isometric views of alternative construction for transducers which may be used in the described imaging systems;

Figure 5 is a block diagram representation of apparatus according to an embodiment not in accordance with the present invention;

Figure 6 illustrates an alternative format to that shown in Figure 2 for writing data on a storage surface in an embodiment in accordance with the present invention;

Figure 7 is a block diagram representation showing an embodiment of a system in accordance with the present invention for reading data on the storage surface of Figure 6; and

Figure 8 is a block diagram showing the circuitry for reading the data from the storage surface of Figure 6 for display.

Figures 1A and 1B illustratively depict the scanning of an object 16 containing a target 10 in a plane 12. A transducer 14 is scanned along the surface of object 16 from position 1 to position 4 along a surface path 18. As the transducer 14 travels, it emits pulses of ultrasound. The transducer is designed to send an expanding circular wave in the plane with the transducer at the centre. At position 1, for example, an echo arrives back at the transducer at time

$$(4)\quad T = \frac{2d_1}{V}$$

where d_1 = distance from the transducer to the reflector

V = velocity of sound propagation

On the basis of the return echo from position 1, there is only enough information to establish that the reflector is somewhere on a circle of radius d_1, centred at position 1 having Cartesian co-ordinates (x_1,y_1).

A storage surface 20, shown in Figure 2, is prepared for imaging by writing the surface to mid grey. The image is started by writing a circular arc 22 on the surface of a storage tube of radius r' and centre x',y' where $r' = Cr$, $x' = Cx$, $y' = Cy$, etc., and where C is the scaling constant required to have the image fill storage surface. The writing beam is set to produce only a few percent increase in grey level above the 50% level already there. A second arc 24 with the same centre but larger radius, $r' + \Delta r'$, is erased. The beam is adjusted to erase the same percentage grey level as the first circle writes. The difference in circle size, $\Delta r'$, is somewhat arbitrary, but best results are achieved if $\Delta r'$ is chosen to be the system resolution, about one wavelength for most modern ultrasound systems.

The write/erase intensity level is determined from the amplitude of the return echoes. Turning to Figure 3, a typical return echo is shown. An envelope 32 of the signal is formed and differentiated as graphically depicted at 34. The write level of the arc 22 (Figure 2) is related to the distance above the zero line 36 (Figure 3) of the curve 34. The erase level for the arc is similarly proportional to the distance below the line 36 of the curve 34.

A transducer 40 which may be used in the systems to be described is shown (Figure 4A) and is made from a piezoelectric cylinder 42 or a section 44 of a cylinder (Figure 4B). The cylinder is long enough to keep the ultrasound signal from expanding from the image plane in the region of interest. The length of the cylinder to do this is approximately

$$(5) \quad L = R\lambda$$

where R = the distance from the transducer where the beam must be columinated

λ = the wavelength of sound

The thickness 46 of the transducer is about ½ the wavelength of the sound pulse. The centre of the transducer is filled with a sound absorbing material 48.

The transducer may be the cylinder 42 if the transducer is scanned through a liquid and imaging of the region on both sides of the path is required. The section 44 of a cylinder may be used if the object to be imaged lies on one side of the scan path.

As the transducer is scanned, pulses are emitted at a constant rate per distance moved. Good results are obtained when about 1000 pulses per image are produced, yielding 1000 write arcs and 1000 erase arcs per target. Figure 2 illustrates the arcs associated with three typical pulses. Each echo is processed as described above, and shown in Figure 2, with write arcs 26, 28 centred at the positive scaled transducer focal spot positions 2, 3 and each having a radius equal to the scaled distance between the transducer focal spot and reflector. Erase arcs 26′, 28′ are formed in a manner similar to arc 24. At the scaled position of the target 10 on the writing surface 20, all the write arcs intersect. This creates a white dot. A black region may occur around the dot due to the build up of erase arcs. On all other parts of the screen, there is one erase and one write arc which cancel each other, leaving mid grey. There will be one erase arc at the start of the scan and one write arc at the end that are not cancelled, but this will be barely visible when viewing the surface because it is only a few percent of the total grey scale. The image is conveniently viewed by adjusting the reading beam so that mid grey is black and white is white. Thus, only the portion of the image above mid grey is viewed.

The image that results is a white dot at a scaled position corresponding to the target. If there were several targets, each would be imaged at its corresponding position. Furthermore, if there were an extended target in the image plane rather than a point target, it would be similarly imaged. An extended target is imaged because the tangent of the write arc "rolls" along the target and is not cancelled by the erase arc. Thus, a cross-sectional image is produced.

Having described the one-step method above, attention is directed to Figure 5 and an analogue system configuration, although it will be understood that digital components and techniques may be used to provide an equivalent system.

The surface on which the image is formed is basic to the system. A scan converter may be used and may be either single-ended (one beam for write, erase and read) or double-ended (write and erase beam on one side of the writing surface and read beam on the other). A storage oscilloscope tube with selective erase capabilities can be used with no read beam required, but at the present state of the art, they lack resolution and dynamic range of grey scale for high quality images. Naturally a digital scan converter may be employed in accordance with knowledge and techniques known in the art.

In this scan converter system, the writing surface is displayed on a television monitor by giving the system a "television read" command.

The writing surface is prepared by taking it to mid grey. A TV write command is given with the video input voltage set to write the screen to mid grey. The writing is in a standard TV raster format. To avoid having raster lines appear, the write beam is de-focused.

A transducer 120 produces a generally cylindrical beam and can be built from a section of a cylindrical piezoelectric as described above. The transducer can have internal focus or external focus. The external focus is preferred when the transducer is in one medium, for example water, and the object to be imaged is another, such as steel. If this is the case, the preferred position of the focal spot is the interface between the two media.

In the system, the transducer 120 has a thickness corresponding to a resonance of 2 MHz, a radius of 1.27 cm and a length of 2.54 cm. As shown in Figure 4, the beam 50 produced by this transducer lies primarily between two planes perpendicular to the axis of the piezoelectric through its centre, although, in fact, the beam has a finite width perpendicular to the plane. The axial length of the transducer is chosen by rules given above.

The image forming system, shown in Figure 5, includes components which are found in many commercial ultrasound systems, namely a pulser 102, timing means 104, a receiver amplifier 106, gain control 108, a sawtooth generator 110 and oscilloscope A display 112.

The image-forming system additionally includes a raster generator which provides the *x* and *y* deflection signals during the image formation process. The raster generator consists of a slow sawtooth voltage generator 122, a reciprocal generator 124, a two-phase voltage controlled oscillator 126, a transducer position sensor 128, a multiplier circuit 180 and an adder circuit 132.

The transducer position mechanism 128 must give two voltages porportional to the Cartesian co-ordinates of the focal point of the transducer. In the simplest case, the transducer is moved along a lead screw. The *x* co-ordinate is therefore the position of the lead screw and the *y* co-ordinate does not change. There is a requirement that the number of pulses per unit travel of the transducer be approximately constant. This can be accomplished by pulsing at a constant rate and traversing the transducer at a constant rate.

In the system, the voltages chosen to position the writing and erase beam are −0.5 to +0.5v for left to right and −0.4 to +0.4v for bottom to top deflection of the video beam. This writes on an area with a 4 × 5 aspect ratio. The position mechanism then produces a +0.4 volt to −0.4 volt signal as the lead screw moves the transducer from left to right. The *y* co-ordinate is a constant chosen to be +0.3 volt because all the targets are below the scan line.

The slow sawtooth generator 122 generates a ramp voltage that represents the range from the centre of the transducer to the point to be imaged.

The two-phase oscillator 126 generates two sine waves 90° out of phase. These voltages create a circulat raster when applied to the *x* and *y* deflection circuits. The frequency of the circle must be high for small diameter circles and low for large circles to achieve a constant slew rate on the writing surface. This is accomplished by generating a voltage proportional to 1/v and using this to control the frequency of the two-phase oscillator 126. The output of the oscillator is multiplied at 180 by the ramp voltage from the slow sawtooth generator 122 to create a circular raster whose diameter is proportional to the ramp voltage.

Voltage from the sensor 128, proportional to the *x* and *y* transducer positions, are then added to the sine waves from the oscillator 126. The signal created consists of expanding circules centred at a position scaled to the *x-y* position of the transducer. These signals provide the *x* and *y* deflection signals during the image formation process.

Turning to the processing of the received reflections from the examined body, the received signal 30 is passed through an envelope detector 140 and differentiator 142 to produce the signals shown in Figure 3.

The intensity (*z*) axis of the system scan converter 160 is actuated by an echo received. The echo is detected in the envelope detector. This initiates a write command for one circle. After a delay period, an erase circle is initiated. Attenuators in the write and erase lines balance the signals so that the write and erase produce equal effects.

The pulser timing 104 is not critical. It is sufficient that the repetition rate be low enough that range ambiguities do not occur. For this example 1000 pulses-per-second were used.

The pulse actuates the fast sawtooth generator 110. The sawtooth voltage 110*a* is compared with the output from the slow sawtooth generator 122. When they are the same, a comparator write/erase sequence is recorded. Because the echo is sampled at only one range during each transmission, several hundred pulses must be transmitted at each transducer location.

Many improvements in the foregoing system are possible. For example, a faster imaging operation could be achieved by storing the received echoes in a memory. Then the slow saw- and fast sawtooth would have the same repetition rate. The speed of the slow sawtooth would be limited by the slow rate limitation of the scan converter. For example, with a frequency limitation of 500 KHz and 500 range resolution elements and pulses at 500 tranducer locations, each raster would take 6 seconds rather than 6 × 500 = 3000 seconds.

There will now be described an embodiment of a system according to the present invention. The transducer, beam shape, signal and scan path are, however, the same as in the above-described one step processing. The raster for recording the ultrasound data does not produce an image, it provides an intermediate storage area. The data is read by a read raster beam, processed, then placed on a second scan converter as an image. The advantage of the two-step processing is that the ultrasound data can be recorded in simple format for fast data collection.

In the first step, the data is written on the recording surface 20 in the format shown in Figure 6. The horizontal raster position H is proportional to the number of pulses transmitted from the beginning of data collection. A vertical sawtooth starts when the pulse is transmitted and proceeds vertically at a rate proportional to the velocity of sound. Approximately 1000 pulses are transmitted to create an image. The circuit block diagram for recording data is shown in Figure 7.

No surface preparation is required as in the previous version. With no echoes, the derivative is constant, and this constant level is chosen to be mid grey. When the derivative is positive, the signal writes above mid grey and when the derivative is negative, the signal writes below mid grey.

The plane in which the transducer is scanned is described by Cartesian co-ordinates *x* and *y*. The position of the focus of the transducer at the n^{th} pulse is x_n and y_n. These co-ordinates are memorised and placed in a memory as the scan proceeds. The n^{th} memory location contains the co-ordinates x_n and y_n.

When the data is to be read from memory, a read reaster is used which scans the data horizontally at a constant rate. If the picture element (pixel) at image location *x* and *y* is being generated the vertical position of the read raster beam at the i^{th} echo position is

$$(6) \quad v_i = \sqrt{(x-x_i)^2 + (y-y_i)^2}$$

where *x* and *y* are the co-ordinates of the transducer focus during the i^{th} pulse.

The read raster is generated by the circuit in Figure 8. A timer circuit 202 creates a pulse for each pixel. The pulse actuates a clock 204 that clocks the *x* and *y* locations of the transducer path from memory 202 *a*, *b* respectively. At the same time a sawtooth is generated by means 208 that deflects the beam horizontally. The sawtooth is synchronised so that when it produces a voltage corresponding to the i^{th} storage pulse, x_i and y_i come out of memory.

The location of the pixel to be imaged is generated with the *x* and *y* sawtooth generators 210, 212 respectively. If the dimension of the image is N by M pixels, the *x* sawtooth generator 210 generates one sawtooth each time the fast sawtooth generator 208 generates N sawtooths, and the *y* sawtooth generator 212 generates M tooths. When the *y* sawtooth generator completes one sawtooth, the image is complete.

The *x* and *y* location of of the pixel is subtracted from the *x* and *y* location of the transducer by means 214. These signals enter a circuit 220 for taking the square-root-of-the-sum-of-the-squares of the inputs. This signal appropriately scaled, produces the *y* deflection.

The intensity output 222 of the scan converter is subtracted from a voltage 224 corresponding to the mid grey level and the resulting signal 226 is integrated by means 228 for the period of time of the fast sawtooth from generator 208. The final value of this integral is used to intensity modulate the intensity axis of the scan converter 230 containing the image.

Attention is directed to our co-pending Patent Application No. 7939202 (Serial No. 2 039 042) of which the present application is a divisional application.

CLAIMS

1. An imaging system for examining an area, comprising:
transducer means for generating and transmitting pulses into the examined area and for receiving echoes reflected from a target in said area, said transducer means further having means for developing a first set of signals in response to return time and magnitude of the echoes;
means for translating said transducer means along a scanning path in the vicinity of the examined area and for developing and recording a second set of signals in response to the position of said transducer means along the scanning path;
means on said transducer means for producing a beam of energy having an angle sufficiently large to impinge on such a target from substantially all positions of the transducer means along the scanning path;
means for displaying multi-grey level images on a display surface, the images having length and width dimensions corresponding to length and width dimensions of targets in the examined area, and including a storage surface; and
means for processing said first and second set of signals and applying the processed signals to said displaying means, wherein said processing means comprises:
means for detecting an envelope of the first set of signals;
means for differentiating said envelope;
means for recording and storing said differentiated envelope in storage means; and
means responsive to the recorded and stored information for generating an image on an image scan converter which comprises the displaying means.

2. Apparatus according to Claim 1, wherein said pulses have a frequency in the ultrasonic range.

3. Apparatus according to Claim 1 or 2, wherein said storage means comprises a scan converter.

4. Apparatus for scanning an area of a body, substantially as hereinbefore described with reference to Figures 6 to 8 and either Figure 4A or Figure 4B of the accompanying drawings.

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