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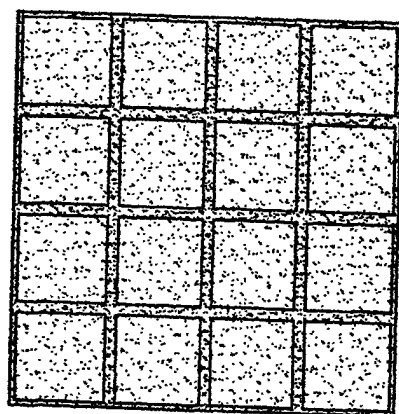
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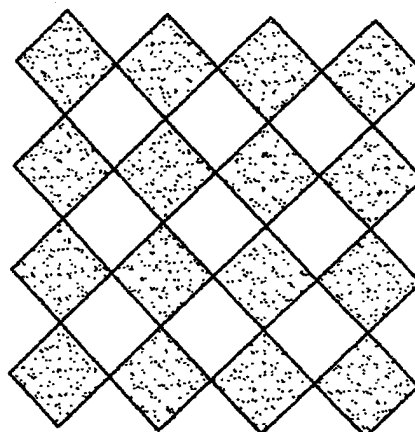
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(54) Title: IMPROVED VOLUMETRIC ULTRASOUND IMAGING WITH A THINNED ARRAY



(a)



(b)

(57) Abstract: A thinned (greater than  $\frac{1}{2}$  wavelength element spacing) array of ultrasound transducers is used to form a large number of received near-field focused beams within an insonated region. Since array thinning allows for unambiguous scanning or imaging over only a limited region or segment, a set of transmitters are fired one at a time to insonate one segment at a time. The receiver is an array of elements, all receiving simultaneously, and a plurality of transmitters is used, each aimed at a different segment. The transmit beam is steered by switching between transmitters, and a large number of focused receive beams are formed digitally for each transmitted pulse. The transmitters are designed to provide very little energy in the direction of the receiver spatial ambiguities or "grating lobes". Also provided is a thinned array wherein the roles of the transmitters and receivers as described above are interchanged.

IMPROVED VOLUMETRIC ULTRASOUND IMAGING  
WITH A THINNED ARRAY

FIELD OF THE INVENTION

5 The present invention relates to a novel and useful thinned array for use with an ultrasound device that permits high-resolution imaging of a large volume a subject's body. More particularly, the present invention involves a thinned array that readily permits cardiac diagnosis and monitoring.

BACKGROUND OF THE INVENTION

10

Conventional ultrasound imaging equipment measures range and only one angle to produce a two dimensional slice through the organ being monitored. Typically, it produces a slice consisting of 256 lines in a 1/30 th of a second time frame. For each depth, this gives 256 picture elements or *pixels* per slice, one slice per frame.

15

The difficulty that arises in three-dimensional imaging is that  $N$  slices require  $N^2$  lines as opposed to  $N$ . A solution is to form many lines at a time.

20

Three dimensional ultrasound imaging systems currently exist, allowing any slice, at any orientation, to be displayed at the discretion of the user. For example, a particular system presently available employs a transmitter beam that insonifies a 4 by 4 array of 16 receiver beams. Since 16 beams are formed for each transmitted pulse, 16 x 256 lines are produced in each frame. This allows for the formation of a three dimensional image in a single frame, with a 64 by 64 array of pixels for each depth. However, this array of pixels limits the resolution of any 3D image produced with this system.

25

30

An ultrasonic device set forth in U.S.S.N. 06/136,364 (the '364 application), which is hereby incorporated by reference in its entirety, provides for far more receive beams per pulse. In particular, an  $N$  by  $N$  receiver array described in the '364 application can provide  $(N/2)^2$  simultaneous receive beams. Thus, choosing  $N=16$ , for example, produces an 8 by 8 array of 64 receiver beams for each transmitted pulse. Moreover, a device of the '364 application utilizes a planar array of rectangular ultrasound

transducer elements comprising multiple transmitters and a thinned receiver array (elements are spaced more than  $\frac{1}{2}$  wavelength apart). A subset of the total aperture is used to transmit for a given time and insonate a number of receive beam positions without insonating the receiver grating lobes that result from thinning. In order to  
5 perform 3-dimensional ultrasound imaging, with a meaningful number of lines in two angular dimensions (called azimuth and elevation), it is necessary to scan a wide transmit beam so as to cover, say, a  $90^\circ$  sector ( $\pm 45^\circ$ ) in both azimuth and elevation.

10 Thus, a device as described in the '364 application allows for a  $128 \times 128$  array of pixels for each depth. Furthermore, a device of the '364 application utilizes a thinned array, reducing the number of array elements and resulting in far less cabling and input electronics.

15 However, a thinned array described in the '364 application has limited applications in evaluating a large volume of a subject's body. Thus, in order to make such an evaluation, it may be necessary to take data from a particular segment of the subject's body, and then physically move the thinned array to an adjacent segment for additional data taking.

20

Accordingly, what is needed is a thinned array that permits high-resolution imaging of a large volume a subject's body, without the necessity of relocating the array. Such a thinned array would improve the performance of presently known ultrasound devices, and further permit their use in fields such as cardiac diagnosis and  
25 monitoring.

What is also needed is a thinned array that has applications with any presently available or subsequently discovered ultrasound device.

30 What is also needed is a thinned array that is configured to suppress, or at least severely limit spatial ambiguities, or "grating lobes" that would interfere with the

application of an ultrasound device, and decrease the resolution of a three dimensional image generated from echoes received from the subject's body.

The citation of any reference herein should not be construed as an admission that such reference is available as "Prior Art" to the instant application.

### SUMMARY OF THE INVENTION

There is provided, in accordance with the present invention a novel, useful, and unobvious thinned array for use with an ultrasound device, that offers the advantage of permitting high-resolution imaging of a large volume of a subject's body.

Broadly, the present invention extends to a thinned array for use with an ultrasound device for evaluating a volume of a subject's body, wherein the volume is formed of a plurality of segments. Such a thinned array comprises:

(a) a plurality of transmitters configured so that one transmitter insonates one individual segment of the volume at a time; and

(b) an array of receivers that simultaneously receive echoes from the volume being evaluated, wherein the array of receivers is electronically aimed and dynamically focused upon sub-segments of the insonated segment of the volume, wherein the spacing among the receivers in the array is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy produced by the transmitters, and the receivers are configured to receive echoes from the sub-segments of the individual insonated segments of the volume of the subject's body in a pattern that is aligned with the insonated segment of the volume insonated by the transmitters, so that receiver grating lobes nearest the echoes coincide with first transmitter nulls, and the deleterious effects of grating lobes are minimized.

In a particular embodiment, the transmitters and receivers of a thinned array of the present invention are in a two-dimensional configuration. The shape of the transmitters can vary. Particular examples include, but certainly are not limited to

rectangles, e.g., a square, and diamond shapes. In an embodiment wherein the transmitters are rectangular in shape, the transmitters are positioned flush against each.

- 5 As explained above a thinned array of the present invention also comprises a plurality of receivers that simultaneously receive echoes from the volume being evaluated, wherein the spacing of the receivers is greater than  $1/2$  the wavelength of the sonic energy produced by the transmitters. In a particular embodiment of the present invention, wherein the transmitters are diamond in shape, the receivers can  
10 optionally be interleaved with the transmitters.

Naturally, a thinned array of the present invention is electronically connected to a particular ultrasound device utilizing the thinned array.

- 15 Thus, a thinned (greater than  $1/2$  wavelength element spacing) array of ultrasound transducers of the present invention is used to form a large number of received and focused beams within an insonated volume. Since array thinning allows for scanning or imaging over only a limited region or segment, a set of transmitters are fired one at a time to insonate one segment at a time. The receiver is an array of receiver  
20 elements, all receiving simultaneously echoes from the volume of the subject's body insonated by the transmitters one at a time. A novel aspect of the present invention, wherein each particular transmitter insonates a segment of the volume subject's body, permits the insonation and evaluation of a larger volume the subject's body than can be evaluated with heretofore known thinned arrays. A large number of  
25 receive beams are formed digitally for each transmitted pulse, and each transmitter is designed to provide very little energy in the direction of undesired receiver spatial ambiguities or "grating lobes".

- In another embodiment, the present invention extends to a thinned array for use with  
30 an ultrasound device for evaluating a volume of a subject's body, comprising:

(a) an array of transmitters having spacing that is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy produced by the transmitters, and the array of transmitters are configured to insonate sub-segments of segments of the volume of the subject's body being evaluated, so that transmitter grating lobes coincide with first receiver  
5 nulls so that deleterious effects of grating lobes are minimized, and the array electronically scans the segments of the volume of the subject's body being evaluated, one sub-segment at a time; and

(b) a plurality of receivers that simultaneously receive echoes from the sub-  
10 segments of the segments of the volume of the subject being evaluated, wherein each receiver points to a particular grating lobe of the transmitter pattern, or to a particular segment of volume.

Naturally, a thinned array of the present invention is electronically connected to a  
15 particular ultrasound device utilizing the thinned array.

Furthermore, the present invention extends to a method for insonating a volume of a subject with a thinned array for use with an ultrasound device, comprising the steps of:

20 (a) providing a thinned array for evaluating a volume of a subject's body, the thinned array comprising:

(i) a plurality of transmitters configured so that one transmitter insonates one individual segment of the volume at a time; and

25 (ii) an array of receivers that simultaneously receive echoes from the volume being evaluated, wherein the array of receivers is electronically aimed and dynamically focused upon sub-segments of the insonated segment of the volume, wherein the spacing among the receivers in the array is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy  
30 produced by the transmitters, and the receivers are configured to receive echoes from the sub-segments of the individual insonated

segments of the volume of the subject's body in a pattern that is aligned with the insonated segment of the volume insonated by the transmitters, so that receiver grating lobes nearest the echoes coincide with first transmitter nulls, and the deleterious effects of grating lobes are minimized; and

(b) electrically connecting the thinned array to the ultrasound device, so that the volume of the subject can be ultrasonically evaluated.

Moreover, the present invention extends to a method for insonating a volume of a subject with a thinned array for use with an ultrasound device, comprising the steps of:

(a) providing a thinned array for evaluating a volume of a subject's body, the thinned array comprising:

(i) an array of transmitters having spacing that is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy produced by the transmitters, and the array of transmitters are configured to insonate sub-segments of segments of the volume of the subject's body being evaluated, so that transmitter grating lobes coincide with first receiver nulls so that deleterious effects of grating lobes are minimized, and the array electronically scans the segments of the volume of the subject's body being evaluated, one sub-segment at a time; and

(ii) a plurality of receivers that simultaneously receive echoes from the sub-segments of the segments of the volume of the subject being evaluated, wherein each receiver points to a particular grating lobe of the transmitter pattern, or to a particular segment of volume; and

(b) electrically connecting the thinned array to the ultrasound device, so that the volume of the subject can be ultrasonically evaluated.

Accordingly, it is an object of the present invention to provide a novel and useful thinned array that permits high-resolution imaging of a large volume a subject's body, without the necessity of relocating the array.

- 5 It is another object of the present invention to provide a novel and useful thinned array that can be readily utilized with any presently known or subsequently developed ultrasound device.

- 10 It is yet another object of the present invention to provide a novel and useful thinned array that is configured to suppress, or at least substantially reduce grating lobes.

These and other aspects of the present invention will be better appreciated by reference to the following drawings and Detailed Description.

15 BRIEF DESCRIPTION OF THE DRAWINGS

- Fig. 1 shows two possible  $N/r$  by  $M/s$  arrays of transmitters corresponding to an  $N$  by  $M$  receiver array, illustrated for the Case  $N/r = M/s = 4$ . Each square or diamond represents a single transmitter. E.g.,  $N=M=8$  and  $r=s=2$ . The rectangular transmitter of Fig. 1A produces the  $\sin x / x$  Pattern in Azimuth and in Elevation Shown in Fig. 2.
- 20 Fig. 1B shows the second, or alternative, transmitter array. The diamond (smaller rotated) transmitters produce a  $(\sin x / x)^2$  pattern in azimuth and in elevation as shown in Fig. 3a.

- Fig. 2 shows a two-dimensional  $\sin(2\pi x) / 2\pi x$  pattern due to a uniformly weighted rectangular aperture as in Fig. 1A. Rotating and shrinking the aperture as shown in
- 25 Figure 1 B rotates and expands the pattern. The resulting pattern is  $(\sin \pi x / \pi x)^2$  in both azimuth and elevation as shown in Fig. 3A. This pattern can also be achieved by applying a triangular shading (amplitude weight taper) across the original (Fig. 1A) rectangular transmitter aperture. By way of example, assume the width (or
- 30 height) of each transmitter is  $2d$ , where  $d$  is the spacing between elements in the  $N$  by  $M$  rectangular receive array.



Fig. 3 plots one-dimensional patterns for a 16 element linear receive array and a two-element long transmitter ( $N=16$  and  $r=2$ ). Figure 3b shows a cluster of eight receiver beams along with the grating lobes of a thinned receiver array. Fig. 3a shows the  $(\sin \pi x / \pi x)^2$  pattern of a triangularly weighted transmitter. Fig. 3c shows the resultant two-way beam pattern with grating lobes suppressed. The two-dimensional counterpart of Figure 3 would use an 8 x8 array of diamond-shaped uniformly weighted transmitters and a 16 by 16 = 256 element planar receive array. This would produce an 8 by 8 cluster of 64 received beams.

Fig. 4 shows the two-way pattern of beam number 8 in Fig. 3C plotted in dB. In this case, the grating lobe is suppressed by 12.5 dB.

Fig. 5 shows the beam configuration for 3-D Imaging with  $(N/2)^2$  by  $(N/2)^2$  beams formed by  $(N/2)^2$  Transmissions and an  $N$  by  $N$  receiver array, illustrated for the Case of  $N = 16$ .

Fig. 6 shows an example of interleaving the receiver array elements with the transmitter array.

#### DETAILED DESCRIPTION OF THE INVENTION

The present invention is based upon the discovery that surprisingly and unexpectedly, a thinned array for use with an ultrasound device can be designed which permits evaluation of a large volume of a subject's body, and increases the number of resolution elements of ultrasound images obtained as compared with images obtained with heretofore known arrays.

In an embodiment, the present invention extends to a thinned array for use with an ultrasound device for evaluating a volume of a subject's body, and the thinned array is electrically connected to the ultrasound device, the thinned array comprising:

- (a) a plurality of transmitters configured so that one transmitter insonates one individual segment of the volume at a time; and

(b) an array of receivers that simultaneously receive echoes from the volume being evaluated, wherein the array of receivers is electronically aimed and dynamically focused upon sub-segments of the insonated segment of the volume, wherein the spacing among the receivers in the array is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy produced by the transmitters, and the receivers are configured to receive echoes from the sub-segments of the individual insonated segments of the volume of the subject's body in a pattern that is aligned with the insonated segment of the volume insonated by the transmitters, so that receiver grating lobes nearest the echoes coincide with first transmitter nulls, and the deleterious effects of grating lobes are minimized.

In another embodiment, the present invention extends to a thinned array for use with an ultrasound device for evaluating a volume of a subject's body, comprising:

15

(a) an array of transmitters having spacing that is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy produced by the transmitters, and the array of transmitters are configured to insonate sub-segments of segments of the volume of the subject's body being evaluated, so that transmitter grating lobes coincide with first receiver nulls so that deleterious effects of grating lobes are minimized, and the array electronically scans the segments of the volume of the subject's body being evaluated, one sub-segment at a time; and

(b) a plurality of receivers that simultaneously receive echoes from the sub-segments of the segments of the volume of the subject being evaluated, wherein each receiver points to a particular grating lobe of the transmitter pattern, or to a particular segment of volume.

Furthermore, the present invention extends to a method for insonating a volume of a subject with a thinned array for use with an ultrasound device, comprising the steps of:

30

(a) providing a thinned array for evaluating a volume of a subject's body, the thinned array comprising:

(i) a plurality of transmitters configured so that one transmitter insonates one individual segment of the volume at a time; and

(ii) an array of receivers that simultaneously receive echoes from the volume being evaluated, wherein the array of receivers is electronically aimed and dynamically focused upon sub-segments of the insonated segment of the volume, wherein the spacing among the receivers in the array is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy produced by the transmitters, and the receivers are configured to receive echoes from the sub-segments of the individual insonated segments of the volume of the subject's body in a pattern that is aligned with the insonated segment of the volume insonated by the transmitters, so that receiver grating lobes nearest the echoes coincide with first transmitter nulls, and the deleterious effects of grating lobes are minimized; and

(b) electrically connecting the thinned array to the ultrasound device, so that the volume of the subject can be ultrasonically evaluated.

Moreover, the present invention extends to a method for insonating a volume of a subject with a thinned array for use with an ultrasound device, comprising the steps of:

(a) providing a thinned array for evaluating a volume of a subject's body, the thinned array comprising:

(i) an array of transmitters having spacing that is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy produced by the transmitters, and the array of transmitters are configured to insonate sub-segments of segments of the volume of the subject's body being evaluated, so that transmitter grating lobes coincide with first receiver nulls so that

deleterious effects of grating lobes are minimized, and the array electronically scans the segments of the volume of the subject's body being evaluated, one sub-segment at a time; and

- 5           (ii)    a plurality of receivers that simultaneously receive echoes from the sub-segments of the segments of the volume of the subject being evaluated, wherein each receiver points to a particular grating lobe of the transmitter pattern, or to a particular segment of volume; and
- (b)    electrically connecting the thinned array to the ultrasound device,
- 10   so that the volume of the subject can be ultrasonically evaluated.

Numerous terms and phrases are used throughout the instant specification and appended claims.

- 15   As used herein, the phrase "element spacing" or "spacing" can be used interchangeably and refer to the distance between the center of receivers or transmitters of a thinned array of the present invention. In one embodiment of the present invention described above, the spacing between transmitters is greater than  $\frac{1}{2}$  the wavelength of ultrasonic energy produced by the transmitters. In another
- 20   embodiment described above, the spacing between the receivers is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy produced by the transmitters.

- As used herein, the phrase "electronically aimed" with respect to an array of receivers or transmitters of a thinned array of the present invention means that
- 25   phase shifts or delays are applied to the individual elements so that a beam is steered or focused on a particular segment or sub-segment of the volume of the subject being evaluated.

- As used herein, the phrase "dynamically focused" with respect to transducers of a
- 30   thinned array of the present invention means that the phase shifts can vary with time so as to depend on range or depth.

In addition, the phrase "first transmitter nulls" as used herein refers to places nearest the insonated segment of the volume of the subject's body being evaluated where the transmitter power is zero or near zero.

- 5 As used herein, the phrase "transmitter sidelobe patterns" refers to the angular distribution of transmitted energy outside the segment intentionally insonated.

As used herein, the terms "transducer" and "element" refer to transmitters and/or receivers of ultrasonic energy.

10

Hence, contrary to heretofore known thinned arrays for use with ultrasound devices, an embodiment of a thinned array of the present invention, as described above, utilizes set of dedicated transmit apertures, each permanently aimed in a different direction. If, for example, the receive array is to be electronically scanned over the  
15 entire 90° by 90° sector, the receiver array elements must be wide-angle, covering an entire octant without significant attenuation.

In another embodiment of a thinned array of the present invention, dedicated receiver apertures are used, and the transmitter array is thinned as described herein.

20

The present invention may be better understood by reference to the following non-limiting Examples, which are provided as exemplary of the invention. The following Examples are presented in order to more fully illustrate the preferred embodiments of the invention. They should in no way be construed, however, as limiting the broad  
25 scope of the invention.

### EXAMPLE I

30

For simplicity, assume an example of a square array, where the receivers lie on a  $N$  by  $N$  grid, at a spacing of  $d$  for both the horizontal and vertical directions. In this case, the transmitters illustrated in Fig. 1 would each be  $2d$  wide and  $2d$  high. High-resolution dynamic volumetric imaging, could, for example, require a 16 by 16 receiver array and hence an 8 by 8 array of 64 transmitters ( $N=16$ ). The two-

dimensional amplitude pattern of a  $2d \times 2d$  square transmitter aperture is plotted as a function of  $x = (d/\lambda) \sin \theta$  and  $y = (d/\lambda) \sin \phi$  in Fig. 2.

Since the receivers are not directive by themselves, suppression of grating lobes must be accomplished entirely by the transmitter pattern. Hence triangular shading is used to produce a low-sidelobe  $(\sin \pi x / \pi x)^2$  pattern in both  $x$  and  $y$  (corresponding to azimuth and elevation) This is illustrated in Fig. 3, (showing azimuth only) for the case of  $N=16$ .

For example, if  $f = 4$  MHz, then  $\lambda = c/f = 1.540/4 = 0.385$  mm. Making  $d$  slightly less than 1mm (so that the receiver array is 1.5 cm by 1.5 cm), results in  $d/\lambda \approx 2.5$ . Thus, in this example, the thinning is five to one, resulting in a reduction in the number of elements in the two dimensional array by a factor of 25.

Figs. 3 and 4 were created using the following MATLAB program:

```

x=-2:1/128:2-1/128;
p=pi*x+eps; T=(sin(p)./p).^2;
N=16
n=0:N-1;
xo=-.175:.05:.175;
w=hanning(N);
E=(1/N)*ones(1,N)*e;
for k=1:8;
    e=exp(j*n'*2*pi*(x-xo(k)));
    E(k,:)=(2/N)*w'*e;
    TE(k,:)=abs(T).*abs(E(k,:));
end
subplot(311); plot(x,abs(T));
ylabel('a. Transmitter Pattern')
subplot(312); plot(x,abs(E));
ylabel('b. Receive Patterns')
subplot(313); plot(x,TE);
ylabel('c. 2-way Pattern')
figure(2); plot(x,10*log10(TE(8,:)));
zoom on;

```

Fig. 3a shows the transmitter pattern as a function of  $x$ . Fig. 3b shows the pattern of a 16 element linear array, using Hanning weighting and steered to 8 different values of  $x$ , with  $|x| < 0.2$ . This corresponds to an  $8 \times 8$  cluster of 64 receiver beams that are digitally produced for each transmitted pulse. Since there are 64 transmitters,

each aimed and focused at a different region, 4096 lines are formed in only 64 pulses. This is  $\frac{1}{4}$  the time it takes a conventional ultrasound imager to produce only 256 lines. Furthermore, only 256 receiver elements and 64 transmitter apertures were used.

5 The resulting beam cluster is illustrated in azimuth only in Fig. 3c. In general, the origin ( $x=0$ ) of Fig. 3 will be translated to correspond to the azimuth angle of the center of the current transmit beam. Fig. 4 plots the rightmost beam of Fig. 3c in dB, to show that the grating lobes are attenuated by at least 25 dB. Figure 5 shows the  
10 beam configuration in two angular dimensions, where Fig. 3c is a horizontal cut through the receiver beams illustrated in Fig. 5. The addition of time delay or depth (range) results in a 3-D image. The 4 to 1 reduction in imaging time allows for increased volumes per second for 3-D color flow imaging.

15 As explained above, conventional imagers view a single slice, with between 64 and 256 lines or beams. This invention views a three dimensional volume with a 64 by 64 array of lines in  $\frac{1}{4}$  the time. The array, is bistatic. However, the transmitters and the receiver elements could be interleaved as shown in Fig. 6. Alternatively, the  
20 arrays could be kept separate and the number of transmitters (and hence the total number of lines) can be doubled by filling in the blank spaces of Figure 1b with another set of  $(N/2)^2$  elements. By way of example, this doubles the number of transmit beams in Fig. 5 (left hand side) so that 8192 beams are created using only 256 receiver elements. By doubling the overall size of the transmitter array, a total of 16384 beams can be formed.

25 The signal processing utilized with a thinned array of the invention can be, for example, the processing described in the '364 application described above. However, a thinned array of the present invention utilizes a set of electronically-aimed fixed-focus transmitters to extend the region imaged beyond the limit imposed  
30 by the necessity to avoid grating lobes of a thinned receive array. Heretofore known thinned arrays do not utilize electronically-aimed and fixed-focus transmitters. Moreover, note that the expanded angular field being imaged with a thinned array of

the present invention permits its use for diagnostic, monitoring, and therapeutic applications. Tracking procedures such as those described in the '364 application can keep the near-field array focused at desired points in 3-D space so as to heat or destroy unwanted tissue, gall stones, kidney stones, etc., or maintain critical  
5 positioning of the image relative to some other device. Since a 3-D image is formed, tracking in three dimensions can also be achieved through image correlation.

## EXAMPLE II

10 In the embodiment of the present invention set forth in Example I above, Figure 3a represents the pattern of one of the transmitters, Figure 3b represents a set of digitally-formed simultaneously-received beams using a thinned receiver array, and Figure 3c is the product of the two. By sequentially using different transmitters, a large region can be imaged.

15 In the embodiment of the present invention set forth in this example, the roles of transmitter and receiver are interchanged. Thus, for purposes of this embodiment, Figure 3b illustrates the sequential scanning of a transmit beam (and its grating lobes) using a thinned transmitter array. Also, for purposes of the embodiment set  
20 forth in this example, Figure 3a illustrates the pattern of one of multiple receivers, designed to each receive signals from only one grating lobe. Figure 3c (the two-way pattern) is the product of the two. Multiple receivers can all receive energy at once, each from a different transmitter grating lobe.

25 The embodiment set forth in this example has the advantage of requiring less computation because the electronically-steered phased-array transmit beams are formed one at a time, while the multiple receivers are fixed-focus.

Many other variations and modifications of the present invention will be apparent to  
30 those skilled in the art without departing from the spirit and scope of the present invention. The above-described embodiments are, therefore, intended to be merely



exemplary, and all such variations and modifications are intended to be included within the scope of the present invention as defined in the appended claims.

WHAT IS CLAIMED IS:

1. A thinned array for use with an ultrasound device for evaluating a volume of a subject's body, and said thinned array is electrically connected to said ultrasound  
5 device, said thinned array comprising:
  - (a) a plurality of transmitters configured so that one transmitter insonates one individual segment of said volume at a time; and
  - (b) an array of receivers that simultaneously receive echoes from said volume  
10 being evaluated, wherein said array of receivers is electronically aimed and dynamically focused upon sub-segments of said insonated segment of said volume, wherein the spacing among said receivers in said array is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy produced by said transmitters, and said receivers are configured to receive echoes from said sub-segments of said  
15 individual insonated segments of said volume of the subject's body in a pattern that is aligned with said insonated segment of the volume insonated by the transmitters, so that receiver grating lobes nearest the echoes coincide with first transmitter nulls, and the deleterious effects of grating lobes are minimized.
- 20 2. The thinned array of Claim 1, wherein said transmitters and receivers are in a two dimensional configuration.
3. The thinned array of Claim 2, wherein said transmitters and receivers are rectangular in shape, and are positioned flush against each other in said thinned  
25 array.
4. The thinned array of Claim 2, wherein said transmitters are diamond in shape to reduce transmitter sidelobe patterns, which improves depression of receiver grating lobes.  
30
5. The thinned array of Claim 4, wherein said receivers are interleaved with said transmitters.

6. A thinned array for use with an ultrasound device for evaluating a volume of a subject's body, and the thinned array is electrically connected to the ultrasound device, the thinned array comprising:

(a) an array of transmitters having spacing that is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy produced by the transmitters, and the array of transmitters are configured to insonate sub-segments of segments of the volume of the subject's body being evaluated, so that transmitter grating lobes coincide with first receiver nulls so that deleterious effects of grating lobes are minimized, and the array electronically scans the segments of the volume of the subject's body being evaluated, one sub-segment at a time; and

(b) a plurality of receivers that simultaneously receive echoes from the sub-segments of the segments of the volume of the subject being evaluated, wherein each receiver points to a particular grating lobe of the transmitter pattern, or to a particular segment of volume.

7. A method for insonating a volume of a subject with a thinned array for use with an ultrasound device, comprising the steps of:

(a) providing a thinned array for evaluating a volume of a subject's body, the thinned array comprising:

(i) a plurality of transmitters configured so that one transmitter insonates one individual segment of the volume at a time; and

(ii) an array of receivers that simultaneously receive echoes from the volume being evaluated, wherein the array of receivers is electronically aimed and dynamically focused upon sub-segments of the insonated segment of the volume, wherein the spacing among the receivers in the array is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy produced by the transmitters, and the receivers are configured to

receive echoes from the sub-segments of the individual insonated segments of the volume of the subject's body in a pattern that is aligned with the insonated segment of the volume insonated by the transmitters, so that receiver grating lobes nearest the echoes coincide with first transmitter nulls, and the deleterious effects of grating lobes are minimized; and

(b) electrically connecting the thinned array to the ultrasound device, so that the volume of the subject can be ultrasonically evaluated.

8. The method of Claim 7 wherein the transmitters and receivers are in a two dimensional configuration.

9. The method of Claim 7, wherein the transmitters and receivers are rectangular in shape, and are positioned flush against each other in the thinned array.

10. The method of Claim 7, wherein the transmitters are diamond in shape to reduce transmitter sidelobe patterns, which improves depression of receiver grating lobes.

11. The method of Claim 10, wherein the receivers are interleaved with the transmitters.

12. A method for insonating a volume of a subject with a thinned array for use with an ultrasound device, comprising the steps of:

(a) providing a thinned array for evaluating a volume of a subject's body, the thinned array comprising:

(i) an array of transmitters having spacing that is greater than  $\frac{1}{2}$  the wavelength of the ultrasonic energy produced by the transmitters, and the array of transmitters are configured to insonate sub-segments of

segments of the volume of the subject's body being evaluated, so that  
transmitter grating lobes coincide with first receiver nulls so that  
deleterious effects of grating lobes are minimized, and the array  
electronically scans the segments of the volume of the subject's body  
being evaluated, one sub-segment at a time; and

- (ii) a plurality of receivers that simultaneously receive echoes from the  
sub-segments of the segments of the volume of the subject being  
evaluated, wherein each receiver points to a particular grating lobe of  
the transmitter pattern, or to a particular segment of volume; and

- (b) electrically connecting the thinned array to the ultrasound device,  
so that the volume of the subject can be ultrasonically evaluated.

FIG. 1A

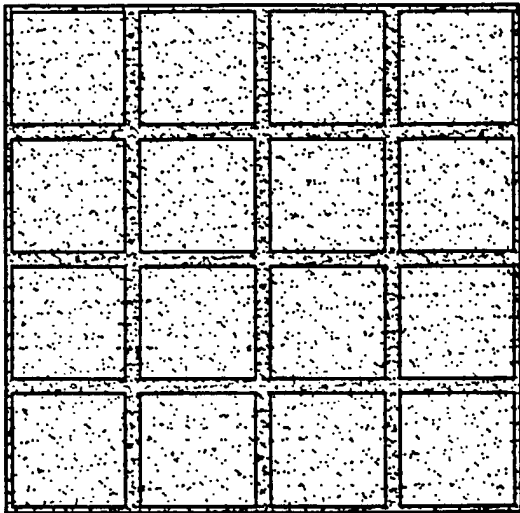


FIG. 1B

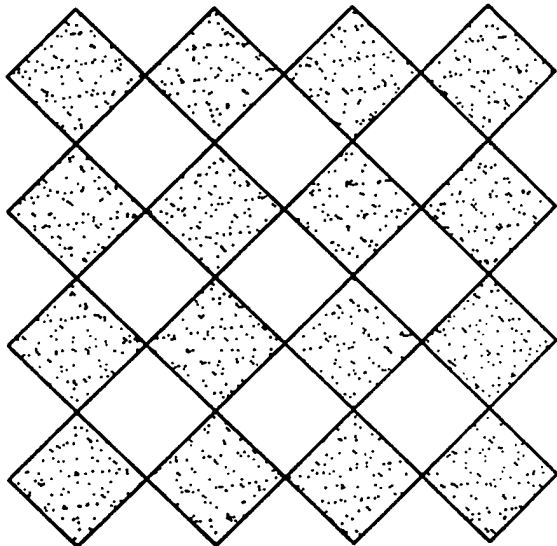
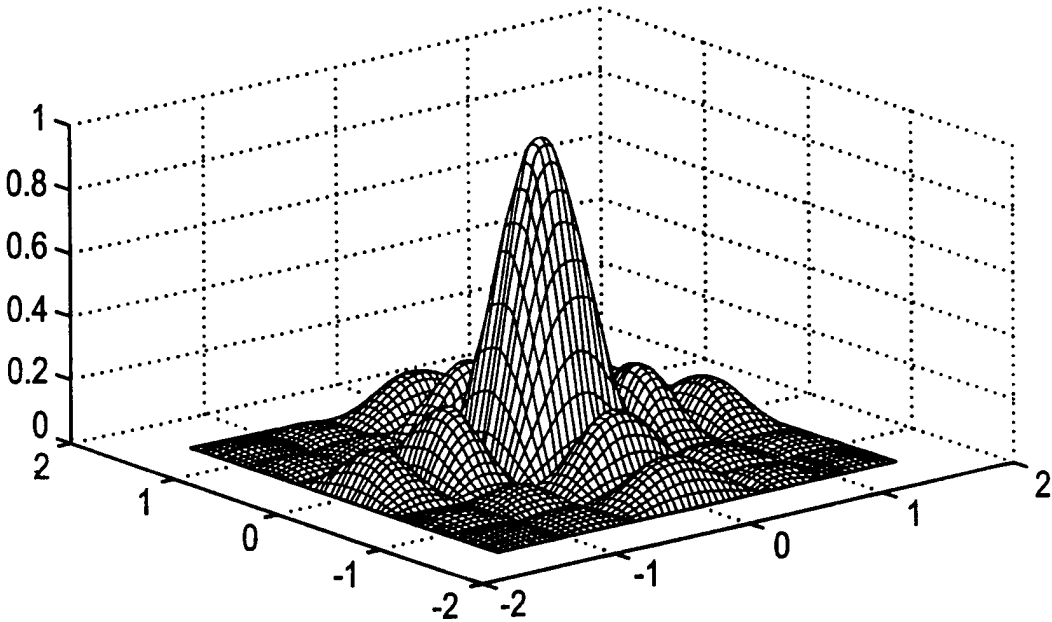


FIG. 2



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FIG. 3A

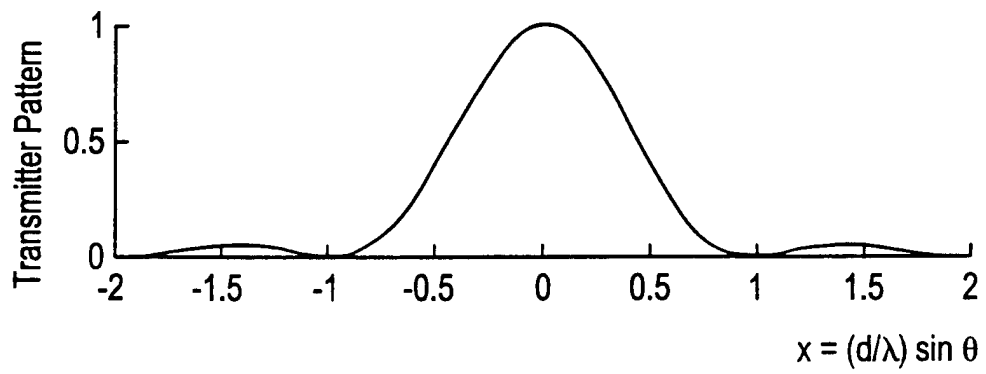


FIG. 3B

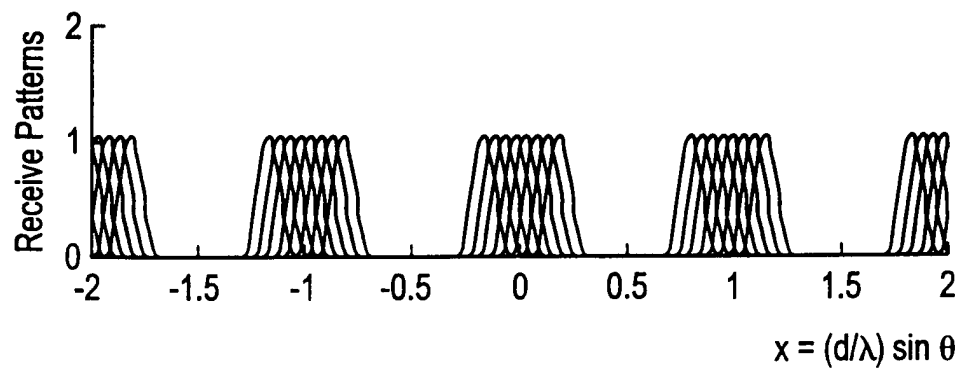


FIG. 3C

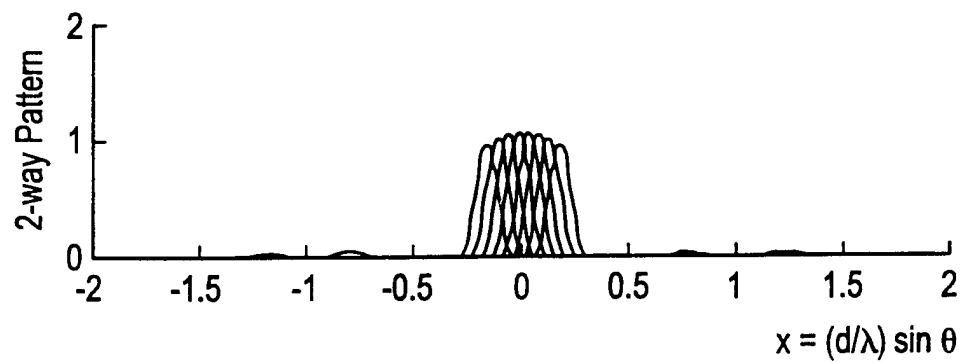


FIG. 4

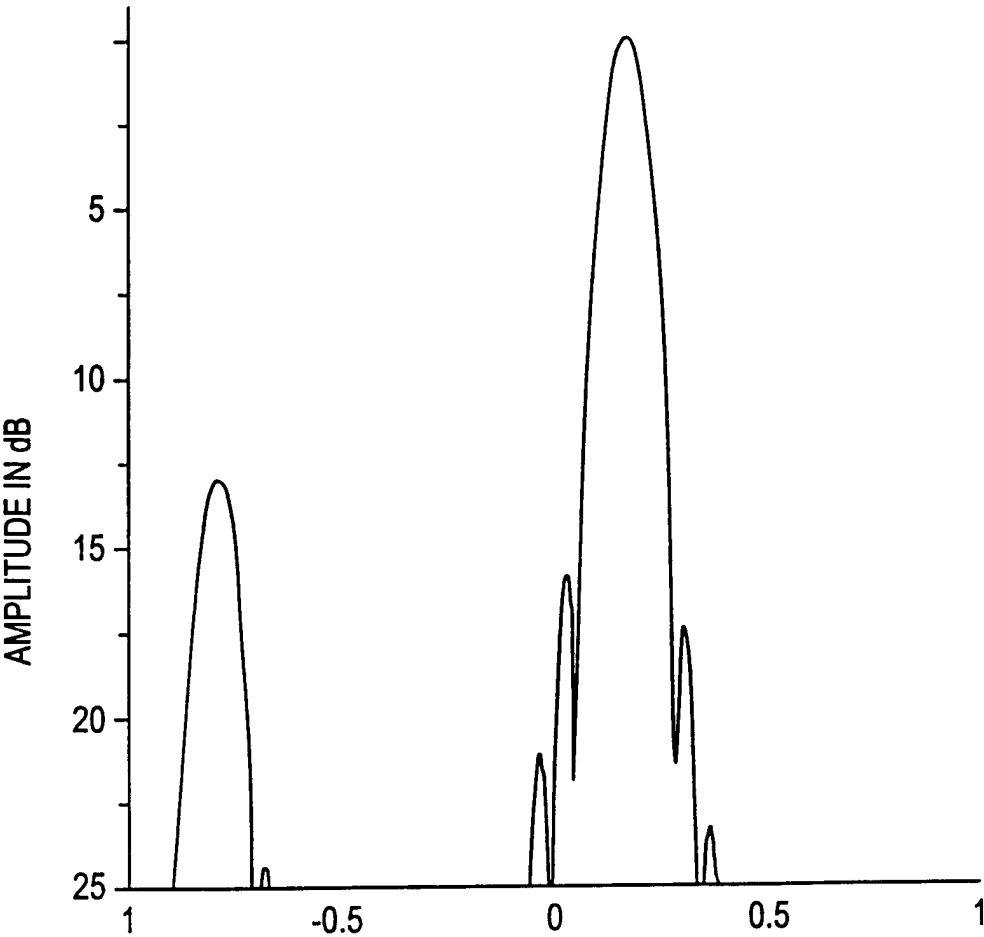




FIG. 5

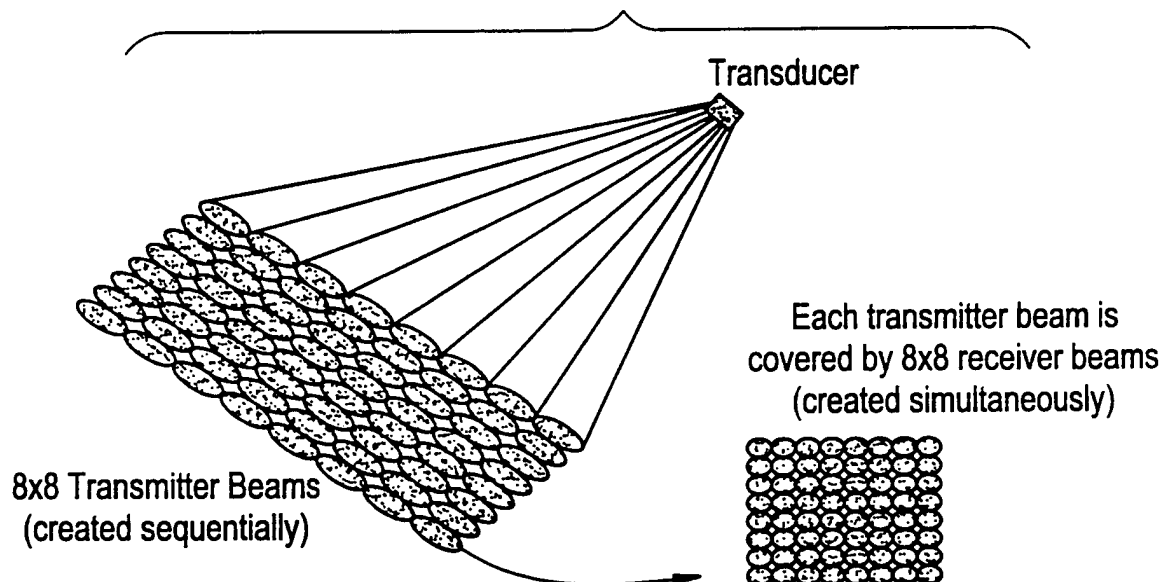
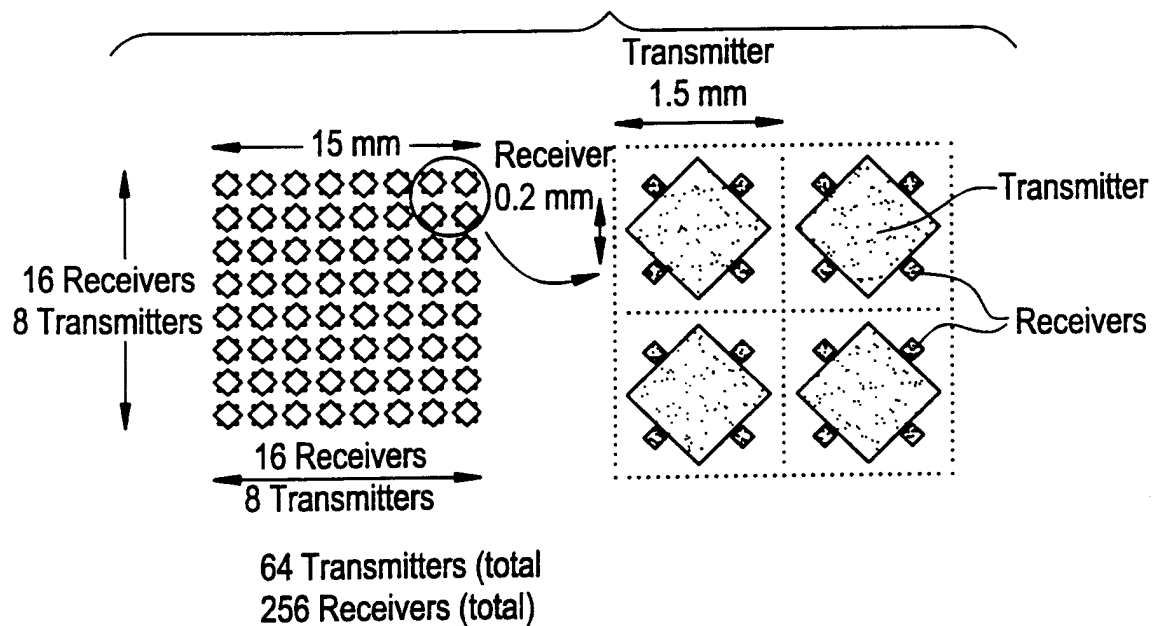


FIG. 6



## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US00/16535**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(7) : A61B 8/00

US CL : 600/447

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 73/620, 625, 626; 128/916; 367/135; 600/439, 443, 447, 456, 459, 463

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST

Search Terms: (sparse or thinned) adj2 array\$1, volumetric,3D or three near dimension\$2 and image\$1 or imaging or scanning

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,P	US 6,066,096 A (SMITH et al.) 23 May 2000, col. 6 line 55 to col. 7 line 7.	1- 12
Y	US 5,546,807 A (OXAAL et al.) 20 August 1996, entire document	1-12
Y	US 5,840,033 A (TAKEUCHI) 24 November 1998, col. 5 line 61 to col. 6 line 8	1-12

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means		
"P" document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

05 SEPTEMBER 2000

Date of mailing of the international search report

04 OCT 2000

Name and mailing address of the ISA/US  
Commissioner of Patents and Trademarks  
Box PCT  
Washington, D.C. 20231

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专利名称(译)	改进的体积超声成像与稀疏阵列		
公开(公告)号	<a href="#">EP1194070A1</a>	公开(公告)日	2002-04-10
申请号	EP2000939906	申请日	2000-06-14
[标]申请(专利权)人(译)	VUESONIX传感器 ABEND KENNETH		
申请(专利权)人(译)	VUESONIX传感器INC. ABEND , KENNETH		
当前申请(专利权)人(译)	VUESONIX传感器 , INC.		
[标]发明人	ABEND KENNETH		
发明人	ABEND, KENNETH		
IPC分类号	A61B8/00 B06B1/06 G01S7/52 G01S15/89 H04R17/00		
CPC分类号	G01S15/8925 B06B1/0629 G01S7/52003 Y10S128/916		
优先权	60/138782 1999-06-14 US		
外部链接	<a href="#">Espacenet</a>		

#### 摘要(译)

超薄换能器的变薄 ( 大于波长元件间隔 ) 阵列用于在声波化区域内形成大量接收的近场聚焦光束。由于阵列细化允许仅在有限的区域或区段上进行明确的扫描或成像，因此一次一个地发射一组发射器以一次声化一个区段。接收器是元件阵列，全部同时接收，并且使用多个发射器，每个发射器瞄准不同的段。通过在发射器之间切换来控制发射波束，并且对于每个发射脉冲数字地形成大量聚焦接收波束。发射器被设计成在接收器空间模糊或“栅瓣”的方向上提供非常小的能量。还提供了一种薄的阵列，其中如上所述的发射器和接收器的作用是互换的。