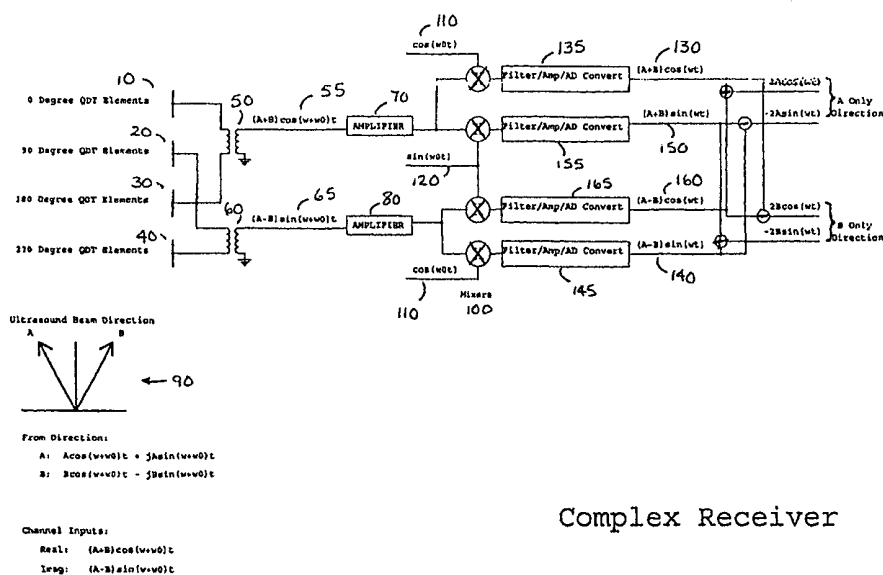




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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**(54) Title:** A COMPLEX RECEIVER AND METHOD FOR IMPROVED ULTRASONIC SIGNAL PROCESSING

**(57) Abstract**

A method and apparatus (10-140) for simultaneously receiving and unambiguously resolving a plurality of propagated ultrasound signals as a composite ultrasound signal, the method including: receiving the composite ultrasound signal; generating a first signal indicative of a real portion of the received composite ultrasound signal; generating a second signal indicative of an imaginary portion of the received composite ultrasound signal; phase shifting the first and second signals; and selectively combining the phase shifted first and second signals to provide a third signal indicative of a first of the plurality of propagated ultrasound signals; and a fourth signal indicative of a second of the plurality of propagated ultrasound signals.

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**A COMPLEX RECEIVER AND METHOD  
FOR IMPROVED ULTRASONIC SIGNAL PROCESSING**

Cross Reference To Related Application

5

This application claims priority from commonly assigned, copending U.S. Provisional Patent Application No. 60/124,256 filed March 12, 1999, entitled A COMPLEX RECEIVER AND METHOD FOR IMPROVED DOPPLER FLOW which is incorporated herein by reference in its entirety and for all purposes.

10

Field of Invention

The invention relates to ultrasound imaging and Doppler flow measurement, and more particularly to an improved method thereof and a complex receiver therefore.

15

Background of Invention

The instant invention represents an improvement on the method of Doppler flow measurement disclosed by Vilkomerson in commonly assigned U.S. Patents 5,488,953, 5,540,230, 5,669,388 and 5,713,362 respectively, the disclosures of which are hereby incorporated by reference, which utilize first order and higher order Quadrature Diffractive grid Transducers (QDT'S, or grids for short).

20

As described in these patents, QDT grid transducers are devices that allow

control of the direction of the ultrasound beam using the frequency and/or phasing of the drive signals. For a given transducer geometry the drive frequency controls the beam angular deviation from the transducer normal direction, while the phasing of the electronic drive signals controls the production of either two beams or one beam and its direction. That is, for a complex grid drive signal

$$s(t) = \cos(\omega_0 t) + j\sin(\omega_0 t), \quad (1)$$

where  $\omega_0$  is the angular frequency of the ultrasound drive and  $j^2 = -1$ , a single beam will be produced at an angle  $\Phi$  to the transducer normal (an "A" direction).

Figure 1 illustrates the application of this signal to the QDT transducer.

While, for a complex grid drive signal

$$s(t) = \cos(\omega_0 t) - j\sin(\omega_0 t) \quad (2)$$

a single beam will be produced at an angle  $-\Phi$  to the transducer normal (a "B" direction). This is due to the quadrature construction and placement of the QDT transducer elements.

Received signals from the "A" and "B" directions will be of the same form, by reciprocity of transmit and receive. The elements are placed at quadrature locations  $d/4$  where  $d$  is the period of the distance cycle. The angle  $\Phi$  of the beam results from the choice of distance  $d$  by the relation involving  $\lambda$ , the ultrasound wavelength, as follows:

$$\sin(\Phi) = \lambda/d. \quad (3)$$

It should be noted that the angles  $\Phi$  and  $-\Phi$  are mirror angles about the normal direction and, as such, are in separate quadrants.

Phasing of the drive signal allows the beam direction to be easily changed, so that, in the case of blood flow measurement, flow may be measured at two different angles, which allows for two independent Doppler shift equations to be solved for two unknown variables, e.g. velocity and angle of beam to flow. Each  
5 beam is used to interrogate a vessel's flow separately and unambiguously from the other beam using a conventional (non-complex) receiver.

For a grid drive signal  $s(t) = \cos(\omega_0 t)$  or  $s(t) = j\sin(\omega_0 t)$ , e.g., driving one grid or the other, two ultrasound beams are produced simultaneously at angles  $\Phi$  and  $-\Phi$  from the transducer normal direction, and the return signals are a mixture  
10 of the signals from both beams. This mixture causes ambiguity to a conventional Doppler receiver, since it cannot resolve the beam directions separately. Therefore, the velocity of the flow and angle of the transducer to the flow cannot be determined using this method. As a result, single independent beams produced as discussed above by phasing are used, first at  $\Phi$  then at  $-\Phi$  and alternating back  
15 and forth between beam positions.

While this method allows the angle and flow velocity to be determined, the two beam directions are each produced at the pulse repetition frequency (PRF) while each beam direction is produced at half this frequency since each beam direction is produced half the time. This has the undesirable effect of halving  
20 both the depth of measurement and maximum Doppler shift measurement that would be expected from a given PRF using a conventional ultrasound transducer.

### Summary of Invention

A method and apparatus for simultaneously receiving and unambiguously resolving a plurality of propagated ultrasound signals as a composite ultrasound signal, the method including: receiving the composite ultrasound signal;  
5 generating a first signal indicative of a real portion of the received composite ultrasound signal; generating a second signal indicative of an imaginary portion of the received composite ultrasound signal; phase shifting the first and second signals; and, selectively combining the phase shifted first and second signals to provide a third signal indicative of a first of the plurality of propagated ultrasound  
10 signals and a fourth signal indicative of a second of the plurality of propagated ultrasound signals.

### Brief Description of the Figures

The advantages and aspects of the present invention will be more fully  
15 understood in conjunction with the following detailed description and accompanying drawings, wherein:

Figure 1 illustrates the application of the complex grid drive signal to a QDT transducer;

Figure 2 illustrates an embodiment of the present invention that  
20 implements multiple beam processing;

Figure 3 illustrates the separation of beam directions at ultrasound frequencies; and,

Figure 4 illustrates upon implementing the 90° phase shift at a mixing level using only cosine waves.

#### Detailed Description of the Invention

5           The instant invention allows for acquisition of Doppler flow data from multiple simultaneous directions interrogated with multiple simultaneous transmit ultrasound beams produced by QDT grid transducers. Additionally, the method according to the present invention allows for receiving and separating a plurality of simultaneous transmit beam directions produced by QDT grid transducers for  
10           the purpose of ultrasound imaging. The use of simultaneous beam directions allows higher velocity flows from deeper vessels to be measured than was previously possible. Also, the use of the instant invention in ultrasound imaging advantageously enables use of higher imaging frame rates. The present invention allows the use of two or more beams simultaneously with each beam at the PRF,  
15           thus enabling full depth measurement.

          To process both beams simultaneously, the present invention effectively transfers the complex directional characteristic of the grid transducer transmitter to the receiver. In other words, the receiver according to the present invention processes a complex input signal from the transducer to perform beam separation.  
20           It should be understood a conventional Doppler receiver processes only a single real input signal. As the grid transducer achieves its directionality by operating as a complex device, the receiver according to the present invention possesses the

property of directionality. This enables two beams in different directions to be simultaneously received and resolved unambiguously, and the velocity and angle to be found to the maximum depth and using the maximum frequency shift corresponding to the PRF rather than to PRF/2 as before.

5           Consider that a transducer drive signal  $s(t) = \cos(\omega_0 t)$  is actually the superposition of the two drive signals:

$$s_A(t) = \cos(\omega_0 t) + j\sin(\omega_0 t) \text{ and (note, the same as EQ. 1)} \quad (4)$$

$$s_B(t) = \cos(\omega_0 t) - j\sin(\omega_0 t) \text{ (note, the same as EQ 2),} \quad (5)$$

and because,

$$10 \quad s(t) = s_A(t) + s_B(t), \quad (6)$$

$s_A(t)$  produces a beam in direction "A" at angle  $\Phi$ , and  $s_B(t)$  produce a beam in direction "B" at angle  $-\Phi$ , where  $\Phi$  is measured from the transducer normal direction. If at time  $t$ , the beam at  $\Phi$  provides a return  $r_A(t)$  from direction "A" of amplitude  $A$ , and simultaneously the beam at  $-\Phi$  provides a return  $r_B(t)$  from direction "B" of amplitude  $B$ , the returned signals are then

$$r_A(t) = A(\cos(\omega_A t) + j\sin(\omega_A t)), \text{ and,} \quad (7)$$

$$r_B(t) = B(\cos(\omega_B t) - j\sin(\omega_B t)), \quad (8)$$

where  $\omega_A$  and  $\omega_B$  are the Doppler shifted ultrasound transducer signals from beams "A" and "B". Accordingly, the composite received signal is

$$20 \quad rs(t) = [A\cos(\omega_A t) + B\cos(\omega_B t)] + j[(A\sin(\omega_A t) - B\sin(\omega_B t))] \quad (9)$$

and contains a mixture of returns from both the "A" direction and "B" direction beams. By use of the Hilbert Transform Pair relations, these signal directions are

separated. This is accomplished according to the present invention by forming a complex analytic signal from both the real and imaginary parts of the return signal  $rs(t)$ .

The utilized Hilbert Transform Pair relations are:

$$5 \quad m(t) \cos(\omega t) \longleftrightarrow m(t) \sin(\omega t), \text{ and} \quad (10)$$

$$m(t) \sin(\omega t) \longleftrightarrow -m(t) \cos(\omega t) \quad (11)$$

and are seen to be 90 degree phase shifters. Forming a complex signal from the real channel using the Hilbert Transform Pair relations gives

$$[A \cos(\omega_A t) + B \cos(\omega_B t)] + j[A \sin(\omega_A t) + B \sin(\omega_B t)] \quad (12)$$

10 in a forward direction  $\Phi$ , and

$$[A \cos(\omega_A t) + B \cos(\omega_B t)] - j[A \sin(\omega_A t) + B \sin(\omega_B t)] \quad (13)$$

in a mirror direction,  $-\Phi$ .

Subtracting these from the return signal gives

$$15 \quad [A \cos(\omega_A t) + B \cos(\omega_B t)] + j[A \sin(\omega_A t) - B \sin(\omega_B t)] \\ - ([A \cos(\omega_A t) + B \cos(\omega_B t)] + j[A \sin(\omega_A t) + B \sin(\omega_B t)]) = -2Bj \sin(\omega_B t) \quad (14)$$

and,

$$[A \cos(\omega_A t) + B \cos(\omega_B t)] + j[A \sin(\omega_A t) - B \sin(\omega_B t)] \\ - ([A \cos(\omega_A t) + B \cos(\omega_B t)] - j[A \sin(\omega_A t) + B \sin(\omega_B t)]) = +2Aj \sin(\omega_A t). \quad (15)$$

20 Analogously, forming a complex signal of the imaginary channel using the Hilbert Transform Pair relations gives

$$-A \cos(\omega_A t) + B \cos(\omega_B t) + j[(A \sin(\omega_A t) - B \sin(\omega_B t))] \quad (16)$$

in a forward direction  $\Phi$ , and

$$- [-A\cos(\omega_A t) + B\cos(\omega_B t)] + j[(A\sin(\omega_A t) - B\sin(\omega_B t))] \quad (17)$$

in a mirror direction.

Subtracting these from the return signal gives

$$\begin{aligned} & [A\cos(\omega_A t) + B\cos(\omega_B t)] + j[(A\sin(\omega_A t) - B\sin(\omega_B t))] \\ 5 \quad & - [-A\cos(\omega_A t) + B\cos(\omega_B t) + j[(A\sin(\omega_A t) - B\sin(\omega_B t))]] = +2A\cos(\omega_A t) \end{aligned} \quad (18)$$

and,

$$\begin{aligned} & [A\cos(\omega_A t) + B\cos(\omega_B t)] + j[(A\sin(\omega_A t) - B\sin(\omega_B t))] \\ & - ([A\cos(\omega_A t) - B\cos(\omega_B t)] + j[(A\sin(\omega_A t) - B\sin(\omega_B t))]) = +2B\cos(\omega_B t). \end{aligned} \quad (19)$$

So, two separate beams may be formed at once as

$$10 \quad -2Bj\sin(\omega_B t) + 2B\cos(\omega_B t) = 2B[\cos(\omega_B t) - j\sin(\omega_B t)] \quad (20)$$

in the "B" direction (14)+(19), and

$$+2A\cos(\omega_A t) + 2Aj\sin(\omega_A t) = 2A[\cos(\omega_A t) + j\sin(\omega_A t)] \quad (21)$$

in the "A" direction (15)+(18), which are recognizable by those possessing ordinary skill in the art as being identical in form to EQs. (1) and (2).

15           Therefore, according to the present invention for Doppler (or imaging where there is no Doppler shift and  $\omega_A = \omega_B$ , multiple beams may be transmitted and received simultaneously. It should also be recognized that multiple beam directions from higher order grids may also be separated in this way, since no condition was placed on beam angles other than that the beams reside in different

20           quadrants. Fig. 2 illustrates a system that implements this beam processing.

Also, since  $\omega_A$  and  $\omega_B$  are the Doppler shifted ultrasound transducer signals from beams "A" and "B", the transmit frequency components of  $\omega_A$  and

$\omega_B$  need not be equal. This allows transmit beams of different frequencies to be used and resolved. In this case, the beams may be in the same quadrant and separated by filtering. In this mode of operation, the complex receiver is used as two parallel channel conventional (real) receivers with mixers operating at the transmit frequency in each channel such as will be discussed in relation to Figure 4.

Referring to Figure 1, it illustrates four QDT elements 10, 20, 30 and 40 suitable positioned to receive a composite beam formed from two simultaneously transmitted drive signals. The  $0^\circ$  element 10 and  $180^\circ$  element 30 are coupled to a first transformer 50 to provide a first signal 55 indicative of the real portion of the received composite beam. Similarly, the  $90^\circ$  element 20 and  $270^\circ$  element 40 are coupled to a second transformer 60 to provide a second signal 65 indicative of the imaginary portion of the received composite beam.

Referring now to Figure 2, the location of the Hilbert transformers ( $90^\circ$  degree phase shifters) may be at the ultrasound frequency before the mixers, or generated at the baseband Doppler audio frequencies by quadrature mixers. Figure 3 shows the separation of beam directions at ultrasound frequencies. The idea is to apply Hilbert transformers in the signal path between the QDT elements 10, 20, 30, 40 and receiver, or in the receiver to allow two or more beams to be resolved simultaneously. That is, the Hilbert Transformers may operate at either ultrasound frequencies or at Doppler audio frequencies. The embodiment of Figure 2 receives beams transmitted in the "A" and "B" directions indicated in

phasor diagram 90. First signal 55 and second signal 65 are respectively fed into amplifiers 70 and 80. Shifting is accomplished using the mixer stage 100. Amplified signals 55 and 65 are separately mixed with signal 110 which is preferably  $\cos(w_0t)$  to provide signals 130 and 140 which respectively preferably take the form of  $(A+B)\cos(wt)$  and  $(A+B)\sin(wt)$ . Analogously, signals 55 and 65 are also separately mixed with signal 120 which is preferably  $\sin(w_0t)$  to provide signals 150 and 160 which respectively preferably take the form of -  $(A+B)\sin(wt)$  and  $(A-B)\cos(wt)$ .

Signals 130 and 160 are preferably added  $[(A+B)\cos(wt) + (A-B)\cos(wt)]$  to provide  $2A\cos(wt)$  and signal 140 is preferably subtracted from signal 150  $[-(A+B)\sin(wt) - (A-B)\sin(wt)]$  to provide  $-2A\sin(wt)$ . These products represent the real and imaginary parts of the beam received from the "A" direction.

Analogously, signal 160 is subtracted from signal 130  $[(A+B)\cos(wt) - (A-B)\cos(wt)]$  to provide  $2B\cos(wt)$  and signals 150 and 140 are added  $[-(A+B)\sin(wt) + (A-B)\sin(wt)]$  to provide  $-2B\sin(wt)$ . These products represent the real and imaginary parts of the beam received from the "B" direction.

Referring to Figure 3, an alternative embodiment is there illustrated. Therein signals 55 and 65 are respectively fed into two  $90^\circ$  hybrids 170 and 180 which respectively provide outputs each indicative of either the "A" or "B" direction. More particularly, each hybrid 170, 180 has a  $-90^\circ$  shifting input 190 and a  $0^\circ$  shifting input 200. Signal 55 is provided to input 200 of the hybrid 170

and input 190 of hybrid 180. Signal 65 is provided to input 190 of hybrid 170 and input 200 of hybrid 180. The resulting output 210 of hybrid 170 is  $2A\cos(\omega t)$  which is indicative of the "A" direction beam. The resulting output 220 of the hybrid 180 is  $-2B\sin(\omega t)$  which is indicative of the "B" direction beam.

5           Referring Figure 4, four beams produced by simultaneously transmitting two ultrasound frequencies as the superposition of cosine waves may be resolved using two parallel complex receivers, with filtering to remove the non-baseband mixing products resulting from the down-mixing of the two transmitted frequencies. Additionally, by using two simultaneous transmit complex  
10 frequencies and the properties of the grid transducer as a complex device, one may implement the 90 degree phase shifts at the mixers, mixing with only cosine waves instead of using sine and cosine waves. The embodiment of Figure 4 receives beams transmitted in the "A" and "B" directions indicated in phasor diagram 230.

15           Referring still to Figure 4, signals 55 and 65 are respectively fed into amplifiers 240 and 250. Shifting is accomplished using the mixer stage 260. Amplified signals 55 and 65 are separately mixed with signal 270 which is preferably  $\cos(\omega_1 t)$  to provide signals 300 and 330 which respectively preferably take the form of  $A\cos(\omega t)$  and  $B\sin(\omega t)$ . Analogously, signals 55 and 65 are also  
20 separately mixed with signal 280 which preferably is  $\cos(\omega_2 t)$  to provide signals 310 and 320 which respectively preferably take the form of  $B\cos(\omega t)$  and  $A\sin(\omega t)$ . Signals 300, 310, 320 and 330 are preferably filtered using low pass

filters 290 to remove the non-base band mixing products introduced by mixers 260.

Accordingly, signals 300 and 320 are indicative of the "A" direction beam and signals 310 and 330 are indicative of the "B" direction beam.

5           Although the invention has been described and pictured in a preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form, has been made only by way of example, and that numerous changes in the details of construction and combination and arrangement of parts may be made without departing from the spirit and scope of  
10           the invention as hereinafter claimed. It is intended that the patent shall cover by suitable expression in the appended claims, whatever features of patentable novelty exist in the invention disclosed.

Claims

We Claim:

1. A method for simultaneously receiving and unambiguously resolving a plurality of propagated ultrasound signals as a composite ultrasound signal, said method comprising:

receiving said composite ultrasound signal;

generating a first signal indicative of a real portion of said received composite ultrasound signal;

generating a second signal indicative of an imaginary portion of said received composite ultrasound signal;

phase shifting said first and second signals; and,

selectively combining said phase shifted first and second signals to provide a third signal indicative of a first of said plurality of propagated ultrasound signals and a fourth signal indicative of a second of said plurality of propagated ultrasound signals.

2. The method of Claim 1, wherein said ultrasound signals are Doppler shifted ultrasound transducer signals.

3. The method of Claim 1, wherein said generating said first signal comprises electrically coupling first and second quadrature diffractive grid

transducer elements to a first transformer.

4. The method of Claim 3, wherein said generating said second signal comprises electrically coupling third and fourth quadrature diffractive grid transducer elements to a second transformer.

5. The method of Claim 4, wherein said first quadrature diffractive grid transducer element is a 0 degree element, said second quadrature diffractive grid transducer element is a 180 degree element, said third quadrature diffractive grid transducer element is a 90 degree element and said fourth quadrature diffractive grid transducer element is a 270 degree element.

6. The method of Claim 1, wherein said phase shifting said first signal comprises:

mixing said first signal with a first given signal to provide a fifth signal;

and,

mixing said first signal with a second given signal to provide a sixth signal.

7. The method of Claim 6, wherein said phase shifting said second signal comprises:

mixing said second signal with said first given signal to provide a seventh

signal; and,

mixing said second signal with said second given signal to provide an eighth signal.

8. The method of Claim 7, wherein said selective combining of said first and second phase shifted signals to generate said third and fourth signals comprises:

adding said fifth and seventh signals to provide a first portion of said third signal;

subtracting said eighth signal from said sixth signal to provide a second portion of said third signal;

subtracting said seventh signal from said fifth signal to provide a first portion of said fourth signal; and,

adding said sixth and eighth signals to provide a second portion of said fourth signal.

9. The method of Claim 8, wherein said first portions of said third and fourth signals are real portions and said second portions of said third and fourth signals are imaginary portions.

10. The method of Claim 7, further comprising low pass filtering said fifth, sixth, seventh and eighth signals, wherein said fifth and seventh signals form said

third signal and said sixth and eighth signals form said fourth signal.

11. The method of Claim 1, wherein said phase shifting said first and second signals comprises inputting said first and second signals into first and second 90 degree hybrids, wherein said first 90 degree hybrid outputs said third signal and said second ninety degree hybrid outputs said fourth signal.

12. The method of Claim 11, wherein each of said first and second 90 degree hybrids includes a 0 degree shifting input and a negative 90 degree shifting input, said first signal is input into said 0 degree input of said first hybrid and said negative 90 degree input of said second hybrid and said second signal is input into said 0 degree input of said second hybrid and negative 90 degree input of said first hybrid.

13. A method for receiving a plurality of separately and simultaneously transmitted ultrasound signals, said method comprising:

receiving a composite ultrasound signal including a first set of signal components having a first amplitude and a second set of signal components having a second amplitude, wherein said composite signal has real and imaginary signal portions;

separating said real portion of said received composite signal from said

imaginary portion of said received composite signal; and

processing said real and imaginary portions of said received composite signal to generate at least a first signal indicative of said first set of signal components and at least a second signal indicative of said second set of signal components.

14. The method of Claim 13, wherein said composite ultrasound signal includes Doppler shifted ultrasound transducer signals.

15. The method of Claim 14, wherein said processing comprises phase shifting said real and imaginary portions.

16. The method of Claim 15, wherein said phase shifting comprises inputting said real and imaginary portions into at least one 90 degree hybrid.

17. The method of Claim 15, wherein said phase shifting comprises mixing said real and imaginary portions with at least one given signal.

18. The method of Claim 17, wherein said processing further comprises selectively combining outputs from said mixing.

19. The method of Claim 15, wherein said separating comprises respectively coupling 0 degree and 180 degree quadrature diffractive grid transducer elements to first and second inputs of a first transformer and 90 degree and 270 degree quadrature diffractive grid transducer elements to first and second inputs of a second transformer.

20. An apparatus suitable for simultaneously receiving and unambiguously resolving a plurality of propagated ultrasound signals received as a composite ultrasound signal including real and imaginary portions, said apparatus comprising:

- a plurality of quadrature diffractive grid transducer elements adapted to receive said composite ultrasound signal;

- a plurality of transformers coupled to said quadrature diffractive grid transducer elements so as to separate said real portion of a received composite signal from said imaginary portion of said received composite signal; and,

- a plurality of phase shifting devices coupled to said transformers so as to phase shift said separated real and imaginary portions of said received composite signal.

21. The apparatus of Claim 20, wherein said ultrasound signals are Doppler shifted ultrasound transducer signals.

22. The apparatus of Claim 20, further comprising combining devices coupled to said phase shifting devices so as to provide at least a first signal indicative of a first propagated ultrasound signal and a second signal indicative of a second propagated ultrasound signal.

23. The apparatus of Claim 22, wherein each of said phase shifting devices comprises a mixer.

24. The apparatus of Claim 20, wherein each of said phase shifting devices comprises a 90 degree hybrid.

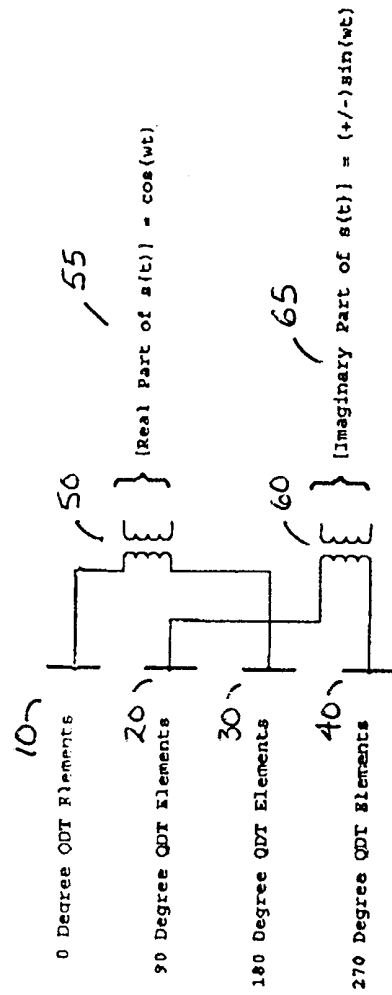


Figure 1

Complex Transducer Signals

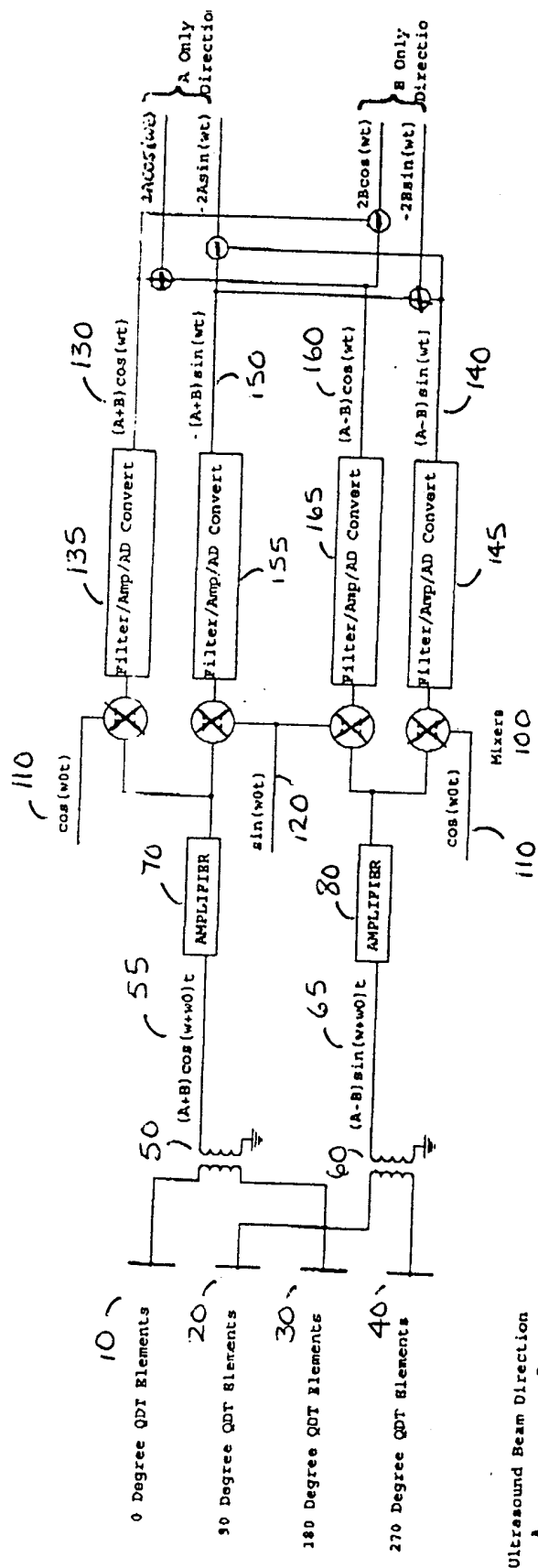


Figure 2  
Complex Receiver

From Direction:  
A:  $A \cos(w_0 t) + jA \sin(w_0 t)$   
B:  $B \cos(w_0 t) - jB \sin(w_0 t)$

Channel Inputs:  
Real:  $(A+B) \cos(w_0 t)$   
Imag:  $(A-B) \sin(w_0 t)$

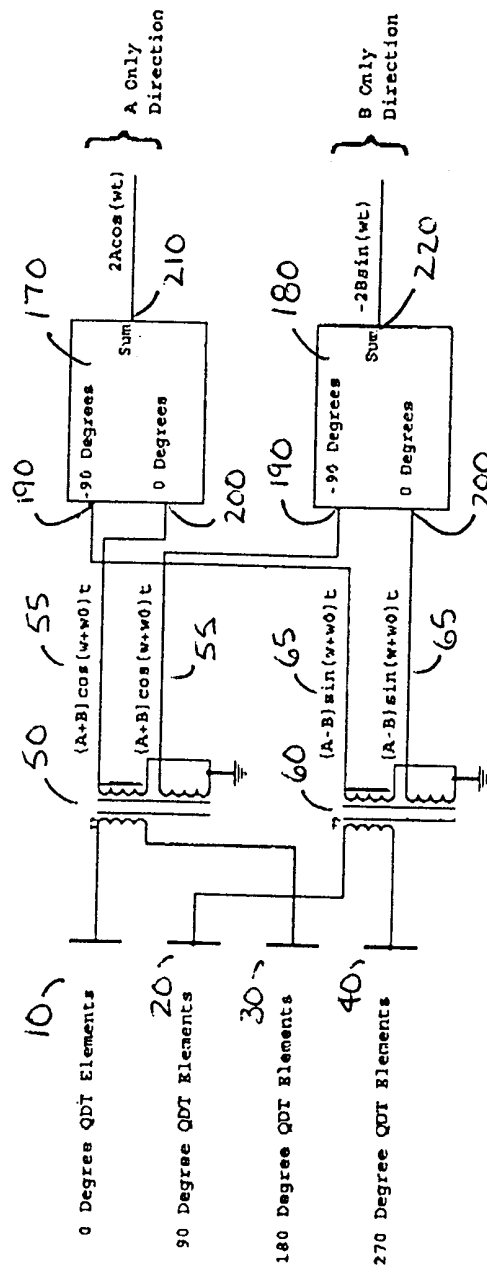


Figure 3  
Phase Shifters  
at Ultrasound  
Frequency

From Direction:

A:  $A \cos(w+w_0)t + jA \sin(w+w_0)t$

B:  $B \cos(w+w_0)t - jB \sin(w+w_0)t$

Channel Inputs:

Real:  $(A+B) \cos(w+w_0)t$

Imag:  $(A-B) \sin(w+w_0)t$

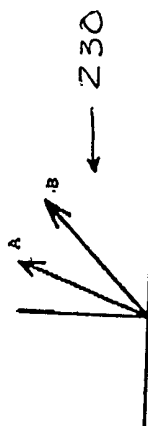
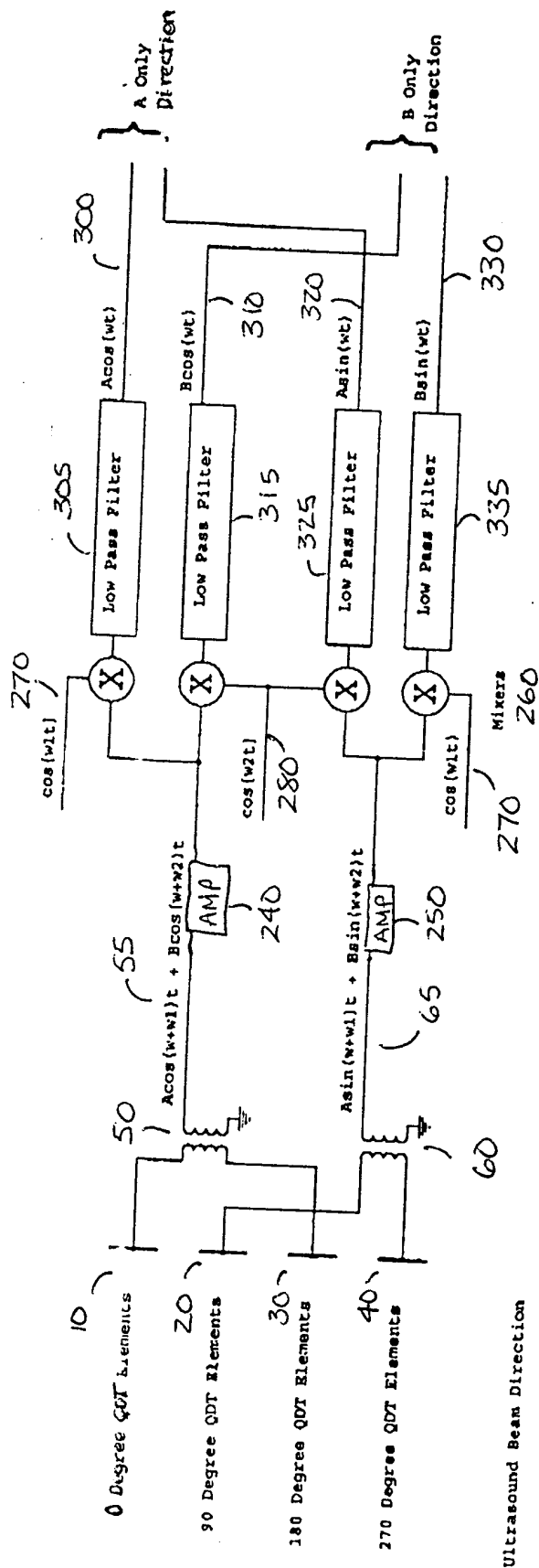


Figure 4

# Complex Receiver

Using All Cosine Mixer Drive

From Direction:

$$A: A\cos(w\omega_1)t + jA\sin(w\omega_1)t$$

$$B: B\cos(w\omega_2)t + jB\sin(w\omega_2)t$$

Channel Inputs:

$$\text{Real: } A\cos(w\omega_1)t + B\cos(w\omega_2)t$$

$$\text{Imag: } A\sin(w\omega_1)t + B\sin(w\omega_2)t$$

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US00/06465

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : A61B 8/00

US CL : 600/437

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. : 600/437, 443, 453-456

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: ultraso\$, quadrature, resolv\$ or resolution\$, real and imaginary, doppler

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|------------------------------------------------------------------------------------|-----------------------|
| Y         | US 5,291,892 A (O'DONNELL) 08 March 1994, col. 14 line 48 to col. 15 line 19.      | 1, 2, 13, 14          |
| Y         | US 4,886,069 A (O'DONNELL) 12 December 1989, col. 4 lines 12-54.                   | 1, 2, 13, 14          |

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

|                                                                                                                                                                         |                                                                                                                                                                                                                                                  |
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| Date of the actual completion of the international search<br>06 JULY 2000 | Date of mailing of the international search report<br><b>14 AUG 2000</b> |
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