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(54) **Title:** BROADBAND BLENDED FUNDAMENTAL AND HARMONIC FREQUENCY ULTRASONIC DIAGNOSTIC IMAGING

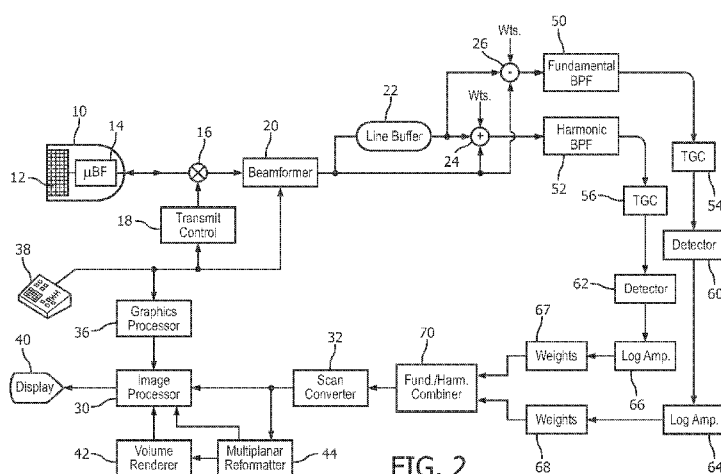


FIG. 2

(57) **Abstract:** An ultrasound system is described which produces blended fundamental and harmonic frequency images. Successively transmitted, differently modulated pulses are transmitted by an ultrasound probe and both fundamental and harmonic frequencies are received in response. The echo signals received from the two pulses are processed by pulse inversion, producing cleanly separated bands of fundamental and harmonic signals in which undesired components have been cancelled. Since the two bands have been separated by signal cancellation rather than filtering, the two bands are allowed to overlap, providing broadband signals in each band. The bands are filtered by bandpass filtering to define the fundamental and harmonic signals to be imaged. The signals are detected, and the detected signals are combined after weighting to produce a blended fundamental/harmonic image.

BROADBAND BLENDED FUNDAMENTAL AND HARMONIC
FREQUENCY ULTRASONIC DIAGNOSTIC IMAGING

5 This application claims benefit of priority to
U.S. Appl. No. 62/109,121, filed on January 29, 2015,
which is incorporated by reference herein in its
entirety.

10 This invention relates to ultrasonic diagnostic
imaging systems and, in particular, to the use of
blended fundamental and harmonic frequency ultrasonic
images.

15 Harmonic imaging is used in ultrasonic imaging
to image ultrasonic contrast agents and to overcome
reverberation clutter which can occur at fundamental
frequencies. While echo signals at higher harmonic
frequencies will exhibit the attenuative effects of
depth dependent frequency attenuation, today's
ultrasound systems have sufficient sensitivity to
largely overcome this drawback at shallower depths in
20 the body. This effect is only prevalent in tissue
harmonic imaging, where near field clutter as from
rib artifacts is obviated by the slower development
of harmonic signal components with depth. Harmonic
contrast agents, on the other hand, elicit a strong
25 harmonic response when stimulated by ultrasound, a
response often even stronger than nearby fundamental
frequency echo signals.

30 The depth dependent attenuation of the higher
harmonic frequencies means that harmonic imaging will
not produce a strong signal response with deeper
penetration, limiting its effectiveness when imaging
tissue and organs at significant depths in the body.
An effective technique for dealing with this problem
and realizing the benefits of both good resolution
35 harmonic imaging and deep penetration fundamental
imaging is described in U.S. Pat. 6,283,919

(Roundhill et al.) Roundhill et al. acquire both fundamental frequency and harmonic frequency signals from all depths and separate them by bandpass filtering. They then produce a blended image of the two types of signals. Preferably, the highly resolved, clutter-free harmonic signals predominate in the near field, while the deeper penetrating fundamental signals are used to the greatest degree in the far field. However, the filtering necessary to separate the fundamental and harmonic frequencies poses an undesirable tradeoff. To cleanly separate the signals into their two distinct bands, the bandwidth of the filters must be narrowly defined so that there is no band overlap, which particularly adversely limits the fundamental signals to a narrow band and resultant limited resolution. Widening the bands for more broadband imaging can cause the two bands to overlap and diminish the distinctive characteristics and benefits of each signal type. Accordingly it is desirable to be able to separate the fundamental and harmonic frequencies of the echo signals in a way which preserves the distinctiveness of each signal type while still affording broadband imaging with either type of signal.

In some aspects, the present invention includes ultrasound systems, such as an ultrasonic diagnostic imaging system for producing fundamental and harmonic frequency images. The systems can include an ultrasound imaging probe having an array transducer which transmits successive, differently modulated ultrasound pulses at a fundamental frequency and receives echo signals at fundamental and harmonic frequencies, a cancellation circuit, responsive to the received echo signals which additively and subtractively combines the echo signals from the

5 differently modulated ultrasound pulses to produce
separate fundamental and harmonic signals, a
fundamental frequency filter having a passband which
defines a band of fundamental frequency signals, a
10 harmonic frequency filter having a passband
overlapping the fundamental frequency passband which
defines a band of harmonic frequency signals, a first
detector which detects fundamental frequency image
signals, a second detector which detects harmonic
15 frequency image signals, a combiner which combines
detected fundamental and harmonic frequency signals,
and a display which displays blended fundamental and
harmonic images.

20 In certain aspects, the ultrasound systems of
the present invention can include an ultrasonic
diagnostic imaging system for producing fundamental
or harmonic frequency images that includes an
ultrasound imaging probe having an array transducer
which transmits successive, differently modulated
25 ultrasound pulses at a fundamental frequency and
receives echo signals at fundamental and harmonic
frequencies, a cancellation circuit, responsive to
the received echo signals which additively and
subtractively combines the echo signals from the
30 differently modulated ultrasound pulses to produce
separate fundamental and harmonic signals, a
fundamental frequency filter having a passband which
defines a band of fundamental frequency signals, a
harmonic frequency filter having a passband
35 overlapping the fundamental frequency passband which
defines a band of harmonic frequency signals, a
detector, responsive to the band of fundamental
frequency or harmonic frequency signals, which
detects fundamental frequency or harmonic frequency
image signals, a scan converter, responsive to

detected fundamental or harmonic frequency image
signals which produces a fundamental or harmonic
image of a desired image format, and a display,
coupled to the scan converter, which displays a
5 fundamental or harmonic image.

In some aspects, the present invention includes
an ultrasonic diagnostic imaging system for producing
fundamental or harmonic frequency images, the system
includes instructions thereon, which when executed
10 cause the system to using an ultrasound imaging probe
having an array transducer, transmit successive,
differently modulated ultrasound pulses at a
fundamental frequency and receive echo signals at
fundamental and harmonic frequencies, additively and
15 subtractively combine the echo signals from
differently modulated ultrasound pulses to produce
separate fundamental and harmonic signals, filter a
band of fundamental frequency signals with a
fundamental frequency filter having a passband,
20 filter a band of harmonic frequency signals with a
harmonic frequency filter having a passband
overlapping the fundamental frequency passband,
detect fundamental frequency or harmonic frequency
image signals, produce a fundamental or harmonic
25 image of a desired image format, and display a
fundamental or harmonic image.

In the drawings:

FIGURE 1 is an illustration of filter separation
of fundamental and harmonic frequency echo signal
30 components.

FIGURE 2 illustrates in block diagram form an
ultrasound system constructed in accordance with the
principles of the present invention.

FIGURE 3 is an illustration of signal component
35 cancellation and bandpass filtering in accordance

with the principles of the present invention.

FIGURES 4a - 4h illustrate a two-pulse imaging sequence suitable for use in an implementation of the present invention.

5 FIGURE 5 illustrates a method in accordance with an implementation of the present invention.

 In accordance with the principles of the present invention, an ultrasonic diagnostic imaging system is described which enable the clean separation of
10 fundamental and harmonic signal components into distinct broadband signals. Two-pulse transmission can be used, transmitting the same pulse twice in succession to each point in an image region but in differently modulated forms. One example technique
15 for doing this is called pulse inversion, in which the same pulse is transmitted with and without phase or polarity inversion. The transmit pulse has a broader bandwidth and a higher center frequency than conventionally used in pulse inversion. The received
20 echo signals from the two transmissions are combined on a spatial basis by both addition and subtraction, resulting in two bands of frequencies, a harmonic band in which fundamental signal components have been cancelled and a fundamental band in which fundamental
25 frequency components from the two echoes reinforce each other. The two bands are then bandpass filtered with filters that are allowed to overlap each other in frequency. Signals from the two bands are detected and combined into a blended
30 fundamental/harmonic image, either before or after scan conversion. The result is an image with the combined benefits of both fundamental and harmonic imaging and with broadband image characteristics.

 In some aspects, the present invention includes
35 ultrasonic diagnostic imaging systems that produce

fundamental and harmonic frequency images. In some
embodiments, the systems can include an ultrasound
imaging probe having an array transducer. The probe
can be configured to transmit successive and
5 differently modulated ultrasound pulses at a
fundamental frequency. The differently modulated
ultrasound pulses can, for example, be differently
modulated in phase or polarity. The probe can also
be configured to receive echo signals at fundamental
10 and harmonic frequencies. In some aspects, the
systems can include a beamformer, responsive to echo
signals received by the array transducer, which
produces coherent fundamental and harmonic frequency
signals. The beamformer can include a multiline
15 beamformer.

The systems can include a cancellation circuit,
responsive to the received echo signals which
additively and subtractively combines the echo
signals from the differently modulated ultrasound
20 pulses to produce separate fundamental and harmonic
signals. In some embodiments, the cancellation
circuit cancels fundamental frequency signals in a
harmonic frequency band by pulse inversion. In some
embodiments, the cancellation circuit can include a
25 line buffer which stores echo signals received in
response to the first of the successive ultrasound
pulses, a first combining circuit which additively
combines echo signals received in response to the
second of the successive ultrasound pulses with echo
30 signals stored by the line buffer, and a second
combining circuit which subtractively combines echo
signals received in response to the second of the
successive ultrasound pulses with echo signals stored
by the line buffer.

35 In certain aspects, the systems can include a

fundamental frequency filter having a passband which defines a band of fundamental frequency signals, and a harmonic frequency filter having a passband overlapping the fundamental frequency passband which defines a band of harmonic frequency signals. The fundamental frequency filter can, for example, include a bandpass filter having a lower frequency passband and the harmonic frequency filter can include a bandpass filter having a higher frequency passband. In some embodiments, the array transducer exhibits a transducer passband, and the lower frequency passband is centered in the lower half of the transducer passband, and the higher frequency passband extends to the upper limit of the transducer passband.

In some aspects, the systems can include a first detector which detects fundamental frequency image signals, a second detector which detects harmonic frequency image signals, and a combiner which combines detected fundamental and harmonic frequency signals. Weighting circuits, coupled to receive detected fundamental and harmonic frequency signals, which relatively weights fundamental and harmonic frequency signals can also be used prior to combining by the combiner. The systems can include a display which displays blended fundamental and harmonic images.

In certain aspects, the systems can include a TGC circuit which amplifies signals in the band of fundamental frequency signals or signals in the band of harmonic frequency signals. The systems can also include a log amplifier which converts signals in the band of fundamental frequency signals or the band of harmonic frequency signals to logarithmically scaled signals.

In some embodiments, the systems of the present invention can include an ultrasound imaging probe having an array transducer which transmits successive, differently modulated ultrasound pulses at a
5 fundamental frequency and receives echo signals at fundamental and harmonic frequencies, a cancellation circuit, responsive to the received echo signals which additively and subtractively combines the echo signals from the differently modulated ultrasound
10 pulses to produce separate fundamental and harmonic signals, a fundamental frequency filter having a passband which defines a band of fundamental frequency signals, a harmonic frequency filter having a passband overlapping the fundamental frequency
15 passband which defines a band of harmonic frequency signals, a detector, responsive to the band of fundamental frequency or harmonic frequency signals, which detects fundamental frequency or harmonic frequency image signals, a scan converter, responsive
20 to detected fundamental or harmonic frequency image signals which produces a fundamental or harmonic image of a desired image format, and a display, coupled to the scan converter, which displays a fundamental or harmonic image.

25 FIGURE 1 illustrates the passbands typical of an ultrasound system which separates fundamental and harmonic signals on the basis of frequency. This drawing illustrates a 46% transmit bandwidth frequency band centered at frequency "f" and shown as
30 a thin black curve 80 in the drawing. The harmonic response to this waveform is plotted adjacent to the fundamental, also as a thin black curve 82. The transmit frequency and bandwidth are chosen so that both the fundamental and harmonic responses lie
35 within the transducer's bandwidth, outlined by curve

Tr.

The two wider outlined spectra 84 and 86 represent the receive bandpass shapes for the fundamental (on the left) and the harmonic (on the right) bands of frequencies. These two shapes are determined by the need to avoid frequencies where the fundamental and harmonic spectra overlap, and by the frequency limits imposed by the transducer passband Tr. It is seen that the fundamental spectrum 84 has a very narrow bandwidth, and the harmonic spectrum limits its lower frequency extent in order to avoid the frequency overlap region 88, cross-hatched in the drawing.

An important criterion for the success of fundamental-harmonic blending is that both components, when adequately received and detected, produce a good quality image. In the case of the spectra of FIGURE 1, the fundamental image will be very low in frequency and very narrow in bandwidth as a result of the narrow band outlined by 84. This will not produce a very good image. The harmonic spectrum delineated by 86 looks much better, but is limited in penetration because it cannot include frequencies lower than those of the overlapped area 88. Thus, the overlapped area both limits the bandwidth of the fundamental frequencies and also the low frequencies of the harmonic spectrum, which would improve penetration.

Referring now to FIGURE 2, an ultrasonic diagnostic imaging system constructed in accordance with the principles of the present invention is shown in block diagram form. In FIGURE 2 a transducer array 12 is provided in an ultrasound probe 10 for transmitting ultrasonic waves and receiving echo information. The transducer array 12 may be a one-

or two-dimensional array of transducer elements capable of scanning in two or three dimensions, for instance, in both elevation (in 3D) and azimuth. The transducer array 12 is coupled to a microbeamformer 14 in the probe which controls transmission and reception of signals by the array elements. Microbeamformers are capable of at least partial beamforming of the signals received by groups or "patches" of transducer elements as described in US Pats. 5,997,479 (Savord et al.), 6,013,032 (Savord), and 6,623,432 (Powers et al.), which are hereby incorporated by reference in their entirety. The microbeamformer is coupled by the probe cable to a transmit/receive (T/R) switch 16 which switches between transmission and reception and protects the main beamformer 20 from high energy transmit signals. The transmission of ultrasonic beams from the transducer array 12 under control of the microbeamformer 14 is directed by a transmit controller 18 coupled to the T/R switch and the beamformer 20, which receives input from the user's operation of the user interface or control panel 38. Among the transmit characteristics controlled by the transmit controller are the amplitude, phase, and polarity of transmit waveforms. Beams formed in the direction of pulse transmission may be steered straight ahead from (orthogonal to) the transducer array, or at different angles for a wider field of view.

The echoes received by a contiguous group of transducer elements are beamformed by appropriately delaying them and then combining them. The partially beamformed signals produced by the microbeamformer 14 from each patch are coupled to a main beamformer 20 where partially beamformed signals from individual

patches of transducer elements are combined into a fully beamformed signal. For example, the main beamformer 20 may have 128 channels, each of which receives a partially beamformed signal from a patch
5 of 12 transducer elements. In this way the signals received by over 1500 transducer elements of a two dimensional array can contribute efficiently to a single beamformed signal.

In this implementation of the present invention the beamformed signals are coupled to a line buffer
10 22. The line buffer 22 stores the echo signals resulting from a pulse, such as those received following a positive polarity pulse of a positive-negative (uninverted/inverted) pulse pair transmitted
15 in rapid succession for pulse inversion processing. When the second pulse of the differently modulated pulse pair is transmitted, the returning echoes are applied to a summer 24 and a subtractor 26 together with the spatially corresponding echoes of the
20 previous pulse stored by the line buffer. This causes the echoes returned from a common point in the image field to be additively combined by the summer 24 and subtracted by the subtractor 26. The additive combination of echoes from oppositely phased or
25 polarity transmit pulses by the summer 22 will result in the cancellation of fundamental frequency components and the production of harmonic frequency components. These harmonic signals are applied to a harmonic bandpass filter 52. The subtraction of
30 echoes from oppositely phased or polarized pulses will result in the reinforcement of fundamental frequency components and elimination of harmonic content. These fundamental frequency signals are applied to a fundamental bandpass filter. Filtering
35 signals in ultrasound applications is well known, and

can be done using hardware, software, or both to process and filter ultrasound signals. Such techniques can be found, e.g., in Thomas Szabo, Diagnostic Ultrasound Imaging: Inside Out, Elsevier Academic Press, 2004, which is herein incorporated by reference in its entirety.

FIGURE 4 illustrates this signal cancellation phenomenon. This two-pulse sequence consists of a first pulse 100 and an oppositely phased or polarized pulse 102 transmitted sequentially in the same direction, that is they both insonify the same scanline in the image field. The differently modulated pulses are transmitted in rapid succession to minimize effects of inter-pulse motion; as soon as the echoes are received in response to the first pulse the second is transmitted. The two transmitted pulses are shown in FIGURE 4 a) and b).

The echoes received in response from a point in the image field are shown in FIGURES 4 c) and d). An echo 104 is produced in response to pulse 100, and an echo 106 is returned in response to pulse 102. When these two echoes are additively combined, this results in the cancellation of fundamental frequency components due to the opposing polarity. But left uncanceled and revealed by this combining are harmonic signal components 110 as shown at FIGURE 4 e). These harmonic signals, left after cancellation of the fundamental frequency components, are applied to the harmonic bandpass filter 52.

Similarly, the echoes 104 returned from one of the pulses, shown in FIGURE 4 f), are subtractively combined with the echoes from the other pulse. Echo 106' in FIGURE 4 g) represents this subtractive combination by illustrating the second echo signal (*i.e.*, 106) in inverted form. When echoes 104 and

106' are combined, this time the fundamental frequency components are the same and will additively combine and reinforce each other, as illustrated by fundamental frequency echo signal 112 in FIGURE 4 h).
5 These fundamental frequency signals are applied to the fundamental frequency bandpass filter 50. Thus, harmonic signals are produced by the cancellation of fundamental frequency components by one combiner (24), and fundamental frequency signals are produced by the
10 other combiner (26).

Since the fundamental and harmonic signal components are separated by pulse inversion cancellation rather than by frequency selectivity, the respective bands can be shifted for improved
15 performance as illustrated in FIGURE 3. The fundamental frequency band 90 no longer is centered at frequency f as it was in FIGURE 1, but is shifted higher in frequency as shown by the spectrum 90. The harmonic spectrum 92 is centered at twice the center
20 frequency of the fundamental spectrum and it, too, occupies a broader band. In addition, the two spectra are allowed to overlap as FIGURE 3 shows. This is acceptable because the components of the other spectrum are cancelled in each spectrum. As in
25 FIGURE 1, the transducer passband is illustrated by band Tr. The fundamental and harmonic bandpass filters 50 and 52 then filter the two overlapping spectra with the passband characteristics 94 and 96. It is seen that the filtered fundamental passband 94
30 is significantly wider than the limited passband 94 of FIGURE 1, thereby producing broadband fundamental signals and images. The filtered harmonic passband 96 also exhibits a broad bandwidth. Since the harmonic spectrum 92 extends beyond the transducer
35 passband Tr, the upper frequency skirt 96' of the

harmonic band is effectively limited to the upper frequency skirt of the transducer passband Tr.

Following the fundamental and harmonic frequency bandpass filters 50 and 52, the two signal paths
5 provide the same processing in each. Time gain control circuits 54 and 56 provide amplification with depth, the fundamental and harmonic signals are detected by detectors 60 and 62, and the signal amplitudes are logarithmically converted by log
10 amplifiers 64 and 66. In accordance with a further aspect of the present invention, the fundamental and harmonic signals are combined by fundamental/harmonic combiner 70. The fundamental and harmonic signals at each point in the image field may be combined as they
15 are produced by the log amps, but preferably they are weighted by weighting circuits 67 and 68. For instance, the harmonic signals may be more greatly weighted in the near field and the fundamental signals lesser so, and the reverse in the far field,
20 in keeping with the idea of the Roundhill et al. patent to provide high resolution in the near field and greater penetration in the far field.

The blended fundamental/harmonic images produced by the combiner 70 are coupled to a scan converter 32
25 and a multiplanar reformatter 44. The scan converter arranges the echo signals in the spatial relationship from which they were received in a desired image format. For instance, the scan converter may arrange the echo signal into a two dimensional (2D) sector-
30 shaped format, or a pyramidal three dimensional (3D) image when 3D scanning is performed. The scan converter can overlay a B mode structural image with colors corresponding to motion at points in the image field corresponding with their Doppler-estimated
35 velocities to produce a color Doppler image which

depicts the motion of tissue and blood flow in the image field. The multiplanar reformatter will convert echoes which are received from points in a common plane in a volumetric region of the body into
5 an ultrasonic image of that plane, as described in US Pat. 6,443,896 (Detmer). A volume renderer 42 converts the echo signals of a 3D data set into a projected 3D image as viewed from a given reference point as described in US Pat. 6,530,885 (Entrekin et
10 al.) The 2D or 3D images are coupled from the scan converter 32, multiplanar reformatter 44, and volume renderer 42 to an image processor 30 for further enhancement, buffering and temporary storage for display on an image display 40. A graphic display
15 overlay containing textual and other graphic information such as patient ID is produced by a graphics processor 36 for display with the ultrasound images.

In a preferred embodiment the beamformer 20 and
20 the microbeamformer 14 perform multiline beamforming as described in U.S. Pat. 8,137,272 (Cooley et al.), which is herein incorporated by reference in its entirety. When implemented by multiline, a plurality of scanline positions are simultaneously insonified
25 by each transmit pulse and the beamformer produces a plurality of scanlines of echoes in response to each pulse. The scanlines of each transmission are spatially aligned so that the corresponding echoes can be combined by pulse inversion to produce
30 fundamental and harmonic signals along a plurality of scanlines in response to two pulse transmissions. The separated harmonic and fundamental signals are processed to produce images as described above.

Other variations will readily occur to those
35 skilled in the art. For instance, the scan converter

may precede the combiner 70, so that the fundamental and harmonic signals are first separately converted into the desired display format before blending.

5 This enables separate display of the harmonic and fundamental images, if desired, before blending or without blending.

In some embodiments, the present invention further includes methods for producing fundamental and harmonic frequency images. The methods can
10 include transmitting successive, differently modulated ultrasound pulses at a fundamental frequency and receiving echo signals at fundamental and harmonic frequencies. The methods include using a cancellation circuit, responsive to the received
15 echo signals, to additively and subtractively combine the echo signals from the differently modulated ultrasound pulses to produce separate fundamental and harmonic signals. The methods include filtering (e.g., with a fundamental frequency filter) a band of
20 fundamental frequency signals, and filtering (e.g., with a harmonic frequency filter) a band of harmonic frequency signals. The methods can include detecting the fundamental and harmonic frequency image signals, e.g., using one or more detectors. The methods can
25 also include combining the detected fundamental and harmonic frequency image signals, and displaying blended fundamental and harmonic images.

It will be understood that each block of the block diagram illustrations, and combinations of
30 blocks in the block diagram illustrations, as well as any portion of the systems and methods disclosed herein, can be implemented by computer program instructions. These program instructions may be provided to a processor to produce a machine, such
35 that the instructions, which execute on the processor,

create means for implementing the actions specified in the block diagram block or blocks or described for the systems and methods disclosed herein. The computer program instructions may be executed by a processor to cause a series of operational steps to be performed by the processor to produce a computer implemented process. The computer program instructions may also cause at least some of the operational steps to be performed in parallel. Moreover, some of the steps may also be performed across more than one processor, such as might arise in a multi-processor computer system. In addition, one or more processes may also be performed concurrently with other processes, or even in a different sequence than illustrated without departing from the scope or spirit of the invention.

The computer program instructions can be stored on any suitable computer-readable hardware medium including, but not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by a computing device. Processors can include hardware such as microprocessors, field programmable gate arrays (FPGAs), integrated circuits, or the like.

30

WHAT IS CLAIMED IS:

1. An ultrasonic diagnostic imaging system which produces fundamental and harmonic frequency images comprising:

an ultrasound imaging probe having an array transducer and being configured transmit successive, differently modulated ultrasound pulses at a fundamental frequency and receive echo signals at fundamental and harmonic frequencies;

a cancellation circuit that is responsive to the received echo signals and is configured to additively and subtractively combine the echo signals from the differently modulated ultrasound pulses to produce separate fundamental and harmonic signals;

a fundamental frequency filter having a passband defining a band of fundamental frequency signals;

a harmonic frequency filter having a passband overlapping the fundamental frequency passband and defining a band of harmonic frequency signals;

a first detector configured to detect fundamental frequency image signals;

a second detector configured to detect harmonic frequency image signals;

a combiner configured to combine detected fundamental and harmonic frequency signals; and

a display for displaying blended fundamental and harmonic images.

2. The ultrasonic diagnostic imaging system of Claim 1, wherein the cancellation circuit is configured to cancel fundamental frequency signals in a harmonic frequency band by pulse inversion.

3. The ultrasonic diagnostic imaging system of

Claim 2, wherein the fundamental frequency filter comprises a bandpass filter having a lower frequency passband and wherein the harmonic frequency filter comprises a bandpass filter having a higher frequency passband.

4. The ultrasonic diagnostic imaging system of Claim 3, wherein the array transducer comprises a transducer passband, wherein a lower frequency passband is centered in a lower half of the transducer passband; and wherein a higher frequency passband extends to an upper limit of the transducer passband.

5. The ultrasonic diagnostic imaging system of Claim 3, wherein differently modulated ultrasound pulses are differently modulated in phase or polarity.

6. The ultrasonic diagnostic imaging system of Claim 5, wherein the cancellation circuit comprises a line buffer configured to store echo signals received in response to the first of the successive ultrasound pulses;

a first combining circuit configured to additively combine echo signals received in response to a second of the successive ultrasound pulses with echo signals stored by the line buffer; and

a second combining circuit configured to subtractively combine echo signals received in response to the second of the successive ultrasound pulses with echo signals stored by the line buffer.

7. The ultrasonic diagnostic imaging system of Claim 6, further comprising:

a TGC circuit configured to amplify signals in a

band of fundamental frequency signals or signals in a band of harmonic frequency signals.

8. The ultrasonic diagnostic imaging system of Claim 7, further comprising a log amplifier configured to convert signals in the band of fundamental frequency signals or the band of harmonic frequency signals to logarithmically scaled signals.

9. The ultrasonic diagnostic imaging system of Claim 1, further comprising weighting circuits, coupled to receive detected fundamental and harmonic frequency signals, and configured to relatively weight fundamental and harmonic frequency signals prior to combining by the combiner.

10. The ultrasonic diagnostic imaging system of Claim 1, further comprising a beamformer, responsive to echo signals received by the array transducer, and configured to produce coherent fundamental and harmonic frequency signals.

11. The ultrasonic diagnostic imaging system of Claim 10, wherein the beamformer comprises a multiline beamformer.

12. An ultrasonic diagnostic imaging system for producing fundamental or harmonic frequency images, the system comprising instructions thereon, which when executed cause the system to:

using an ultrasound imaging probe having an array transducer, transmit successive, differently modulated ultrasound pulses at a fundamental frequency and receive echo signals at fundamental and harmonic frequencies;

additively and subtractively combine the echo
signals from differently modulated ultrasound pulses
to produce separate fundamental and harmonic signals;
filter a band of fundamental frequency signals
5 with a fundamental frequency filter having a passband;
filter a band of harmonic frequency signals with
a harmonic frequency filter having a passband
overlapping the fundamental frequency passband;
detect fundamental frequency or harmonic
10 frequency image signals;
produce a fundamental or harmonic image of a
desired image format; and
display a fundamental or harmonic image.

15 13. The ultrasonic diagnostic imaging system of
Claim 12, wherein the instructions further cause the
system to cancel fundamental frequency signals in a
harmonic frequency band by pulse inversion.

20 14. The ultrasonic diagnostic imaging system of
Claim 13, wherein the differently modulated
ultrasound pulses are differently modulated in phase
or polarity.

25 15. The ultrasonic diagnostic imaging system of
Claim 13, wherein the instructions further cause the
system to produce coherent fundamental and harmonic
frequency signals using a multiline beamformer.

30

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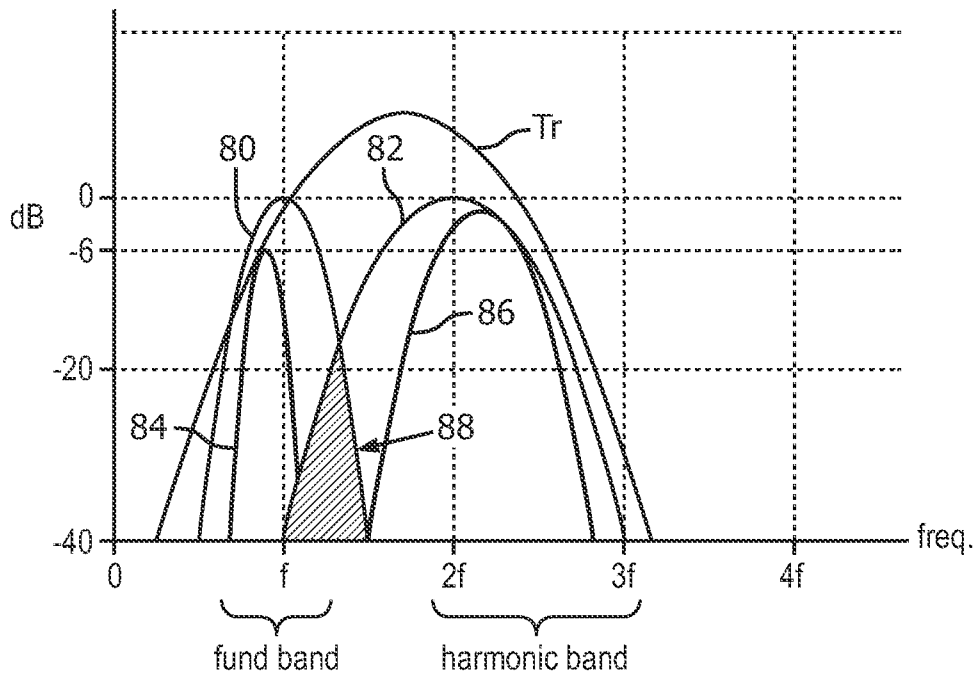


FIG. 1

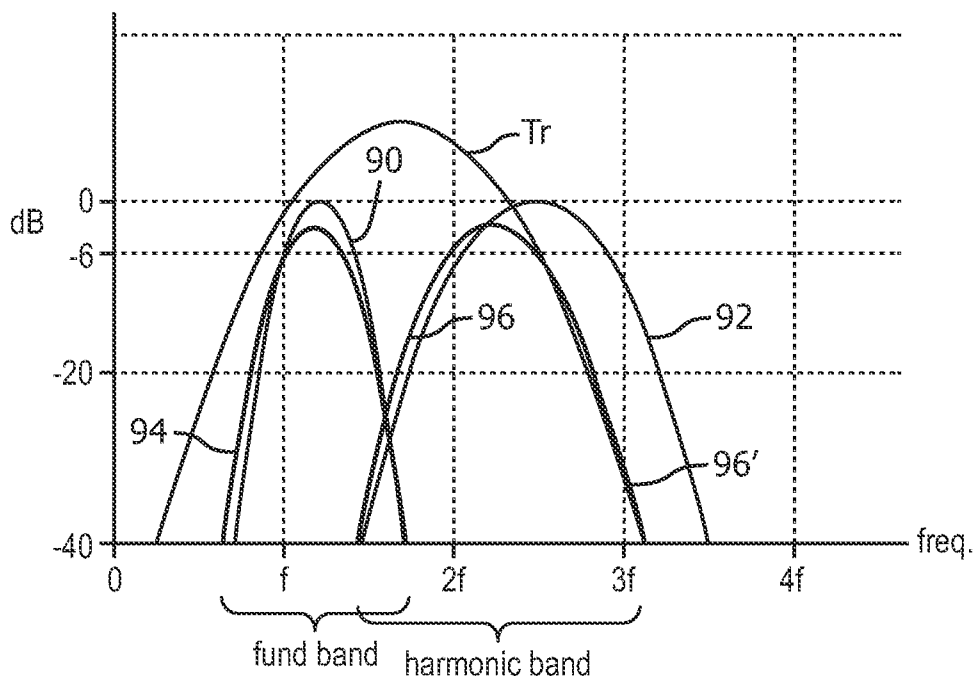


FIG. 3

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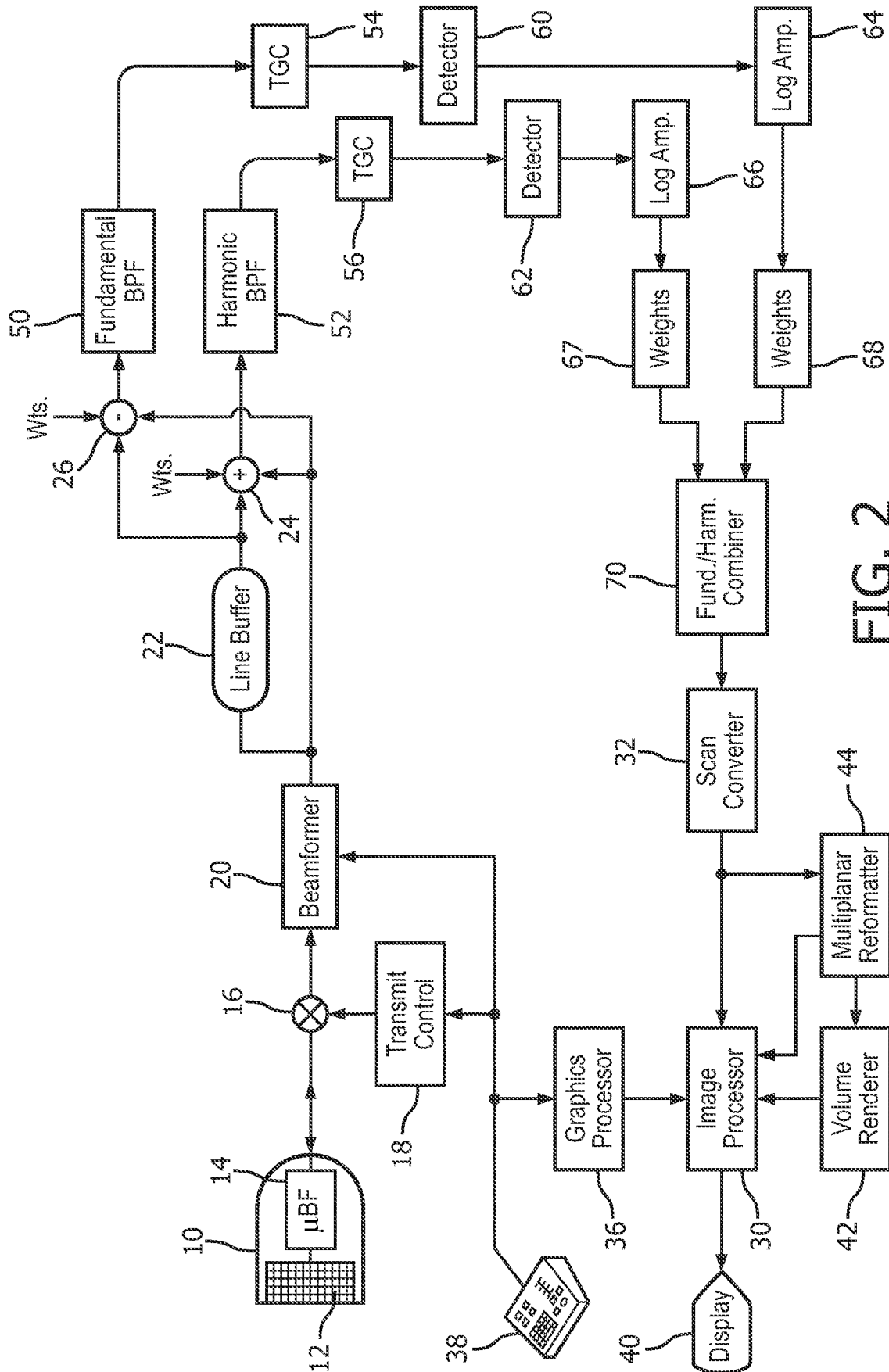


FIG. 2

3/3

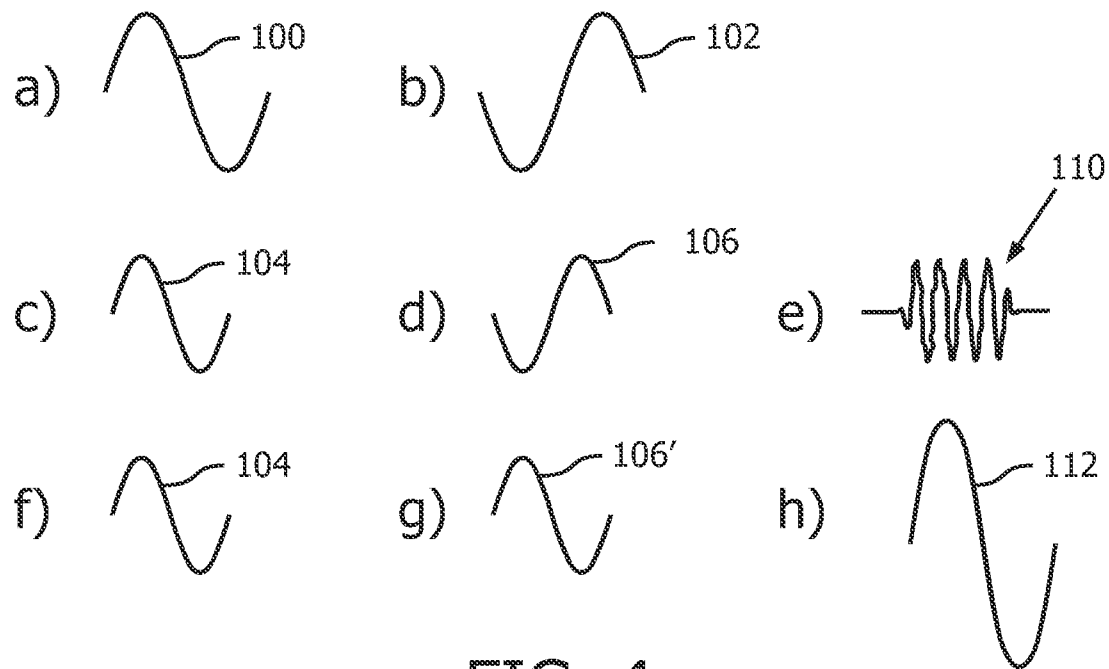


FIG. 4

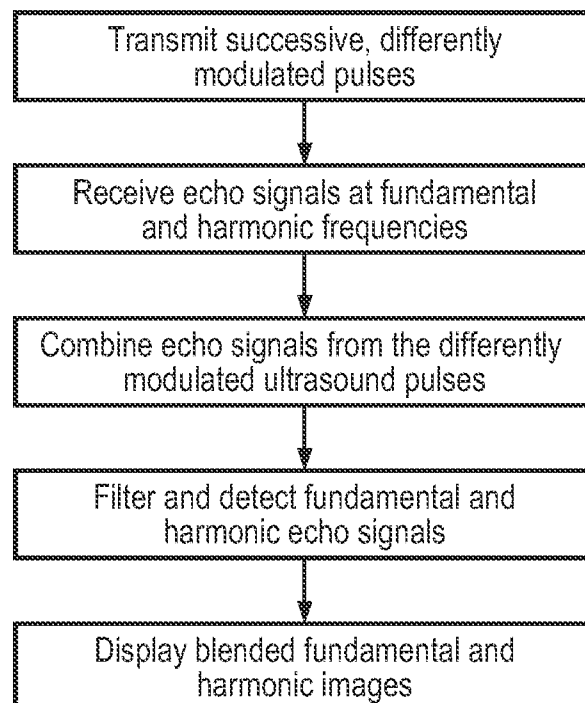


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2016/050216

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01S7/52 G01S15/89
ADD.

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)

G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99/53309 A1 (ACUSON [US]) 21 October 1999 (1999-10-21) abstract; figures 1, 18, 20 page 1, line 3 - line 6 page 7, line 18 - line 24 page 11, line 27 - line 28 page 12, line 3 - line 12 page 28, line 22 - page 34, line 9 -----	1-15
A	US 2014/254307 A1 (ZHAO DANHUA [US] ET AL) 11 September 2014 (2014-09-11) abstract; figures 1, 2 paragraph [0037] - paragraph [0050] paragraphs [0055], [0057] ----- -/--	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

13 April 2016

Date of mailing of the international search report

22/04/2016

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Knoll, Bernhard

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2016/050216

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 283 919 B1 (ROUNDHILL DAVID N [US] ET AL) 4 September 2001 (2001-09-04) cited in the application abstract; figures 7, 14 column 3, line 19 - line 44 column 7, line 9 - line 21 column 9, line 26 - line 40 column 10, line 7 - line 13 column 11, line 18 - line 62 -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2016/050216

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			US 6023977 A	15-02-2000
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			US 8454516 B1	04-06-2013
