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Kristoffersen

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(54) **ULTRASOUND METHOD AND APPARATUS FOR MULTI-LINE ACQUISITION**

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(51) **Int. Cl.**
A61B 8/00 (2006.01)

(52) **U.S. Cl.** **600/447**

(58) **Field of Classification Search** 600/443–449, 600/454–456, 458; 128/916; 73/625–626; 367/103–105
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,117,238	A *	5/1992	Silverstein et al.	342/373
5,349,525	A	9/1994	Dunki-Jacobs et al.	
5,369,624	A	11/1994	Fukukita et al.	
5,388,079	A	2/1995	Kim et al.	
5,469,851	A	11/1995	Lipschutz	
5,477,859	A *	12/1995	Engeler	600/447
5,544,128	A	8/1996	Kim et al.	
5,549,111	A *	8/1996	Wright et al.	600/443
5,566,675	A	10/1996	Li et al.	
5,568,813	A	10/1996	Deitrich et al.	
5,591,911	A	1/1997	Masuzawa et al.	
5,675,554	A	10/1997	Cole et al.	
5,685,308	A	11/1997	Wright et al.	
5,795,297	A	8/1998	Daigle	
5,827,188	A	10/1998	Wright et al.	
5,831,168	A	11/1998	Shinomura et al.	
5,832,923	A *	11/1998	Engeler et al.	600/459
5,856,955	A	1/1999	Cole et al.	
5,882,307	A	3/1999	Wright et al.	
5,882,309	A	3/1999	Chiao et al.	
5,897,501	A	4/1999	Wildes et al.	
5,905,692	A	5/1999	Dolazza et al.	
5,919,137	A	7/1999	Finger et al.	
5,957,852	A	9/1999	Hossack et al.	
5,995,450	A	11/1999	Cole et al.	
5,997,479	A	12/1999	Savord et al.	

(Continued)

FOREIGN PATENT DOCUMENTS

JP	07 313508	A	5/1995

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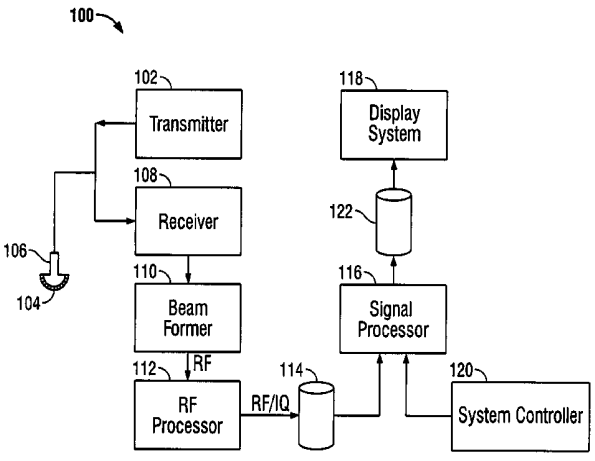
(57) **ABSTRACT**

A method and apparatus for acquiring multi-line acquisition ultrasound data. Ultrasound signals are transmitted into an area of interest. Echo signals are acquired and analyzed to produce a first data stream associated with a first receive beam. The first data stream is decimated by removing at least two consecutive data samples therefrom, while passing at least two consecutive data samples to form a first decimated data stream. Using this decimation pattern, a bandwidth of one-half to three-quarters of the data sampling rate after decimation may be achieved.

18 Claims, 5 Drawing Sheets



U.S. PATENT DOCUMENTS

6,013,032	A	1/2000	Savord
6,042,547	A	3/2000	Wright et al.
6,066,099	A	5/2000	Thomenius et al.
6,089,096	A	7/2000	Alexandru
6,104,673	A	8/2000	Cole et al.
6,172,939	B1	1/2001	Cole et al.
6,292,433	B1	9/2001	Gilbert et al.
6,363,033	B1	3/2002	Cole et al.
6,366,227	B1	4/2002	Rigby
6,409,667	B1	6/2002	Hossack
6,491,634	B1	12/2002	Leavitt et al.
6,497,664	B1	12/2002	Randall et al.
6,500,120	B1	12/2002	Anthony
6,666,823	B2	12/2003	Yao
6,669,640	B2	12/2003	Bae
6,673,016	B1	1/2004	Bolorforosh et al.
6,679,845	B2	1/2004	Ritter et al.
6,695,783	B2	2/2004	Henderson et al.
2001/0051772	A1	12/2001	Bae

* cited by examiner

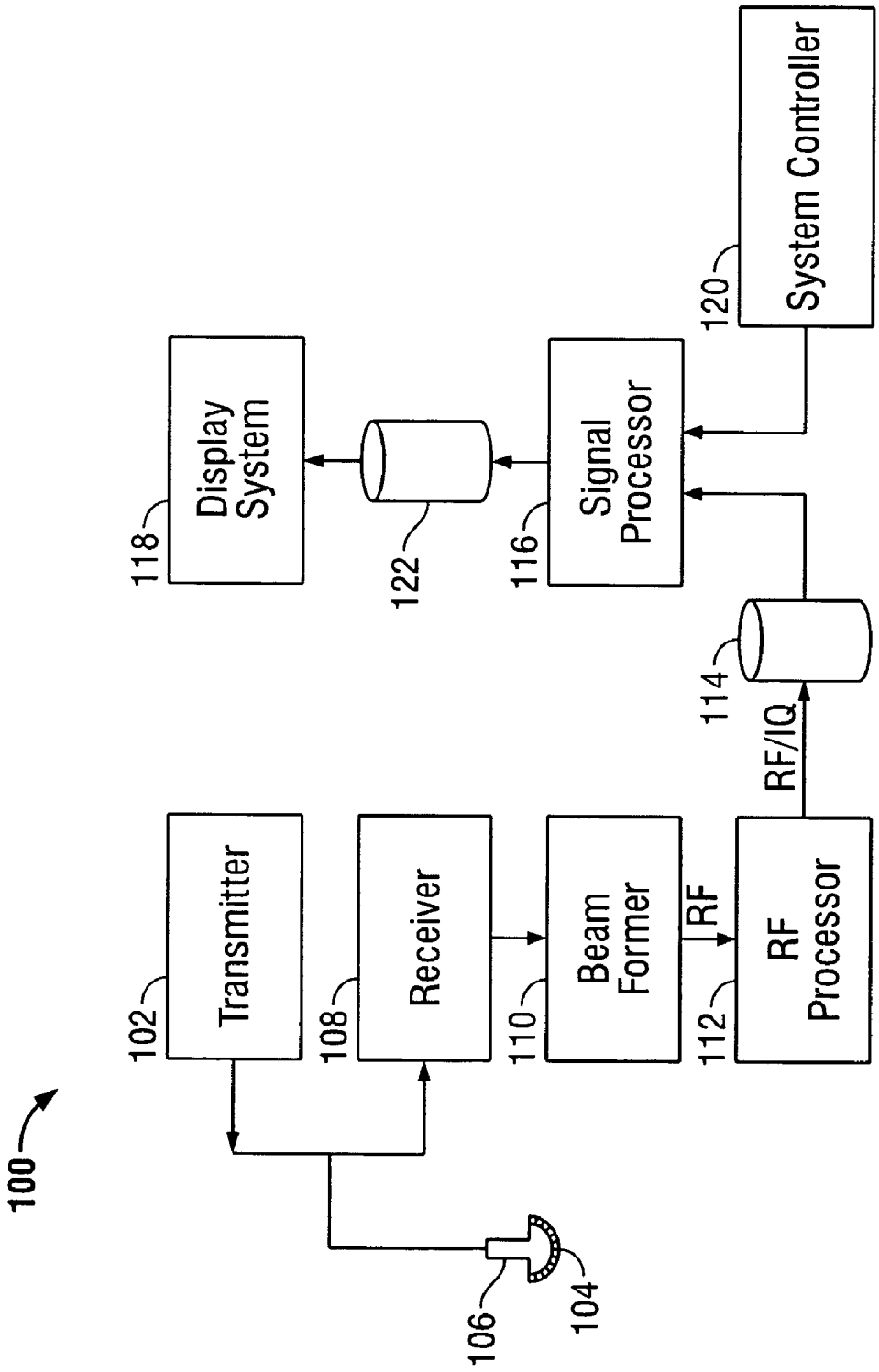

100
102
Transmitter
108
Receiver
110
Beam Former
RF
112
RF Processor
RF/IQ
114
116
Signal Processor
120
System Controller
118
Display System
122
104
106

FIG. 1

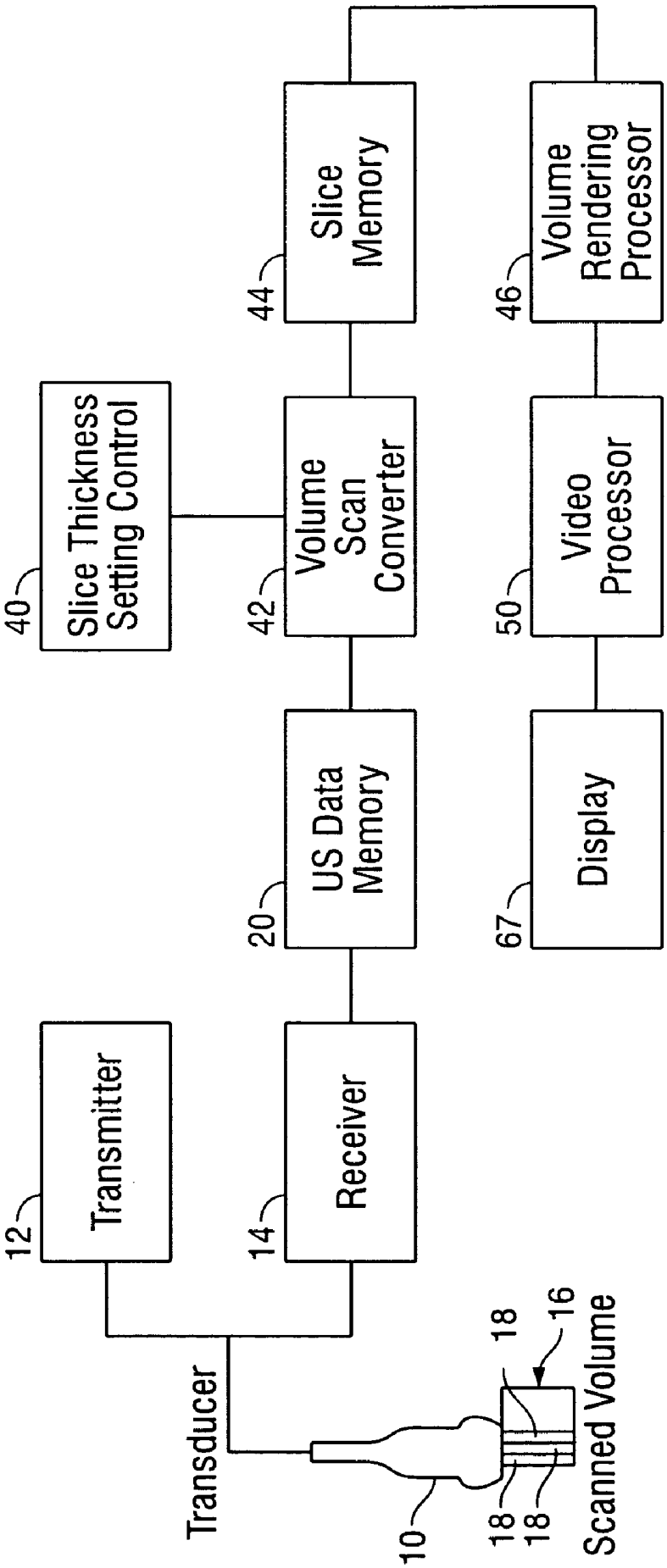

Slice Memory
44
Volume Rendering Processor
46
Slice Thickness Setting Control
40
Volume Scan Converter
42
Video Processor
50
US Data Memory
20
Display
67
Transmitter
12
Receiver
14
Transducer
10
18
16
18
18
Scanned Volume

FIG. 2

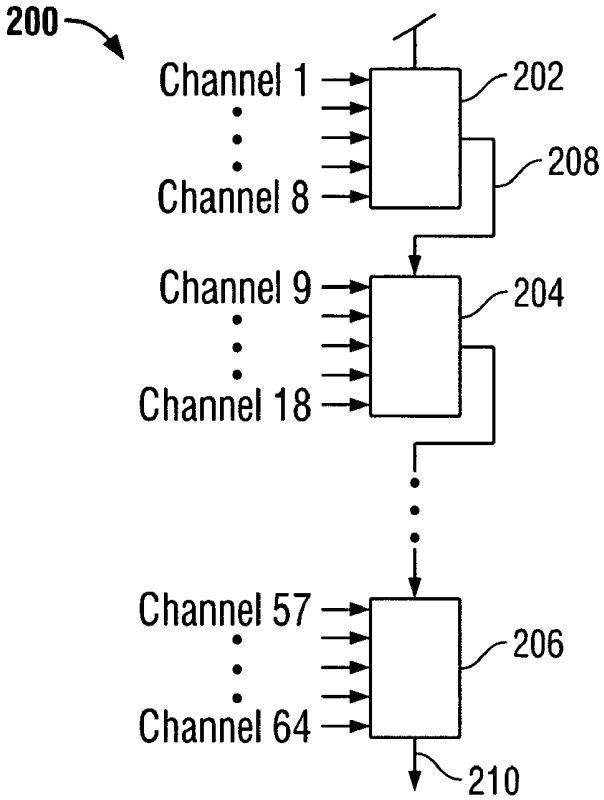


FIG. 3
(Prior Art)

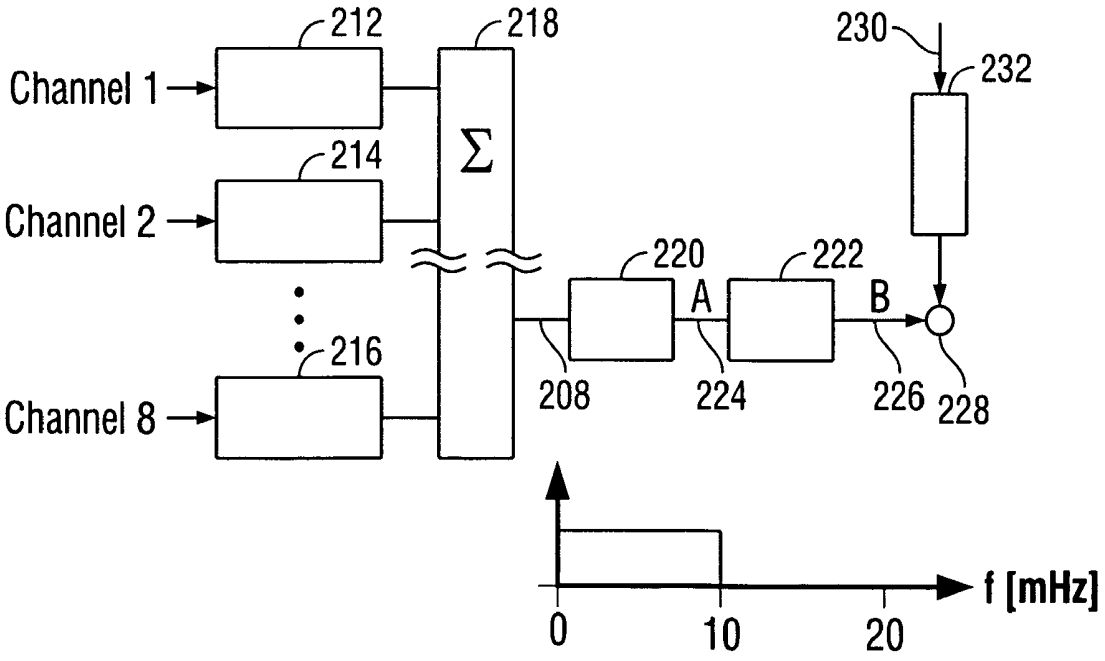


FIG. 4
(Prior Art)

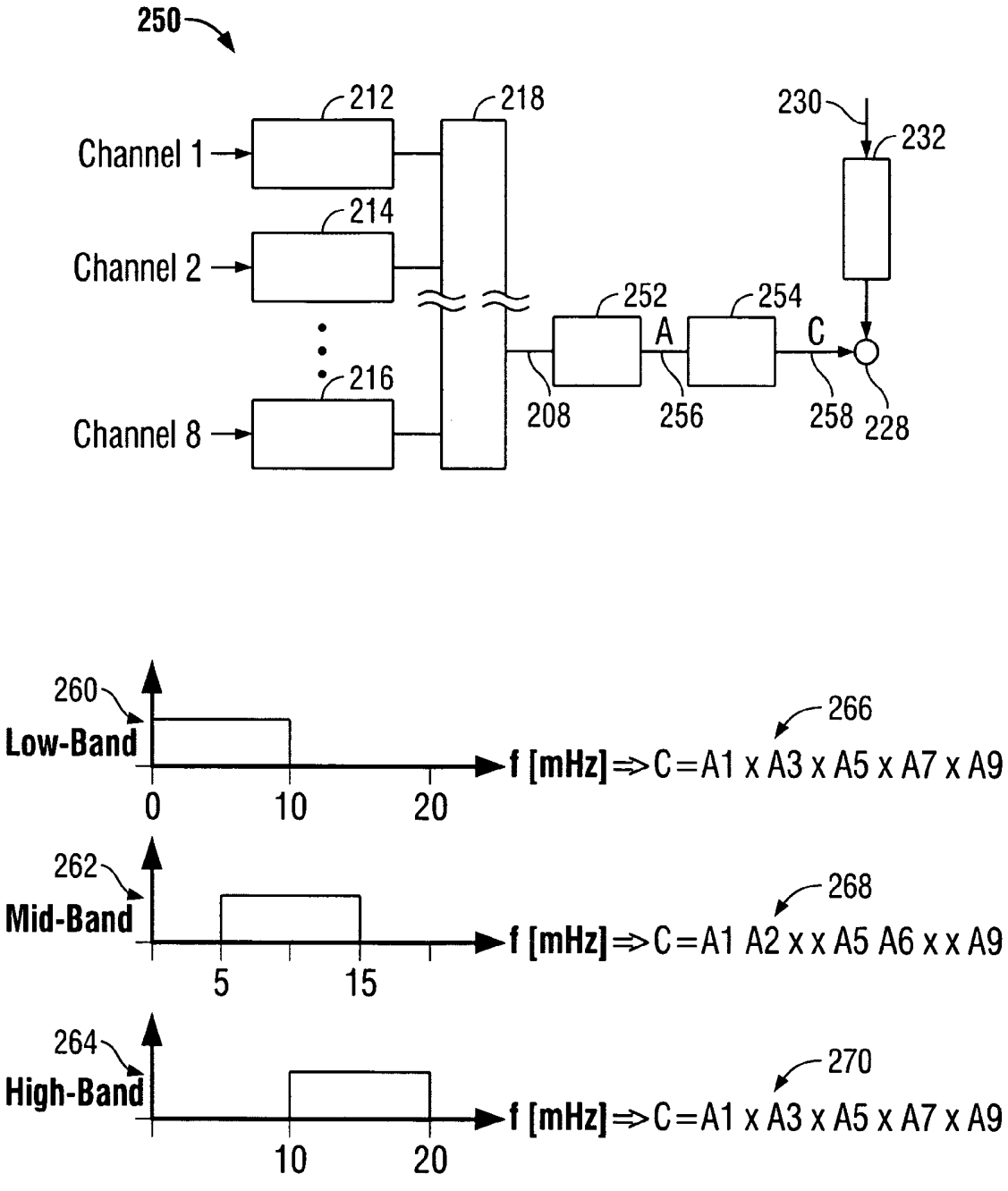
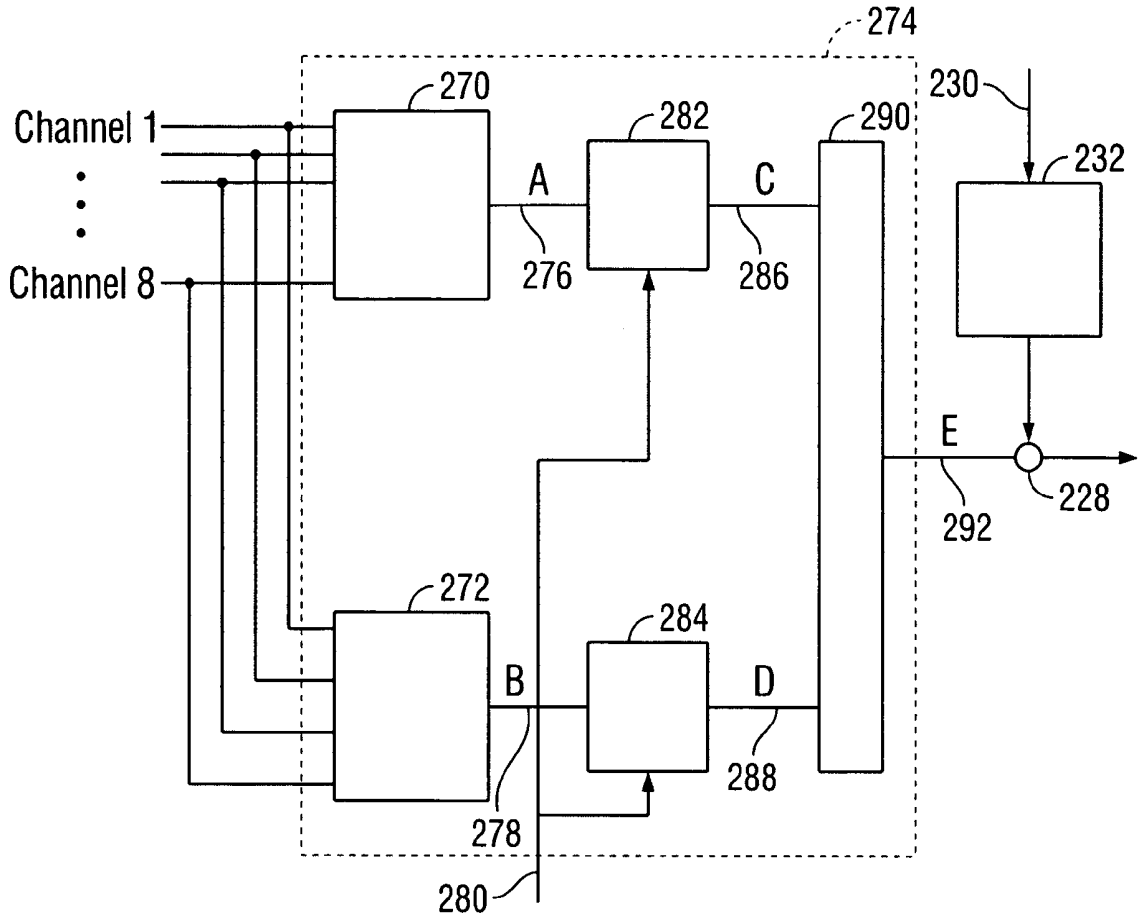

250
212
218
230
232
Channel 1
214
Channel 2
252
254
A
C
216
Channel 8
208
256
258
228
260
Low-Band
266
f [mHz] ⇒ C = A1 x A3 x A5 x A7 x A9
0
10
20
262
Mid-Band
268
f [mHz] ⇒ C = A1 A2 x x A5 A6 x x A9
5
15
264
High-Band
270
f [mHz] ⇒ C = A1 x A3 x A5 x A7 x A9
10
20

FIG. 5



A	A1	A2	A3	A4	A5	A6	A7	A8	
B	B1	B2	B3	B4	B5	B6	B7	B8	
C	A1	A2	X	X	A5	A6	X	X	MID-BAND
D	B1	B2	X	X	B5	B6	X	X	
E	A1	A2	B1	B2	A5	A6	B5	B6	

FIG. 6

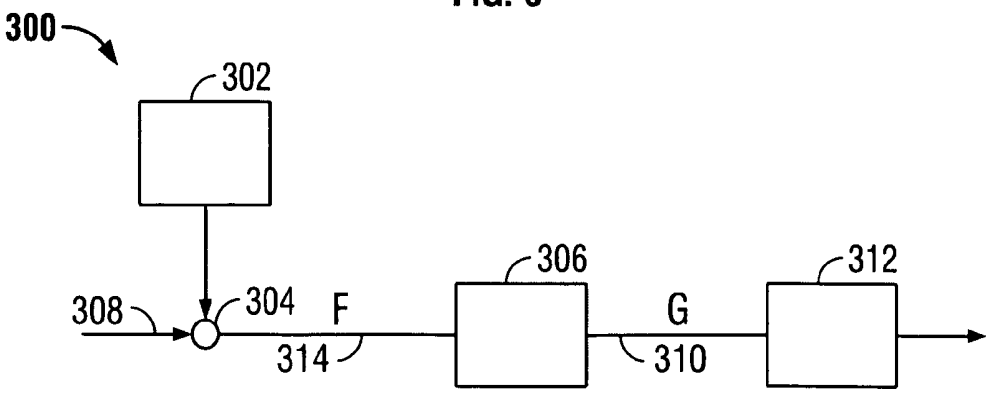


FIG. 7

ULTRASOUND METHOD AND APPARATUS FOR MULTI-LINE ACQUISITION

CROSS REFERENCE TO RELATED APPLICATION

The application relates to and claims priority from provisional patent application Ser. No. 60/477,826, titled "Ultrasound Method and Apparatus for Multi-Line Acquisition", filed Jun. 12, 2003, the complete subject matter of which is expressly hereby incorporated herein in its entirety.

BACKGROUND OF THE INVENTION

The present invention relates to diagnostic ultrasound systems. In particular, the present invention relates to method and apparatus for acquiring and processing ultrasound data streams to reduce the bandwidth of the data without deteriorating the performance of the beamformer, and to share the bandwidth between two or more data streams belonging to different beams in multi-line acquisition.

FIG. **3** illustrates a typical configuration of a receive beamformer **200**. Digitized channel signals are input to a number of identical signal processing devices (beamformer ASICs) **202-206**, that are interconnected in a beamsum pipeline. The ASIC **202** performs a partial beam formation of channels **1-8**. The partial beamsum **208** is then input to ASIC **204** and added to the partial beamsum of channels **9-18** within ASIC **204**. This process is continued down the beamsum pipeline until the final beamsum **210** is coming out of the last ASIC **206** in the chain.

For a time-delay beamformer, such as receive beamformer **200**, the data may typically be 20 bit wide and have a data rate of 40 MHz per beam, i.e. 800 Mbit/s data bandwidth. With simultaneous reception of parallel beams, or multi-line acquisition (MLA), this data rate is multiplied by the number of parallel beams. The cost of the interconnect infrastructure within the ultrasound system increases with data bandwidth, as more pins are required on integrated circuits for signal processing, more pins on circuit board connectors, or a faster clock rate of the data paths.

FIG. **4** illustrates the contents of the partial beamformer ASICs **202-206** of FIG. **3**. An input data rate (sampling rate) of 40 MHz is assumed, although other data rates may be used. Each channel **1-8** is processed through a per-channel beamformer **212-216**. The per-channel beamformers **212-216** perform per-channel beamforming (time delay and optionally per-channel amplitude weighting).

The output from the beamsummer **218**, the partial beamsum **208**, is then passed through a low-pass anti-aliasing filter **220** that cuts off frequencies above 10 MHz, reducing the bandwidth of the signal. Data output from the low-pass anti-aliasing filter **220** is represented as data stream A **224**, following a sequence of samples A1 A2 A3 A4 A5 . . . and so on. A decimator **222** then reduces the data rate by throwing away every other sample of the data stream A **224** to produce data stream B **226**, giving the sample sequence of A1 X A3 X A5 X . . . and so on. The X's in data stream B **266**, and all subsequent data streams discussed herein, represent data samples which have been thrown away. Data stream B **226** is then summed by summer **228** with a cascading input **230**. The cascading input **230** may be supplied through an optional delay line **232** to allow for summing with a subsequent device. The delay line **232** may not be required for certain beamformer architectures.

Alternatively, the cutoff-rate of the anti-aliasing filter **220** may be 20 MHz/n, wherein n=1,2,3,4 . . . , allowing for a data output rate of 40 MHz/n by throwing away (n-1) samples for every sample that is retained. A larger value of n results in a greater reduction of the data rate. Unfortunately, the maximum usable frequency of the receive beamformer **200** becomes reduced by a factor n, for example, from 20 MHz to 20 MHz/n.

Thus, a system and method are desired to acquire data with a maximum frequency which is not limited to one-half the data sampling rate of the output stream that addresses the problems noted above and others previously experienced.

BRIEF DESCRIPTION OF THE INVENTION

A method for acquiring ultrasound data comprising acquiring echo signals from an area of interest, analyzing the echo signals to produce a first data stream associated with a first receive beam, and decimating the first data stream by removing at least two consecutive data samples therefrom to form a first decimated data stream.

An ultrasound system comprising a transmitter transmitting ultrasound signals into an area of interest, a receiver receiving echo signals from transmitted ultrasound signals, and a beamformer processing the echo signals to simultaneously form first and second data streams associated with different first and second receive beams. The beamformer includes a decimator removing from at least one of the first and second data streams at least two consecutive data samples, and an output outputting information based on an output of the decimator.

A decimation subsystem comprising an input receiving a first data stream comprising data samples. The decimation subsystem further comprises a first decimator receiving the first data stream and removing at least two consecutive data samples therefrom, while passing at least two consecutive data samples to output a decimated subset of the first data stream.

A method for acquiring ultrasound data comprising acquiring echo signals from an area of interest, producing first and second data streams associated with first and second receive beams based on the echo signals, and filtering the first and second data streams to form first and second filtered data sets having partially overlapping frequency bands. The method also comprises decimating the first and second filtered data sets to form first and second decimated data sets.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a block diagram of an ultrasound system formed in accordance with an embodiment of the present invention.

FIG. **2** illustrates an ultrasound system formed in accordance with one embodiment of the present invention.

FIG. **3** illustrates a typical configuration of a receive beamformer.

FIG. **4** illustrates the contents of the partial beamformer ASIC of FIG. **3**.

FIG. **5** illustrates the contents of a partial beamformer ASIC comprising a programmable anti-aliasing (a-a) filter in accordance with one embodiment.

FIG. **6** illustrates multiplexing two data streams into a single data stream in accordance with one embodiment

FIG. **7** illustrates a complex demodulator which may be used in connection with the systems of FIGS. **4** and **5** in accordance with one embodiment.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** illustrates a block diagram of an ultrasound system **100** formed in accordance with an embodiment of the present invention. The ultrasound system **100** includes a transmitter **102** which drives an array of elements **104** within a transducer **106** to emit pulsed ultrasonic signals into a body. A variety of geometries may be used. The ultrasonic signals are back-scattered from structures in the body, like blood cells or muscular tissue, to produce echoes which return to the elements **104**. The echoes are received by a receiver **108**. The received echoes are passed through a beamformer **110**, which performs beamforning and outputs an RF signal. The RF signal then passes through an RF processor **112**. Alternatively, the RF processor **112** may include a complex demodulator (not shown) that demodulates the RF signal to form IQ data pairs representative of the echo signals. The RF or IQ signal data may then be routed directly to RF/IQ buffer **114** for temporary storage. A system controller **120** controls the operation of the components of the ultrasound system **100**.

The ultrasound system **100** also includes a signal processor **116** to process the acquired ultrasound information (i.e., RF signal data or IQ data pairs) and prepare frames of ultrasound information for display on display system **118**. The signal processor **116** is adapted to perform one or more processing operations according to a plurality of selectable ultrasound modalities on the acquired ultrasound information. Acquired ultrasound information may be processed in real-time during a scanning session as the echo signals are received. Additionally or alternatively, the ultrasound information may be stored temporarily in RF/IQ buffer **114** during a scanning session and processed in less than real-time in a live or off-line operation.

The ultrasound system **100** may continuously acquire ultrasound information at a frame rate that exceeds **50** frames per second—the approximate perception rate of the human eye. The acquired ultrasound information is displayed on the display system **118** at a frame-rate that may be different than that of the acquired data. An image buffer **122** is included for storing processed frames of acquired ultrasound information that are not scheduled to be displayed immediately. Preferably, the image buffer **122** is of sufficient capacity to store at least several seconds worth of frames of ultrasound information. The frames of ultrasound information are stored in a manner to facilitate retrieval thereof according to its order or time of acquisition. The image buffer **122** may comprise any known data storage medium.

FIG. **2** illustrates an ultrasound system formed in accordance with one embodiment of the present invention. The system includes a transducer **10** connected to a transmitter **12** and a receiver **14**. The transducer **10** transmits ultrasonic pulses and receives echoes from structures inside of a scanned ultrasound volume **16**. Memory **20** stores ultrasound data from the receiver **14** derived from the scanned ultrasound volume **16**. The volume **16** may be obtained by various techniques (e.g., 3D scanning, real-time 3D imaging, volume scanning, 2D scanning with an array of elements having positioning sensors, freehand scanning using a Voxel correlation technique, 2D or matrix array transducers and the like).

The transducer **10** is moved, such as along a linear or arcuate path, while scanning a region of interest (ROI). At each linear or arcuate position, the transducer **10** obtains scan planes **18**. The scan planes **18** are collected for a thickness, such as from a group or set of adjacent scan planes **18**. The scan planes **18** are stored in the memory **20**, and then passed to a volume scan converter **42**. In some embodiments, the transducer **10** may obtain lines instead of the scan planes **18**, and the memory **20** may store lines obtained by the transducer **10** rather than the scan planes **18**. The volume scan converter **20** may store lines obtained by the transducer **10** rather than the scan planes **18**. The volume scan converter **42** receives a slice thickness setting from a control input **40**, which identifies the thickness of a slice to be created from the scan planes **18**. The volume scan converter **42** creates a data slice from multiple adjacent scan planes **18**. The number of adjacent scan planes **18** that are obtained to form each data slice is dependent upon the thickness selected by slice thickness control input **40**. The data slice is stored in slice memory **44** and is accessed by a volume rendering processor **46**. The volume rendering processor **46** performs volume rendering upon the data slice. The output of the volume rendering processor **46** is passed to the video processor **50** and display **67**.

The position of each echo signal sample (Voxel) is defined in terms of geometrical accuracy (i.e., the distance from one Voxel to the next) and ultrasonic response (and derived values from the ultrasonic response). Suitable ultrasonic responses include gray scale values, color Doppler values, and angio or power Doppler information.

FIG. **5** illustrates the contents of a partial beamformer for a single beam in accordance with the present invention. ASIC **250** comprises a programmable anti-aliasing (a-a) filter **252**. Elements corresponding to the elements in FIG. **4** have the same item numbers. Their function is similar to the previous discussion regarding FIG. **4**, and thus will not be further discussed. The a-a filter **252** has a pass-band that is either "low-pass" or low-band **260**, i.e. from 0-10 MHz, "band-pass" or mid-band **262** from 5-15 MHz, or "high-pass" or high-band **264** from 10-20 MHz. The a-a filter **252** provides three discrete modes of operation for the beamformer **110**, with a useable frequency range corresponding to the selected pass-band of the associated a-a filter **252**. The data stream A **256** output by the a-a filter **252** follows a sequence of A1 A2 A3 A4 A5 . . . and so on.

A decimator **254** functions differently for the different modes of the a-a filter **252**. For the low-band **260** and high-band **264** modes, the decimator **254** decimates every other data sample in the data stream A **256**, and outputs data stream C **258** following a sequence of A1 X A3 X A5 X . . . and so on. Mathematically, the data stream C **258** corresponds to multiplication of the sample stream [A1 A2 A3 A4 A5 A6 . . .] with the sequence [101010101010. . .]. The spectrum of the resultant waveform has frequency components centered around 0 Hz and 20 MHz, so the spectra of the a-a filtered signals in the low-band **260** and high-band **264** modes will not overlap after decimation. Those skilled in the art will recognize that all of the information in the a-a filtered signal (data stream A **256**) will be fully preserved through the decimation process even for the high-band **264** filtered signal. FIG. **5** illustrates the applicable data stream C **258** for the associated a-a filter **252** mode. Data stream C **266** is associated with the low-band **260** mode, and data stream C **270** is associated with the high-band **264** mode.

When the a-a filter **252** is in the mid-band **262** mode, the a-a filter **252** outputs the data stream A **256** following the pattern of A1 A2 A3 A4 A5 A6 A7 A8 A9 A10 . . . and so on. The decimator **254** passes two consecutive data samples of the data stream A **256**, and decimates two consecutive data samples of the data stream A **256**. The decimator **254** therefore outputs the data stream C **258** following a

sequence of A1 A2 X X A5 A6 X X A9 A10 . . . and so on. Mathematically, the data stream C **258** corresponds to multiplication of the sample stream [A1 A2 A3 A4 A5 A6 . . .] with the sequence [110011001100110 0 . . .]. The spectrum of the resultant waveform has frequency components centered around 0 Hz and 10 MHz only, so even in this case the spectrum of the a-a filtered signals will not overlap after decimation. Those skilled in the art will recognize that all of the information in the a-a filtered signal (data stream A **256**) will be fully preserved through the decimation process. FIG. **5** illustrates the data stream C **268** for the associated mid-band **262** mode.

From the previous description, it is clear that the entire frequency range from 0 to 20 MHz is now covered with three overlapping frequency bands with a (real) data rate of only 20 MHz. Although FIG. **5** illustrates a 40 MHz sampling frequency, it should be understood that sampling frequencies other than 40 MHz may be used.

Reducing the data rate by decimation does not affect the delay or phase of different data streams. Therefore, the decimation process may be performed at any stage of the beamforming process. Alternatively, the a-a filter **252** and decimator **254** may be moved up within the process and replicated as a part of the per-channel beamformer **212**.

FIG. **6** illustrates how the data streams from two partial beamformers can be multiplexed into a single 40 MHz data stream. Each single beam partial beamformer **270** and **272** comprises a set of per-channel beamformers **212-216**, such as for 8 or 16 channels. The number of per-channel beamformers **212-216** in each single beam partial beamformer **270** and **272** is determined by the hardware implementation. Therefore, single beam partial beamformers **270** and **272** receive signals through channels as discussed previously in relation to FIG. **4**. The single beam partial beamformers **270** and **272**, however, receive signals from the same set of channels, and are typically receiving beams that are spatially different. The single-beam partial beamformers **270** and **272** output data stream A **276** and data stream B **278**, respectively. Data stream A **276** follows a sequence of A1 A2 A3 A4 A5 A6 A7 A8 A9 A10 . . . and so on. Data stream B **278** follows a sequence of B1 B2 B3 B4 B5 A6 B7 B8 B9 B10 . . . and soon.

The function of the a-a filter **252** and decimator **254** remain the same as previously discussed for FIG. **5**, and have been illustrated in FIG. **6** as a-a filter/decimators **282** and **284**. A mode select line **280** provides an input to the a-a filter/decimators **282** and **284** from the system controller **120** that selects the band-pass mode, either low-band **260**, mid-band **262**, or high-band **264**. The input indicates to the ultrasound system **100** which band to operate for a given beam.

When either low-band **260** or high-band **264** are selected, the data streams C **286** and D **288** follow the patterns: C=A1 X A3 X A5 X A7 X A9 X . . . and so on, and D=B1 X B3 X B5 X B7 X B9 X . . . and so on. The data streams C **286** and D **288** are input to a MUX/FIFO **290**. The MUX/FIFO **290** multiplexes the two inputs and outputs data stream E **292**, which follows the pattern of A1 B1 A3 B3 A5 B5 A7 B7 A9 B9 . . . and so on.

If the mid-band **262** mode is selected, the data streams C **286** and D **288** follow the sequences: C=A1 A2 X X A5 A6 X X A9 A10 . . . and so on, and D=B1 B2 X X A5 A6 X X A9 A10 . . . and so on. The data streams C **286** and D **288** are input to the MUX/FIFO **290**, which multiplexes the two inputs and outputs data stream E **292**, which follows the sequence of E=A1 A2 B1 B2 A5 A6 B5 B6 A9 A10. and so on. The data streams A **276**, B **278**, C **286**, D **288**, and E **292** for the mid-band **262** mode are illustrated on FIG. **6** for clarity. It should be understood that other forms of multiplexing that provide equivalent function also exist, for example data stream E **292** may be E=A1 B1 A2 B2 A5 B5 A6 B6 A9 B9 A10 B10 . . . and so on.

The data stream E **292** is sent to the summer **228**, which sums the data stream E **292** with the cascading input **230**. As previously discussed, the delay line **232** is optional. Typically, a single ASIC **274** may be used to perform the function of one or more of the single-beam partial beamformers **270-272**, a-a filter/decimators **282-284**, and MUX/FIFO **290**. The complete multi-beam beamformer topology comprises a plurality of partial beamformers **270-272**, or ASICS **274**, in cascade, interconnected with a single 40 MHz data stream in the same way as shown in FIG. **3**, i.e. using a single data stream connecting the partial beamformers **270-272** or ASICS **274**. Therefore, a 2-factor reduction of the interconnect data rate between the partial beamformers **270-272**, or ASICS **274**, may be accomplished without compromising the operating frequency range of the beamformer **110**, as two (or N) single-beam partial beamformers **270-272** or ASICs **274**, each having a data rate of 20 MHz, may be multiplexed into the 40 MHz output data stream.

FIG. **7** illustrates a complex demodulator **300** which may be used in connection with the systems of FIGS. **5** and **6**. The complex demodulator **300** may be included in the RF processor **112**. The beamsum output data streams **308** from the last partial beamformer in the cascade topology is input to the multiplier **304**, such as data stream C **258** (FIG. **5**) or data stream E **292** (FIG. **6**).

In the case of low-band **260** or high-band **264**, data demodulation can be done in the following way. The input data stream **308** may be either low-band **260** or high-band **264** data and comprise data samples from data streams C **286** and D **288** (FIG. **6**). A RAM table **302** provides a complex, time dependent demodulation waveform to a multiplier **304**. For example, the waveform may be M=exp (–j*2*pi*f*k/fs/2), k=0,1,2 . . . , where a constant demodulation frequency f and a demodulation amplitude of 1 has been assumed for simplicity. The sampling frequency fs=40 MHz and k is the running time index. Therefore, assume that the desired demodulation data stream for the decimated data stream C **286** is Mc1 Mc2 Mc3 Mc4, and that the desired demodulation data stream for data stream D **288** is Md1 Md2 Md3 Md4. The multiplier **304** interleaves M, input from the RAM table **302**, with data streams C **286** and D **288**, and outputs data stream F **314**, where F=Mc1 Md1 Mc2 Md2 Mc3 Md3 Mc4 Md4 . . . and so on.

The data stream F **314** is filtered by a FIR filter **306**, typically with real coefficients. For simplicity, assume that the desired impulse response of the FIR filter **306** is the same for both data streams, such as h1 h2 h3 h4 . . . , h(N). The desired operations if the demodulator in this case are, therefore, c=h conv (C*Mc) and d=h conv (D*Md) where "conv" means "convolved with". By selecting the FIR filter **306** coefficients as the desired impulse response interleaved with zeros, H={h1 0 h2 0 h3 0 . . . h(N)}, one who is skilled in the art will realize that the output demodulation data stream G **310** then becomes G=c1 d1 c2 d2 c2 d3 c3 d3 . . . and so on, as desired.

The following applies if the beamsum input data stream **308** is mid-band **262** data, such as data stream C **268** (FIG. **5**). Mathematically demodulation can be done by inserting two zero samples between the mid-band **262** sample pairs, such that input data stream **308** may be represented by Cz=A1 A2 0 0 A5 A6 0 0 A9 A10 0 0 . . . and so on. The RAM table **302** provides the complex, time dependent signal

to the multiplier, for example Mz=exp (−j*2*pi*f*k/fs), k=0,1,2, . . . where a constant demodulation frequency f and a demodulation amplitude of 1 has been assumed for simplicity. The demodulation waveform Mz has been sampled at the original sampling frequency, such as fs=40 MHz. The data stream F **314** output by the multiplier **304** is then filtered by the FIR filter **306** with the desired coefficients {h(k)}, k=1,2,3, . . . N. The output of the filter is decimated by two by throwing away every other sample to give a data output rate that is the same as the input data rate of 20 MHz. The 20 MHz output demodulation data stream G **310** will be G=g1 g2 g3 g4 g5 . . . .

It may be noted in the above example that one-half of the samples of the sequence Mz*Cz (or data stream F **314**) are zeros that don't contribute to the output sum. Moreover, because the bandwidth of the input data stream **308** is limited to 10 MHz, the sampling rate of the complex data output can be reduced to 10 MHz without loss of information.

Therefore, an alternative demodulation sequence requiring only half the data rate in the FIR filter **306** /multiplier **304** may be accomplished even when the beamsum input data stream **308** is mid-band **262** data. The input data stream **308** may be represented by Cz=A1 A2 A5 A6 A9 A10 . . . and so on. The input data stream **308** is input at a **20** MHz rate. The multiplier **304** interleaves the input data stream **308** and the samples of Mz from the RAM table **302** that correspond to the non-zero samples of Cz, i.e. {Mz(k)}, k=1, 2, 5, 6, 9, 10, . . . and so on.

The FIR filter **306** filters the data stream F **314** with a coefficient set that is different for the odd and even numbered time index. Assuming for simplicity that N=4*m−2, where m is an integer, the odd-sample coefficients are {ho}={h1 h2 h5 h6 h9 h10 . . . h(N−1) h(N)} and the even-sample {he}={h7 h8 h11 . . . h(N−2) 0} Thus, the coefficients of the FIR filter **306** toggle back and forth between {ho} and {he} for every other sample. The output becomes G=g1 g2 g3 g4 g5 . . . as in the previous example. If the output rate is limited to 10 MHz, the complication of using time dependent coefficients can be avoided. It is then possible to use only one coefficient set, such as {ho}, and use only the odd numbered output data from the FIR filter **306**. The even samples need to be thrown away by the decimator **312**, so the output becomes G=g1 x g3 x g5 x . . . .

The following example illustrates demodulating multiplexed mid-band **262** data, such as data stream E **292** (FIG. **6**), wherein the data are interleaved two and two as discussed previously. For simplicity, assume that the desired demodulation waveform for data stream C **286** is Mc1 Mc2 Mc3 Mc4 . . . and so on, and that the desired demodulation waveform for data stream D **288** is Md1 Md2 Md3 Md4 . . . and so on. Moreover, assume that the desired impulse response of the FIR filter **306**, {h1 h2 h3 h4 . . . , h(N)} is the same for both data streams C **286** and D **288**. The desired operations are, in other words, c=h conv (C*Mc) and d=h conv (D*Md) where conv means "convolved with".

Complex demodulation will result by making M an interleaved version of data streams C **286** and D **288**, taking two samples of each at a time, M=Mc1 Mc2 Md1 Md2 Mc3 Mc4 Md3 Md4 . . . and so on, and selecting the FIR filter **306** coefficients as the desired impulse response interleaved with zeros. Assuming a 10 MHz output rate (decimation by two on the output) only one set of coefficients is necessary. These coefficients become Ho={ho(1) ho(2) 0 0 ho(3) ho(4) 0 0 ho(5) ho(6) 0 0 . . . ho(N−1) ho(N))} The demodulation data stream G **310** output from the FIR filter **306** will be {x c1 x d1 x c3 x d3 x c5 x d5 x c7 x d3 . . . }. For clarity, x indicates that a data sample is thrown away by the decimator **312**, and the output data are {c1 c3 c5 . . . }and {d1 d3 d5 . . . }, and G=c1 d1 c3 d3 . . . and so on.

It should be noted that the data streams C **258** (FIG. **5**) and E **292** (FIG. **6**) may be sent to a common complex demodulator, such as the complex demodulator as shown in FIG. **7**. Therefore, the same FIR filter **306** may be used for data streams having every other data sample removed, and for data streams having two or more consecutive data samples removed by changing the coefficients of the FIR filter **306** through software, without modifying any hardware within the beamformer **110**.

Thus, by using the decimation and multiplexing system as illustrated in FIGS. **5** and **6**, namely, by decimating at least two consecutive data samples, an additional bandwidth (mid-band **262** of 5-15 MHz), or data sampling rate of one-quarter to three-quarters of the data sampling rate after decimation, may be achieved. Therefore, the maximum usable frequency range of the beamformer in a decimating mode may be expanded while maintaining the data rate at 20 MHz, for example. As overlapping frequency bands may be obtained, the image performance of transducers **10** having a center frequency close to 10 MHz is improved. As stated previously, transducers **10** having other center frequencies may also be used and achieve improved image performance.

While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.

What is claimed is:

1. A method for acquiring ultrasound data, comprising:

transmitting ultrasound signals from a transducer into an area of interest;

receiving, at the transducer, ultrasound echo signals from the area of interest;

converting said ultrasound echo signals received at the transducer into a first data stream associated with a first receive beam; and

decimating said first data stream by passing at least two consecutive data samples and by removing at least two other consecutive data samples therefrom to form a first decimated data stream.

2. The method of claim **1**, further comprising:

analyzing said echo signals to produce a second data stream associated with a second receive beam that is spatially different from said first receive beam; and

multiplexing said first and second data streams together.

3. The method of claim **1**, further comprising:

analyzing said echo signals to produce a second data stream associated with a second receive beam that is spatially different from said first receive beam; and

decimating said second data stream by passing at least two consecutive data samples and by removing at least two other data samples therefrom to form a second decimated data stream.

4. The method of claim **1**, further comprising

analyzing said echo signals to produce a second data stream associated with a second receive beam that is spatially different from said first receive beam; and

decimating said second data stream to pass at least two consecutive data samples that align in time with said two other data samples removed from said first data stream.

5. The method of claim **1**, further comprising acquiring said echo signals simultaneously from multiple different

receive beams and repeating said analyzing and decimating steps for multiple data streams associated with said multiple different receive beams.

6. An ultrasound system, comprising:

a transmitter for transmitting ultrasound signals into an area of interest;

a receiver for receiving ultrasound echo signals from the area of interest from transmitted ultrasound signals;

a beamformer processing said echo signals to simultaneously form first and second data streams associated with different first and second receive beams;

a decimator for passing consecutive data samples from at least one of said first and second data stream and for removing consecutive data samples from said first and second data streams, said decimator removing a different number of consecutive said data samples based on a band-pass mode; and

a multiplexor for combining said first and second data streams such that data samples passed in said first data streams are intermixed with data samples passed in said second data stream to form a multiplexed data stream.

7. The ultrasound system of claim **6**, further comprising at least two processors receiving and dividing said echo signals from said receiver into said first and second data streams, said first and second receive beams differing spatially with respect to said receiver.

8. The ultrasound system of claim **6**, further comprising an anti-aliasing filter passing data based on said band-pass mode, said band-pass mode being one of low-band, mid-band, and high-band.

9. The ultrasound system of claim **6**, further comprising a system controller identifying said band-pass mode.

10. The ultrasound system of claim **6**, farther comprising said band-pass mode being one of low-band, mid-band, and high-band, said at least one decimator removing two consecutive said data samples when said band-pass mode is said mid-band, said at least one decimator removing every other said data sample when said band-pass mode is said high-band.

11. A demodulator for use with an ultrasound system to demodulate ultrasound data streams, the ultrasound system having a transmitter for transmitting ultrasound signals into an area of interest, a receiver for receiving ultrasound echo signals from the area of interest from transmitted ultrasound signals, a beamformer for processing said echo signals to form a data stream, the demodulator comprising:

an input receiving the data stream, said data stream comprising mid-band data;

a multiplier interleaving said data stream with a time dependent signal; and

a filter filtering said data stream, said filter further comprising coefficients having two consecutive data samples representative of a desired impulse response interleaved with two consecutive data samples being zeros, said filter outputting a filtered data stream.

12. The demodulator of claim **11**, said data stream further comprising data pairs, said filter further comprising coefficients interleaved with zeros.

13. The demodulator of claim **11**, said filter filtering said data stream with a coefficient set that is different for odd and even numbered time index.

14. The demodulator of claim **11**, said data stream further comprising multiplexed mid-band data, said multiplexed mid-band data being interleaved every two consecutive data samples.

15. The demodulator of claim **11**, said data stream having a first frequency, said filter outputting said filtered data stream at a sampling rate being one of equal to said first frequency and two times said first frequency.

16. A method for acquiring ultrasound data, comprising:

transmitting ultrasound signals from a transducer into an area of interest;

receiving, at the transducer, ultrasound echo signals from the area of interest;

converting said ultrasound echo signals into first and second data streams associated with first and second receive beams, said first and second data streams having a total bandwidth;

filtering said first and second data streams to form first and second filtered data streams, said first and second filtered data streams having a bandwidth comprising one of a low-band, mid-band, and high-band, said low-band, mid-band, and high-band bands being based on said total bandwidth; and

decimating said first and second filtered data streams to form first and second decimated data streams; and

multiplexing said first and second decimated data streams to form a multiplexed data stream.

17. The method of claim **16**, said first and second decimated data steams having a bandwidth of one-quarters to three-quarters of said total bandwidth.

18. The method of claim **16**, said filtering step applying coefficients based on said bandwidth, said coefficients being different for each of said low-band, mid-hand, and high-band bands.

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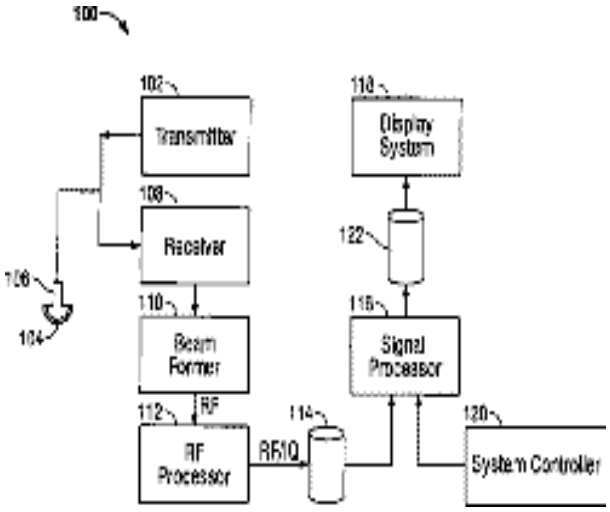
一种用于获取多线采集超声数据的方法和装置。超声信号被传输到感兴趣的区域中。获取并分析回波信号以产生与第一接收波束相关联的第一数据流。通过从其中移除至少两个连续数据样本，同时传递至少两个连续数据样本以形成第一抽取数据流，来抽取第一数据流。使用该抽取模式，可以实现抽取之后的数据采样率的一半到四分之三的带宽。