US 20090112096A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2009/0112096 A1**

Tamura (43) **Pub. Date: Apr. 30, 2009**

(54) **METHODS AND APPARATUS FOR ULTRASOUND IMAGING**

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(21) Appl. No.: **11/926,228**

(22) Filed: **Oct. 29, 2007**

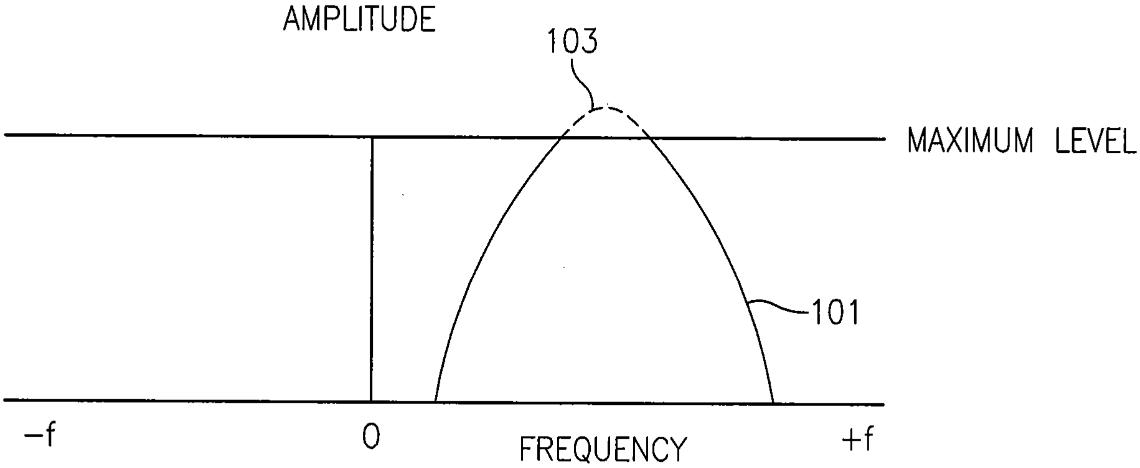
Publication Classification

(51) **Int. Cl.**
A61B 8/06 (2006.01)

(52) **U.S. Cl.** **600/454**

(57) **ABSTRACT**

A system and method is disclosed that examines Doppler spectrum signals output by an ultrasound system when measuring blood flow velocity to determine a proper Doppler gain and to suppress noise manifest in the Doppler spectrum. Noise present in the Doppler spectrum is examined and used as a criterion for optimal gain. If the Doppler gain is too high or too low in accordance with predetermined levels, overall gain is adjusted accordingly.



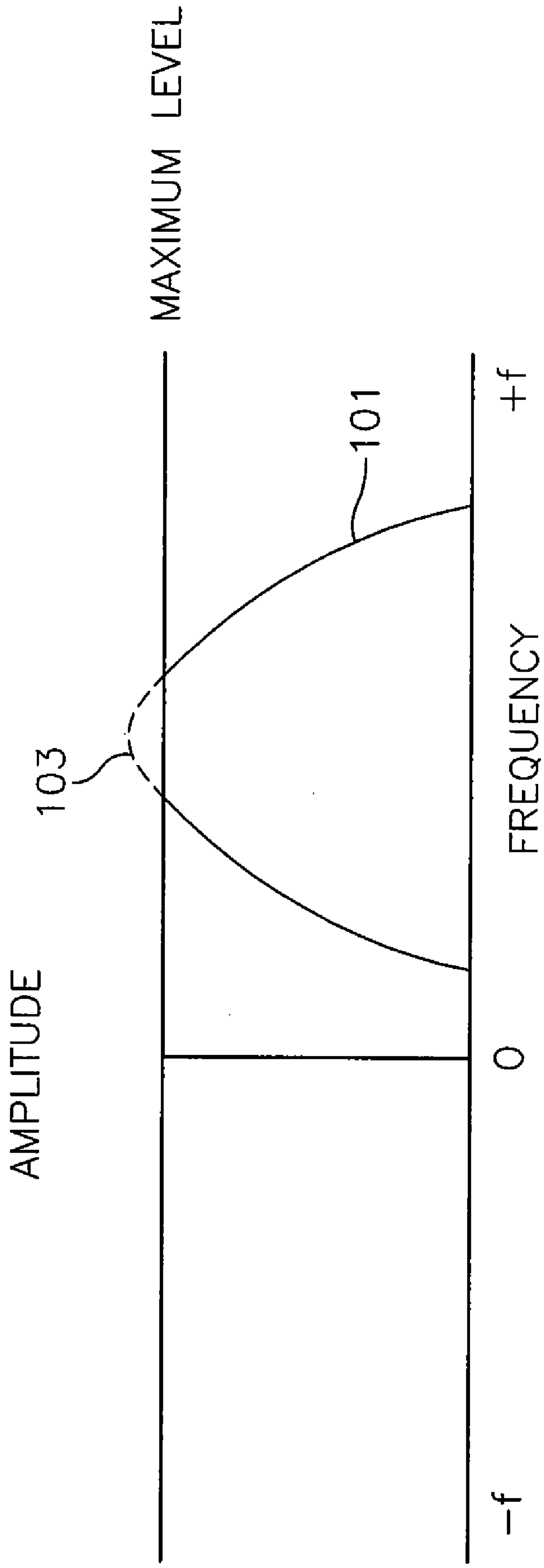


FIG. 1

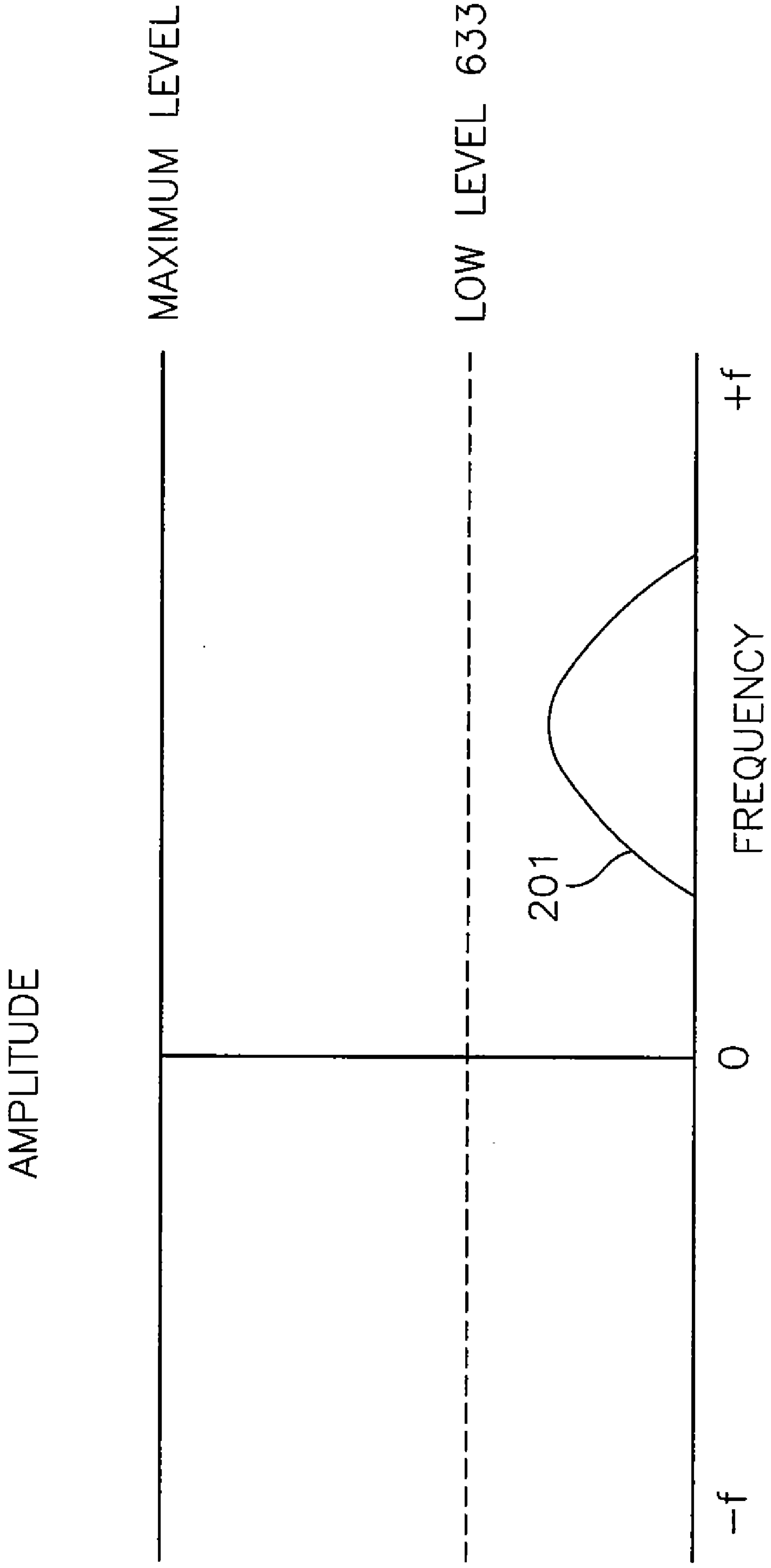


FIG. 2

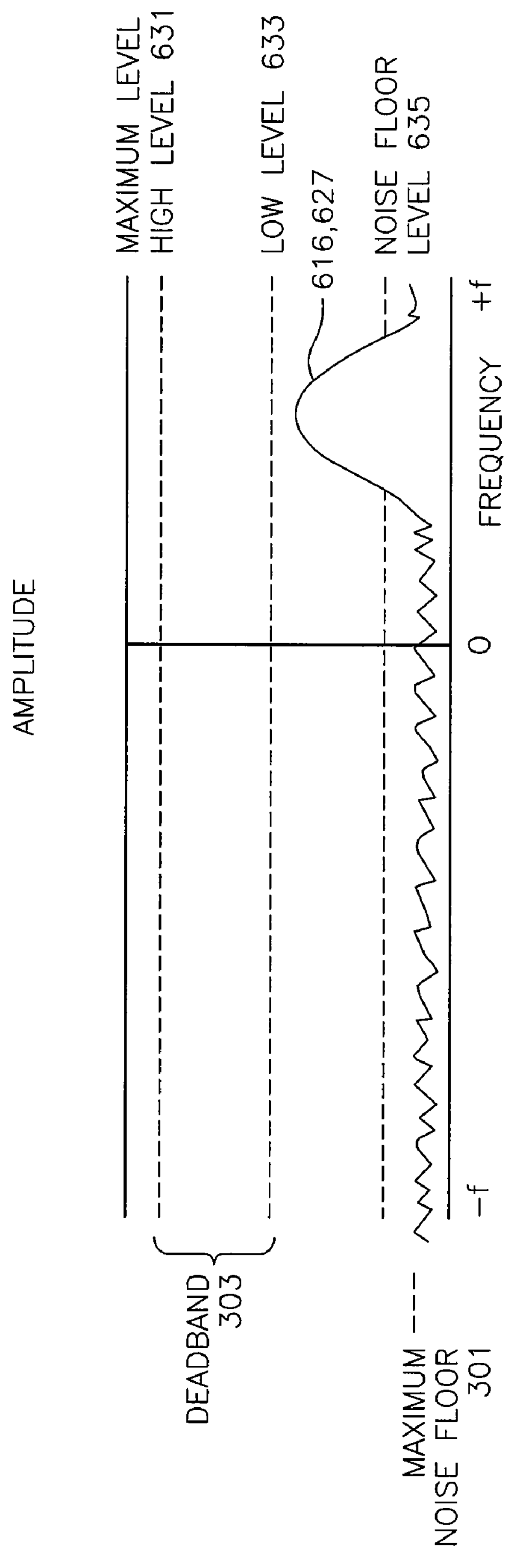

AMPLITUDE
MAXIMUM LEVEL
HIGH LEVEL 631
LOW LEVEL 633
616,627
NOISE FLOOR
LEVEL 635
+f
FREQUENCY
0
−f
DEADBAND
303
MAXIMUM
NOISE FLOOR
301

FIG. 3

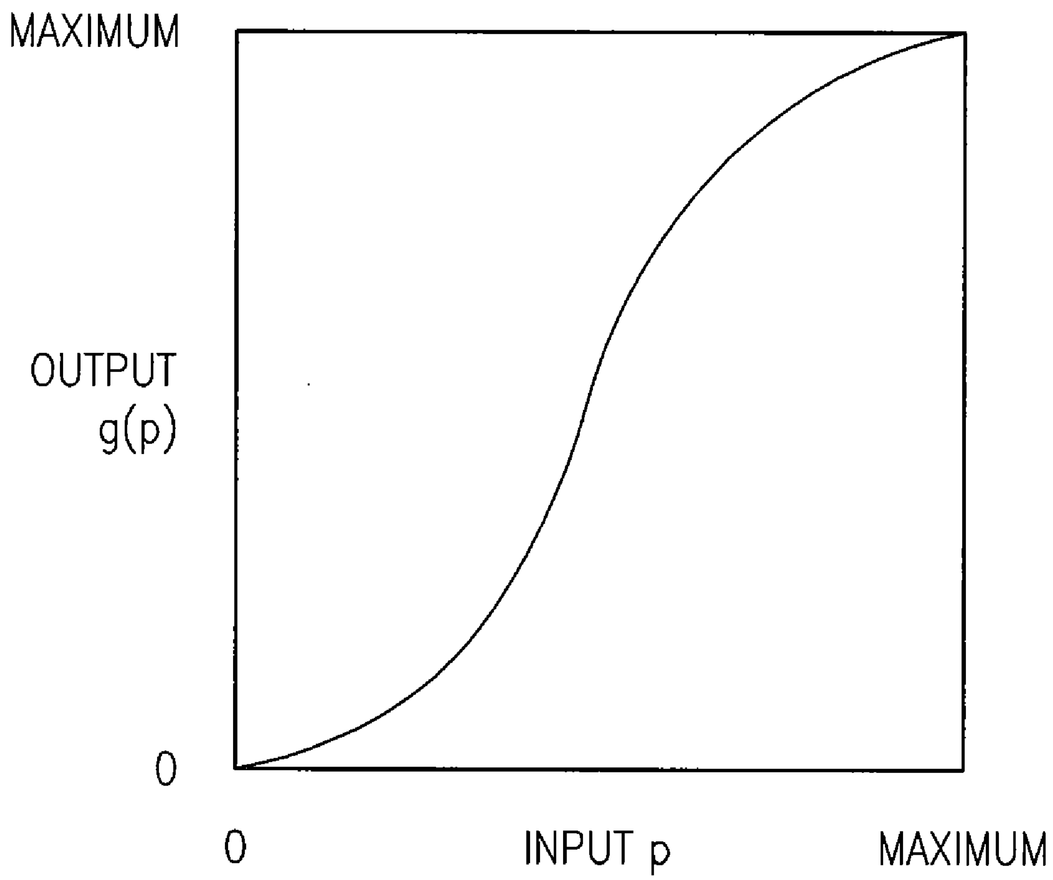


FIG. 4

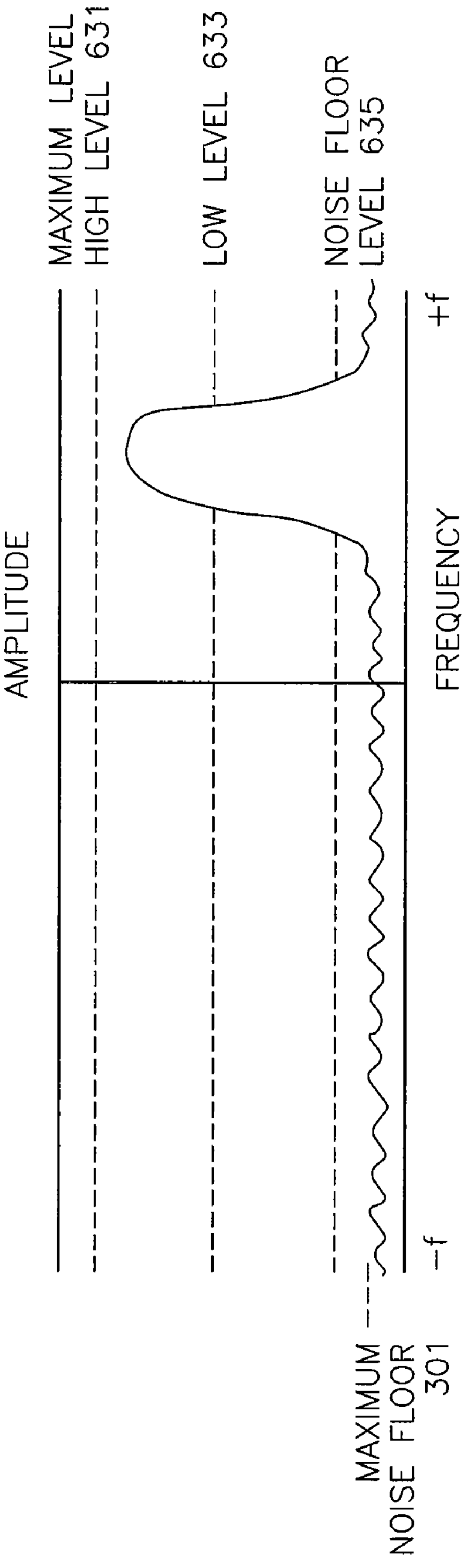

MAXIMUM LEVEL
HIGH LEVEL 631
LOW LEVEL 633
NOISE FLOOR LEVEL 635
AMPLITUDE
FREQUENCY
+f
−f
MAXIMUM NOISE FLOOR 301

FIG. 5A

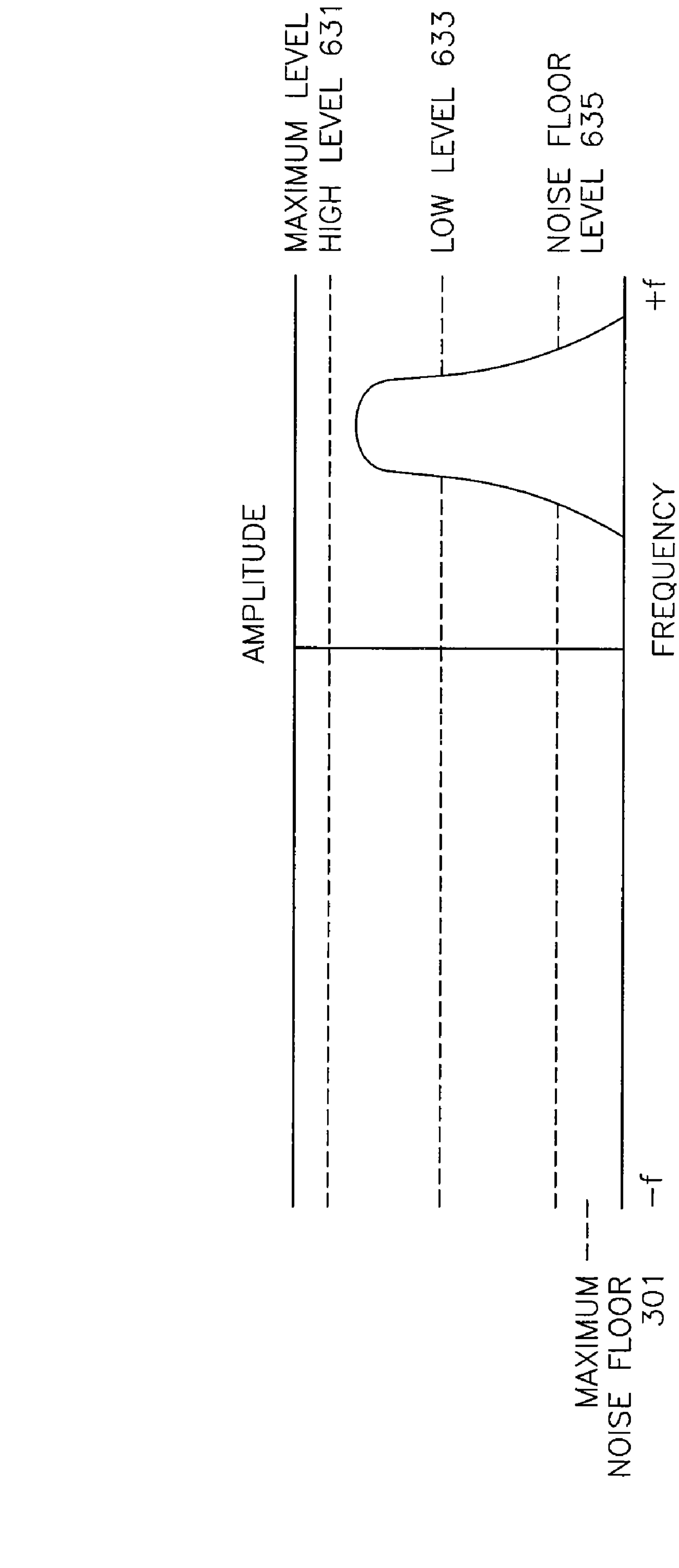

MAXIMUM LEVEL
HIGH LEVEL 631
LOW LEVEL 633
NOISE FLOOR LEVEL 635
AMPLITUDE
FREQUENCY
+f
−f
MAXIMUM NOISE FLOOR 301

FIG. 5B

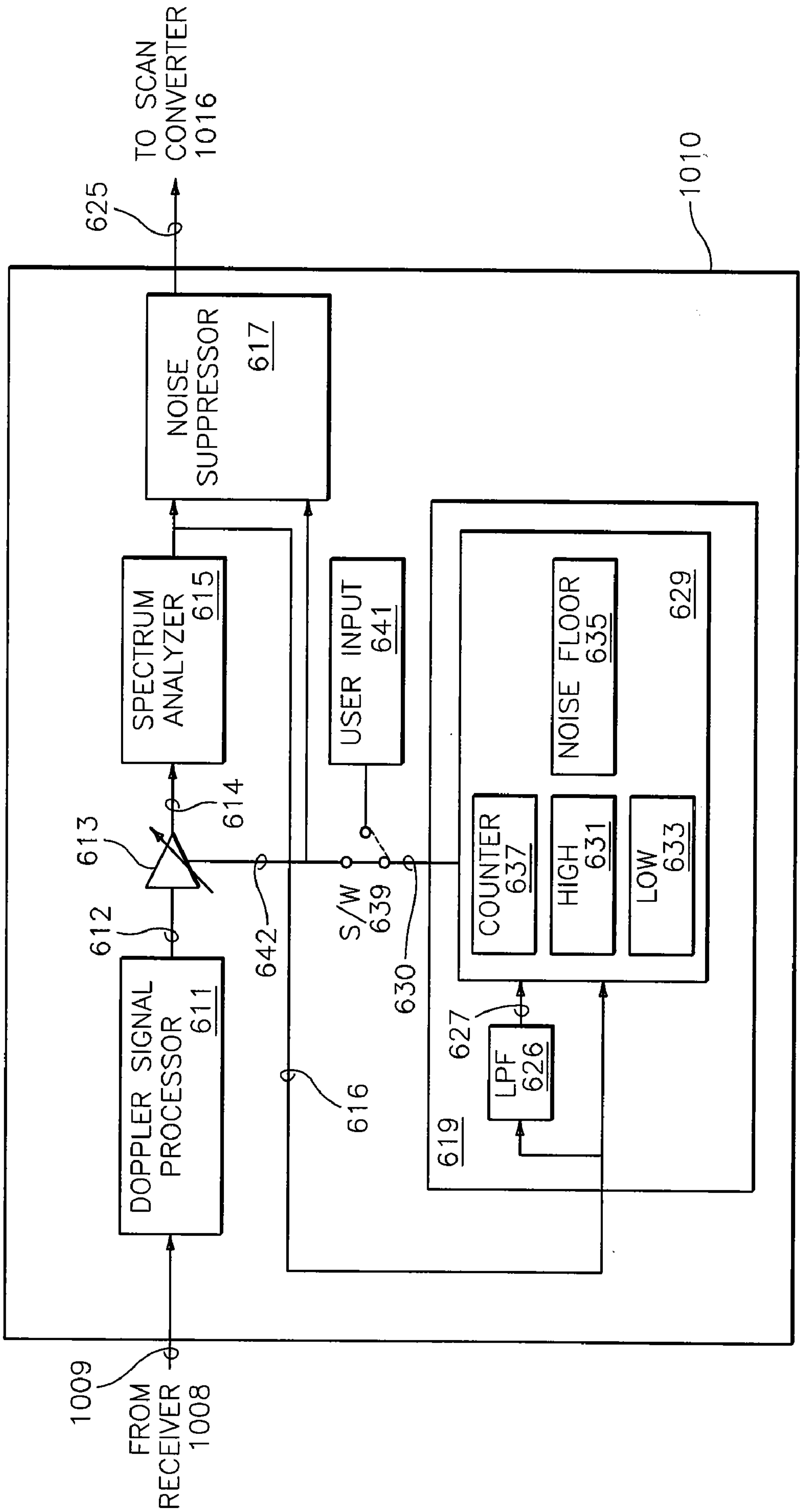

TO SCAN CONVERTER 1016
625
1010
NOISE SUPPRESSOR 617
SPECTRUM ANALYZER 615
USER INPUT 641
NOISE FLOOR 635
629
613
614
612
DOPPLER SIGNAL PROCESSOR 611
642
S/W 639
630
COUNTER 637
HIGH 631
LOW 633
627
LPF 626
616
619
1009
FROM RECEIVER 1008

FIG. 6

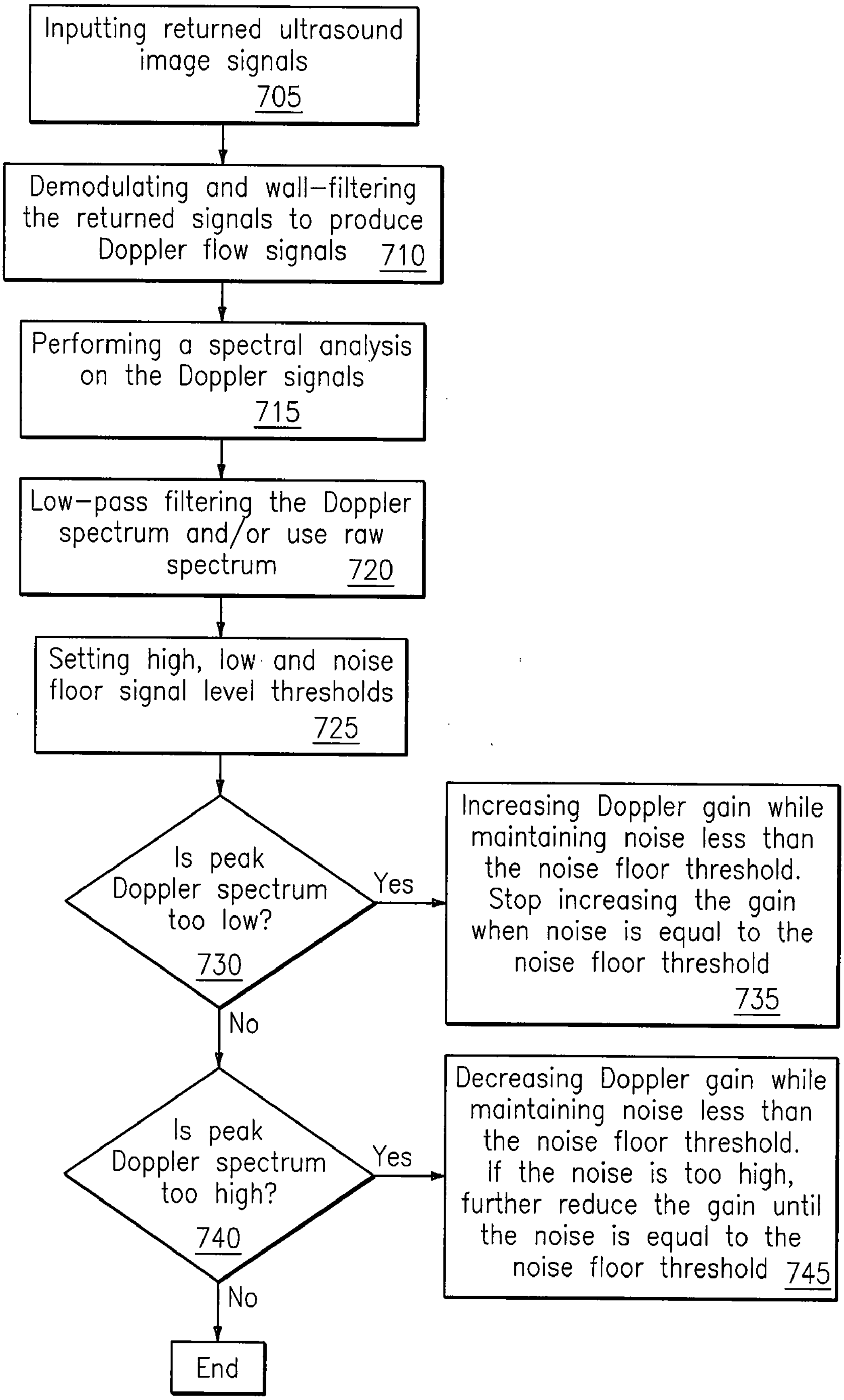

Inputting returned ultrasound image signals 705
Demodulating and wall-filtering the returned signals to produce Doppler flow signals 710
Performing a spectral analysis on the Doppler signals 715
Low-pass filtering the Doppler spectrum and/or use raw spectrum 720
Setting high, low and noise floor signal level thresholds 725
Is peak Doppler spectrum too low? 730
Yes
Increasing Doppler gain while maintaining noise less than the noise floor threshold. Stop increasing the gain when noise is equal to the noise floor threshold 735
No
Is peak Doppler spectrum too high? 740
Yes
Decreasing Doppler gain while maintaining noise less than the noise floor threshold. If the noise is too high, further reduce the gain until the noise is equal to the noise floor threshold 745
No
End

FIG. 7

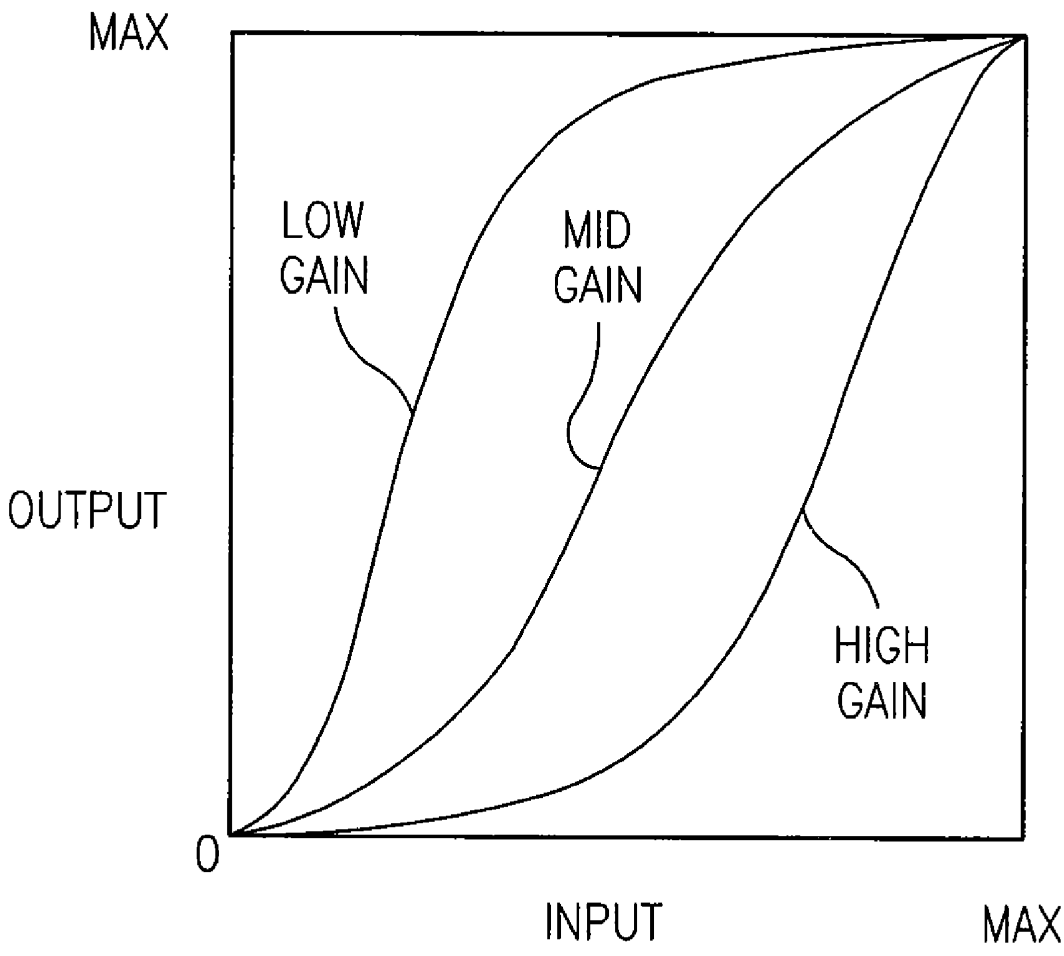


FIG. 8

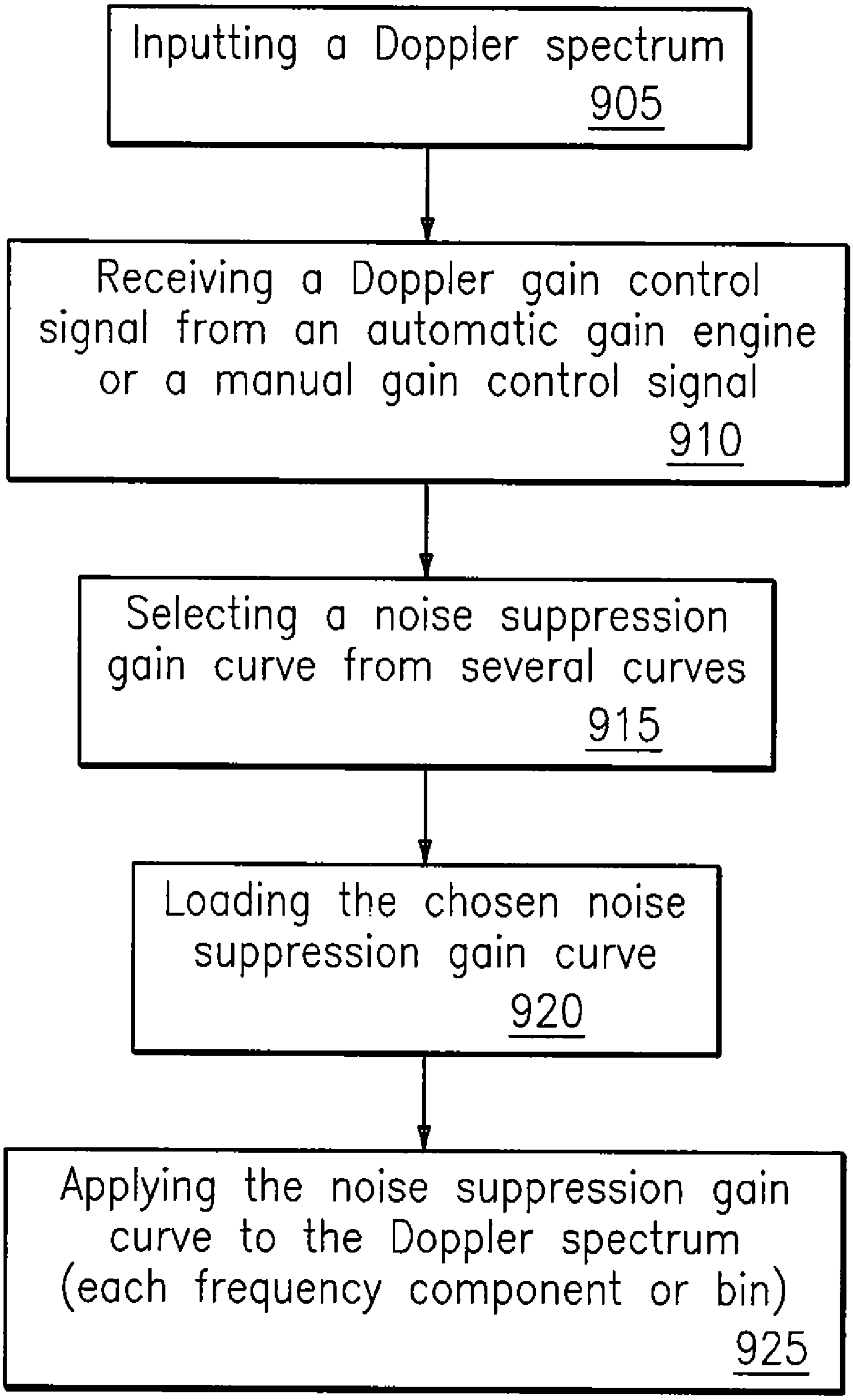

Inputting a Doppler spectrum
905
Receiving a Doppler gain control signal from an automatic gain engine or a manual gain control signal
910
Selecting a noise suppression gain curve from several curves
915
Loading the chosen noise suppression gain curve
920
Applying the noise suppression gain curve to the Doppler spectrum (each frequency component or bin)
925

FIG. 9

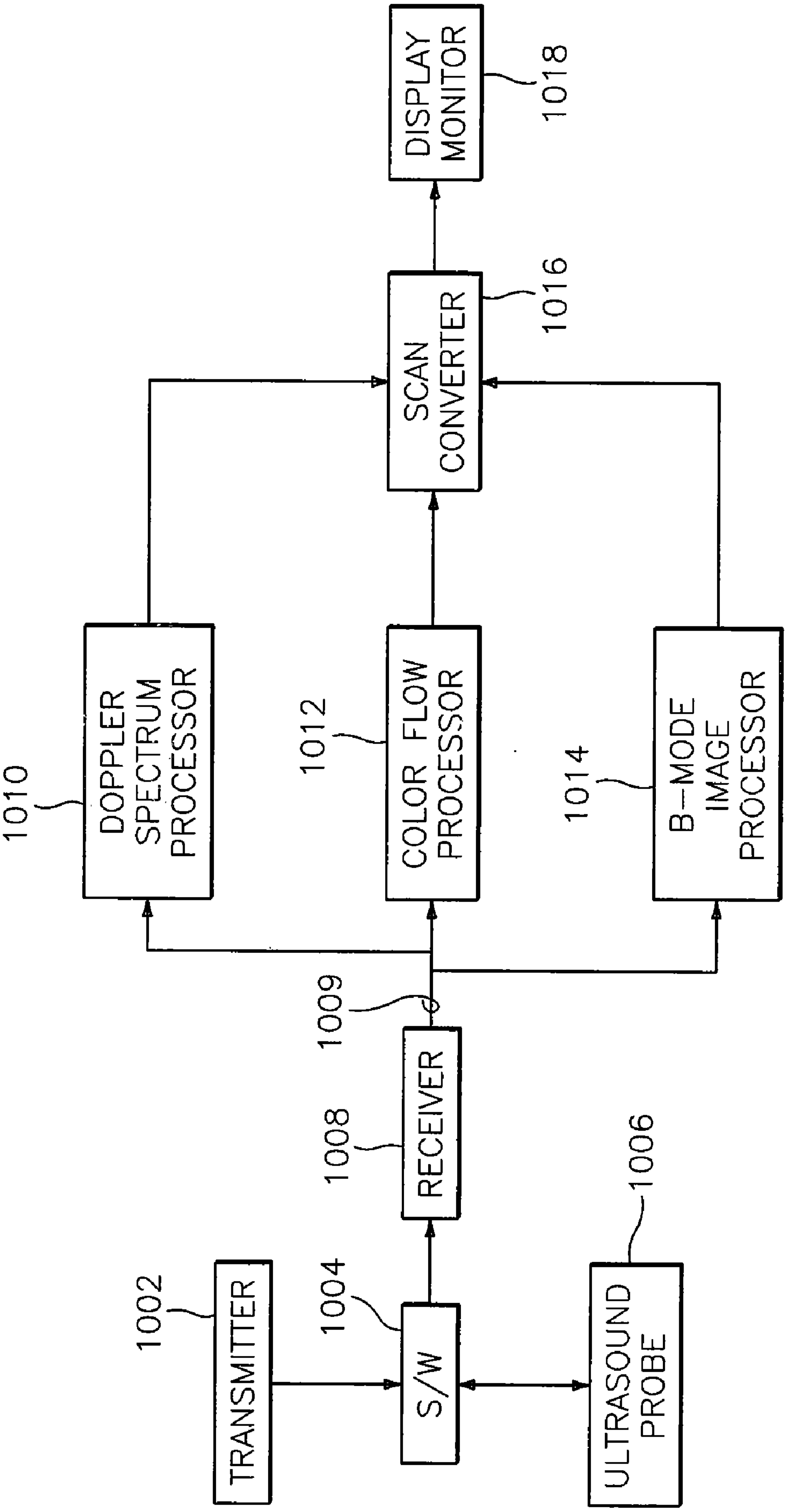
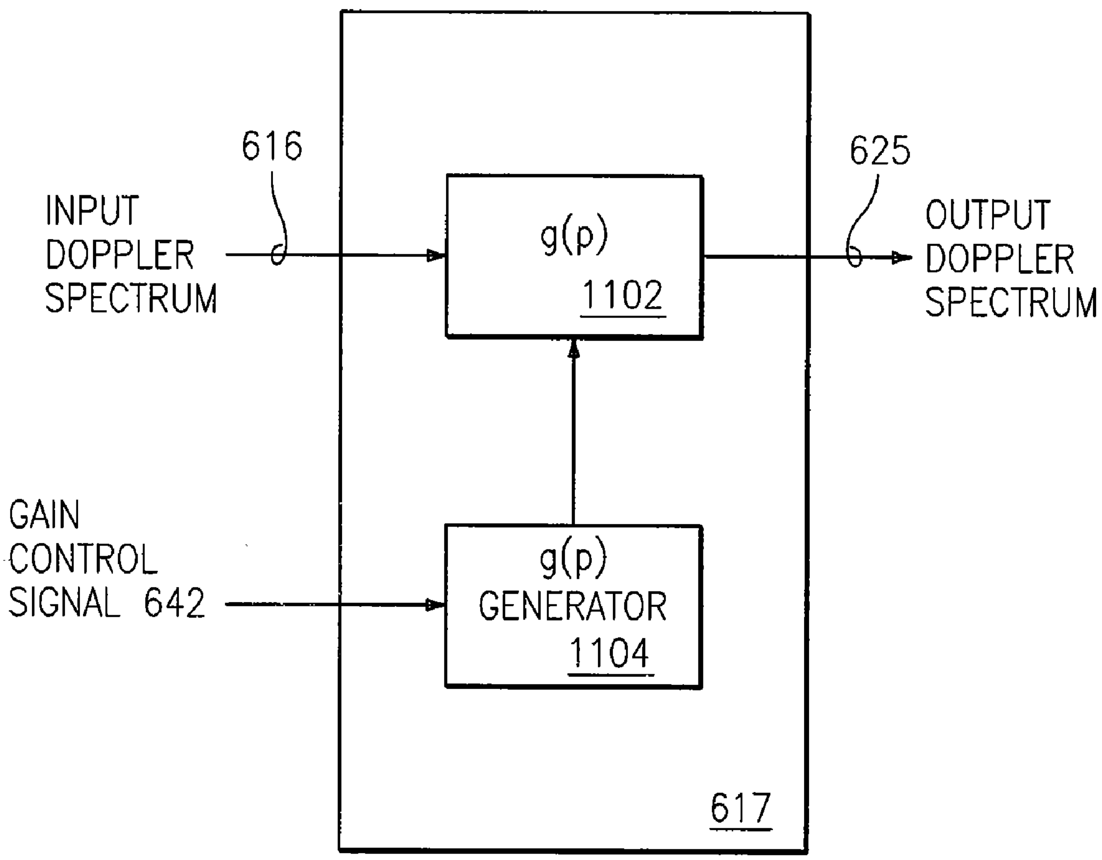

TRANSMITTER
1002
S/W
1004
ULTRASOUND PROBE
1006
RECEIVER
1008
1009
DOPPLER SPECTRUM PROCESSOR
1010
COLOR FLOW PROCESSOR
1012
B-MODE IMAGE PROCESSOR
1014
SCAN CONVERTER
1016
DISPLAY MONITOR
1018

FIG. 10



616
INPUT DOPPLER SPECTRUM
g(p)
1102
625
OUTPUT DOPPLER SPECTRUM
GAIN CONTROL SIGNAL 642
g(p) GENERATOR
1104
617

FIG. 11A

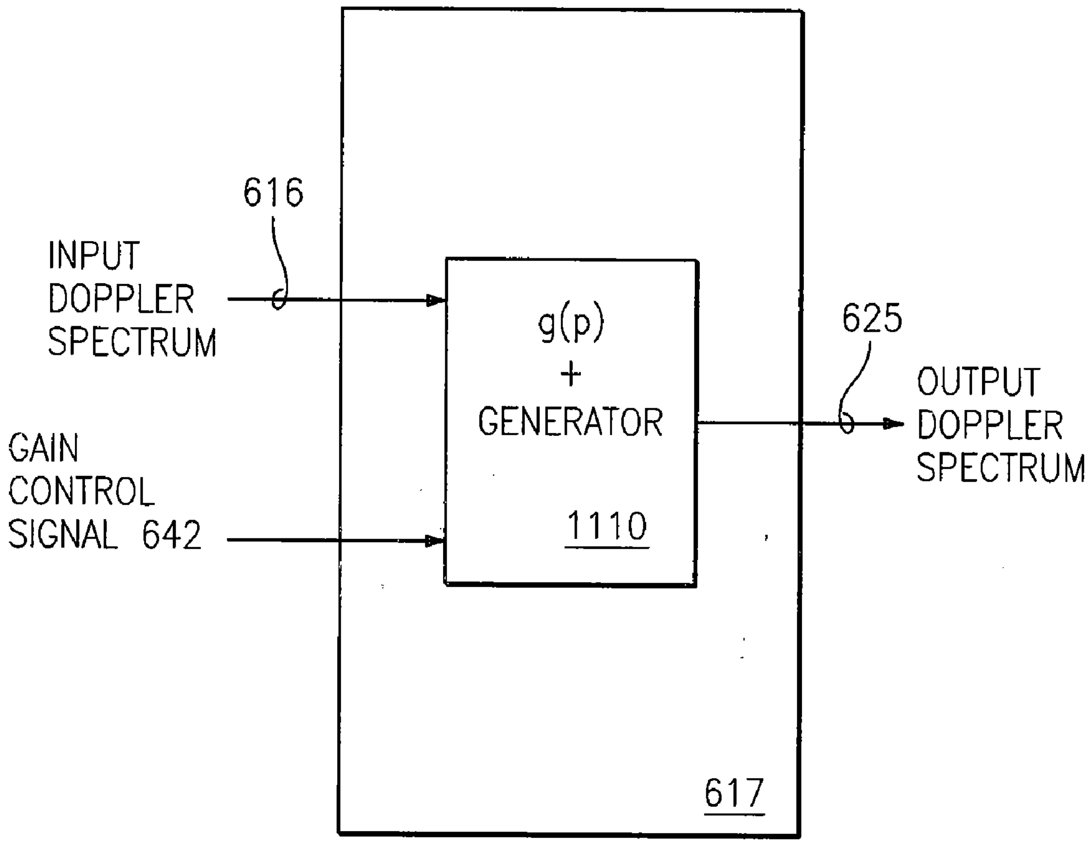

616
INPUT
DOPPLER
SPECTRUM
GAIN
CONTROL
SIGNAL 642
g(p)
+
GENERATOR
1110
625
OUTPUT
DOPPLER
SPECTRUM
617

FIG. 11B

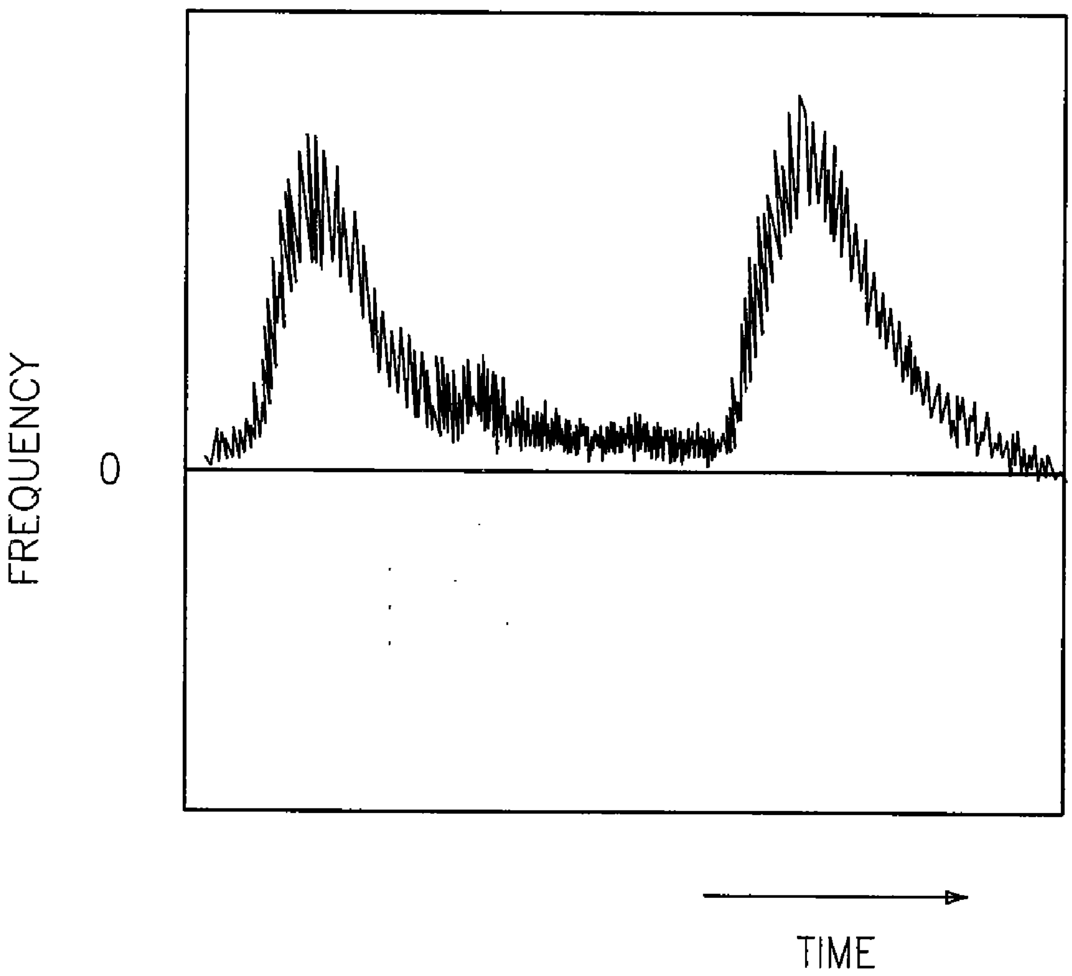


FIG. 12

METHODS AND APPARATUS FOR ULTRASOUND IMAGING

FIELD OF THE INVENTION

[0001] The invention relates generally to the field of ultrasound imaging. More specifically, embodiments of the invention relate to methods and systems for automatically adjusting the gain and suppressing noise manifest in Doppler signals used to measure flow velocity.

BACKGROUND OF THE INVENTION

[0002] Ultrasound is used to image various organs, heart, liver, fetus, and blood vessels. For diagnosis of cardiovascular diseases, spectral Doppler is usually used to measure blood flow velocity. The pulsed Doppler technique is often used due to its inherent spatial sampling capability which permits the sampling of velocity in a blood vessel compared with continuous-wave (CW) Doppler which does not have spatial discrimination capability and samples all signals along the ultrasound beam. CW Doppler is used especially when a high blood velocity is expected to be measured since CW Doppler is not limited by the pulse repetition frequency (PRF) limits (Nyquist sampling theorem). CW Doppler may still be limited in maximum velocity due to signal sampling when performing analyses such as FFT (fast Fourier transform) and others.

[0003] A Doppler system typically transmits ultrasound and detects blood flow velocity as the shift in frequency (Doppler shift frequency) in the received ultrasound signal. The received ultrasound is demodulated with the reference signals as a complex signal having in-phase (I) and quadrature (Q) at the same frequency as the transmitted frequency. After low-pass filtering, high frequency components such as the second harmonics are blocked, passing only baseband signals. Wall-filtering (i.e., high-pass filtering) is applied to the baseband signals to remove clutter noise manifest from stationary tissue and slowly moving tissues such as blood vessel walls, resulting in complex Doppler I-Q signals. The complex I-Q Doppler signals are input to a spectrum analyzer such as an FFT analyzer to obtain the Doppler frequency spectrum which represents blood velocities. Typically, 128-point, 256-point, and 512-point FFTs are used.

[0004] The Doppler spectrum is generally displayed with time as shown in FIG. **12** because of the time varying nature of blood flow. The horizontal axis is time and the vertical axis is frequency. Spectrum power is displayed as the brightness as shown in FIG. **12**. The spectrum power can be plotted as the spectrum power vs. frequency at a given time as shown in FIG. **3**. The Doppler spectrum may exhibit noise due in part by the ultrasound system electronics and other sources. FIG. **3** shows a Doppler spectrum having a noise floor which is indicative of random noise broadly distributed by an FFT. The noise may mask the true blood flow signal if the Doppler flow signal gain is too low. Conversely, FIG. **1** shows a Doppler spectrum having a Doppler flow signal gain that is too high where the peak Doppler spectrum is clipped.

[0005] The Doppler flow signal gain determines the amplitude of the Doppler signal input to an FFT spectrum analyzer. The output of the Doppler spectrum is usually compressed in dynamic range as 8-bit, 12-bit, 16-bit or other resolutions. It can be seen that a proper Doppler flow signal gain output to an ultrasound system improves the Doppler spectrum's SNR (signal-to-noise ratio), thereby improving the image quality when displayed.

[0006] Most ultrasound systems today allow a user to manually adjust Doppler gain settings to obtain the best spectrum. However, in adjusting these settings, the user consumes time that could be better spent performing diagnosis. There exists a need to overcome these problems.

SUMMARY OF THE INVENTION

[0007] The inventor has discovered that it would be desirable to have a system and method that examines the Doppler spectrum signals output by an ultrasound system when measuring blood flow velocity to determine the proper Doppler gain and to suppress noise manifest in the Doppler spectrum. Noise present in the Doppler spectrum is examined and used as a criterion for optimal gain. If the Doppler gain is too high or too low according to predetermined levels, the overall gain is adjusted.

[0008] One aspect of the invention provides methods for automatically controlling the gain from a Doppler signal processor during ultrasound imaging. Methods according to this aspect of the invention comprise inputting returned ultrasound signals, demodulating the returned ultrasound signals, wall-filtering the returned ultrasound signals producing Doppler flow signals, performing spectral analysis on the Doppler flow signals producing a Doppler spectrum, setting a high level signal threshold, setting a low level signal threshold, setting a noise floor level threshold, detecting a peak Doppler spectrum level and a Doppler spectrum maximum noise floor from the Doppler flow signals, increasing Doppler flow signal gain if the peak Doppler spectrum amplitude is less than the low level signal threshold until the peak Doppler spectrum amplitude equals the high level signal threshold or the maximum noise floor is equal to the noise floor level threshold, and decreasing the Doppler flow signal gain if the peak Doppler spectrum amplitude is greater than the high level signal threshold until the peak Doppler spectrum amplitude equals the high level signal threshold or the maximum noise floor is equal to the noise floor level threshold.

[0009] Another aspect of the invention provides systems for automatically controlling the gain of a Doppler spectrum processor during ultrasound imaging. Systems according to this aspect of the invention comprise a receiver configured to receive returned ultrasound signals and having an output, a Doppler signal processor having an input coupled to the receiver output and an output, the Doppler signal processor configured to demodulate and wall-filter the returned ultrasound signals and output Doppler flow signals, a variable gain amplifier having an input coupled to the Doppler signal processor output, a gain control signal input and an output, the variable gain amplifier configured to vary the gain of the Doppler flow signals, a spectrum analyzer having an input coupled to the variable gain amplifier output and an output, the spectrum analyzer configured to convert the Doppler flow signals into their corresponding frequency spectrum, and an automatic gain engine coupled to the spectrum analyzer output, the automatic gain engine configured to receive the Doppler spectrum and detect a peak Doppler spectrum amplitude and a maximum noise floor wherein a gain control signal is calculated and coupled to the variable gain amplifier gain control signal input based on the maximum noise floor present in the Doppler flow signals spectrum and predetermined high, low and noise floor signal level thresholds wherein if the peak Doppler spectrum amplitude is greater than the high level signal threshold, or less than the low level signal threshold, overall gain is adjusted to maintain the peak Doppler spectrum amplitude greater than the low level signal threshold and less than the high level signal threshold.

[0010] Another aspect of the invention provides methods for suppressing noise manifest on Doppler spectrum signals. Methods according to this aspect of the invention comprise inputting the Doppler spectrum signals, receiving a Doppler gain control signal, using a noise suppression gain curve g(p) corresponding to the Doppler gain control signal, and processing the Doppler spectrum amplitudes with the noise suppression gain curve g(p) wherein each frequency of the Doppler spectrum amplitude is adjusted according to a response of the noise suppression gain curve.

[0011] Another aspect of the invention provides systems for a noise suppressor for suppressing noise manifest on Doppler spectrum signals. Systems according to this aspect of the invention comprise an input configured to receive gain adjusted Doppler spectrum signals, a gain control signal input configured to receive a gain control signal that is used to adjust the gain for the gain adjusted Doppler spectrum signals to generate a noise suppression gain curve g(p), a gain function processor configured to process the gain adjusted Doppler flow signals with the noise suppression gain curve g(p), wherein each spectrum component of the Doppler spectrum signal input is adjusted in amplitude according to the response of the noise suppression gain curve g(p), and an output configured to output noise suppressed, gain adjusted Doppler flow signals.

[0012] The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. **1** is an exemplary high gain Doppler spectrum plot.

[0014] FIG. **2** is an exemplary low gain Doppler spectrum plot.

[0015] FIG. **3** is an exemplary Doppler spectrum with noise floor.

[0016] FIG. **4** is an exemplary noise suppression gain function g(p).

[0017] FIG. **5**A is an exemplary Doppler spectrum before noise suppression.

[0018] FIG. **5**B is an exemplary Doppler spectrum after noise suppression.

[0019] FIG. **6** is an exemplary Doppler spectrum processor with the automatic Doppler gain control system and the noise suppressor.

[0020] FIG. **7** is an exemplary flow chart to describe the automatic Doppler gain control method.

[0021] FIG. **8** is an exemplary plurality of noise suppression gain curves.

[0022] FIG. **9** is an exemplary flow chart to describe the noise suppression method.

[0023] FIG. **10** is an exemplary ultrasound imaging system with automatic Doppler gain control and noise suppression.

[0024] FIG. **11**A is an exemplary gain function processor g(p) and a g(p) generator.

[0025] FIG. **11**B is an exemplary gain function processor g(p) with generator.

[0026] FIG. **12** is an exemplary Doppler spectrum with time.

DETAILED DESCRIPTION

[0027] Embodiments of the invention will be described with reference to the accompanying drawing figures wherein like numbers represent like elements throughout. Before embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of the examples set forth in the following description or illustrated in the figures. The invention is capable of other embodiments and of being practiced or carried out in a variety of applications and in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having," and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. The terms "mounted," "connected," and "coupled," are used broadly and encompass both direct and indirect mounting, connecting, and coupling. Further, "connected," and "coupled" are not restricted to physical or mechanical connections or couplings.

[0028] It should be noted that the invention is not limited to any particular software language described or that is implied in the figures. One of ordinary skill in the art will understand that a variety of alternative software languages may be used for implementation of the invention. It should also be understood that some of the components and items are illustrated and described as if they were hardware elements, as is common practice within the art. However, one of ordinary skill in the art, and based on a reading of this detailed description, would understand that, in at least one embodiment, components in the method and system may be implemented in software or hardware.

[0029] FIG. **10** shows an ultrasound system including a Doppler spectrum processor **1010** with the automatic Doppler gain and noise suppression system. FIG. **6** shows the Doppler processor **1010** with the automatic gain engine **619** and noise suppressor **617**. FIG. **7** shows a flow chart to describe the automatic Doppler gain method. FIG. **9** shows a flow chart to describe the noise suppression method. An ultrasound signal is transmitted from an ultrasound probe **1006** driven by a transmitter **1002** through a transmit/receive switch **1004**. A receiver **1008** receives the ultrasound signal from the probe **1006** through the switch **1004** and processes the signal **1009** (step **705**).

[0030] The receiver **1008** outputs the processed signal **1009** to the Doppler spectrum processor **1010**, a color flow processor **1012** and a B-mode image processor **1014**. The Doppler spectrum processor **1010** processes the signal **1009** and outputs a Doppler spectrum to a scan converter **1016**. The color flow processor **1012** processes the signal **1009** and outputs a color flow image to the scan converter **1016**. The B-mode image processor **1014** processes the signal **1009** and outputs a B-mode image to the scan converter **1016**. The scan converter **1016** receives one or more signals from the B-mode image, the color flow image and the Doppler spectrum and converts the images to a scan-converted image for output to a display monitor **1018**.

[0031] The processed signal **1009** is coupled to a Doppler signal processor **611** for computing Doppler flow signals **612** in the time domain (step **710**). The Doppler flow signals **612** are coupled to a variable gain amplifier (VGA) **613** for adjusting the gain of the Doppler signals. The gain adjusted Doppler signals **614** are coupled to a spectrum analyzer **615** that converts the time domain Doppler signals into their spectrum frequency components (step **715**). The frequency components, or spectrum **616**, are coupled to the noise suppressor **617** and the automatic gain engine **619**. The noise suppressor **617** has an input-output relationship which may be a curve g(p) as shown in FIG. **4**. The noise suppressor **617** may be implemented as a look-up table (LUT) with the input-output relationship g(p) **1102** or **1110**, or a calculator **1110** or a combination, and a gain curve generator **1104** which may also be a LUT or a calculator as shown in FIGS. **11**A and **11**B. For the case of a LUT combined with a calculator as the generator **1104**, a noise suppression curve may be stored in the LUT, and the calculator receives the suppression curve and generates a curve corresponding to the gain control signal **642**.

[0032] For the case of a LUT alone for the generator **1104**, a plurality of noise suppression curves are stored in the LUT and a noise suppression curve is selected corresponding to the gain control signal **642**. Alternately, a calculator alone as the generator **1104** can generate a noise suppression curve corresponding to the Doppler gain curve. The generator **1104** then transfers the curve to the gain function processor **1102** which may be a LUT and applies the noise suppression curve g(p) to the Doppler spectrum **616**. Alternately, the gain function g(p) processor **1102** and the noise suppression curve generator **1104** can be implemented as one device **1110** as shown in FIG. **11**B. A LUT with a Doppler spectrum **616** input and a gain control signal **642** input may be used. Alternately, the calculator **1110** may be used to generate a noise suppression curve as well as applying the gain function g(p) to the Doppler spectrum **616**.

[0033] The noise suppressor **617** suppresses noise manifest on the Doppler spectrum **616**. The noise suppressor **617** outputs a noise suppressed Doppler spectrum (output **625**). The automatic gain engine **619** includes a low-pass filter **626** and a signal threshold processor **629**. The low-pass filter **626** filters the spectrum frequency components **616** output by the spectrum analyzer **615**, producing a smoothed spectrum **627**, and outputs to the signal threshold processor **629**. The raw Doppler spectrum **616** is also coupled to the signal threshold processor **629** (step **720**).

[0034] The signal threshold processor **629** includes high **631**, low **633** and noise floor **635** level thresholds for detecting the levels of the smoothed spectrum **627** and a frequency bin counter **637** for detecting frequency components. Likewise, the signal threshold processor **629** includes high **631**, low **633** and noise floor **635** level thresholds for detecting the levels of the raw Doppler spectrum **616** and a frequency bin counter **637** for detecting frequency components (step **725**). FIG. **3** shows an exemplary smoothed Doppler spectrum with the high **631**, low **633** and noise floor **635** level thresholds against a maximum spectrum amplitude level. The maximum spectrum amplitude level is typically 255 (8-bit), 511 (9-bit), 1023 (10-bit), or other levels. The high signal level threshold **631** may be, for example, 255, 250, 225 or 200 for a maximum of 255. The low signal level threshold **633** may be, for example, 128, for the maximum spectrum level of 255, and the noise floor level threshold **635** may be, for example, 16 for the maximum spectrum level of 255.

[0035] The automatic gain engine **619** optimizes the Doppler flow signal gain by comparing the peak Doppler spectrum output **616** by the spectrum analyzer **615** to the high **631** and low **633** signal level thresholds. The frequency bin counter **637** counts a number of consecutive Doppler spectrum frequencies **616** whose amplitudes are greater than the high signal level threshold **631**. The frequency bin counter **637** also counts a number of consecutive Doppler spectrum frequencies whose amplitudes are greater than the low signal level threshold **633**. The frequency bin counter **637** also detects the maximum level of noise floor **301** which is a flat part in the Doppler spectrum.

[0036] FIG. **1** shows a Doppler spectrum **101** exhibiting a clipped **103** peak Doppler spectrum **627**. Clipping occurs when the Doppler spectrum amplitude exceeds the maximum spectrum level. Clipping indicates that the Doppler gain is too high. In this invention, the Doppler gain **613** is considered too high if a number of consecutive spectrum frequencies (or frequency bins), whose amplitudes are greater than the high signal level threshold **631**, is greater than a predetermined number, for example, 10.

[0037] FIG. **2** shows a Doppler spectrum exhibiting a low **201** peak Doppler spectrum **627** or **616** amplitude (or power) which indicates a Doppler gain that is too low. In this invention, the gain (Doppler gain) of the variable gain amplifier **613** is considered too low if a number of consecutive spectrum frequencies (or frequency bins), whose amplitudes are greater than the low signal level threshold **633**, is less than a predetermined number, for example, 10.

[0038] Instead of a raw (i.e. single) Doppler spectrum **616**, a smoothed (low-pass filtered) Doppler spectrum **627** may be used with a smaller preset (count) number and/or a lower high signal level.

[0039] The automatic gain engine **619** detects a noise floor which may be spread across the entire frequency range since most electronic noise is random. When the Doppler spectrum is calculated, noise spreads over the entire frequency range due to its wideband nature. Noise is easily detected if the blood flow velocity is smaller than the maximum velocity or the Doppler spectrum bandwidth is smaller than the PRF. FIG. **3** shows a maximum noise floor **301** in conjunction with a Doppler spectrum and a deadband **303** between the high signal level **631** and low signal level **633** thresholds. A frequency band which consists of only the noise floor can be easily recognized as shown in FIG. **3** (low level ripple) and the maximum level **301** of the noise floor is determined in this frequency range. For example, an average amplitude of a predetermined number, for example, 10, of consecutive frequency components (bins) may be calculated for all spectrum frequency components excluding near the baseline (0 frequency) because the noise is absent in this area due to the wall filter's effects. The average amplitude from the noise floor region will be much smaller than that of the spectrum frequency components for blood flow as can be seen in FIG. **3**. Thus, the noise floor area is determined in comparison to the blood flow area. The minimum average amplitude is obtained and is multiplied by a predetermined factor to estimate the maximum noise floor. Blood flow velocity changes with time as the blood velocity is high during systole and is low during diastole. Therefore, during diastole, the noise floor usually appears in high frequency region because the blood flow is low and high frequencies are absent (i.e. showing only noise floor). This can be further used to identify the noise floor.

[0040] If the peak Doppler spectrum **627** or **616** is less than the low signal level threshold **633**, the automatic gain engine **619** generates a gain control signal **630** which is output to the variable gain amplifier **613** (step **730**). The gain control signal **630** is coupled to the variable gain amplifier **613** through an automatic/manual Doppler gain mode switch **639**. The switch **639** allows a user to select between the automatic gain control and the user gain control by switching between derived gain control signal **630** and a user adjusted manual gain control signal **641**. The gain control signal **630** may be derived from several control strategies and corresponds to an amount of correction necessary to elevate the peak Doppler spectrum until a correct gain is achieved, i.e. the number of consecutive spectrum frequencies **627** whose amplitudes exceed the high level threshold **631**, equals the predetermined number or the predetermined number minus a small preset number. If a noise floor **301** is present and rises commensurately above the noise floor level threshold **635** with the peak Doppler spectrum **627**, the gain control signal **630** is adjusted, reducing the Doppler gain such that the noise floor is equal to or less than the noise floor level threshold **635** (step **735**).

[0041] If the number of consecutive Doppler spectrum frequencies (i.e. frequency bins) whose amplitudes exceed the high level threshold **631** is more than the predetermined number, a high gain is detected and the automatic gain engine **619** generates a gain control signal **630** which is output to the variable gain amplifier **613** (step **740**). The gain control signal **630** corresponds to an amount of correction necessary to decrease the peak Doppler spectrum **627** until a correct gain is achieved, i.e. the number of consecutive spectrum frequencies **627** or **616**, whose amplitudes exceed the high level threshold **631**, equals the predetermined number or the predetermined number minus a preset number. If a noise floor **301** is present and is greater than the noise floor level threshold **635**, the gain control signal **630** is adjusted, reducing the Doppler gain such that the noise floor is equal to or less than the noise floor level threshold **635** (step **745**).

[0042] If the peak Doppler spectrum **627** or **616** is less than or equal to the high signal level threshold **631** condition (i.e. if the number of consecutive spectrum frequencies, whose amplitudes exceed the high level, exceeds the predetermined number), and if a maximum noise floor **301** is greater than the noise floor level threshold **635**, the gain control signal **630** is adjusted. The Doppler gain is reduced such that the maximum noise floor is equal to or less than the noise floor level threshold **635**.

[0043] The noise suppressor **617** suppresses noise manifest on the Doppler signal **616**. FIG. **9** shows a flow chart which describes the noise suppression method. The noise suppressor **617** is dependent on the gain control signal **642** since the noise floor varies with gain (Doppler gain) (steps **905**, **910**). If the Doppler gain is increased, the noise suppressor **617** receives the gain control signal **642** and selects a noise suppression gain curve from a plurality of gain curves stored or generated in the gain curve generator **1104** or **1110** (step **915**).

[0044] FIG. **8** shows an example of three noise suppression gain curves for low gain, mid gain, and high gain conditions stored or generated in the generator **1104** or **1110**. The suppression gain curves stored or generated in the gain curve generator **1104** or **1110** correspond with a gain setting. If the Doppler gain is low as indicated by the gain control signal, the "low gain" noise suppression curve is selected or generated as shown in FIG. **8**. If the Doppler gain is middle, the "mid gain" noise suppression curve is selected or generated. If the gain is high, the "high gain" noise suppression curve is selected or generated. The selected noise suppression gain curve is loaded as the gain function g(p) in the gain function processor **1102** or **1110** (step **920**). In another example, if the Doppler gain control signal **642** is set at 1, the #1 suppression curve is selected or generated. If the Doppler gain control signal **642** is set at 2, the #2 suppression curve is selected or generated. Likewise, if the Doppler gain control signal is N, the N^{th} suppression curve is selected or generated. The selected noise suppression gain curve is loaded as the gain function g(p) **1102** or **1110** (step **920**). The noise suppressor **617** may comprise a calculator alone, a calculator with a LUT, or a plurality of LUTs, and uses the gain control signal **642** as shown in FIGS. **11**A and **11**B.

[0045] The noise suppressor **617** receives the Doppler spectrum **616** and converts each spectrum magnitude p using the response g(p) **1102** or **1110**. The gain function g(p) **1102** or **1110** is the gain curve from the gain curve generator **1104** or **1110**. FIG. **4** shows a gain function g(p) that is a curve.

[0046] FIG. **5**A shows a Doppler spectrum with noise. FIG. **5**B shows the result of the noise suppressor **617** (step **925**). The noise suppressor **617** applies a noise suppression curve technique, which lowers the noise floor.

[0047] One or more embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. The processing order of signals in this invention may be changed. The order of the system processors in this invention may be also changed. Each processor may be also replaced by another processor. The order of method steps may be changed. Methods may be modified. Accordingly, other embodiments are within the scope of the following claims.

What is claimed is:

1. A method for automatically controlling the gain from a Doppler signal processor during ultrasound imaging comprising:
- inputting returned ultrasound signals;
- demodulating the returned ultrasound signals;
- wall-filtering the returned ultrasound signals producing Doppler flow signals;
- performing spectral analysis on the Doppler flow signals producing a Doppler spectrum;
- setting a high level signal threshold;
- setting a low level signal threshold;
- setting a noise floor level threshold;
- detecting a peak Doppler spectrum level and a Doppler spectrum maximum noise floor from the Doppler flow signals;
- increasing Doppler flow signal gain if the peak Doppler spectrum amplitude is less than the low level signal threshold until the peak Doppler spectrum amplitude equals the high level signal threshold or the maximum noise floor is equal to the noise floor level threshold; and
- decreasing the Doppler flow signal gain if the peak Doppler spectrum amplitude is greater than the high level signal threshold until the peak Doppler spectrum amplitude equals the high level signal threshold or the maximum noise floor is equal to the noise floor level threshold.

2. The method according to claim **1** further comprising smoothing the Doppler spectrum using a low-pass filter.

3. The method according to claim **1** wherein the determination of whether the peak Doppler spectrum amplitude is greater than the high level signal threshold further comprises:
- counting a number of consecutive Doppler spectrum frequency components whose amplitudes are greater than the high level signal threshold; and
- comparing the number of consecutive Doppler spectrum frequency components whose amplitudes are greater

than the high level signal threshold with a predetermined number, wherein if the number of consecutive frequency components is greater than the predetermined number, the peak Doppler spectrum amplitude is greater than the high level signal threshold.

4. The method according to claim **1** wherein the determination of whether the peak Doppler spectrum is less than the low level signal threshold further comprises:

counting a number of consecutive Doppler spectrum frequency components whose amplitudes are greater than the low level signal threshold; and

comparing the number of consecutive Doppler spectrum frequency components whose amplitudes are greater than the low level signal threshold with a predetermined number, wherein if the number of consecutive frequency components is less than the predetermined number, the peak Doppler spectrum amplitude is less than the low level signal threshold.

5. The method according to claim **1** wherein detecting the Doppler spectrum maximum noise floor further comprises:

calculating an average amplitude of a predetermined number of the consecutive Doppler spectrum frequency components, for all spectrum frequency components excluding frequency components near a zero frequency baseline;

determining a minimum average amplitude among the average amplitudes; and

determining the maximum noise floor as the minimum average amplitude multiplied by a predetermined factor.

6. A system for automatically controlling the gain of a Doppler spectrum processor during ultrasound imaging comprising:

a receiver configured to receive returned ultrasound signals and having an output;

a Doppler signal processor having an input coupled to the receiver output and an output, the Doppler signal processor configured to demodulate and wall-filter the returned ultrasound signals and output Doppler flow signals;

a variable gain amplifier having an input coupled to the Doppler signal processor output, a gain control signal input and an output, the variable gain amplifier configured to vary the gain of the Doppler flow signals;

a spectrum analyzer having an input coupled to the variable gain amplifier output and an output, the spectrum analyzer configured to convert the Doppler flow signals into their corresponding frequency spectrum; and

an automatic gain engine coupled to the spectrum analyzer output, the automatic gain engine configured to receive the Doppler spectrum and detect a peak Doppler spectrum amplitude and a maximum noise floor wherein a gain control signal is calculated and coupled to the variable gain amplifier gain control signal input based on the maximum noise floor present in the Doppler flow signals spectrum and predetermined high, low and noise floor signal level thresholds wherein if the peak Doppler spectrum amplitude is greater than the high level signal threshold, or less than the low level signal threshold, overall gain is adjusted to maintain the peak Doppler spectrum amplitude greater than the low level signal threshold and less than the high level signal threshold.

7. The system according to claim **6** wherein if the peak Doppler spectrum amplitude is less than the low level signal threshold, the automatic gain engine is further configured to increase the Doppler gain signal until the peak Doppler spectrum equals the high level signal threshold or the maximum noise floor is equal to the noise floor level threshold.

8. The system according to claim **6** wherein if the peak Doppler spectrum amplitude is greater than the high level signal threshold, the automatic gain engine is further configured to decrease the Doppler gain signal until the peak Doppler spectrum amplitude equals the high level signal threshold or the maximum noise floor is equal to the noise floor level threshold.

9. The system according to claim **6** wherein the automatic gain engine further comprises a low-pass filter configured to smooth the Doppler spectrum.

10. The system according to claim **6** wherein the automatic gain engine is further configured to count a number of consecutive frequency components of the peak Doppler spectrum whose amplitudes are greater than the high level signal threshold and compare the number of consecutive frequency components whose amplitudes are greater than the high level signal threshold with a predetermined number, wherein if the number of consecutive frequency components is greater than the predetermined number, the peak Doppler spectrum amplitude is greater than the high level signal threshold.

11. The system according to claim **6** wherein the automatic gain engine is further configured to count a number of consecutive frequency components of the peak Doppler spectrum whose amplitudes are greater than the low level signal threshold and compare the number of consecutive frequency components whose amplitudes are greater than the low level signal threshold with a predetermined number, wherein if the number of consecutive frequency components is less than the predetermined number, the peak Doppler spectrum amplitude is less than the low level signal threshold.

12. The system according to claim **6** wherein the automatic gain engine is further configured to detect the Doppler spectrum maximum noise floor from an average amplitude of a predetermined number of the consecutive Doppler spectrum frequency components, for all spectrum frequency components excluding frequency components near a zero frequency baseline, and among the average amplitudes determines a minimum average amplitude wherein the maximum noise floor is the minimum average amplitude multiplied by a predetermined factor.

13. A method for suppressing noise manifest on Doppler spectrum signals comprising:

inputting the Doppler spectrum signals;

receiving a Doppler gain control signal;

using a noise suppression gain curve g(p) corresponding to the Doppler gain control signal; and

processing the Doppler spectrum amplitudes with the noise suppression gain curve g(p) wherein each frequency of the Doppler spectrum amplitude is adjusted according to a response of the noise suppression gain curve.

14. The method according to claim **13** wherein using a noise suppression gain curve further comprises generating a noise suppression curve g(p) corresponding to the Doppler gain control signal.

15. The method according to claim **13** wherein using a noise suppression gain curve further comprises selecting a noise suppression curve g(p) corresponding to the Doppler gain control signal.

16. A noise suppressor for suppressing noise manifest on Doppler spectrum signals comprising:

an input configured to receive gain adjusted Doppler spectrum signals;

a gain control signal input configured to receive a gain control signal that is used to adjust the gain for the gain adjusted Doppler spectrum signals to generate a noise suppression gain curve g(p);

a gain function processor configured to process the gain adjusted Doppler flow signals with the noise suppression gain curve g(p), wherein each spectrum component of the Doppler spectrum signal input is adjusted in amplitude according to the response of the noise suppression gain curve g(p); and

an output configured to output noise suppressed, gain adjusted Doppler flow signals.

17. The noise suppressor according to claim **16** wherein the gain function processor further comprises a first look-up table containing a noise suppression gain curve g(p) which is received from a noise suppression curve generator which generates a noise suppression gain curves in response to the gain control signal.

18. The noise suppressor according to claim **16** wherein the gain control signal selects one of the plurality of noise suppression gain curves g(p) having a predetermined response that corresponds to the gain control signal.

19. The noise suppressor according to claim **16** wherein the gain function processor further comprises a calculator combined with a LUT which generates a noise suppression curve from a stored noise suppression and the gain suppression curve.

20. The noise suppressor according to claim **16** wherein the gain function processor is selected from the group consisting of a calculator, a calculator and look-up table, or a plurality of look-up tables.

21. The noise suppressor according to claim **17** wherein the suppression curve generator further comprises a calculator and a look-up table which includes a plurality of noise suppression gain curves.

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专利名称(译)	用于超声成像的方法和设备		
公开(公告)号	US20090112096A1	公开(公告)日	2009-04-30
申请号	US11/926228	申请日	2007-10-29
[标]申请(专利权)人(译)	日立阿洛卡医疗株式会社		
申请(专利权)人(译)	ALOKA CO.，LTD.		
当前申请(专利权)人(译)	日立ALOKA MEDICAL.，LTD.		
[标]发明人	TAMURA TADASHI		
发明人	TAMURA, TADASHI		
IPC分类号	A61B8/06		
CPC分类号	A61B8/06 G01S15/8979 G01S7/52077 G01S7/52033		
外部链接	Espacenet USPTO		

摘要(译)

公开了一种系统和方法，其在检测血流速度时检查由超声系统输出的多普勒频谱信号，以确定适当的多普勒增益并抑制多普勒频谱中的噪声。检查多普勒频谱中存在的噪声并将其用作最佳增益的标准。如果多普勒增益根据预定水平太高或太低，则相应地调整总增益。