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**(54) INTRAVASCULAR ULTRASOUND SYSTEM FOR CO-REGISTERED IMAGING**

INTRAVASKULÄRES ULTRASCHALLSYSTEM FÜR DIE COREGISTERIERTE ABBILDUNG

SYSTÈME ULTRASONORE INTRAVASCULAIRE POUR UNE IMAGERIE CO-ENREGISTRÉE

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## Description

### Background

[0001] The present invention generally relates to intravascular ultrasound (IVUS) imaging. The present invention more specifically relates to IVUS systems for co-registered imaging.

[0002] Intravascular ultrasound imaging is generally performed to guide and assess percutaneous coronary interventions, typically the placement of a bare-metal or drug-eluting stent. Other applications of IVUS imaging comprise further assessment of coronary artery disease.

[0003] Coronary stents generally have struts made of a metal, such as stainless steel or a cobalt chromium alloy. The metal stent struts provide a substantially larger reflected ultrasound signal than blood and soft tissue, such as neotissue grown over stent struts. The ability to detect and measure neotissue growth is particularly relevant for evaluating the stent healing process. Current commercially available IVUS systems have limited ability to detect early neotissue growth, because of a limited detectable range of reflected ultrasound signals.

[0004] Atherosclerotic lesions that are prone to rupture, so called vulnerable plaques, are of increasing interest to interventional cardiologists. One type of vulnerable plaque thought to be responsible for a large percentage of plaque ruptures is a thin-cap fibroatheroma wherein a thin ( $<65 \mu\text{m}$ ) fibrous cap overlies a mechanically unstable lipid-rich or necrotic core. Current commercially available IVUS systems operate up to only 40 MHz and have axial resolutions that are limited to approximately  $100 \mu\text{m}$ . Consequently, current commercially available IVUS systems cannot reliably detect vulnerable plaques.

[0005] It is generally necessary to increase the imaging frequency in order to improve spatial resolution. However, increased imaging frequency also leads to reduced contrast between blood and non-blood tissue that in turn makes difficult segmentation of the blood-filled lumen from the intimal plaque. Some automatic segmentation algorithms exploit the frequency-dependent ultrasound properties of blood and non-blood tissues as described for example in U.S. Pat. No. 5,876,343 by Teo. Real-time, automatic segmentation tools are often prone to errors which reduce their utility in clinical practice.

[0006] Multi-frequency imaging has been developed for transthoracic echocardiographic applications. U.S. Pat. No. 6,139,501 by Roundhill et al. describes a system that simultaneously displays two B-mode images of different imaging frequencies and bandwidths. However, this technique uses both fundamental and harmonic imaging techniques and relies upon non-linear propagation properties of tissue. Although harmonic imaging can potentially provide better spatial resolution, harmonic imaging performance in the near-field is limited. Further, harmonic IVUS imaging has not been found to be practically useful.

[0007] Multi-frequency IVUS imaging can also be achieved by use of multiple transducer imaging catheters. However, multiple transducers add complexity and cost to the disposable imaging catheter and the imaging system. The potential need to co-register the images from the separate transducers further complicates their practical use.

[0008] US 2008/200815 A1 is relates to methods and apparatus for ultrasound detection and imaging in intravascular applications.

[0009] There exists a need for a technology that provides sufficient contrast resolution to guide percutaneous coronary interventions and sufficient contrast and spatial resolution to detect stent healing and vulnerable plaques. Further, it is desirable that such a technology does not require any co-registration step between multiple images. Still further, it is desirable that such a technology does not substantially increase system and catheter complexity and cost over existing commercial systems and catheters.

### Summary

[0010] The invention provides an intravascular ultrasound imaging system according to claim 1.

[0011] Each sequence of energy pulses may include at least two pulses, as for example, three pulses. The varying characteristic may be pulse energy, frequency, or bandwidth.

[0012] The imaging engine may be arranged to process only reflected ultrasonic energy pulses having a common detected characteristic. The imaging engine may be further arranged to provide a composite image based upon the varying characteristics of the sequences of reflected ultrasonic energy pulses.

[0013] The imaging engine may include a processor that processes the reflected ultrasonic energy pulses in separate image frames, each image frame corresponding to each different energy pulse characteristic and the imaging engine may provide display signals for simultaneously displaying the separate image frames.

[0014] The invention further provides a method according to claim 11.

### Brief Description Of The Drawings

[0015] The invention, together with further features and advantages thereof, may best be understood by making reference to the following descriptions taken in conjunction with the accompanying drawings, in the several figures of which like reference numerals identify identical elements, and wherein:

FIG. 1 is a high-level diagram of an IVUS system;

FIG. 2a is a block diagram of signal processing paths of an IVUS system for co-registered imaging;

FIG. 2b is another block diagram of signal processing paths of an IVUS system for co-registered imaging;

FIGS. 3a and 3b illustrate a time-domain signal and power spectrum, respectively, of short-time pulses; 5

FIG. 4a illustrates a pass band of a broadband power spectrum;

FIG. 4b illustrates another pass band of a broadband power spectrum; 10

FIG. 5a is a block diagram of an imaging engine;

FIG. 5b is another block diagram of an imaging engine; 15

FIG. 5c is still another block diagram of an imaging engine 20

**FIGS. 6a - 6d** illustrate first, second, third, and fourth representative transmit pulse sequences, respectively;

**FIG. 7** is a block diagram of signal processing paths of an IVUS system for co-registered imaging; 25

**FIG. 8** is a block diagram of signal processing steps for calculation of an integrated backscatter parameter; 30

**FIG. 9** illustrates a display comprising multiple co-registered images;

**FIGS. 10a and 10b** illustrate feature mapping between co-registered images; 35

**FIG. 11** is a high-level diagram of an IVUS system;

**FIG. 12** is a block diagram of a further imaging engine; 40

**FIGS. 13 - 17** are block diagrams of digital signal processing engines; 45

**FIG. 18** is a block diagram of the signal processing path of an IVUS system for co-registered imaging;

**FIG. 19** is a cross-sectional view of a stenosed coronary artery; 50

**FIG. 20** is a cross-sectional view of a coronary artery with an implanted stent;

**FIG. 21** shows a transverse IVUS image of a stented coronary artery acquired using a high-transmit energy pulse; 55

**FIG. 22** illustrates a repeating high-energy, medium-energy, and low-energy transmit pulse sequence;

**FIG. 23** shows a transverse IVUS image of a stented coronary artery acquired using a medium-transmit energy pulse;

**FIG. 24** shows a transverse IVUS image of a stented coronary artery acquired using a low-transmit energy pulse;

**FIG. 25** shows a transverse IVUS image with a selected dynamic range of a stented coronary artery acquired using a high-transmit energy pulse;

**FIG. 26** shows a transverse IVUS image with a selected dynamic range of a stented coronary artery acquired using a medium-transmit energy pulse;

**FIG. 27** shows the stent regions of a transverse IVUS image with a selected dynamic range of a stented coronary artery acquired using a low-transmit energy pulse;

**FIG. 28** shows a composite image of a high-transmit energy transverse IVUS image of a stented coronary artery, a medium-transmit energy transverse IVUS image of a stented coronary artery, and a low-transmit energy transverse IVUS image of a stented coronary artery; and

**FIG. 29** is a flow diagram of the signal processing path of an IVUS system for imaging with a high-transmit, medium-transmit and low-transmit energy pulse sequence.

#### **Detailed Description Of The Embodiments**

**[0016] FIG. 1** is a high-level block diagram of an IVUS system comprised of an IVUS imaging catheter **1000**, a patient interface module **2000**, and an imaging engine **3100**. The catheter is typically delivered to a coronary artery via a transfemoral or transradial retrograde route. The imaging catheter **1000** is coupled mechanically and electrically to the patient interface module **2000**. The imaging engine **3100** is used to control operation of the patient interface module **2000** and catheter **1000** for purposes of coronary artery imaging. The following descriptions of an IVUS imaging catheter are directed to the case of a mechanically rotating imaging core. Each IVUS image comprises a pre-determined number of vectors (or scan lines) and samples per vector. Most currently available commercial IVUS systems utilize 256 vectors per image. The number of samples per vector varies generally between approximately 256 and 2048 samples for commercially available IVUS systems and depends in part on imaging frequency and data type (e.g., RF or baseband).

**[0017]** FIG. 2a is a block diagram of one embodiment of signal processing paths of an IVUS system for co-registered imaging. A waveform is selected in step **102**, generally within the imaging engine. A transmit waveform is then generated by a transmit pulser in step **104** that is generally located in the patient interface module. The transmit waveform is sent through a transmit/receive (T/R) switch in step **106** to an ultrasound transducer **1100**. The transducer may operate over frequency ranges of 10 MHz to 80 MHz, generally between 20 MHz and 60 MHz for intracoronary imaging.

**[0018]** The transducer emits an ultrasonic pressure field **1110** to insonify the coronary artery. Some ultrasonic energy is backscattered and received by the transducer. The received ultrasound passes through the T/R switch in step **106** and a rotary coupler in step **108**. The rotary coupler may be an inductive rotary coupler or a liquid metal rotary coupler. Alternatively, the rotary coupler may be a rotary capacitive coupler as described, for example, in co-pending U.S. Patent Application Serial No. 12/465,853 filed May 14, 2009, in the names of Silicon Valley Medical Instruments, Inc. and titled IVUS System with Rotary Capacitive Coupling, which application is hereby incorporated herein by reference in its entirety. The rotary coupler interfaces the mechanically rotating imaging core of the catheter to the non-rotating electronics of the patient interface module.

**[0019]** The received signal then passes through a gain amplifier in step **109**, a high-pass filter in step **110**, and a time-gain compensation amplifier in step **112**. The time-gain compensation is provided, because of the increased attenuation of the ultrasound signal as the signal propagates further into the coronary artery. The signal is next sent through an anti-aliasing low-pass filter in step **114** before digitization in step **116**.

**[0020]** The digitized signals are then processed according to multi-frequency techniques comprising a low-frequency path **120** and a high-frequency path **130**. The low-frequency and high-frequency processing paths comprise similar processing stages that may differ due to imaging parameters such as pass band, field of view, and signal-to-noise ratio.

**[0021]** Referring now to FIGS. 3 and 4, the time-domain response **202** and power spectrum **204** are respectively shown in FIGS. 3a and 3b for a short-time pulse of a 60 MHz IVUS imaging transducer having a fractional bandwidth >60 %. An important aspect of the present invention is the use of transducers with large fractional bandwidths, generally >50 % fractional bandwidth. Transducers having fractional bandwidths <50 % may also be used, but the use of such transducers is expected to be less effective with reduced utility. Another important aspect of the present invention is the use of transducers with uniformly high sensitivities across the useful bandwidths. The selected low and high frequencies may comprise overlapping bandwidths **222**, **224** or non-overlapping bandwidths **226**, **228** with corresponding pass band center frequencies **F1**, **F2** as illustrated respectively in

FIGS. 4a and 4b. A potential benefit of the use of overlapping bandwidths is that wider bandwidths generate images having better spatial resolution. In one embodiment of the present invention, the low pass band center frequency **F1** is 40 MHz, the high pass band center frequency **F2** is 60 MHz, the low pass band **222** is 30 MHz to 50 MHz, and the high pass band **224** is 45 MHz to 75 MHz. In another embodiment of the present invention, the catheter comprises a broadband 40 MHz transducer, the low pass band center frequency is 30 MHz, and the high pass band center frequency is 50 MHz. In still another embodiment of the present invention, the catheter comprises a broadband 35 MHz transducer, the low pass band center frequency is 25 MHz, and the high pass band center frequency is 40 MHz.

**[0022]** Referring again to FIG. 2a, the low-frequency path digitized data are first pre-processed in step **122**. Pre-processing, as known in the art, may generally comprise bandpass filtering and vector processing techniques. The envelope of the pre-processed data is detected in step **124** followed by post-processing in step **126**. Post-processing generally comprises logarithmic compression and gamma correction to generate a visually appealing and useful image. The post-processed data are then scan converted in step **128** from polar coordinates to Cartesian coordinates. Pre-processing, detection, post-processing, and scan conversion are signal and image processing techniques known to those skilled in the art of medical ultrasound imaging.

**[0023]** The high-frequency path digitized data are processed in an analogous manner. The high-frequency path digitized data are first pre-processed in step **132**. Pre-processing, again, generally comprises bandpass filtering and vector processing. The envelope of the pre-processed data is detected in step **134** followed by post-processing in step **136**. Post-processing generally comprises logarithmic compression and gamma correction to generate a visually appealing and useful image. The post-processed data are then scan converted in step **138** from polar coordinates to Cartesian coordinates.

**[0024]** The low-frequency and high-frequency scan-converted images **152**, **154** are then simultaneously displayed in step **150**. A low-frequency image comprises better contrast between blood and non-blood tissues to facilitate lumen border detection. A high-frequency image comprises better spatial resolution of lesion features such as thin fibrous caps. The low-frequency and high-frequency scan-converted images **152**, **154** are co-registered, because the same ultrasound data are used to generate both images.

**[0025]** The signal processing paths illustrated in FIG. 2a can be implemented in numerous physical configurations. An important aspect of the present invention is the physical configuration of the imaging engine. FIG. 5a is a block diagram for one embodiment of the imaging engine **3100** comprising a single board computer **3102**, a dedicated digital signal processing (DSP) module **3120**, and an interface board **3180**. The DSP module **3120** is

used to select the transmit waveform **3182** to be sent to the patient interface module.

The time-gain compensation amplifier **3184** and anti-aliasing low-pass filter **3186** are located on the interface board **3180**. The analog-to-digital converter (or digitizer) **3128** is located in the DSP module **3120**. The DSP module **3120** may further comprise a field-programmable gate array (FPGA) **3122**. The low-frequency signal and high-frequency signal processing paths **120, 130** illustrated in **FIG. 2a** are generally implemented in the FPGA. An important aspect of this embodiment is that the co-registered imaging is performed by an imaging engine comprising a single analog-to-digital converter and a single FPGA.

**[0026]** **FIG. 5b** is a block diagram of another embodiment of the imaging engine of the present invention comprising a first DSP module **3120** and a second DSP module **3140** wherein a single analog-to-digital converter (or digitizer) **3128** and two FPGAs **3122, 3142** are available. The addition of a second DSP module comprising an FPGA provides increased computational processing power at the expense of increased device complexity and cost. The same digitized data are processed by both FPGAs.

**[0027]** **FIG. 5c** is a block diagram of still another embodiment of the imaging engine of the present invention comprising a first DSP module **3120** and a second DSP module **3140** wherein two analog-to-digital converters (or digitizers) **3128, 3148** and two FPGAs **3122, 3142** are available. A sampling clock **3126** synchronizes both digitizers **3128, 3148**. The embodiment of the 2 digitizer/2 FPGA imaging engine further comprises a second time-gain compensation amplifier **3188** and second anti-aliasing low-pass filter **3190**. The addition of a second digitizer **3148**, time-gain compensation amplifier **3188**, low-pass filter **3190** provides increased computational processing power and flexibility at the expense of increased device complexity. The added flexibility enables compensation for differing attenuation of the ultrasound pressure wave through the tissue resulting from the different frequency bands.

**[0028]** **FIG. 2b** is a block diagram of another embodiment of signal processing paths of an IVUS system for co-registered imaging comprising an embodiment of the imaging engine illustrated in **FIG. 5c**. The signal scattered back from the tissue is received by the transducer **1100** and then passes through a transmit/receive switch in step **106**, a rotary coupler in step **108**, a gain amplifier in step **109**, and a high-pass filter in step **110**. The high-pass filtered signals are then processed according to multi-frequency techniques comprising a low-frequency processing path **120A** and a high-frequency processing path **130A**. The low-frequency processing path **120A** and high-frequency processing path **130A** include similar processing stages that may differ due to imaging parameters such as pass band, field of view, and signal-to-noise ratio. Time-gain compensation in step **112** is first applied to the low-frequency path signal. Time-gain compensa-

tion is provided, because of the increased attenuation of the ultrasound signal as the signal propagates further into the coronary artery. The TGC-amplified low-frequency path signal is next sent through an anti-aliasing low-pass filter in step **114** before analog-to-digital (A/D) conversion (or digitization) in step **116**. The low-frequency path digitized data are first pre-processed in step **122**. Pre-processing generally comprises bandpass filtering and vector processing techniques. The envelope of the pre-processed data is detected in step **124** followed by post-processing in step **126**. Post-processing generally comprises logarithmic compression and gamma correction to generate a visually appealing and useful image. The post-processed data are then scan converted in step **128** from polar coordinates to Cartesian coordinates.

**[0029]** The high-frequency path **130A** signals are processed in an analogous manner. Time-gain compensation in step **112A**, anti-aliasing low-pass filter in step **114A**, and A/D conversion in step **116A** occur first after high-pass filtering in step **110**. The high-frequency digitized data are then pre-processed in step **132**. Pre-processing generally comprises bandpass filtering and vector processing. The envelope of the pre-processed data is detected in step **134** followed by post-processing in step **136**. Post-processing generally comprises logarithmic compression and gamma correction to generate a visually appealing and useful image. The post-processed data are then scan converted in step **138** from polar coordinates to Cartesian coordinates. The low-frequency and high-frequency scan-converted images **152, 154** are then simultaneously displayed in step **150**. The multi-frequency signal processing paths split after high-pass filtering in step **110** in the embodiment of the signal processing paths shown in **FIG. 2b** whereas the multi-frequency signal processing paths split after A/D conversion in step **116** in the embodiment of the signal processing paths shown in **FIG. 2a**. The split of the multi-frequency signal processing paths after high-pass filtering provides for time-gain compensation appropriate for different imaging frequencies.

**[0030]** Referring now to **FIGS. 6a - 6d**, a series of imaging waveform sequences are illustrated. **FIG. 6a** illustrates one embodiment in which a single pulse sequence **10** comprises transmitting the same waveform **Xc** for each vector of an IVUS image. **FIG. 6b** illustrates another embodiment comprising a pulse sequence **20** of alternating low-frequency **X1** and high-frequency **X2** waveforms. A potential advantage of an alternating pulse sequence over a single pulse sequence is that the transmitted energy can be increased or decreased for the selected pass bands of the multi-frequency processing. The ability to adjust transmit energy may benefit image quality of co-registered images that are simultaneously displayed. **FIG. 6c** illustrates still another embodiment comprising a pulse sequence **30** of alternating imaging **Xi** and parametric imaging **Xp** waveforms. The imaging waveform **Xi** may include a **Xc, X1, or X2** waveform. The parametric imaging waveform **Xp** is selected to optimize

analysis of at least one ultrasound tissue classification parameter including integrated backscatter, attenuation, strain, and motion. The use of a more narrowband waveform may provide benefit to correlation-based or Doppler-based motion analysis. **FIG. 6d** illustrates still yet another embodiment including a pulse sequence **40** of alternating imaging and parametric imaging waveforms ***X<sub>i</sub>***, ***X<sub>p</sub>*** wherein multiple parametric imaging waveforms ***X<sub>p</sub>*** are transmitted between imaging waveforms ***X<sub>i</sub>***. The use of repeated pulses may provide additional benefits for signal-to-noise conditions.

**[0031]** Thus, as may be seen from the above, and in accordance with aspects of the present invention, an imaging engine coupled to an imaging core may be arranged to provide the imaging core with energy pulses to cause the imaging core to transmit ultrasonic energy pulses. The energy pulses may be arranged in repeated sequences and the energy pulses of each sequence may have varying characteristics. For example, each sequence of energy pulses may include at least two pulses. Also, the varying characteristic may be pulse energy.

**[0032]** **FIG. 7** shows a block diagram of one embodiment of signal processing paths of an IVUS system for co-registered imaging wherein the co-registered images include a grayscale image **182** and a parametric image **184**. The parametric image **184** may include a multi-parametric image. The transmit waveform selected in step **102** and sent from the imaging engine may include a single pulse sequence **10** or an imaging and parametric imaging pulse sequence **30** as illustrated in **FIGS. 6a** and **6c**. The signal processing path to the digitization step **116** is similar to the signal processing path for the multi-frequency imaging illustrated in **FIG. 2a**.

**[0033]** The digitized signals are then processed according to a grayscale imaging path **160** and a parametric imaging path **170**. The grayscale imaging path digitized data are first pre-processed in step **162**. Pre-processing generally comprises bandpass filtering and vector processing techniques. The envelope of the pre-processed data is detected in step **164** followed by post-processing in step **166**. Post-processing generally comprises logarithmic compression and gamma correction to generate a visually appealing and useful image. The post-processed data are then scan converted in step **168** from polar coordinates to Cartesian coordinates.

**[0034]** The processing stages of the parametric imaging path **170** include a pre-processing step **172**, a parametric analysis step **174**, a post-processing step **176**, and a scan conversion step **178**. The particular details of each parametric imaging processing step depend upon the at least one parameter to be calculated.

**[0035]** In one embodiment of the present invention a parametric image of integrated backscatter is generated. The integrated backscatter pre-processing step **172** comprises bandpass filtering and vector processing techniques. The filter pass band may be determined from the -3 dB bandwidth of the transducer. The integrated backscatter parametric analysis in step **174** may include a

sliding window technique. Sliding window techniques are known to those skilled in the art of ultrasound tissue characterization.

**[0036]** Referring now to **FIG. 8**, a block diagram illustrates one embodiment of the signal processing stages for calculation of the integrated backscatter parameter using a sliding window technique. A region of interest (ROI) of the pre-processed data **500** is first selected in step **502**. A time-domain window such as a Hamming or Hann window may be applied to each vector of the ROI to minimize edge discontinuities in Fast Fourier Transform (FFT) spectral analysis at the cost of reduced frequency resolution. The ROI comprises a pre-determined number of vectors and vector samples. The number of vectors and vector samples depends upon details including vector density, sample rate, optimal ROI size, and signal-to-noise metrics.

**[0037]** In one embodiment of the present invention the system provides a vector density of 1024 vectors per IVUS image and a sample rate of 400x10<sup>6</sup> samples/s. An optimal ROI size balances a minimal radial extent of the ROI with a maximal signal-to-noise ratio. A lateral extent of the ROI comparable to the radial extent can facilitate subsequent parametric image analysis. Multiple vectors also permit signal averaging. Further, the selected ROI size may be range dependent, because the physical vector spacing increases with range. An ROI size of 7 vectors and 32 samples at a range of 1.5 mm provides a ROI that is approximately 60 μm x 60 μm. This size may be suitable for small-scale atherosclerotic lesion features such as thin-fibrous caps.

**[0038]** The average power spectrum is calculated in step **504** for the ROI by calculating the power spectrum of each vector and then averaging. The power spectrum is calculated generally using FFT techniques. Averaging is performed generally in the logarithmic (dB) domain, but may be performed in the linear domain. The average power spectrum may then be compensated for system and transducer effects in step **506** comprising range-dependent sensitivity and frequency-dependent transducer sensitivity. The integrated backscatter parameter is calculated in step **508** by summing the compensated, average power spectrum values of the selected bandwidth and dividing by said selected bandwidth. Additional ROIs are selected by sliding the window (or ROI) over the pre-processed data **500** or pre-defined subset of the pre-processed data. The degree of overlap of ROIs is selected to balance smoothing in the parametric image by maximizing overlap with computational cost by minimizing overlap. For a ROI size of 7 vectors x 32 samples, the sliding window overlap generally comprises between 16 samples (or 50 %) and 24 samples (or 75 %) along a vector and between 4 vectors (or approximately 50 %) and 6 vectors (or approximately 85 %) across vectors. The integrated backscatter parametric data are sent to the post-processing step **176** (of **FIG. 7**) when there are no more ROIs remaining to be analyzed.

**[0039]** Post-processing in step **176** of the integrated

backscatter image includes thresholding and gamma correction. In one embodiment of the present invention, the integrated backscatter image is thresholded to display lipid-rich ROIs which are known to have relatively low integrated backscatter values. In alternative embodiments, the integrated backscatter image is thresholded at multiple levels to distinguish multiple tissue types. The post-processed integrated backscatter image is then scan converted in step **178**.

**[0040]** The scan-converted grayscale image and scan-converted integrated backscatter parametric image are then simultaneously displayed in step **180**. A grayscale image may provide better structural detail. An integrated backscatter parametric image may provide better plaque composition detail. Further, the grayscale and integrated backscatter parametric images **182, 184** are co-registered, because the same ultrasound data are used to generate both images.

**[0041]** FIG. 9 illustrates a display **190** comprising four co-registered images **192, 194, 196, 198**. The four co-registered images may comprise at least one grayscale image and at least one parametric image. In one embodiment of the present invention, the display comprises a 40 MHz grayscale image, a 60 MHz grayscale image, and an integrated backscatter parametric image.

**[0042]** The present invention facilitates mapping of image features between co-registered images. IVUS images of lower ultrasound frequencies generally provide better contrast between blood and non-blood tissues whereas IVUS images of higher ultrasound frequencies generally provide better spatial resolution of atherosclerotic lesions. FIG. 10a illustrates a first IVUS image **300** of lower frequency and second IVUS image **320** of higher frequency. Catheter masks **302, 322** represent catheter position relative to a coronary artery section. A lumen contour **308** identified in the first image **300** can be mapped **312** to a lumen contour **328** in the second image **320**. The lumen contour segments blood **304** from non-blood tissues. A vessel contour **310** identified in the first image **300** can be mapped **314** to a vessel contour **330** in the second image **320**. The lumen and vessel contours **308, 310** segment atherosclerotic plaque **306** from other tissues. The mapped contours **328, 330** of the higher-frequency IVUS image enable further processing of the atherosclerotic plaque.

**[0043]** FIG. 10b illustrates mapping features more prominent in a first image **340** to a second image **360** and mapping features more prominent in said second image **360** to said first image **340**. The first image may comprise a grayscale image, and the second image may comprise a parametric image. A lumen contour **348** in the first image **340** is mapped **352** to a lumen contour **368** in the second image **360**. A vessel contour **370** and ROI **372** in the second image **360** are respectively mapped **374, 376** to a second vessel contour **350** and second ROI **352** in the first image **340**.

**[0044]** It is desirable that the present invention provide optimal imaging performance and computational efficien-

cy with minimal device complexity. FIG. 11 shows a high-level diagram of one embodiment of an IVUS system for co-registered imaging. The following descriptions of an IVUS system for co-registered imaging are directed to the case of an IVUS system for display of two co-registered grayscale images. The IVUS system comprises two images **3802, 3803**, an imaging engine **3804**, a patient interface module (PIM) **2000**, and an IVUS imaging catheter **1000**. The following descriptions of the IVUS imaging catheter **1000** are directed at the case of a mechanically rotating imaging core. The imaging engine **3804** comprises a display engine **3806**, a DSP engine **3808**, transmit (Tx) logic **3810**, a transmit buffer **3812**, a receive (Rx) signal conditioning stage **3814**, and an analog-to-digital converter (ADC) **3816**.

**[0045]** The DSP engine **3808** provides computing power for real-time, simultaneous co-registered imaging. The DSP engine **3808** sends control signals to the transmit logic **3810** that generates an analog transmit pulse sequence. The transmit pulse passes through the transmit buffer **3812** before going to the PIM **2000**. The PIM **2000** is the interface between the catheter **1000** and the imaging engine **3804**. The PIM **2000** provides for transmitting transducer excitation energy, receiving transducer signal returns, and sending signal returns to the imaging engine **3804**. The return signals pass through a receive signal conditioning stage **3814** and analog-to-digital converter **3816**. The digitized return signals are then processed in the DSP engine **3808**. Image data are sent to the display engine **3806** and streamed for real-time simultaneous display of co-registered images **3802, 3803**.

**[0046]** FIG. 12 illustrates one embodiment of a physical configuration of the imaging engine **3100**. The imaging engine **3100** performs all image generation, display, and control of the entire system. The imaging engine **3100** may include a general processing unit **3500**, a DSP module **3600**, and an interface board **3700**.

**[0047]** The general processing unit **3500** may include a central processing unit (CPU) **3502**, a memory controller **3504**, dynamic random access memory (DRAM) **3506**, a digital bus interface **3508**, and a peripheral controller **3510**. The DSP module **3600** may include a DSP engine **3610**, transmit logic circuitry **3612**, a digital-to-analog converter (DAC) **3620**, an analog-to-digital converter (ADC) **3630**, and a sampling clock **3640**. A high-speed digital bus **3512** connects the digital bus interface **3508** to the DSP engine **3610**. The interface board **3700** may include a transmit buffer **3702**, a time gain compensation (TGC) amplifier **3704**, and an anti-aliasing low-pass filter (LPF) **3706**.

**[0048]** The DSP engine **3610** controls the transmit logic circuitry **3612** to send an analog transmit signal to the transmit buffer **3702**. The analog transmit signal may include a pulse wherein the pulse may include at least one rectangular pulse. The analog transmit signal is sent from the interface board **3700** to the PIM. The DSP engine **3610** further generates a digital TGC signal that is converted by the DAC **3620** to an analog TGC signal. The

analog TGC signal provides the level of TGC amplification **3704** applied to signals received from the PIM. The low-pass filter **3706** minimizes aliasing in the TGC-amplified signals.

**[0049]** The anti-aliased TGC-amplified return signals are digitized and then processed by the DSP engine **3610** for co-registered imaging. A sampling clock **3640** synchronizes the ADC (or digitizer) **3630** and DSP engine **3610**. Co-registered images are streamed from the DSP engine **3610** to the general processing unit **3500** for display of images.

**[0050]** Referring now to **FIGS. 13 - 17**, the DSP engine **3610** may include different forms of signal processors. **FIGS. 13 - 15** show diagrams of a DSP engine **3610** including a field-programmable gate array (FPGA) **3902**, a DSP chip **3904** and random-access memory (RAM) **3906**, or an application-specific integrated circuit (ASIC) **3908**. The DSP engine may further include multiple signal processors. **FIG. 16** shows a diagram of a DSP engine **3610** that includes a first FPGA **3910** and a second FPGA **3912**. **FIG. 17** shows a diagram of a DSP engine **3610** that includes a massively parallel processor array (MP-PA) **3914** of CPUs and RAM modules. The most cost effective and computationally efficient signal processor will depend on the specific application. Field-programmable gate arrays are commonly used in IVUS imaging systems.

**[0051]** **FIG. 18** illustrates a signal processing path for co-registered multi-frequency imaging that provides for optimizing co-registered grayscale imaging performance while minimizing device cost and complexity. The following descriptions are directed at the case of an alternating transmit pulse sequence **20** as illustrated in **FIG. 6b** wherein a first pulse sequence **X1** has a lower imaging frequency and a second pulse sequence **X2** has a higher imaging frequency. A potential advantage of the alternating pulse sequence **20** over a single pulse sequence **10** shown in **FIG. 6a** is that the transmitted energy can be increased or decreased for the selected pass bands of the multi-frequency processing. The ability to adjust transmit energy may benefit image quality of co-registered images that are simultaneously displayed.

**[0052]** The received signal is converted from analog to digital (A/D) in step **300**. The digitized signals are pre-processed in step **302** wherein pre-processing generally includes bandpass filtering and vector processing techniques. The specific form of pre-processing depends on whether the transmit signal is an X1 pulse or X2 pulse. A digital multiplexer **330** receives a first set of pre-processing coefficients **332** and a second set of pre-processing coefficients **334**. The pre-processing coefficients include filter coefficients for band-pass filtering. A vector processing control **320** determines which set of pre-processing coefficients to use for pre-processing. The envelope of the pre-processed signal is detected in step **304**. The vector processing control **320** determines whether a digital multiplexer **340** selects a first set of detection coefficients **342** or a second set of detection co-

efficients **344** for detection processing. The detected signal is then post-processed in step **306** wherein post-processing generally comprises logarithmic compression and gamma correction to generate a visually appealing and useful image. The post-processed signals are then scan converted in step **308** from polar coordinates to Cartesian coordinates.

**[0053]** The low-frequency and high-frequency scan-converted images **312, 314** are then simultaneously displayed in step **310**. A low-frequency image may provide better contrast between blood and non-blood tissues to facilitate lumen border detection. A high-frequency image may provide better spatial resolution of lesion features. The low-frequency and high-frequency scan-converted images **312, 314** are co-registered, because both sets of image data are acquired at substantially the same time when using alternating transmit pulse sequences.

**[0054]** In another embodiment, the alternating transmit pulse sequence may include alternating groups of pulses. A pulse sequence may include alternating groups of X1 and X2 pulse sequences wherein each group of X1 and X2 pulses includes at least two (2) pulses. The temporal delay will be larger between acquisitions of the X1 and X2 images, but there may be advantages to fewer alternations between X1 and X2 pulse sequences.

**[0055]** A key advantage of the signal processing path illustrated in **FIG. 18** is that only one digitizer is required. Further, the digital signal processing can be performed in a single FPGA. Still further, the multi-frequency processing can be performed without duplication of signal processing stages.

**[0056]** An important aspect of the present invention is the use of an IVUS system for co-registered imaging comprising an imaging engine, a patient interface module, and an IVUS catheter. The imaging engine may comprise a general processing unit, a DSP module, and an interface board. The DSP module comprises an analog-to-digital converter and a DSP engine. The DSP engine may comprise a FPGA, DSP chip, or ASIC. The DSP engine may alternatively comprise multiple FPGAs or a massively parallel processing array of CPUs and RAM modules. Another important aspect of the present invention is the use of an IVUS catheter comprising a broadband (>50 % fractional bandwidth) ultrasound transducer with high sensitivity wherein both a low pass band and a high pass band can be used to generate grayscale images. Low pass band and high pass band center frequencies may respectively comprise 40 MHz and 60 MHz, 30 MHz and 50 MHz, 25 MHz and 40 MHz, and other combinations with different frequency spacing. Still another important aspect of the present invention is the use of a programmable transmit pulse sequence. The transmit pulse sequence may comprise a single pulse imaging sequence, an alternating low-frequency and high-frequency imaging sequence, or an alternating imaging and parametric imaging sequence. Still yet another important aspect of the present invention is the display of at least two (2) co-registered images comprising at least one



grayscale image. The co-registered images may further comprise at least one parametric image. A further important aspect of the present invention is the mapping of image features between co-registered images wherein image features comprise contours and regions of interest.

[0057] It is also desirable to provide improved contrast resolution for imaging of coronary arteries having implanted stents. The ability to detect and measure stent healing, or early neotissue growth over coronary stent struts, is of particular relevance. FIG. 19 shows an illustration of a cross-section of a stenosed coronary artery 400. The coronary artery includes a blood-filled lumen 402, an intimal plaque layer 404, a medial layer 406, and an adventitial layer 408. The lumen generally has a cross-sectional area less than 4 mm<sup>2</sup>. FIG. 20 shows an illustration of the same coronary artery 400 as in FIG. 19 after stent implantation. The stent struts 410 are positioned in proximity to the lumen-plaque border. The stent provides for an increased lumen cross-sectional area to enable improved blood flow through the artery.

[0058] FIG. 21 shows a transverse IVUS image 420 of a stented coronary artery acquired with a high-transmit energy pulse having an amplitude generally greater than 50 V. The transverse IVUS image 420 includes a catheter mask 422 to indicate position of the IVUS catheter relative to the coronary artery. The IVUS image 420 further shows ultrasound reflections from a blood-filled lumen 424, neotissue growth 426, an intimal plaque layer 428, a medial layer 430, and an adventitial layer 432. The neotissue growth 426 is a result of the stent healing process. Uncovered struts of drug-eluting stents are considered a factor in the adverse event of late stent thrombosis. The transverse IVUS image 420 still further includes substantially strong ultrasound reflections from the stent struts 434 as well as so-called stent blooming artifacts 436. The stent blooming artifacts can result from saturation of the receive-side electronics that are part of the IVUS system and characteristically appear on the side of the stent struts 434 away from the catheter mask 422. The combined thickness of the stent reflection 434 and stent blooming artifact 436 is generally substantially larger than the physical thickness of the stent struts, which is approximately 100 microns or smaller. The stent blooming artifacts 436 degrade image quality.

[0059] Stent blooming artifacts can be prevented by sufficiently decreasing the energy of the transmit pulse to avoid saturation of the receive-side electronics of the IVUS system. In one embodiment of the present invention, a three-pulse sequence that includes a high-transmit energy pulse, a medium-transmit energy pulse, and a low-transmit energy pulse may be used to visualize neotissue growth, provide adequate penetration of the ultrasound energy into the coronary artery, and prevent stent blooming artifacts. FIG. 22 illustrates a repeating pulse sequence 22 of high-energy transmit pulses XH, medium-energy transmit pulses XM, and low-energy transmit pulses XL.

[0060] The transverse IVUS image 420 shown in FIG. 21 is acquired with a high-transmit energy pulse and enables visualization of neotissue growth and penetration beyond the medial layer 430. FIG. 23 shows a transverse IVUS image 440 of the same stented coronary artery shown in FIG. 21, but acquired with a medium-transmit energy pulse having an amplitude less than the amplitude of the high-transmit energy pulse. The transverse IVUS image 440 includes a catheter mask 422 to indicate position of the IVUS catheter relative to the coronary artery. The IVUS image 440 further shows ultrasound reflections from a blood-filled lumen 424, neotissue growth 426, and an intimal plaque layer 428. The transverse IVUS image 440 still further includes ultrasound reflections from the stent struts 442 and stent blooming artifacts 444.

[0061] FIG. 24 shows a transverse IVUS image 450 of the same stented coronary artery shown in FIG. 21, but acquired with a low-transmit energy pulse having an amplitude less than the amplitude of the high-transmit energy pulse. The transverse IVUS image 450 includes a catheter mask 422 to indicate position of the IVUS catheter relative to the coronary artery. The IVUS image 440 further shows ultrasound reflections from neotissue growth 426 and parts of the intimal plaque layer 428. The transverse IVUS image 440 still further includes ultrasound reflections from the stent struts 454. Because of the low-transmit energy level of the pulse, there will be no stent blooming artifact and more distant sections of the coronary artery such as the medial and adventitial layers may not be visualized. The low-transmit energy level of the pulse may degrade the ability to detect and visualize the small ultrasound reflections from a blood-filled lumen.

[0062] A high-transmit energy IVUS image, a medium-transmit energy IVUS image, and a low-transmit energy IVUS image can be co-registered by using a sequence of repeated high-transmit energy, medium-transmit energy and low-transmit energy pulses. Referring now to FIG. 25, a high-transmit energy IVUS image 460 can be further processed to include deeper tissues that are visualized with a high-transmit energy pulse such as the medial layer 430 and the adventitia 432. Referring now to FIG. 26, a medium-transmit energy IVUS image 470 can be further processed to have sections 472 of the image that include the stents and stent blooming artifacts removed from the image. Referring now to FIG. 27, a low-transmit energy IVUS image 480 can be further processed to include the neotissue growth 426 and only those sections 454, 472 that map to the sections of the medium-transmit energy IVUS image 470 that include the stents and stent blooming artifacts 472. Referring now to FIG. 28, the further processed high-transmit energy IVUS image 460 the further processed medium-transmit energy IVUS image 470, and the further processed low-transmit energy IVUS image 480 can be combined into a composite image 490 that visualizes neotissue growth 426 over stent struts 454, visualizes tissue beyond and including the medial layer 430, and avoids stent blooming

artifacts.

**[0063]** FIG. 29 illustrates one embodiment of a signal processing path generating a composite image from images acquired using high-transmit, medium-transmit, and low-transmit energy pulses. The following descriptions are directed to the case of an transmit pulse sequence 22 as illustrated in FIG. 22 wherein a first pulse **XH** has a high-transmit energy, a second pulse **XM** has a medium-transmit energy, and a third pulse **XL** has a low-transmit energy.

**[0064]** A high-transmit energy, medium-transmit energy, or low-transmit energy waveform, generally stored within an imaging engine, is selected in step 550. A transmit waveform is then generated by a transmit pulser in step 552. The transmit waveform is sent through a transmit/receive (T/R) switch in step 554 to an ultrasound transducer 1100. The transducer may operate over frequency ranges of 10 MHz to 80 MHz, generally between 20 MHz and 60 MHz for intracoronary imaging.

**[0065]** The transducer emits an ultrasonic pressure field 1110 to insonify the coronary artery. Some ultrasonic energy is backscattered and received by the transducer. The received ultrasound passes through the T/R switch in step 554 and a rotary coupler in step 556. The rotary coupler may be an inductive rotary coupler or a liquid metal rotary coupler. The rotary coupler interfaces the mechanically rotating imaging core of the catheter to the non-rotating electronics of the patient interface module.

**[0066]** Gain is then applied to the received signal in step 558. A high-pass filter is next applied to the amplified signal in step 560. A time-varying gain is applied to the high-pass filtered signal in step 562. The time-gain compensation is provided, because of the increased attenuation of the ultrasound signal as the signal propagates further into the coronary artery. An anti-aliasing low-pass filter is next applied to the signal in step 564 before the signal is digitized in step 566.

**[0067]** The digitized signals are pre-processed in step 568 wherein pre-processing generally includes band-pass filtering and vector processing techniques. The specific form of pre-processing depends on whether the transmit signal is a high-transmit energy pulse **XH** or a low-transmit energy pulse **XL**. A digital multiplexer 584 receives a first set of pre-processing coefficients **PH** 584, a second set of pre-processing coefficients **PM** 585, and a third set of pre-processing coefficients **PL** 586. The pre-processing coefficients include filter coefficients for band-pass filtering. A vector processing control 580 determines which set of pre-processing coefficients to use for pre-processing. The envelope of the pre-processed signal is detected in step 570. The vector processing control 580 determines whether a digital multiplexer 588 selects a first set of detection coefficients **DH** 590, a second set of detection coefficients **DM** 585, or a third set of detection coefficients **DL** 592 for detection processing. The detected signal is then post-processed in step 572 wherein post-processing generally includes logarithmic compression and gamma correction to generate a visu-

ally appealing and useful image.

**[0068]** The post-processed signals can then be scan converted from polar coordinates to Cartesian coordinates in step 574. The high-transmit energy, medium-transmit energy, and low-energy transmit scan-converted images are then combined into a composite image in step 576. The combination or fusion of the three images into a single composite image are achieved by selecting a portion of the dynamic range of each individual image. The composite image may then have a wider dynamic range than any single image. The composite image may then be compressed to satisfy parameters of the display device. The composite image includes neotissue growth over stent struts and tissue beyond and including the medial layer. The composite image further avoids stent blooming artifacts. The individual high-transmit energy, medium-transmit energy, and low-transmit energy images can be first aligned during post-processing to minimize motion artifacts. In addition, the images can be acquired during a period of relatively little motion, such as end diastole of the cardiac cycle, to further minimize motion artifacts. Motion artifacts can be further minimized by minimizing the depth or range of acquired data in order to minimize time between pulse transmissions.

**[0069]** While particular embodiments of the present invention have been shown and described, modifications may be made, and it is therefore intended to cover in the appended claims all such changes and modifications.

## Claims

1. An intravascular ultrasound imaging system, comprising:

a catheter (1000) having an elongated body having a distal end and an imaging core arranged to be inserted into the elongated body, the imaging core being arranged to transmit ultrasonic energy pulses and to receive reflected ultrasonic energy pulses; and  
an imaging engine (3100) coupled to the imaging core and arranged to provide the imaging core with energy pulses to cause the imaging core to transmit the ultrasonic energy pulses, the energy pulses being arranged in repeated sequences, wherein the energy pulses of each sequence have varying characteristics, and each energy pulse is associated with an image frame,

### characterized in that

the imaging engine comprises a processor that processes the reflected ultrasonic energy pulses in the image frames and a detector that detects the varying characteristic in the reflected ultrasonic energy pulses, and wherein the imaging engine processes the frames according to the detected varying characteristic.

2. The system of claim 1, wherein each sequence of energy pulses includes at least two pulses.
3. The system of claim 1, wherein each sequence of energy pulses includes three pulses. 5
4. The system of claim 3, wherein a first one of the three pulses has a high energy characteristic, wherein a second one of the three pulses has a medium energy characteristic, and wherein a third one of the three pulses has a low energy characteristic. 10
5. The system of claim 1, wherein the varying characteristic is pulse energy. 15
6. The system of claim 1, wherein the varying characteristic is frequency.
7. The system of claim 1, wherein the varying characteristic is bandwidth. 20
8. The system of claim 1, wherein the imaging engine (3100) is arranged to process only reflected ultrasonic energy pulses having a common detected characteristic. 25
9. The system of claim 1, wherein the imaging engine (3100) is further arranged to provide a composite image based upon the varying characteristics of the sequences of reflected ultrasonic energy pulses. 30
10. The system of claim 1, wherein the imaging engine (3100) includes a processor that processes the reflected ultrasonic energy pulses in separate image frames, each image frame corresponding to each different energy pulse characteristic and wherein the imaging engine provides display signals for simultaneously displaying the separate image frames. 35
11. A method comprising: 40
  - providing a catheter (3100) having an elongated body having a distal end and an imaging core arranged to be inserted into the elongated body, the imaging core being arranged to transmit ultrasonic energy pulses and to receive reflected ultrasonic energy pulses; and
  - providing the imaging core with energy pulses to cause the imaging core to transmit the ultrasonic energy pulses, wherein the energy pulses are arranged in repeated sequences, wherein the energy pulses of each sequence have varying characteristics, and
  - each energy pulse is associated with an image frame, 50

**characterized in that**

an imaging engine comprises a processor that processes the reflected ultrasonic energy pulses

es in the image frames and a detector that detects the varying characteristic in the reflected ultrasonic energy pulses, and wherein the imaging engine processes the frames according to the detected varying characteristic.

#### Patentansprüche

1. System zur intravaskulären Ultraschallbildgebung, umfassend:
 

einen Katheter (1000) mit einem länglichen Körper mit einem distalen Ende und einem Bildgebungskern, der dazu eingerichtet ist, in den länglichen Körper eingeführt zu sein, wobei der Bildgebungskern zum Senden von Ultraschallenergieimpulsen und Empfangen von reflektierten Ultraschallenergieimpulsen eingerichtet ist; und eine Bildgebungsmaschine (3100), die an den Bildgebungskern gekoppelt ist und dazu eingerichtet ist, den Bildgebungskern mit Energieimpulsen zu versorgen, um zu bewirken, dass der Bildgebungskern die Ultraschallenergieimpulse sendet, wobei die Energieimpulse in wiederholten Sequenzen angeordnet sind, wobei die Energieimpulse einer jeden Sequenz variierende Charakteristiken haben und jeder Energieimpuls einem Einzelbild zugeordnet ist,

**dadurch gekennzeichnet, dass**

die Bildgebungsmaschine einen Prozessor, der die reflektierten Ultraschallenergieimpulse in den Einzelbildern verarbeitet, und einen Detektor, der die variierende Charakteristik in den reflektierten Ultraschallenergieimpulsen detektiert, umfasst, und wobei die Bildgebungsmaschine die Einzelbilder entsprechend der detektierten variierenden Charakteristik verarbeitet.
2. System gemäß Anspruch 1, bei dem jede Sequenz von Energieimpulsen mindestens zwei Impulse aufweist.
3. System gemäß Anspruch 1, bei dem jede Sequenz von Energieimpulsen drei Impulse aufweist.
4. System gemäß Anspruch 3, bei dem ein erster der drei Impulse eine hohe Energiecharakteristik hat, wobei ein zweiter der drei Impulse eine mittlere Energiecharakteristik hat und wobei ein dritter der drei Impulse eine niedrige Energiecharakteristik hat.
5. System gemäß Anspruch 1, bei dem die variierende Charakteristik die Impulsenergie ist.
6. System gemäß Anspruch 1, bei dem die variierende Charakteristik die Frequenz ist.

7. System gemäß Anspruch 1, bei dem die variierende Charakteristik die Bandbreite ist.
8. System gemäß Anspruch 1, bei dem die Bildgebungsmaschine (3100) dazu eingerichtet ist, nur reflektierte Ultraschallenergieimpulse mit einer gemeinsamen detektierten Charakteristik zu verarbeiten. 5
9. System gemäß Anspruch 1, bei dem die Bildgebungsmaschine (3100) weiter dazu eingerichtet ist, ein zusammengesetztes Bild auf Basis der variierenden Charakteristiken der Sequenzen von reflektierten Ultraschallenergieimpulsen zu liefern. 10
10. System gemäß Anspruch 1, wobei die Bildgebungsmaschine (3100) einen Prozessor aufweist, der die reflektierten Ultraschallenergieimpulse in separaten Einzelbildern verarbeitet, wobei jedes Einzelbild jeder unterschiedlichen Energieimpulscharakteristik entspricht und wobei die Bildgebungsmaschine Anzeigesignale zum gleichzeitigen Anzeigen der separaten Einzelbilder liefert. 15 20
11. Verfahren, welches umfasst: 25

Bereitstellen eines Katheters (3100) mit einem länglichen Körper mit einem distalen Ende und einem Bildgebungskern, der dazu eingerichtet ist, in den länglichen Körper eingeführt zu sein, wobei der Bildgebungskern zum Senden von Ultraschallenergieimpulsen und Empfangen von reflektierten Ultraschallenergieimpulsen eingerichtet ist; und

Versorgen des Bildgebungskerns mit Energieimpulsen, um zu bewirken, dass der Bildgebungskern die Ultraschallenergieimpulse sendet, wobei die Energieimpulse in wiederholten Sequenzen angeordnet sind, wobei die Energieimpulse einer jeden Sequenz variierende Charakteristiken haben und jeder Energieimpuls einem Einzelbild zugeordnet ist, 30 35 40

**dadurch gekennzeichnet, dass**

eine Bildgebungsmaschine einen Prozessor, der die reflektierten Ultraschallenergieimpulse in den Einzelbildern verarbeitet, und einen Detektor, der die variierende Charakteristik in den reflektierten Ultraschallenergieimpulsen detektiert, umfasst, und wobei die Bildgebungsmaschine die Einzelbilder entsprechend der detektierten variierenden Charakteristik verarbeitet. 45 50

## Revendications

1. Système d'imagerie intravasculaire à ultrasons, comprenant :

un cathéter (1000) possédant un corps allongé ayant un embout distal et une base d'imagerie disposée afin d'être insérée dans le corps allongé, la base d'imagerie étant disposée afin de transmettre des impulsions d'énergie ultrasoniques et de recevoir des impulsions d'énergie ultrasoniques réfléchies ; et

un moteur d'imagerie (3100) relié à la base d'imagerie et disposé pour desservir la base d'imagerie en impulsions d'énergie afin d'inciter la base d'imagerie à transmettre les impulsions d'énergie ultrasoniques, les impulsions d'énergie étant disposées par séquences répétées, dans lequel les impulsions d'énergie de chaque séquence possèdent des caractéristiques variables, et chaque impulsion d'énergie est associée à une trame d'image, 15 20

**caractérisé en ce que**

le moteur d'imagerie comprend un processeur qui traite les impulsions d'énergie ultrasoniques réfléchies dans les trames d'image et un détecteur qui détecte la caractéristique variable dans les impulsions d'énergie ultrasoniques réfléchies, et dans lequel le moteur d'imagerie traite les trames selon la caractéristique variable détectée. 25

2. Système selon la revendication 1, dans lequel chaque séquence d'impulsions d'énergie comporte au moins deux impulsions. 30
3. Système selon la revendication 1, dans lequel chaque séquence d'impulsions d'énergie comporte au moins trois impulsions. 35
4. Système selon la revendication 3, dans lequel une première des trois impulsions possède une caractéristique de haute énergie, dans lequel une seconde des trois impulsions possède une caractéristique de moyenne énergie, dans lequel une troisième des trois impulsions possède une caractéristique de basse énergie. 40
5. Système selon la revendication 1, dans lequel la caractéristique variable est l'énergie d'impulsion. 45
6. Système selon la revendication 1, dans lequel la caractéristique variable est la fréquence. 50
7. Système selon la revendication 1, dans lequel la caractéristique variable est la largeur de bande.
8. Système selon la revendication 1, dans lequel le moteur d'imagerie (3100) est disposé pour traiter uniquement des impulsions d'énergie ultrasoniques réfléchies possédant une caractéristique détectée commune. 55

9. Système selon la revendication 1, dans lequel le moteur d'imagerie (3100) est disposé par ailleurs pour livrer une image composite basée sur les caractéristiques variables des séquences d'impulsions d'énergie ultrasoniques réfléchies. 5
10. Système selon la revendication 1, dans lequel le moteur d'imagerie (3100) comporte un processeur qui traite les impulsions d'énergie ultrasoniques réfléchies dans des trames d'image séparées, chaque trame d'image correspondant à chaque caractéristique d'impulsions d'énergie différente et dans lequel le moteur d'imagerie livre des signaux d'affichage en vue d'afficher simultanément les trames d'image séparées. 10 15
11. Méthode comprenant:
- la livraison d'un cathéter (3100) possédant un corps allongé ayant un embout distal et une base d'imagerie disposée afin d'être insérée dans le corps allongé, la base d'imagerie étant disposée afin de transmettre des impulsions d'énergie ultrasoniques et de recevoir des impulsions d'énergie ultrasoniques réfléchies ; et 20 25
- la desserte de la base d'imagerie en impulsions d'énergie afin d'inciter la base d'imagerie à transmettre les impulsions d'énergie ultrasoniques, dans laquelle les impulsions d'énergie sont disposées par séquences répétées, dans laquelle les impulsions d'énergie de chaque séquence possèdent des caractéristiques variables, et 30
- chaque impulsion d'énergie est associée à une trame d'image, 35
- caractérisée en ce**
- qu'un** moteur d'imagerie comprend un processeur qui traite les impulsions d'énergie ultrasoniques réfléchies dans les trames d'image et un détecteur qui détecte la caractéristique variable dans les impulsions d'énergie ultrasoniques réfléchies, et dans lequel le moteur d'imagerie traite les trames selon la caractéristique variable détectée. 40 45

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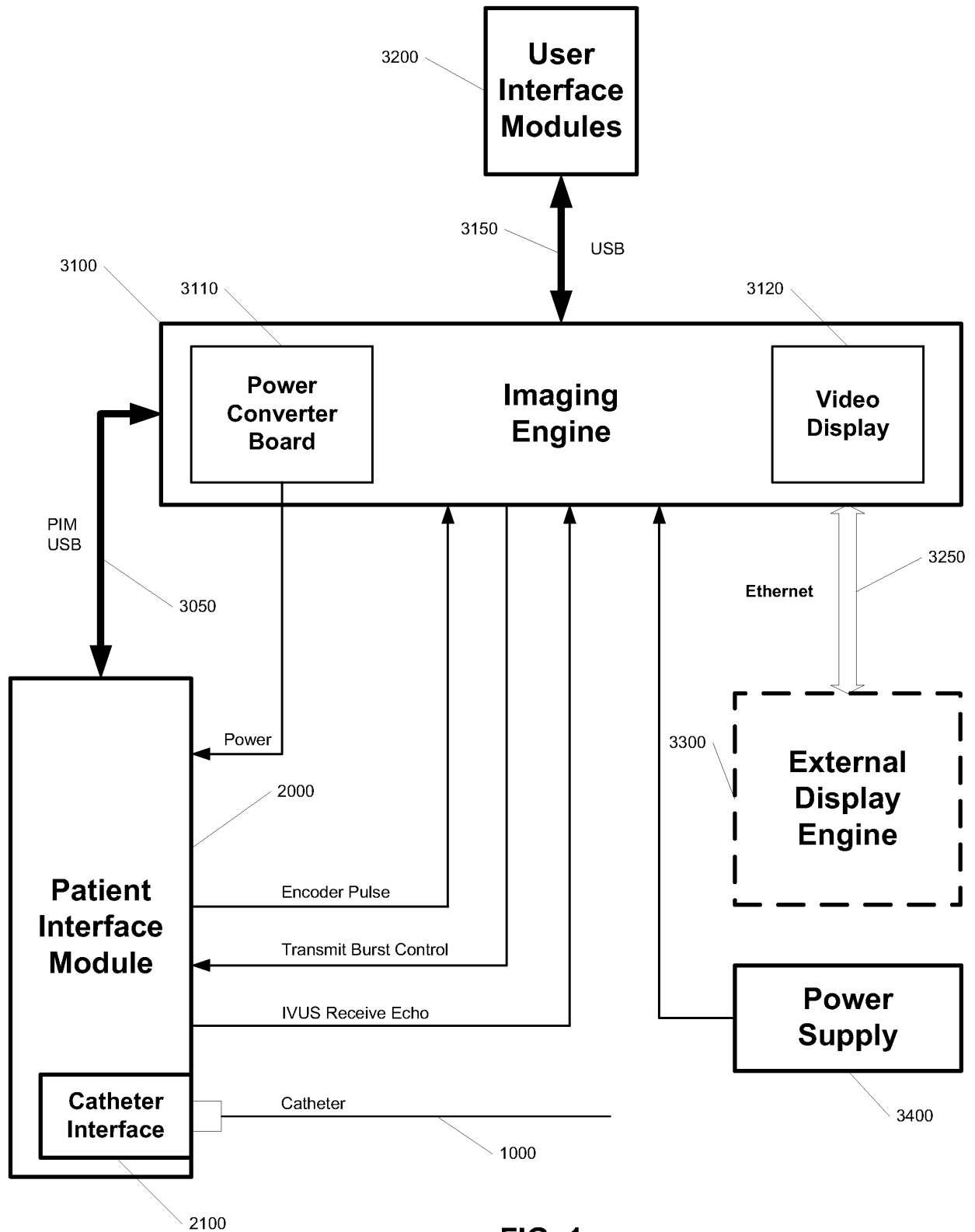
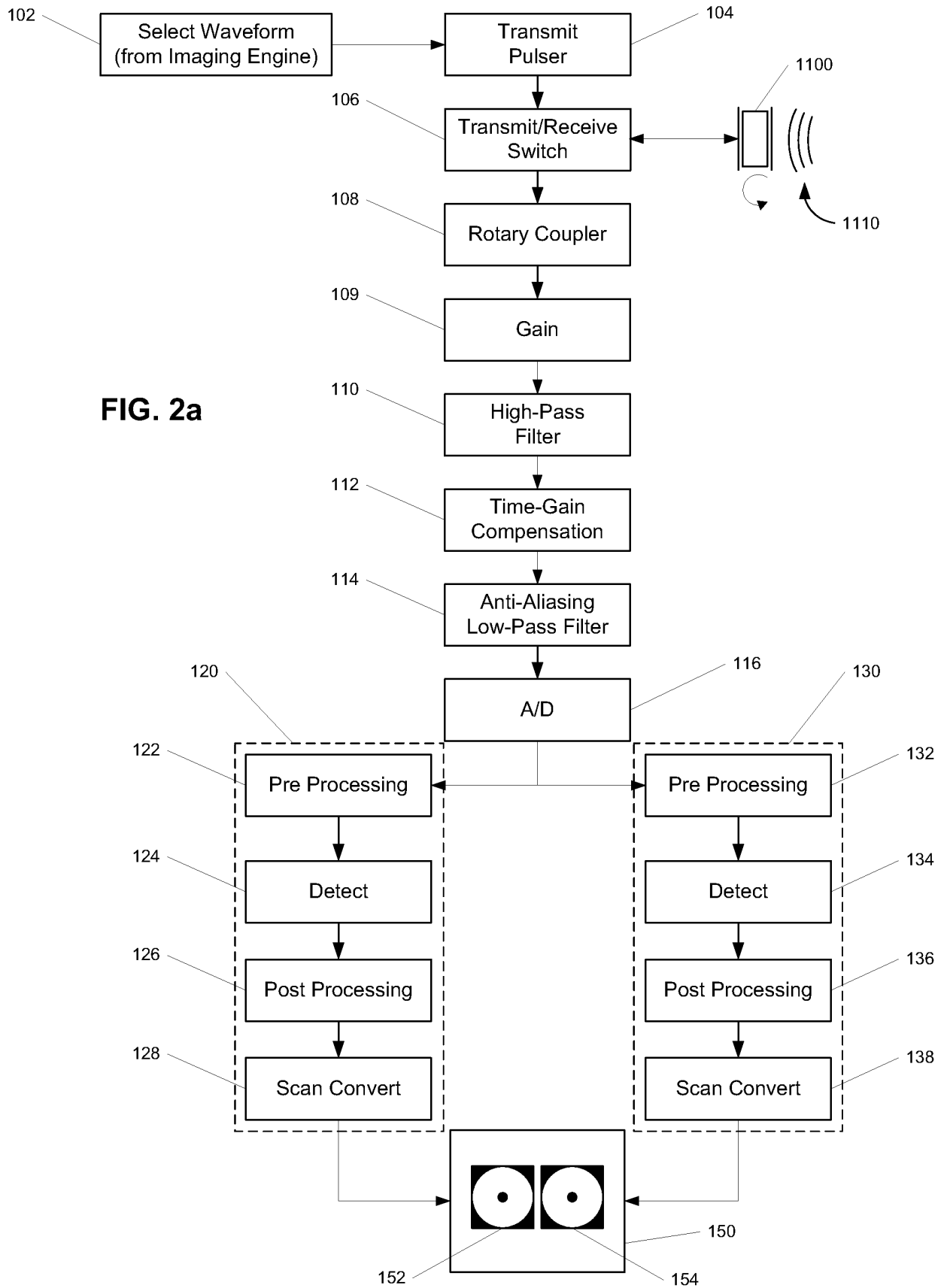
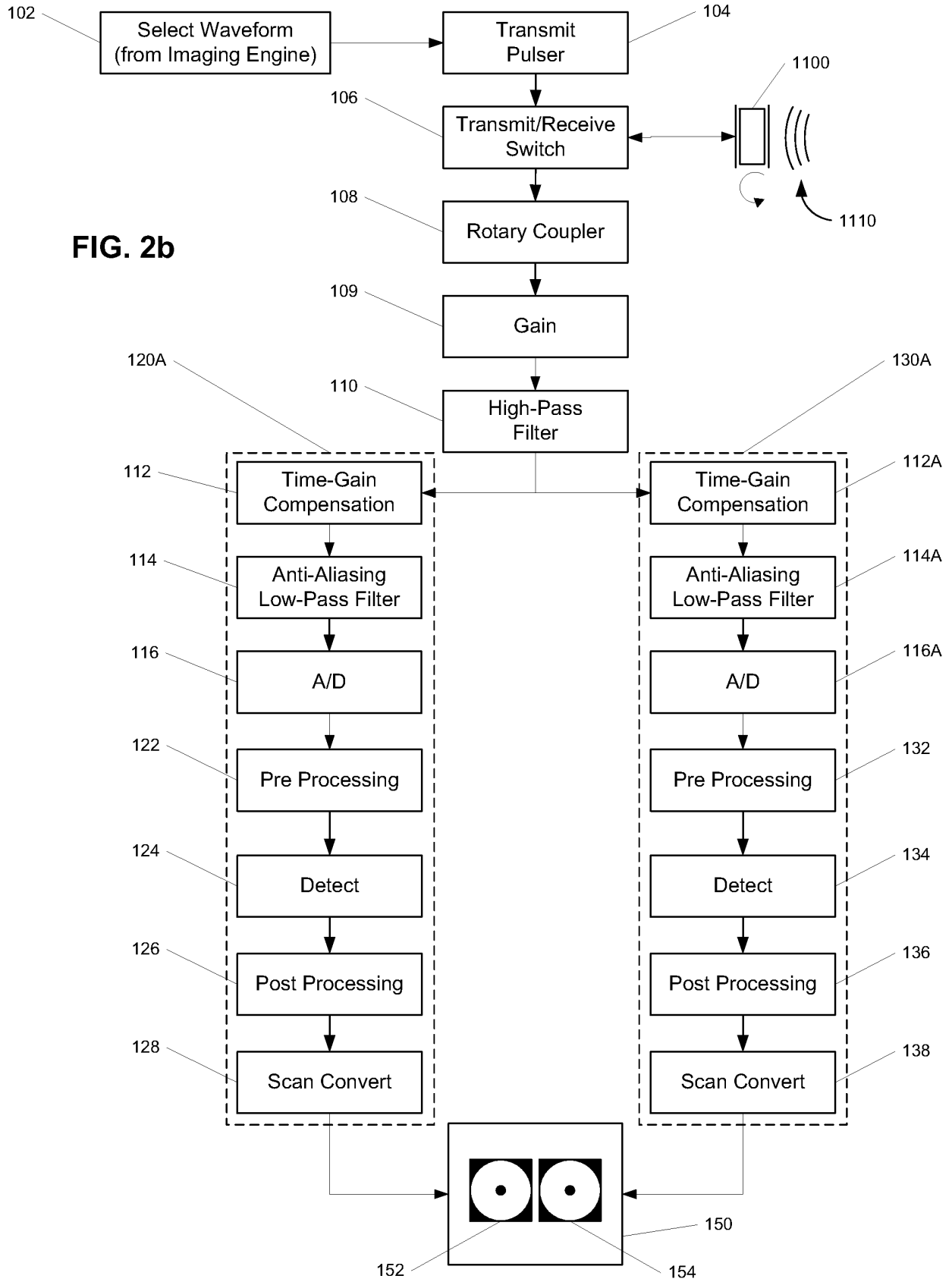
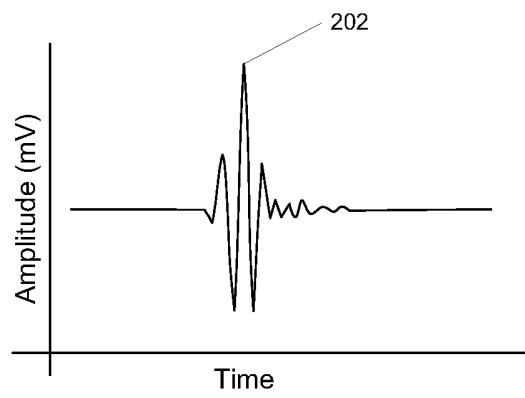


FIG. 1

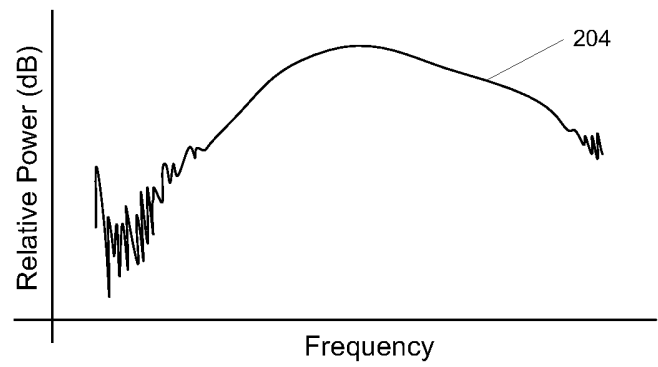




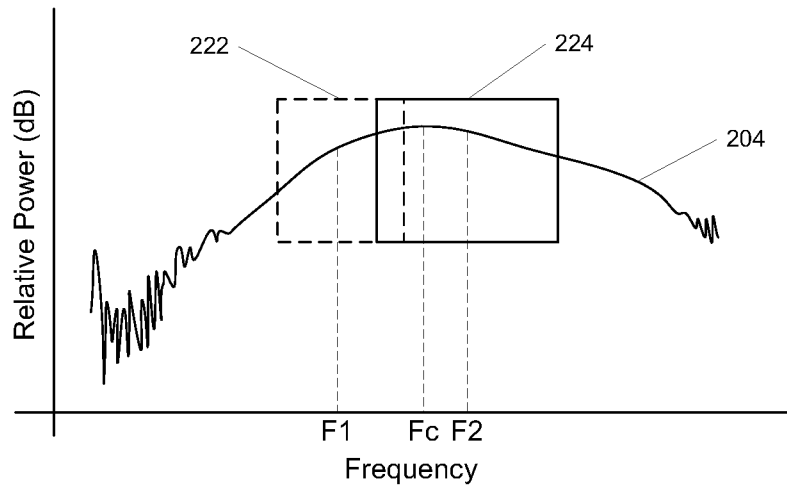




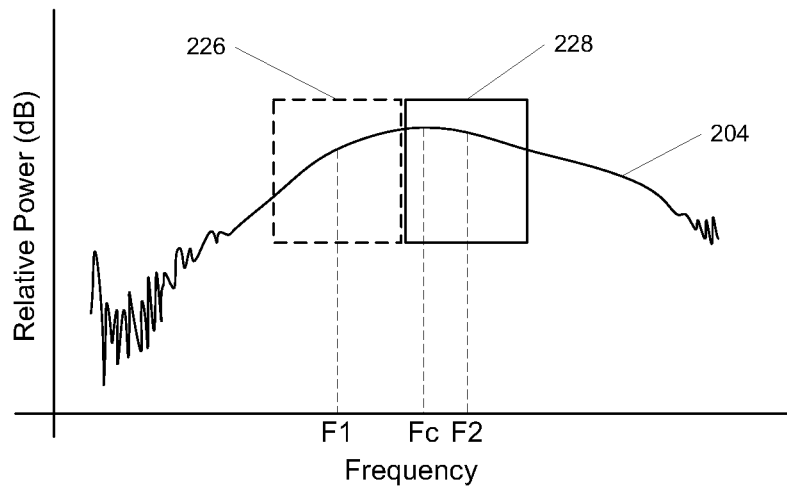
**FIG. 3a**



**FIG. 3b**



**FIG. 4a**



**FIG. 4b**

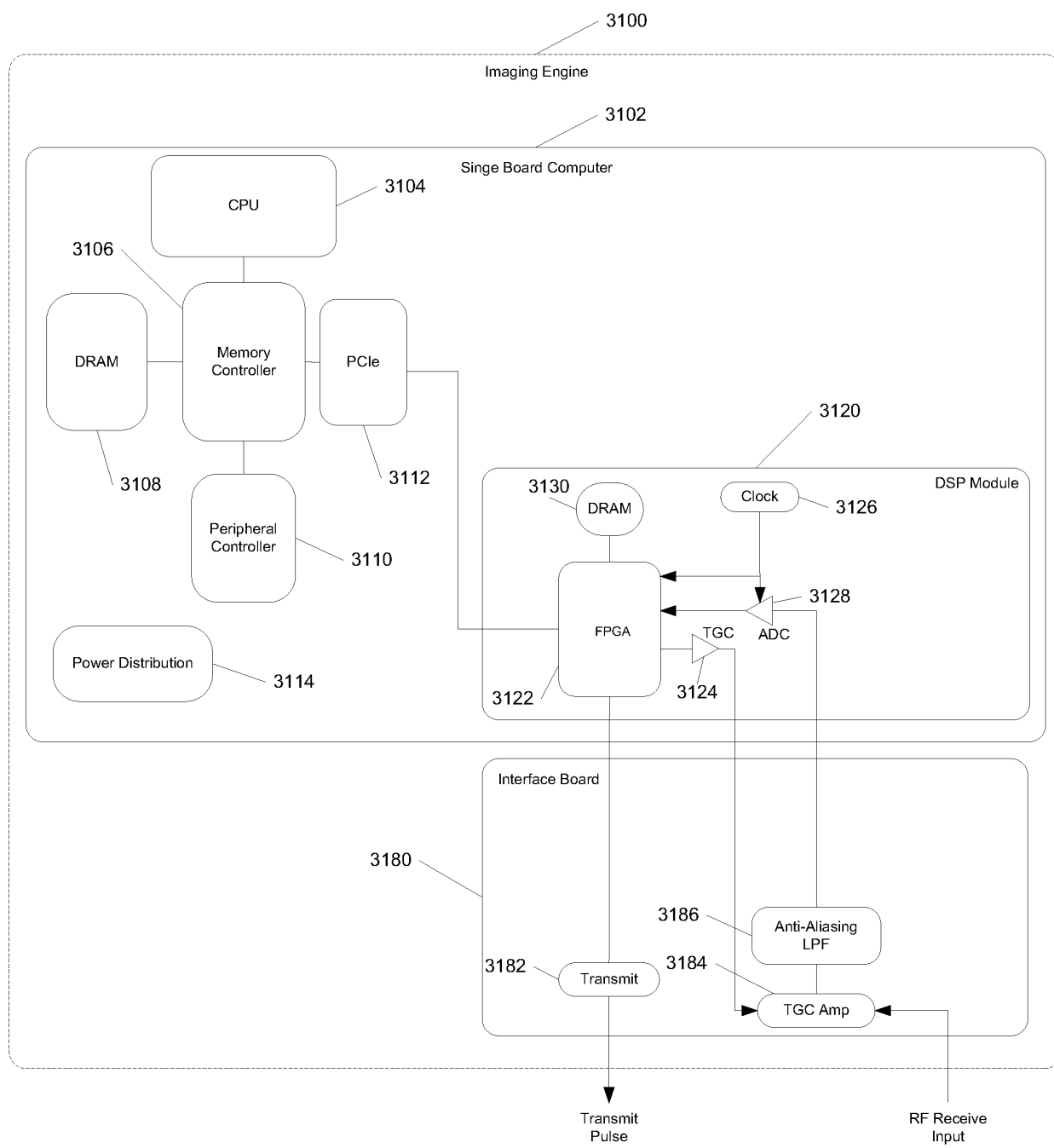


FIG. 5a

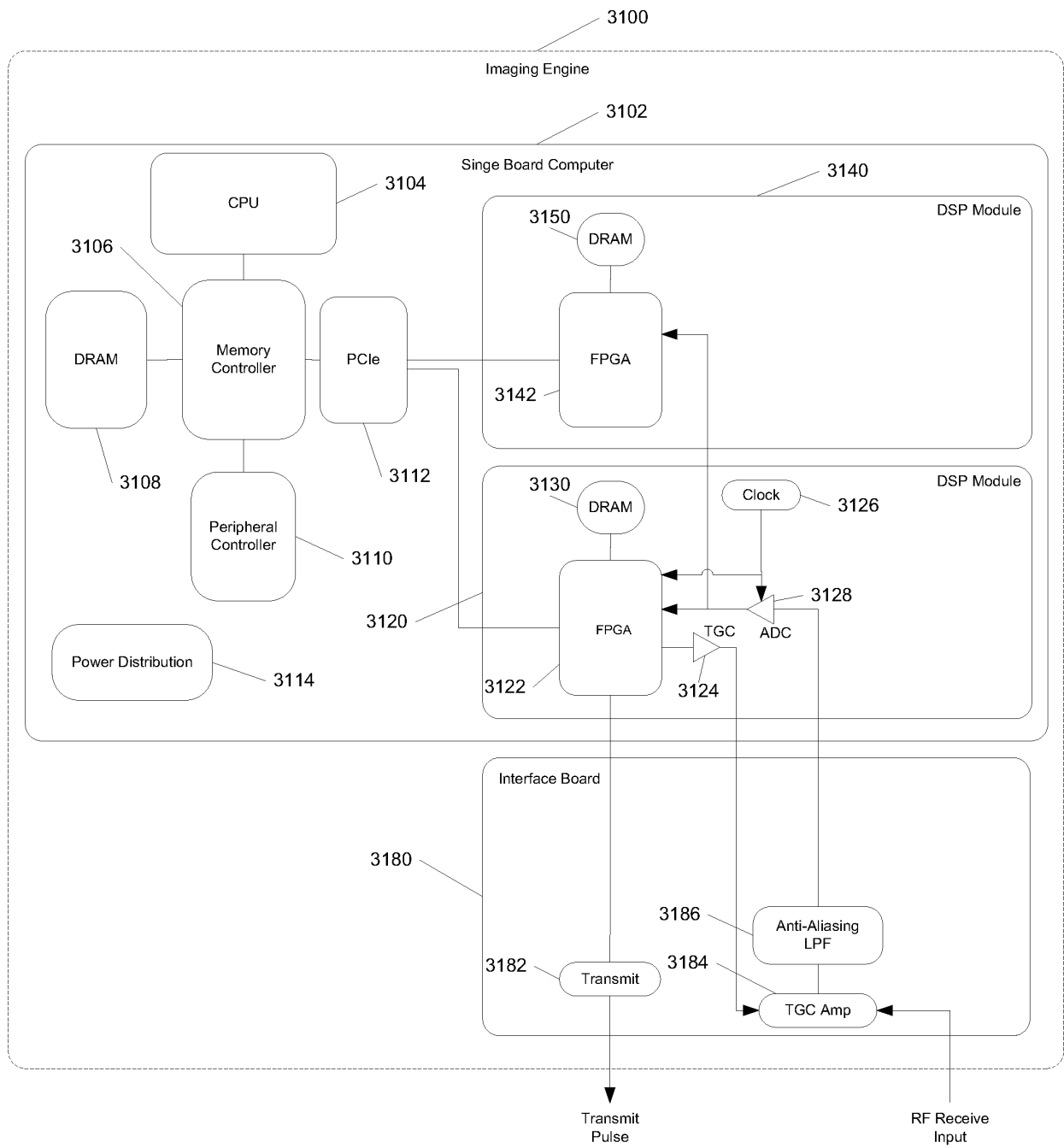


FIG. 5b

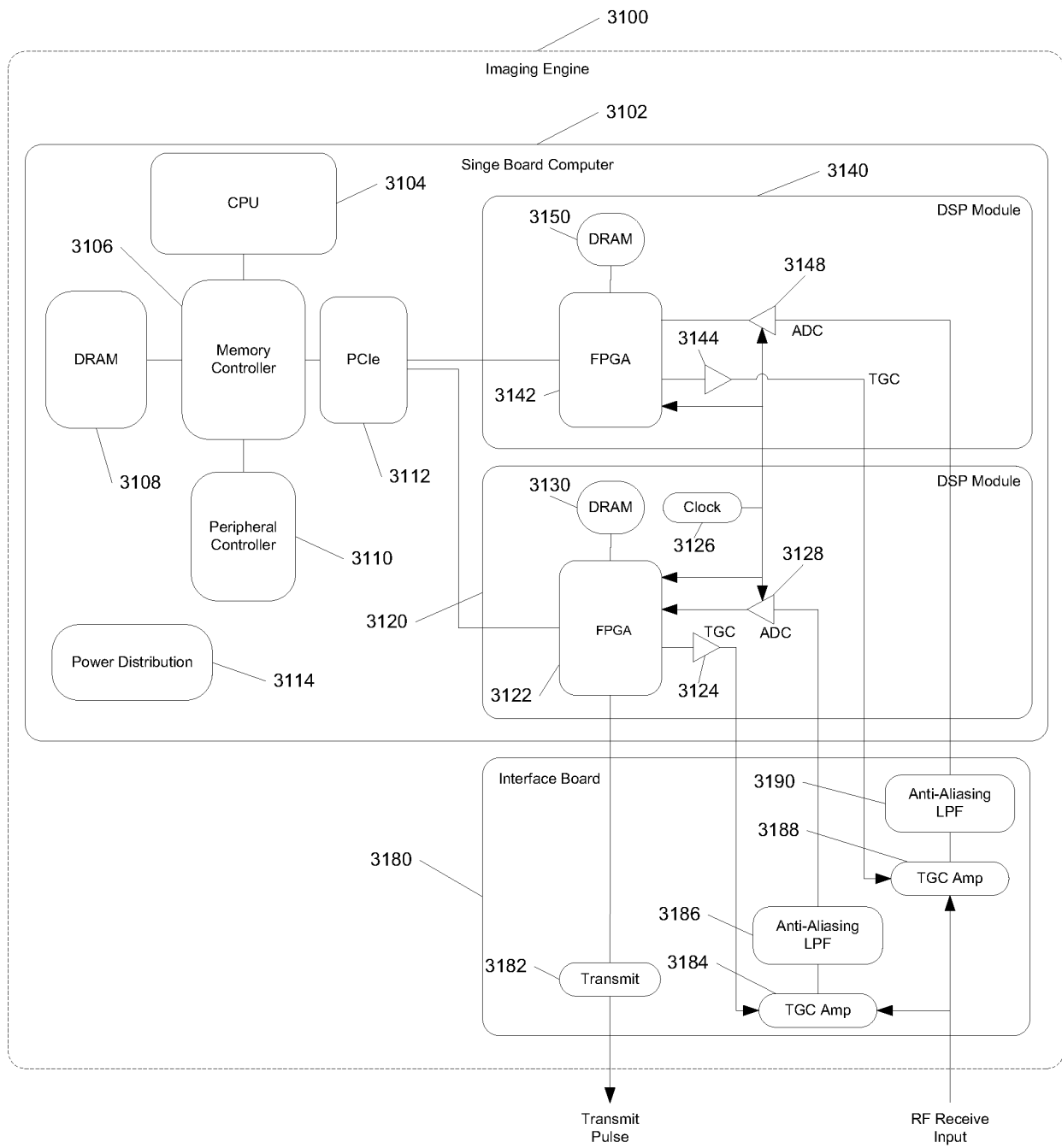
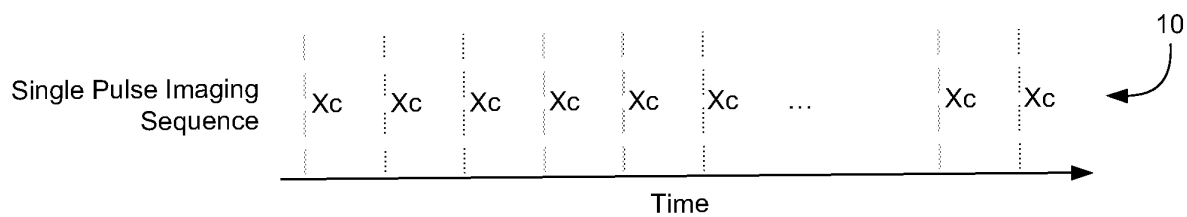
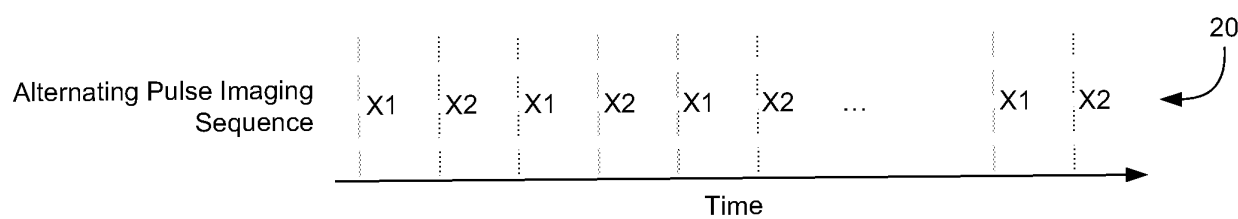


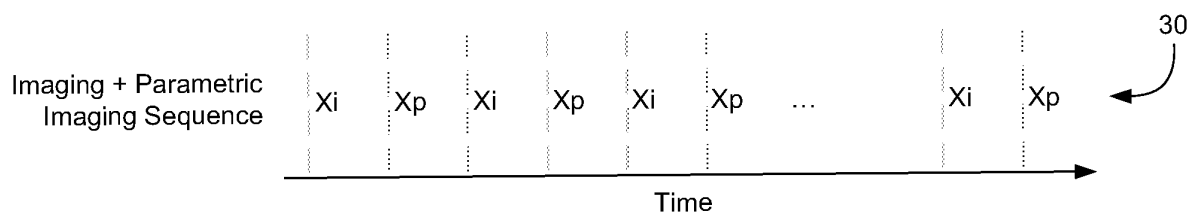
FIG. 5c



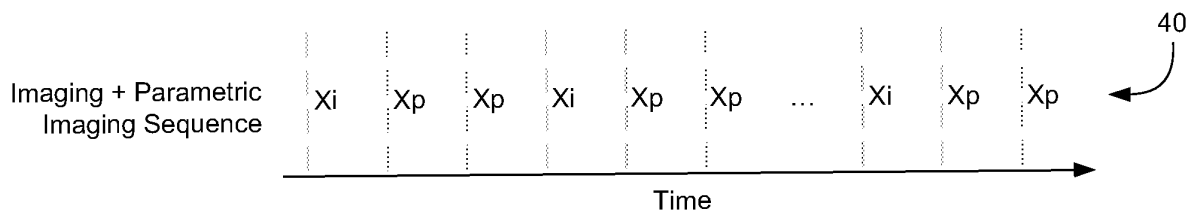
**FIG. 6a**



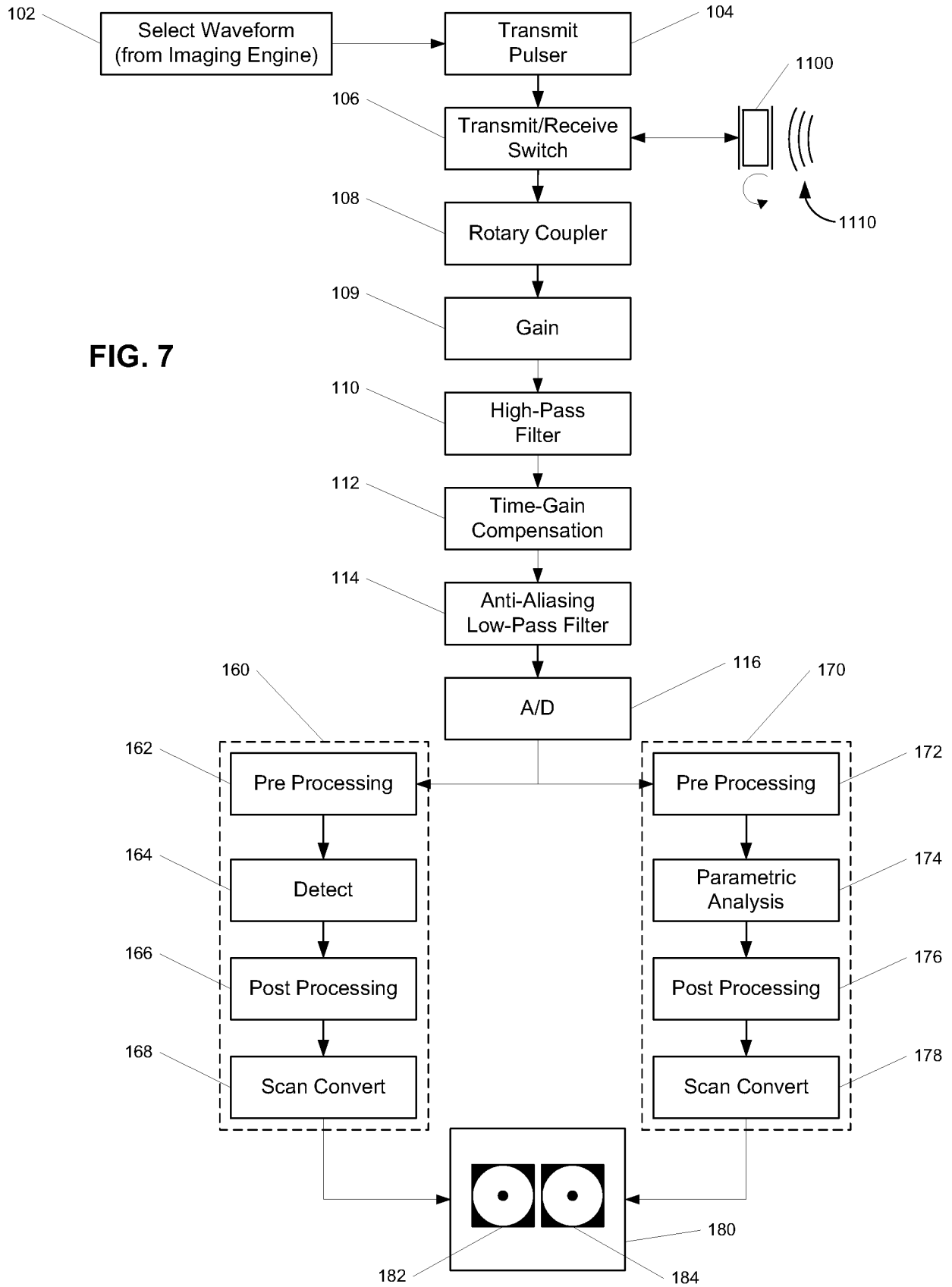
**FIG. 6b**

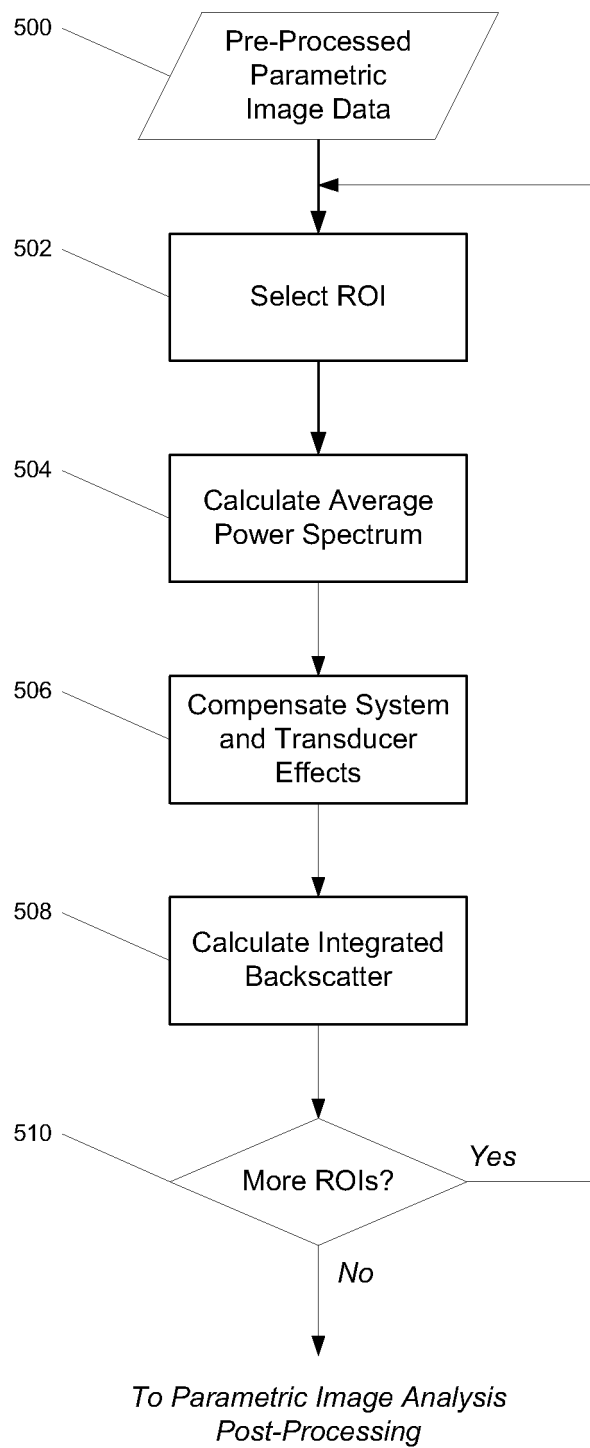


**FIG. 6c**



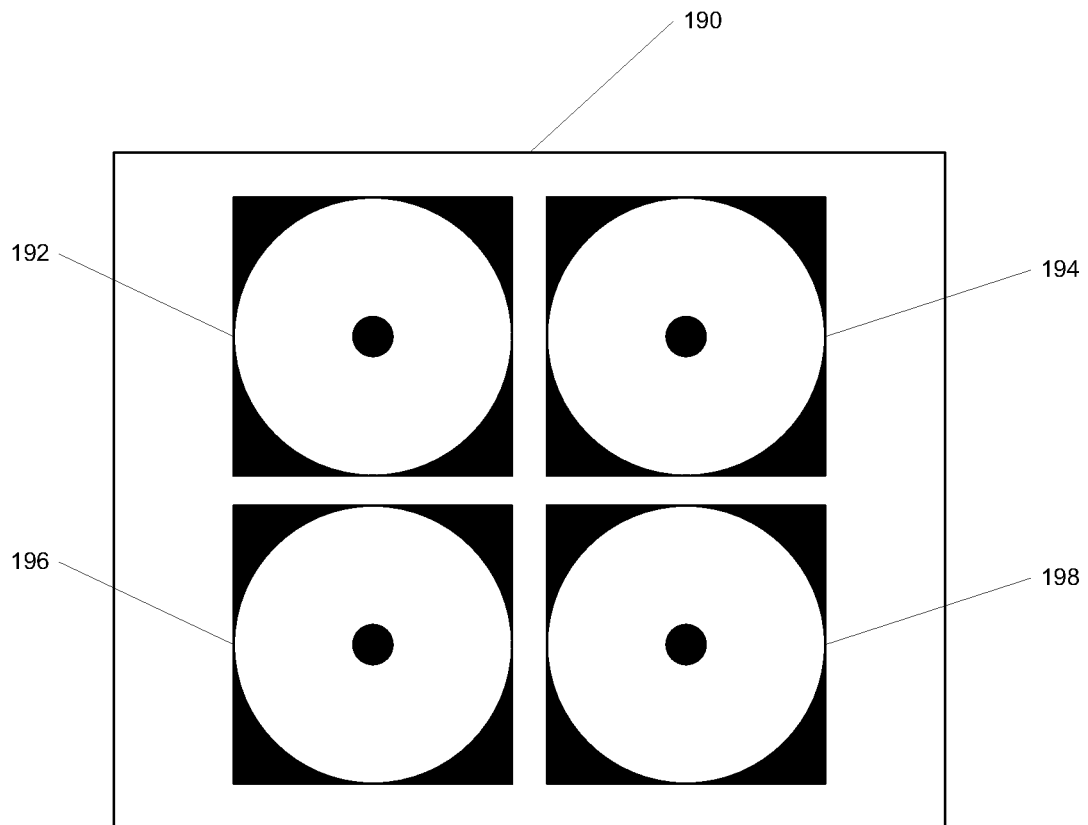
**FIG. 6d**





**FIG. 8**





**FIG. 9**

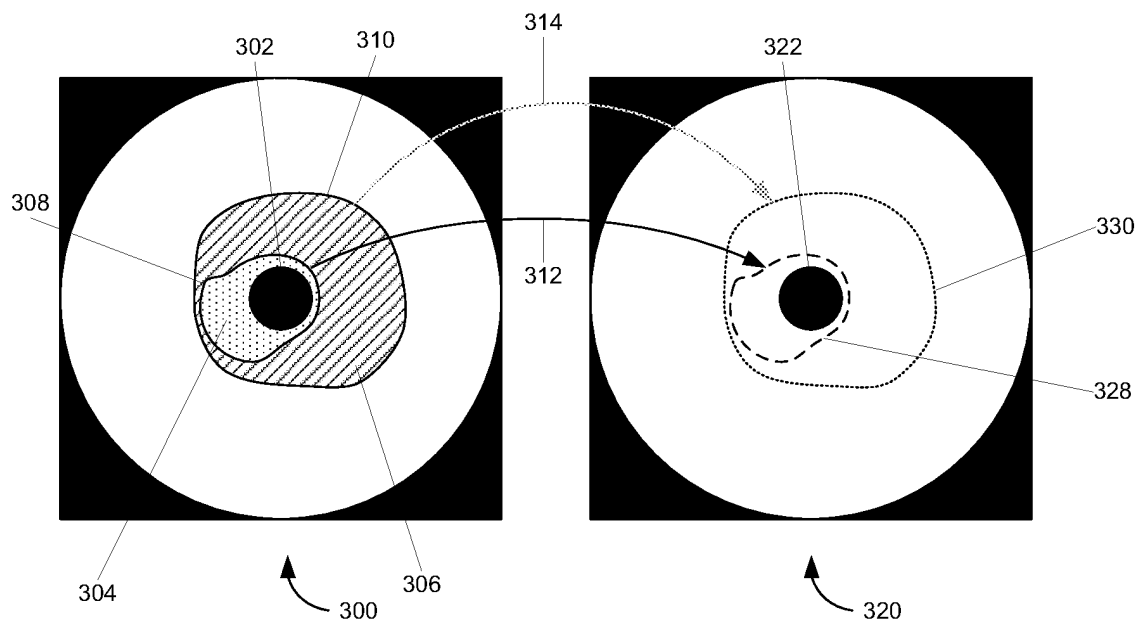


FIG. 10a

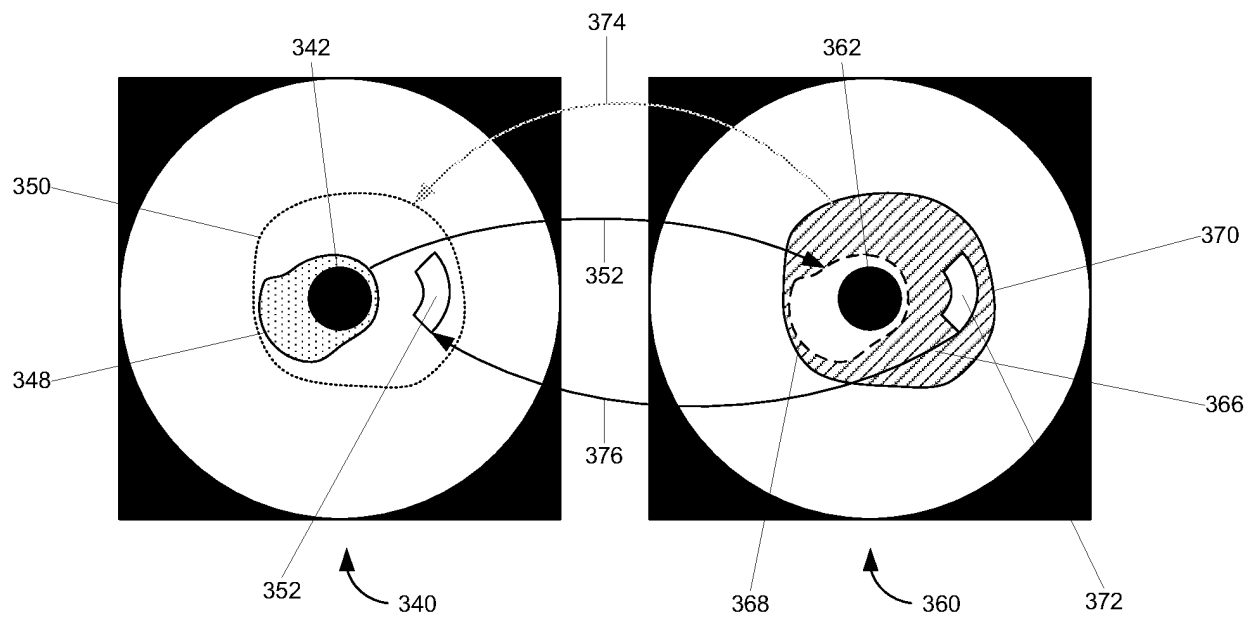


FIG. 10b

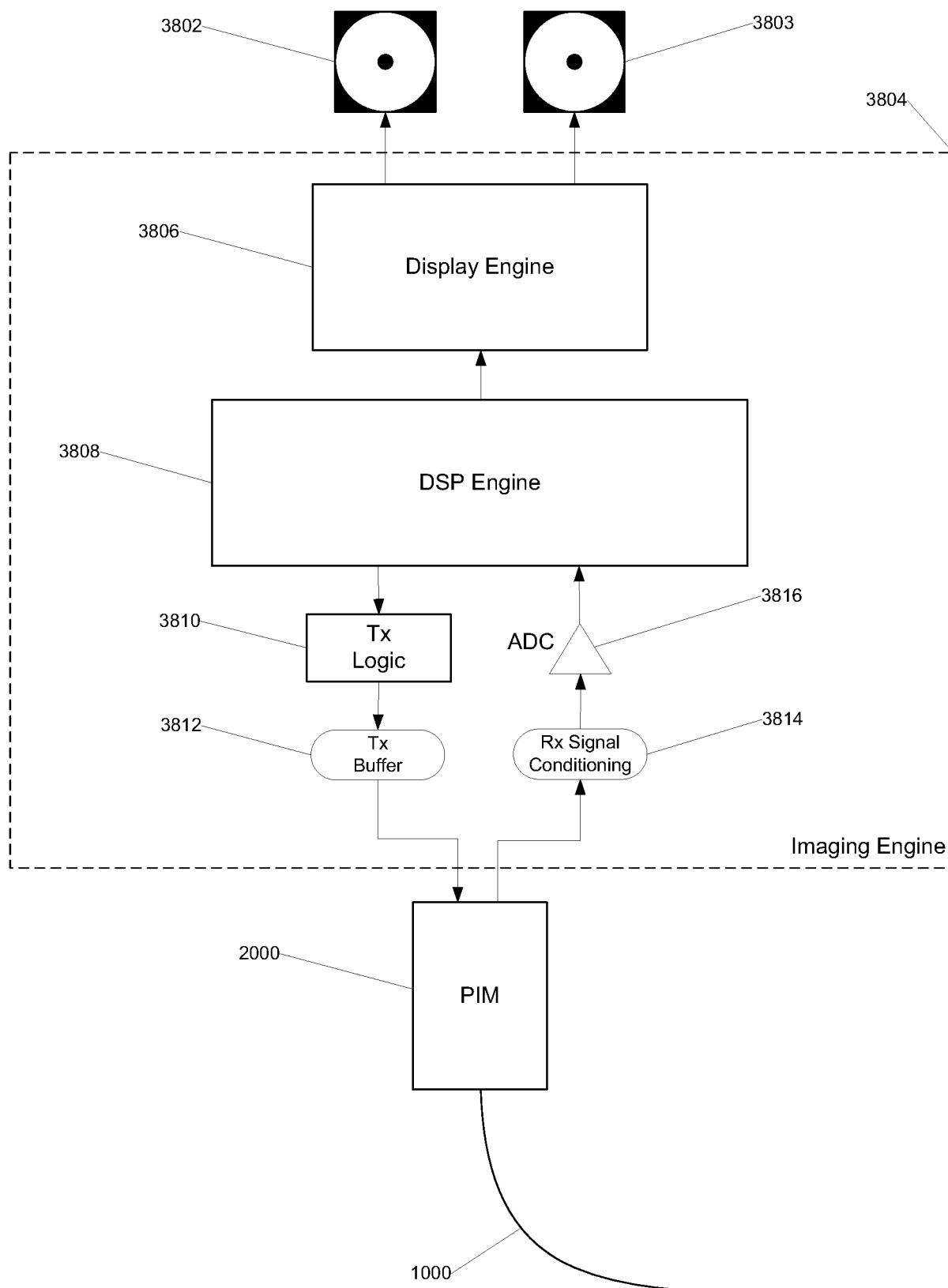


FIG. 11

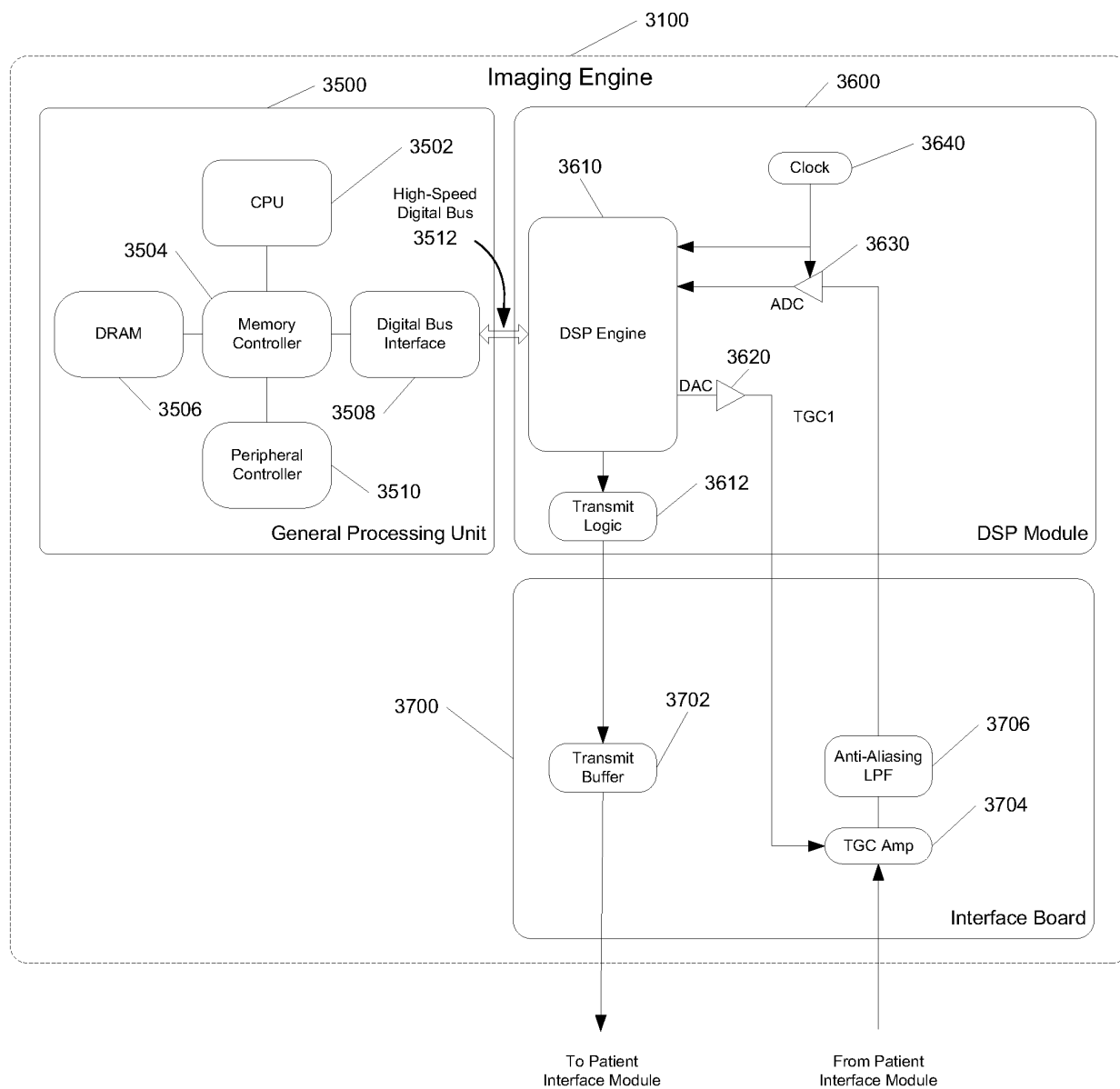


FIG. 12

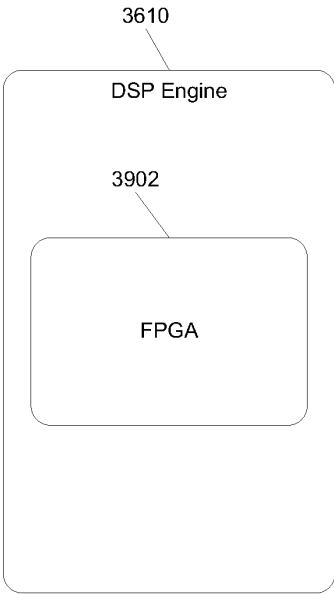


FIG. 13

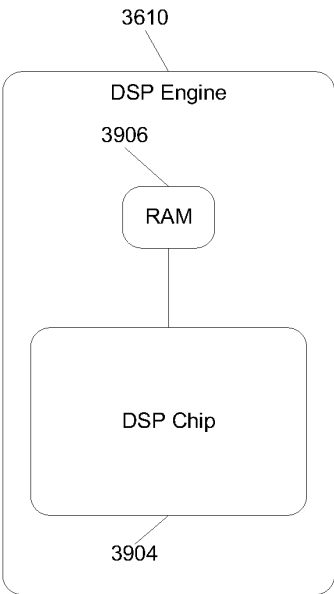


FIG. 14

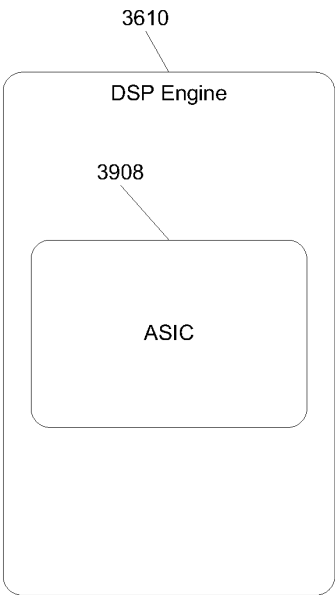


FIG. 15

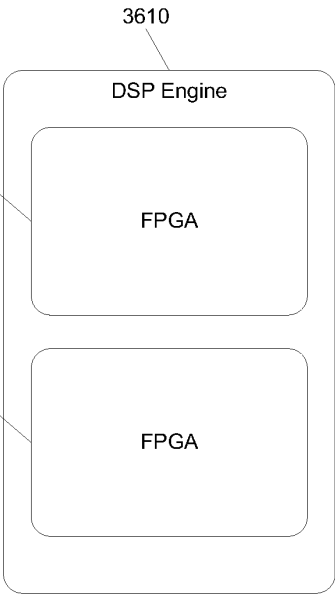


FIG. 16

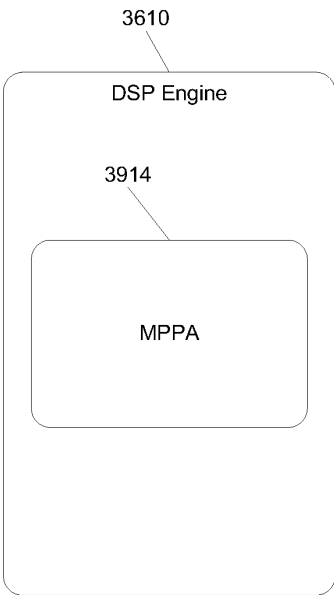


FIG. 17

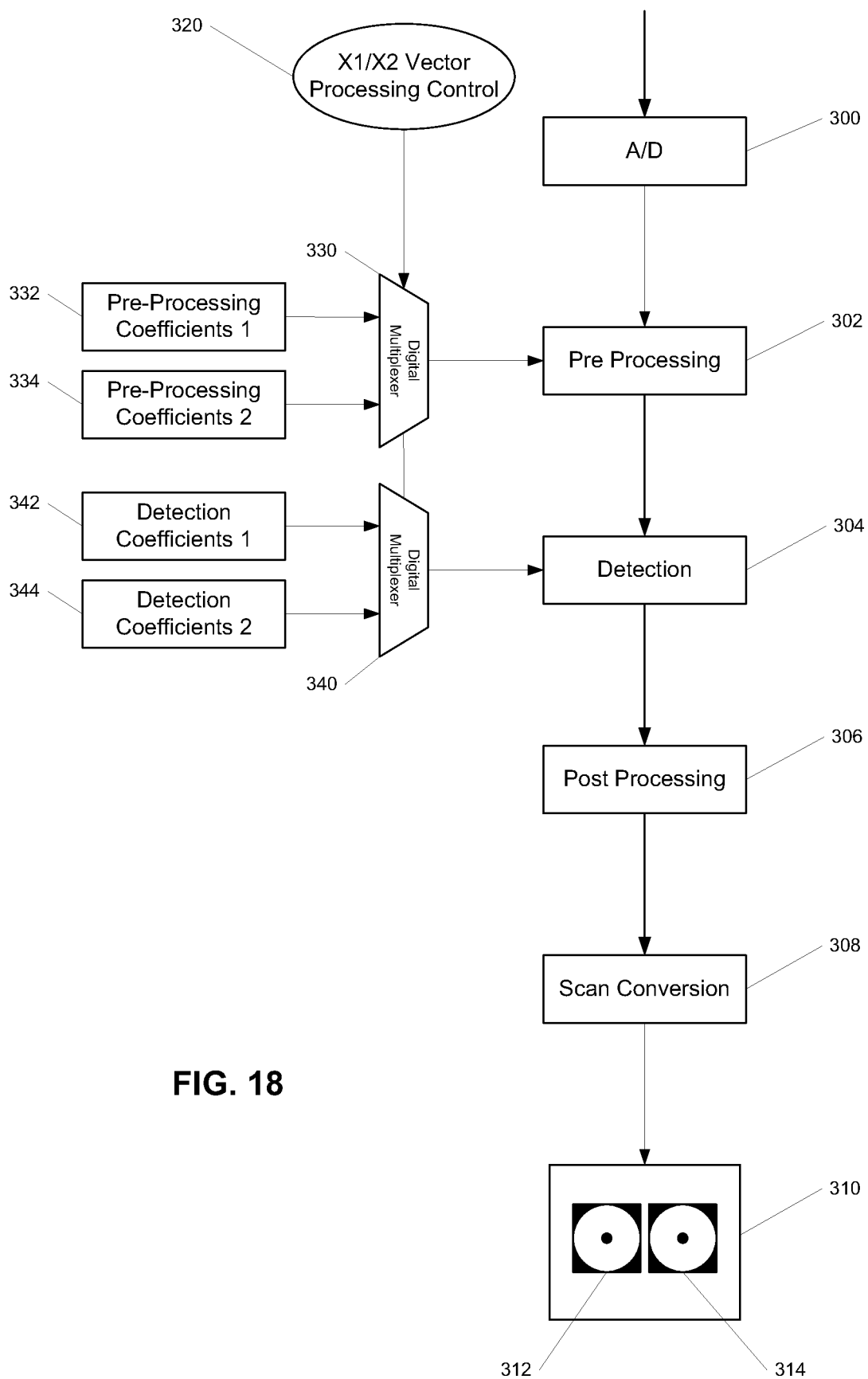
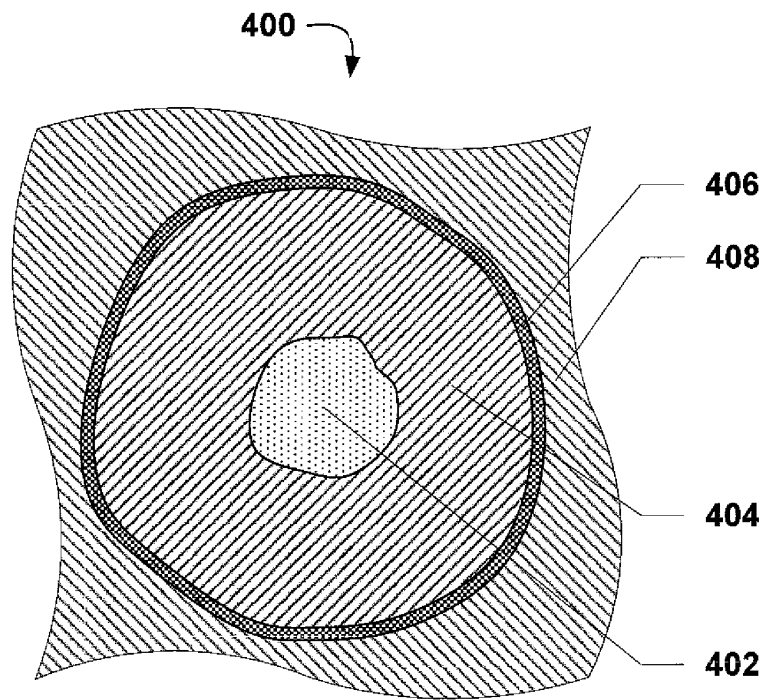
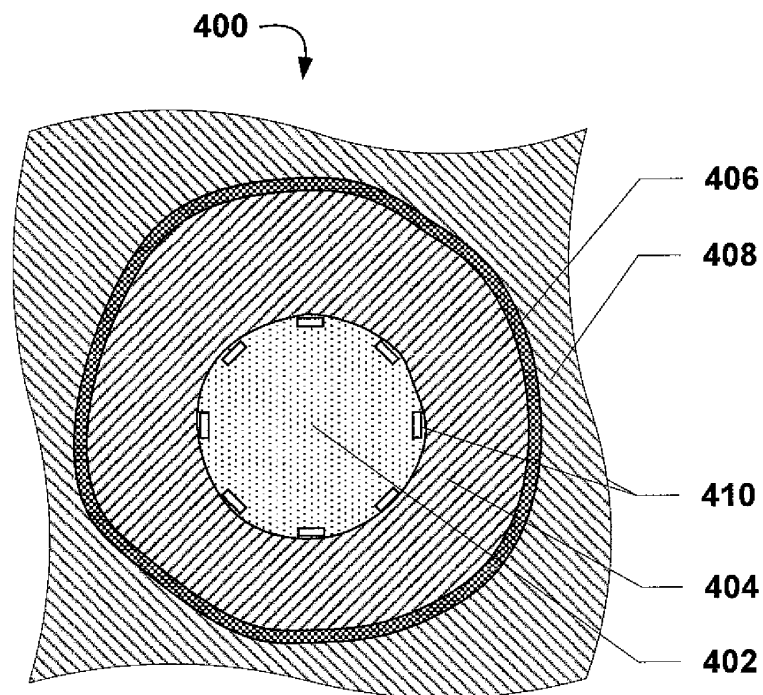


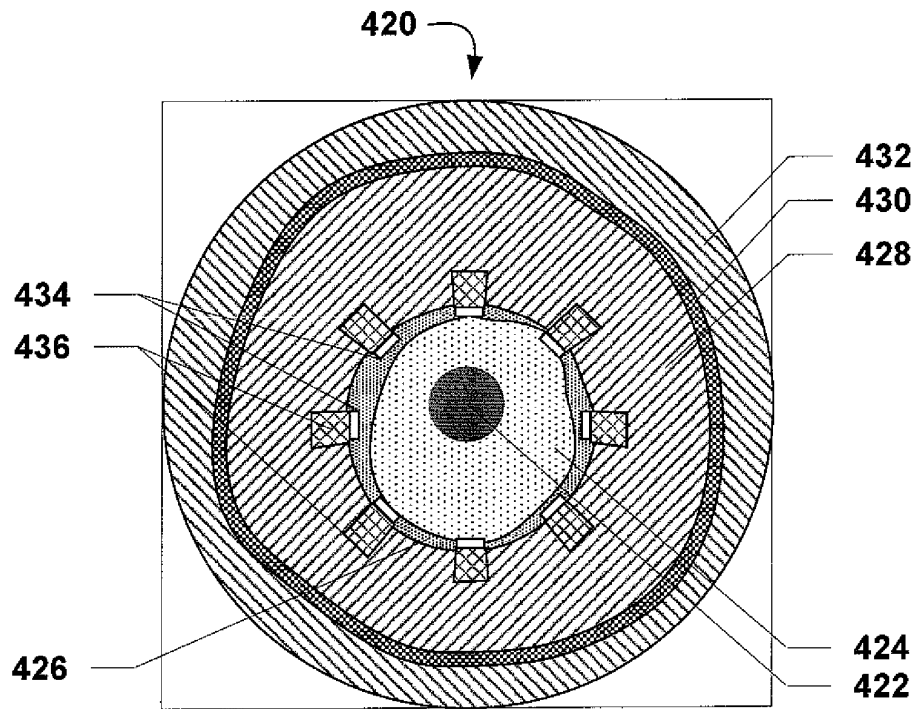
FIG. 18



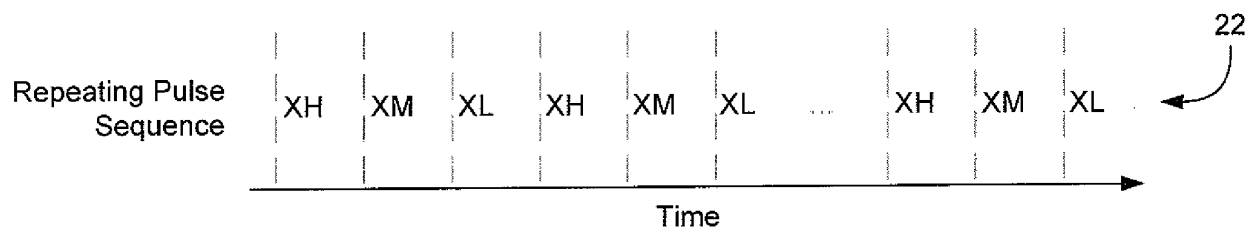
**FIG. 19**



**FIG. 20**



**FIG. 21**



**FIG. 22**



FIG. 23

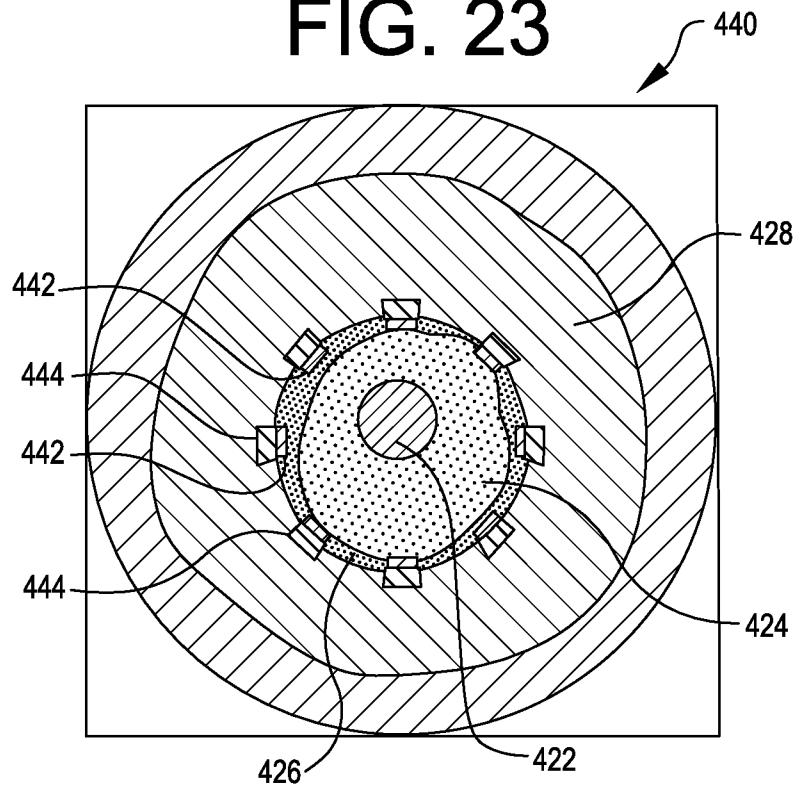


FIG. 24

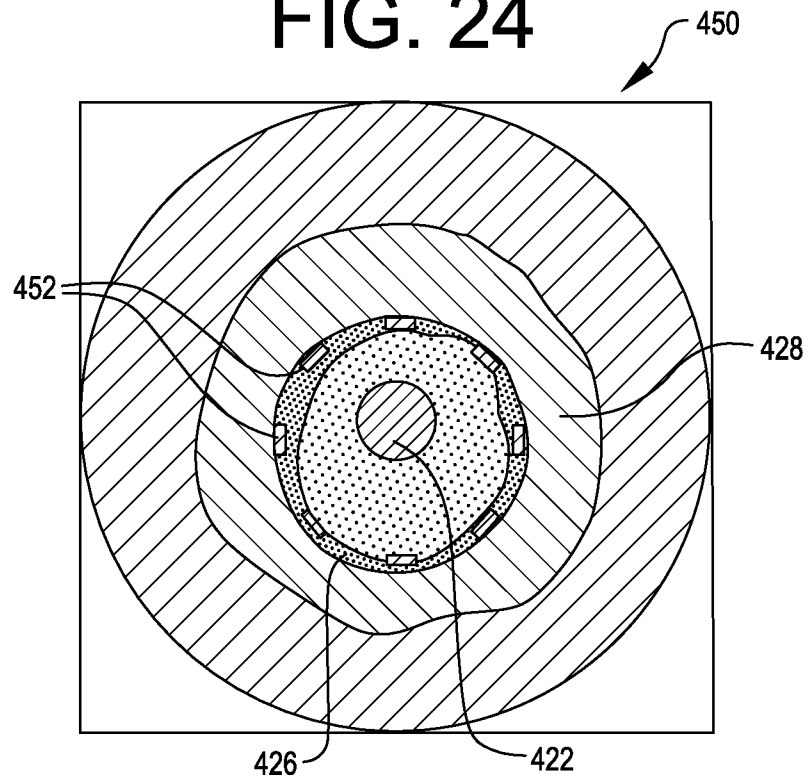


FIG. 25

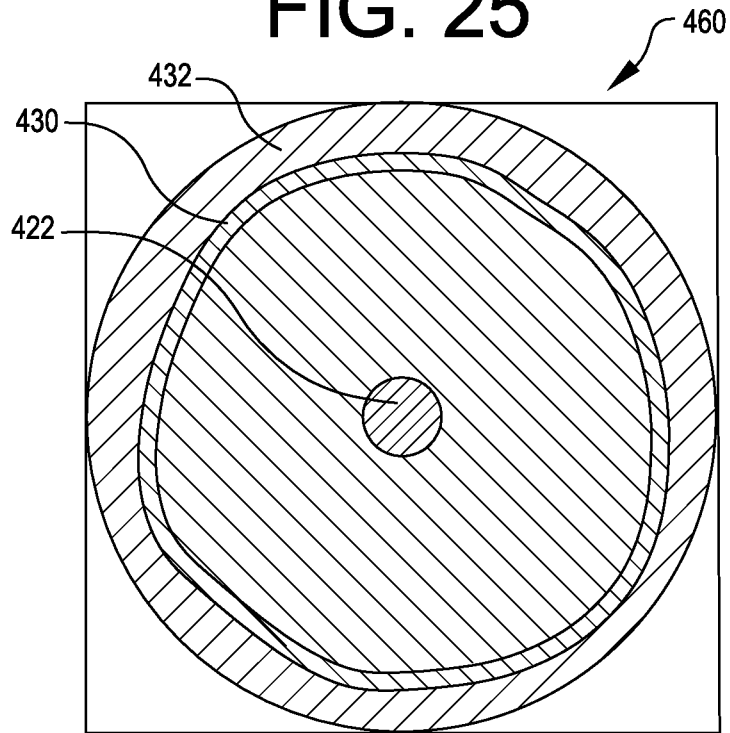


FIG. 26

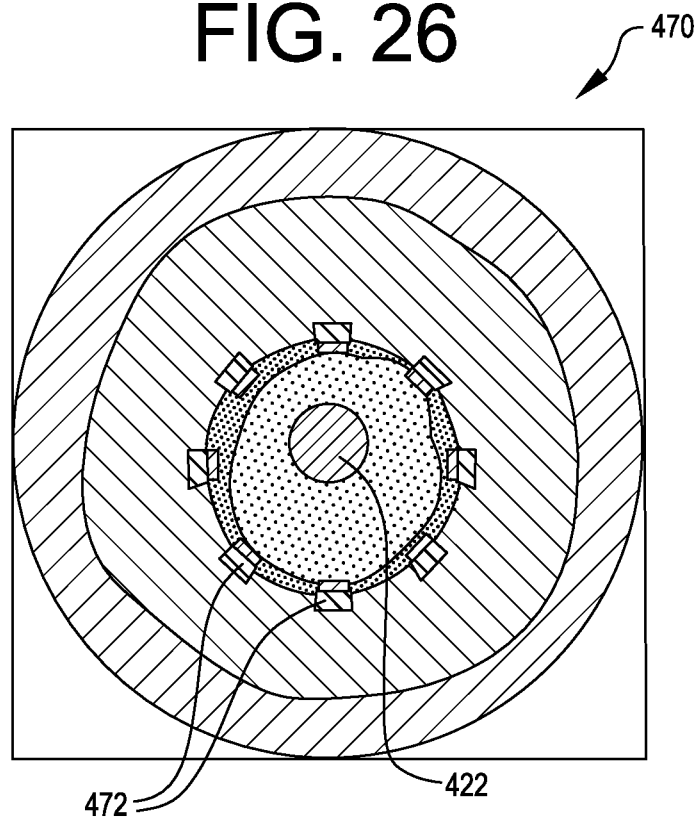


FIG. 27

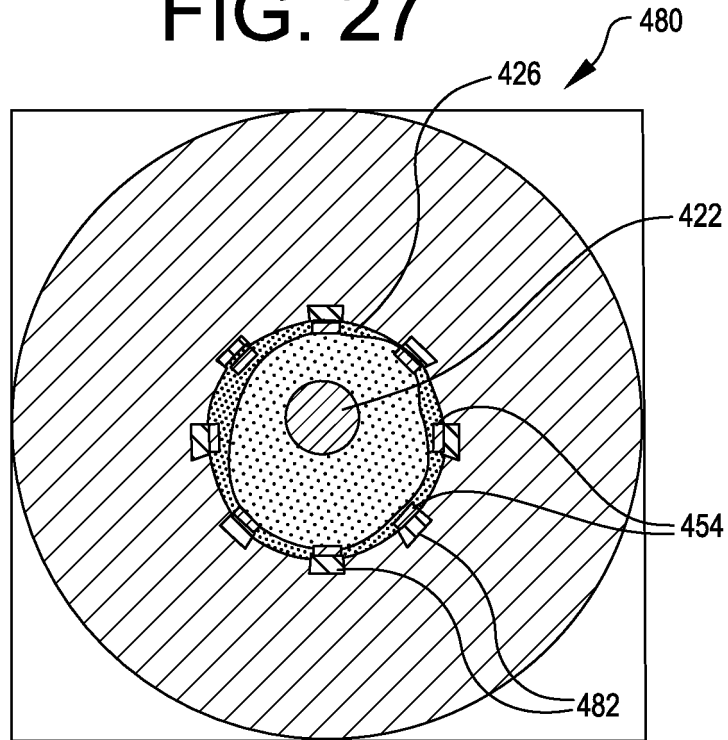
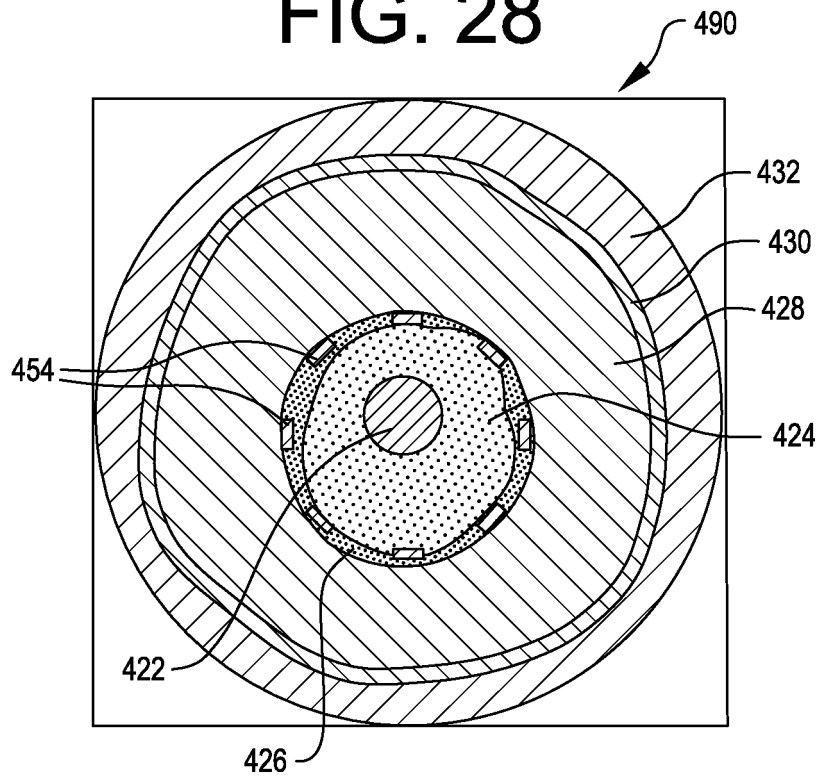


FIG. 28



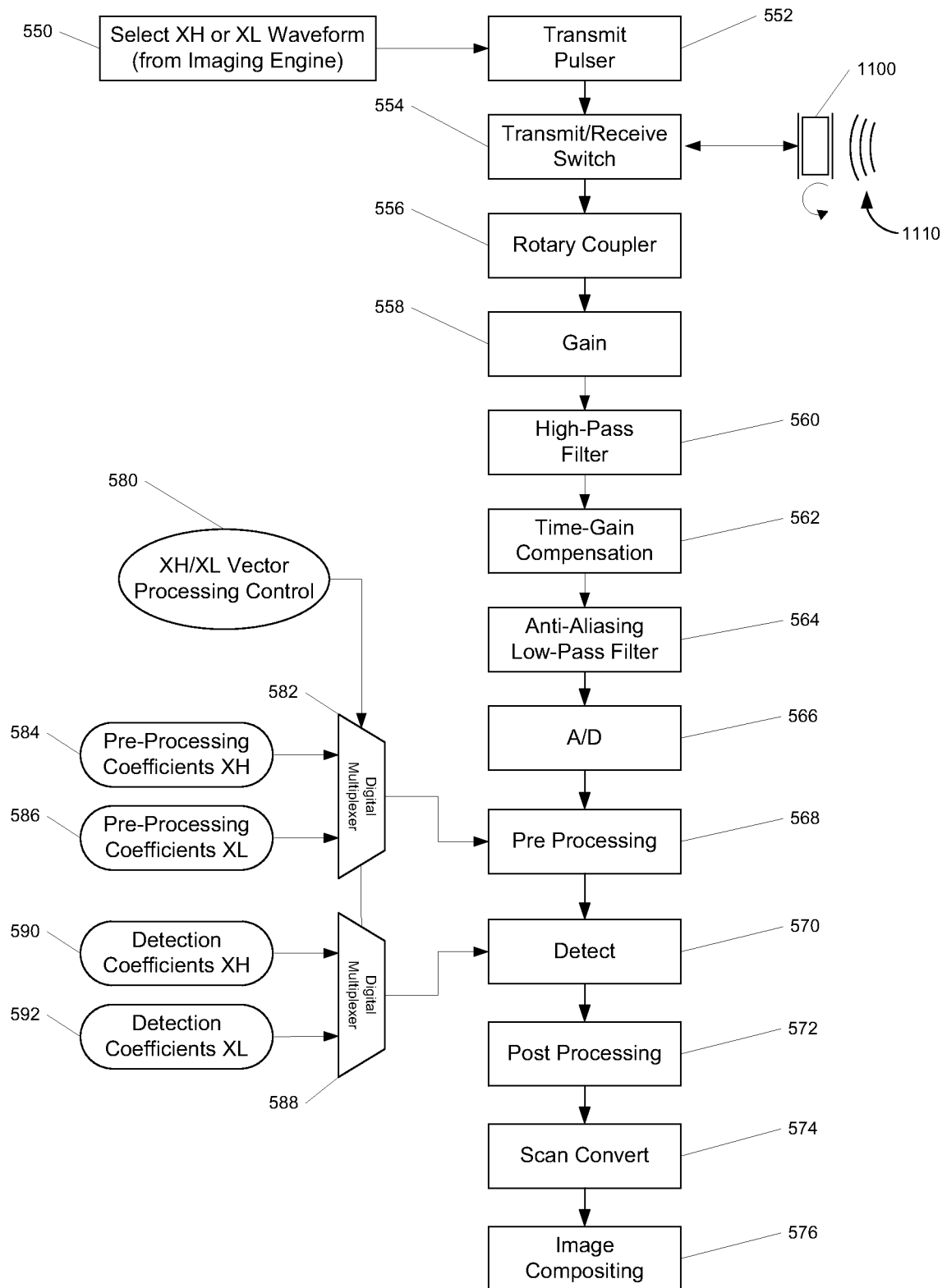


FIG. 29

**REFERENCES CITED IN THE DESCRIPTION**

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- US 6139501 A, Roundhill [0006]
- US 2008200815 A1 [0008]
- US 46585309 A [0018]

专利名称(译)	用于共同配准成像的血管内超声系统		
公开(公告)号	<a href="#">EP2488107A4</a>	公开(公告)日	2013-05-15
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[标]申请(专利权)人(译)	SILICON VALLEY MEDICAL INSTR		
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优先权	61/250781 2009-10-12 US 61/256543 2009-10-30 US		
其他公开文献	EP2488107A2 EP2488107B1		
外部链接	<a href="#">Espacenet</a>		

#### 摘要(译)

一种具有导管的血管内超声成像系统，该导管具有细长主体，该细长主体具有远端，并且该成像核心被布置为插入该细长主体中。成像芯被布置为发射超声能量脉冲并接收反射的超声能量脉冲。该系统还包括成像引擎，该成像引擎耦合至成像核心并且被布置为向成像核心提供能量脉冲，以使成像核心发送超声能量脉冲。能量脉冲以重复的顺序排列，并且每个序列的能量脉冲具有变化的特性。反射脉冲可以被处理以提供由每个不同特性产生的图像的合成图像。