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(54) **Title**: IVUS SYSTEM WITH ROTARY CAPACITIVE COUPLING

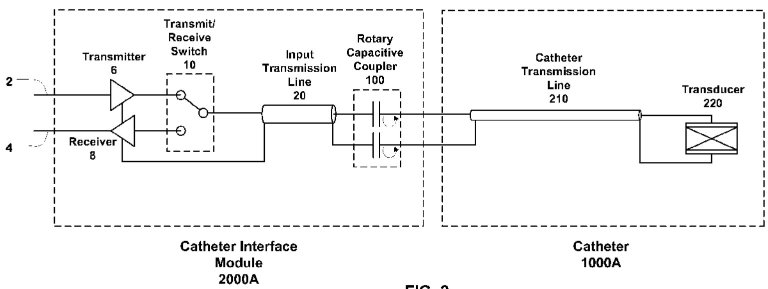

FIG. 2

(57) **Abstract**: An imaging system comprises a catheter having a lumen, a rotatable imaging probe within the catheter lumen including a distal transducer and first and second conductors coupled to the transducer, and a coupler that couples the rotatable first and second conductors to non-rotatable third and fourth conductors, respectively. The coupler includes a rotary capacitive coupler.

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IVUS SYSTEM WITH ROTARY CAPACITIVE COUPLING

PRIORITY CLAIM

[1] The present application claims the benefit of copending United States Provisional Patent Application No. 61/127,943, filed 15 May 2008, which application is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[2] The present invention generally relates to rotary couplers. The present invention more specifically relates to a capacitively coupled rotary coupler for use in a minimally invasive imaging catheter and system.

[3] Intravascular catheters such as intravascular ultrasonic (IVUS) catheters enable imaging of internal structures in the body. In particular, coronary IVUS catheters are used in small arteries of the heart to visualize coronary artery disease. An IVUS catheter will, in general, employ at least one high frequency (20 MHz - 45 MHz) ultrasonic transducer that creates pressure waves for visualization. At least one transducer is typically housed within a surrounding sheath or catheter member and mechanically rotated for 360° visualization.

[4] The highest frequencies at which commercially available coronary imaging catheters operate are 40 MHz and 45 MHz. These high frequency probes have an axial resolution of approximately 200 microns. An axial resolution of 200 microns is insufficient to resolve structures with size features smaller than 200 microns. For example, thin-cap fibroatheromas having a thin fibrous cap of 65 microns or less in thickness cannot currently be resolved. The concern regarding thin-cap fibroatheromas is that they are prone to rupture. Plaque rupture can lead to thrombus formation and critical blockages in the coronary artery. The ability to reliably identify thin-cap fibroatheromas can aid interventional cardiologists to develop and evaluate clinical treatment strategies in order to reduce post percutaneous coronary intervention morbidity rates. Therefore, IVUS catheters and systems having improved axial resolution capable of more clearly visualizing micron sized features such as vulnerable plaques are needed in the art. The ability for such systems to operate at high transducer frequencies will be important in that effort.

[5] One of the challenges of these minimally invasive imaging systems is coupling the stationary ultrasound transceiver (transmitter/receiver) to the mechanically rotating transducer. Rotary inductive couplers are used in commercially available IVUS systems. However, rotary inductive couplers are non-ideal for very high frequency (30 MHz-300 MHz) operation because of their relatively high series inductance. At such high frequencies, series inductance will result in an insertion loss into a transmission line of the IVUS catheter. Furthermore, the insertion loss increases with increasing ultrasound imaging frequency which degrades system performance. Rotating inductive couplers also exhibit electrical impedance that can vary with rotational position. The variation of impedance with rotational position causes output signal amplitudes to vary with angular positions and further degrades system performance. The present invention addresses these and other issues towards providing imaging catheters having improved resolution and more constant level output.

SUMMARY

[6] In one embodiment, an imaging system comprises a catheter having a lumen, a rotatable imaging probe within the catheter lumen including a distal transducer and first and second conductors coupled to the transducer. The system further includes a coupler that couples the rotatable first and second conductors to non-rotatable third and fourth conductors. The coupler includes a rotary capacitive coupler.

[7] The coupler may comprise a parallel plate capacitor. The coupler may comprise a first parallel plate capacitor that couples the first conductor to the third conductor and a second parallel plate capacitor that couples the second conductor to the fourth conductor or a parallel plate capacitor that couples the first conductor to the third conductor and a cylindrical surface concentric capacitor that couples the second conductor to the fourth conductor.

[8] The coupler may comprise a cylindrical surface concentric capacitor. The coupler may comprise a first cylindrical surface concentric capacitor that couples the first conductor to the third conductor and a second cylindrical surface concentric capacitor that couples the second conductor to the fourth conductor.

[9] The coupler may comprise a conical surface concentric capacitor. The coupler comprises a conical surface concentric capacitor that couples the first conductor to the third conductor and a parallel plate capacitor that couples the second conductor to the fourth conductor, a conical surface concentric capacitor that couples the first conductor to the third conductor and a cylindrical surface concentric capacitor that couples the second conductor to the fourth conductor, or a first conical

surface concentric capacitor that couples the first conductor to the third conductor and a second conical surface concentric capacitor that couples the second conductor to the fourth conductor.

[10] The coupler may be within the catheter or outside of the catheter.

[11] In another embodiment, an imaging system comprises a catheter having a lumen and a distal rotatable imaging probe within the catheter lumen including a first transducer, first and second conductors coupled to the first transducer, a second transducer, and third and fourth conductors coupled to the second transducer. The system further includes a rotary capacitive coupler that couples the rotatable first and second conductors to non-rotatable fifth and sixth conductors, respectively, and a rotary inductive coupler that couples the rotatable third and fourth conductors to non-rotatable seventh and eighth conductors, respectively.

[12] The coupler may comprise a parallel plate capacitor. The coupler may comprise a first parallel plate capacitor that couples the first conductor to the third conductor and a second parallel plate capacitor that couples the second conductor to the fourth conductor or a parallel plate capacitor that couples the first conductor to the third conductor and a cylindrical surface concentric capacitor that couples the second conductor to the fourth conductor.

[13] The coupler may comprise a cylindrical surface concentric capacitor. The coupler may comprise a first cylindrical surface concentric capacitor that couples the first conductor to the third conductor and a second cylindrical surface concentric capacitor that couples the second conductor to the fourth conductor.

[14] The coupler may comprise a conical surface concentric capacitor. The coupler comprises a conical surface concentric capacitor that couples the first conductor to the third conductor and a parallel plate capacitor that couples the second conductor to the fourth conductor, a conical surface concentric capacitor that couples the first conductor to the third conductor and a cylindrical surface concentric capacitor that couples the second conductor to the fourth conductor, or a first conical surface concentric capacitor that couples the first conductor to the third conductor and a second conical surface concentric capacitor that couples the second conductor to the fourth conductor.

[15] In a further embodiment, an imaging system comprises a catheter having a lumen, a rotatable imaging probe within the catheter lumen including a distal transducer, and a coupler including a rotary capacitive coupler that couples the rotatable transducer to non-rotatable first and second conductors and a rotary inductive coupler that couples the rotatable transducer to third and fourth non-rotatable conductors.

BRIEF DESCRIPTION OF THE DRAWINGS

[16] The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. 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:

[17] **FIG. 1** is a high-level diagram of a catheter-based imaging system comprising a rotary coupler as part of a catheter interface module;

[18] **FIG. 2** is a schematic representation of electrical signal paths of a catheter-based imaging system comprising a rotary coupler as part of a catheter interface module;

[19] **FIG. 3** is a high-level diagram of a catheter-based imaging system comprising a rotary coupler as part of a catheter;

[20] **FIG. 4** is a schematic representation of electrical signal paths of a catheter-based imaging system comprising a rotary coupler as part of a catheter;

[21] **FIG. 5** is a side perspective view of a parallel plate capacitor;

[22] **FIG. 6** is a side perspective view of a cylindrical surface concentric capacitor;

[23] **FIG. 7** is a side perspective view of a conical surface concentric capacitor;

[24] **FIG. 8** is a diagram of a rotary capacitive coupler located in a catheter interface module and comprised of a cylindrical surface concentric capacitor and a parallel plate capacitor;

[25] **FIG. 9** is a diagram of a rotary capacitive coupler located in a catheter and comprised of a cylindrical surface concentric capacitor and a parallel plate capacitor;

[26] **FIG. 10** is a diagram of a rotary capacitive coupler comprised of a conical surface concentric capacitor and a parallel plate capacitor;

[27] **FIG. 11** is a diagram of a rotary capacitive coupler comprised of cylindrical surface concentric capacitors;

[28] **FIG. 12** is a diagram of a rotary capacitive coupler comprised of conical surface concentric capacitors;

[29] **FIG. 13** is a diagram of a rotary capacitive coupler comprised of parallel plate capacitors; and

[30] **FIG. 14** is a schematic representation of electrical signal paths for a two channel system comprised of a rotary inductive coupler and a rotary capacitive coupler.

DETAILED DESCRIPTION OF THE INVENTION

[31] A high-level diagram of the components of a catheter-based imaging system is shown in **FIG. 1.** A catheter ***1000A*** is coupled mechanically and electrically to a catheter interface module ***2000A*** comprised of a rotary coupler ***100.*** An imaging engine ***3000*** is in electrical communication with the catheter interface module. Following the imaging engine ***3000*** is a display engine ***4000*** and a display ***5000.***

[32] **FIG. 2** shows an electrical schematic representation of the transmit and receive signal paths of a catheter interface module ***2000A*** and catheter ***1000A*** having a primary purpose of coupling a signal from a stationary electrical conduit to a rotating electrical conduit. Diagrams for a rotary capacitive coupler ***100*** and ultrasonic transducer ***220*** are shown. In accordance with this embodiment,

the rotary capacitive coupler ***100*** is located outside of the catheter ***1000A*** and within the catheter interface module ***2000A***.

[33] **FIG. 3** shows a high-level diagram of the components of another catheter-based imaging system. The components ***1000B***, ***2000B***, ***3000***, ***4000***, ***5000*** of the catheter-based imaging system in **FIG. 3** are substantially the same as the components ***1000A***, ***2000A***, ***3000***, ***4000***, ***5000*** of the catheter-based imaging system in **FIG. 1** and hence, reference characters for like elements are repeated in **FIG. 3**. However, in this embodiment, a rotary coupler ***100*** is located in the catheter ***1000B***.

[34] **FIG. 4** is an electrical schematic representation of the system signal paths of the system of **FIG. 3** and to the extent that it is the same as the electrical schematic representation in **FIG. 2**, reference characters for like elements are repeated. However, as may be noted in **FIG. 4**, the rotary capacitive coupler ***100*** is located in the catheter ***1000B***.

[35] **FIGS. 5-7** show illustrations of parallel plate and concentric capacitors which may be employed in the various embodiments described hereinafter. **FIG. 5** shows a side perspective view of a parallel plate capacitor. The capacitance of the parallel plate capacitor depends on the cross-sectional area A_{plate} and separation distance d_{plate} of two parallel plates ***Plate1***,***Plate2*** and is closely approximated by $C = \frac{\epsilon_0 \epsilon_r A_{plate}}{d_{plate}}$ where C is the capacitance in Farads (F), A_{plate} is the area of each plate in square meters (m^2), ϵ_r is the relative static permittivity or dielectric constant, ϵ_0 is the permittivity of free space (i.e.,

8.854×10^{-12} F/m), and d_{plate} is the separation distance between the plates in meters (m).

[36] **FIG. 6** shows a side perspective view of a concentric capacitor comprised of cylindrical surfaces. The capacitance per unit length of the cylindrical surface concentric capacitor depends on the radii r_1, r_2 of the drums (or cylinders) ***Drum1***, ***Drum2*** and is approximately $\frac{2\pi\varepsilon_0\varepsilon_r}{\ln\left(\frac{r_2}{r_1}\right)}$. The reactive impedance experienced by a signal of frequency f across the capacitor is $|Xc| = (2\pi f C)^{-1}$.

[37] **FIG. 7** shows a side perspective view of a concentric capacitor comprised of conical surfaces. The capacitance of the conical surface concentric capacitor is similar to the capacitance of the cylindrical surface concentric capacitor. The cone separation distance d_{cone} can be varied by adjusting the relative axial position of the cones ***Cone1***, ***Cone2***. The ability to adjust the separation distance enables variation of the capacitance.

[38] For a given capacitance C of the capacitors of **FIGS. 5-7**, the reactive impedance |Xc| decreases as frequency f increases. Insertion loss for a rotary capacitive coupler decreases with increasing frequency and increasing capacitance. Capacitance can be increased by increasing the relative static permittivity of the capacitor gap filler material, increasing the surface area of the capacitor surfaces, or decreasing the gap between capacitor surfaces. The gap filler material can be a variety of materials including air, polyethylene, quartz, or glass. The benefit of decreased insertion loss to imaging performance is improved axial resolution of the imaging system due to use of higher transducer frequencies.

[39] **FIGS. 8 and 9** illustrate separate embodiments of an IVUS system and catheter wherein a rotary capacitive coupler can either be located in a catheter interface module (**FIG. 8**)or a catheter (**FIG. 9**). **FIG. 8** shows a diagram of a catheter interface module ***2000A*** and catheter ***1000A*** wherein a rotary capacitive coupler ***100A*** is located in the catheter interface module. The rotary capacitive coupler comprises a cylindrical surface concentric capacitor ***110*** including concentric drums ***110A,112A*** and a parallel plate capacitor ***120*** including plates ***120A,122A***, respectively. The advantage of this design is that the fixed non-rotatable drum ***120A*** acts as a shield to electrical noise for the parallel plate capacitor.

[40] A high frequency (>40 MHz) signal travels from a send path ***2*** to the center conductor ***212*** of a catheter transmission line ***210*** in the catheter imaging core, through an ultrasound transducer ***220***, back through a transmission line shield ***214***, and finally back to the return path conductor ***4***. The imaging core ***200*** components ***212,214,220*** rotate inside a catheter sheath by means of a drive motor ***30***. The imaging core conductors ***212,214*** are electrically loaded by a transducer ***220***. The rotary coupler ***100A*** comprising the cylindrical surface concentric capacitor ***110*** and the parallel plate capacitor ***120*** is used to electrically couple the fixed and rotating components. A drive shaft ***32*** is mechanically coupled to the rotating drum ***112A*** and rotating plate ***122A***.

[41] When operating in a send mode the send signal along conductor ***2*** passes through a transmit/receive (T/R) switch ***10*** to the conductor ***12*** leading to an input transmission line ***20***. The outputs of the input transmission line ***20*** are a send signal conductor ***22*** and a return signal conductor ***24***. The conductors ***22,24*** are the inputs to the

rotational coupler. The rotary coupler transfers (or couples) electrical signals between the send signal conductor **22** and the proximal end of the catheter transmission line **210** center conductor **202**. The rotary coupler also transfers electrical signals between the return signal conductor **24** and the proximal end of the catheter transmission line shield **204**. This is achieved with two capacitors.

[42] The send coupling capacitor **110** comprises concentric drums **110A,112A**. The return coupling capacitor **120** comprises parallel plates **120A,122A**. Regarding the two capacitors, fixed components **110A,120A** remain stationary while rotating components **112A,122A** rotate with the motor **30**, drive shaft **32**, and catheter imaging core **200**. Input transmission line center conductor **22** electrically connects to drum **110A**, and the send signal on conductor **22** is coupled to drum **112A** which is electrically connected to catheter transmission line center conductor **212**. The input transmission line shield **24** electrically connects to the fixed plate **120A**, and the signal on conductor **24** gets coupled to rotating plate **122A** which is electrically connected to catheter transmission line shield conductor **214**. A radiofrequency (RF) connector (not shown) is used to connect conductors **102,104** of the catheter interface module and conductors **202,204** of the catheter. Any RF connector can generally be used, but a subminiature RF connector such as an SMB connector is typically used. Consequently, signals on stationary input transmission line conductors **22,24** get coupled to the rotating catheter transmission line conductors **202,204**.

[43] The same rotational coupler serves to couple high frequency (>40 MHz) signals generated by the transducer **220** (from ultrasound reflections) back in the reverse (or return) direction. In the return case, signals generated from the transducer ***220*** are sent to the receiver ***8*** through the imaging core conductors ***202,204*** and input transmission line input-side conductors ***12,14***. The rotary coupler capacitively couples the signals on the imaging core proximal conductors ***202,204*** to input transmission line output-side conductors ***22,24***. The input transmission line ***20*** outputs the receive signals on input-side conductors ***12,14***. The signal on conductor ***12*** is sent to conductor ***4*** via the T/R switch ***10*** which would be set for the receive path. Note that the send and receive cases are never allowed to occur simultaneously. A transmit signal is sent to the transducer ***220*** (with the T/R switch ***10*** set to send) before the T/R switch ***10*** is set to receive.

[44] The diagram of a catheter interface module ***2000B*** and catheter ***1000B*** in **FIG. 9** is substantially the same as the diagram of the catheter interface module ***2000A*** and catheter ***1000A*** in **FIG. 8** and hence, reference characters for like elements are repeated in **FIG. 9**. A rotary capacitive coupler ***100A*** comprises a cylindrical surface concentric capacitor ***110*** having concentric drums ***110A,112A*** and a parallel plate capacitor ***120*** having parallel plates ***120A,122A*** and is located in the catheter. An RF connector (not shown) is used to connect conductors ***22,24*** of the catheter interface module and conductors ***106,108*** of the catheter. A subminiature RF connector such as an SMB connector is typically used. Signals on stationary input transmission line conductors ***22,24*** are coupled to the rotating catheter transmission line conductors ***202,204***.

[45] **FIGS. 10-13** show various embodiments of rotary capacitive couplers that may be employed in practicing the present invention. The diagrams of the rotary capacitive couplers, drive motor, and drive shaft in **FIGS. 10-13** are substantially the same as the diagram of the rotary capacitive couplers, drive motor, and drive shaft in **FIG. 8** and hence, reference characters for like elements are repeated in **FIGS. 10-13.**

[46] The rotary capacitive coupler ***100B*** illustrated in **FIG. 10** comprises a conical surface concentric capacitor ***111*** having concentric conical surfaces ***110B,112B*** and a parallel plate capacitor ***120*** having plates ***120B,122B.*** The output-side input transmission line conductors ***22,24*** are electrically connected to the rigidly fixed conical surface ***110B*** and parallel plate ***120B.*** The rotatable conical surface ***112B*** is electrically connected to conductor ***102*** and mechanically connected to the drive shaft ***32.*** The rotatable parallel plate ***122B*** is electrically connected to conductor ***104*** and mechanically connected to the drive shaft ***32.***

[47] **FIG. 11** shows a rotary capacitive coupler ***100C*** comprised of two cylindrical surface concentric capacitors ***113*** and ***115*** having concentric drums ***110C***, ***112C*** **and** ***120C***, ***122C,*** respectively. The output-side input transmission line conductors ***22,24*** are electrically connected to the rigidly fixed cylindrical surfaces ***110C,120C.*** The rotatable cylindrical surface ***112C*** is electrically connected to conductor ***102*** and mechanically connected to the drive shaft ***32.*** The rotatable cylindrical surface ***122C*** is electrically connected to conductor ***104*** and mechanically connected to the drive shaft ***32.***

[48] **FIG. 12** shows a rotary capacitive coupler ***100D*** comprised of two conical surface concentric capacitors ***117*** and ***119*** having concentric surfaces ***110D***, ***112D*** **and** ***120D***, ***122D,*** respectively. The output-side input transmission line conductors ***22,24*** are electrically connected to the rigidly fixed conical surfaces ***110D,120D.*** The rotatable conical surface ***112D*** is electrically connected to conductor ***102*** and mechanically connected to the drive shaft ***32***. The rotatable conical surface ***122D*** is electrically connected to conductor ***104*** and mechanically connected to the drive shaft ***32***.

[49] **FIG. 13** shows a rotary capacitive coupler ***100E*** comprised of two parallel plate capacitors ***121*** and ***123*** having plate pairs ***110E***, ***112E*** **and** ***120E***, ***122E***, respectively. The output-side input transmission line conductors ***22,24*** are electrically connected to the rigidly fixed parallel plates ***110E,120E***. The rotatable parallel plate ***112E*** is electrically connected to conductor ***102*** and mechanically connected to the drive shaft ***32***. The rotatable parallel plate ***122E*** is electrically connected to conductor ***104*** and mechanically connected to the drive shaft ***32***.

[50] **FIG. 14** illustrates still another embodiment wherein an IVUS system comprises a rotary capacitive coupler ***100*** and a rotary inductive coupler **100-HF**. A catheter interface module ***2000C*** comprises the rotary inductive coupler **100-HF** and the rotary capacitive coupler ***100*** on a single rotating shaft with two sets of independent electrical connections. The catheter ***1000C*** comprises a high frequency (less than approximately 30 MHz) transducer **220-HF** and very high frequency (greater than approximately 30 MHz) transducer ***220***.

[51] This invention overcomes drawbacks associated with rotary inductive couplers used in minimally invasive, high-frequency IVUS imaging systems and catheters. In particular, rotary capacitive couplers improve system performance by reducing insertion loss and impedance variation with angular position. The rotary capacitive couplers disclosed heretofore comprise parallel plate capacitors, cylindrical surface concentric capacitors, and conical surface concentric capacitors. A parallel plate capacitor comprises a first rigidly fixed plate and a second rotatable plate. A cylindrical surface concentric capacitor comprises a first rigidly fixed cylindrical surface and a second rotatable cylindrical surface. A conical surface concentric capacitor comprises a first rigidly fixed conical surface and a second rotatable conical surface. The exemplary rotary capacitive couplers can be combined for system performance advantages. Furthermore, a rotary inductive coupler and a rotary capacitive coupler can be used in a two channel IVUS system and catheter for high frequency and very high frequency operation.

[52] 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 which fall within the true spirit and scope of the invention as defined by those claims.

What is claimed is:

1. An imaging system comprising:

a catheter having a lumen;

a rotatable imaging probe within the catheter lumen including a distal transducer and first and second conductors coupled to the transducer; and

a coupler that couples the rotatable first and second conductors to non-rotatable third and fourth conductors, respectively, the coupler including a rotary capacitive coupler.

2. The system of claim 1, wherein the coupler comprises a parallel plate capacitor.

3. The system of claim 1, wherein the coupler comprises a first parallel plate capacitor that couples the first conductor to the third conductor and a second parallel plate capacitor that couples the second conductor to the fourth conductor.

4. The system of claim 1, wherein the coupler comprises a parallel plate capacitor that couples the first conductor to the third conductor and a cylindrical surface concentric capacitor that couples the second conductor to the fourth conductor.

5. The system of claim 1, wherein the coupler comprises a cylindrical surface concentric capacitor.

6. The system of claim 1, wherein the coupler comprises a first cylindrical surface concentric capacitor that couples the first conductor to the third conductor and a second cylindrical surface concentric capacitor that couples the second conductor to the fourth conductor.

7. The system of claim 1, wherein the coupler comprises a conical surface concentric capacitor.

8. The system of claim 1, wherein the coupler comprises a conical surface concentric capacitor that couples the

first conductor to the third conductor and a parallel plate capacitor that couples the second conductor to the fourth conductor.

9. The system of claim 1, wherein the coupler comprises a conical surface concentric capacitor that couples the first conductor to the third conductor and a cylindrical surface concentric capacitor that couples the second conductor to the fourth conductor.

10. The system of claim 1, wherein the coupler comprises a first conical surface concentric capacitor that couples the first conductor to the third conductor and a second conical surface concentric capacitor that couples the second conductor to the fourth conductor.

11. The system of claim 1, wherein the coupler is within the catheter.

12. The system of claim 1, wherein the coupler is outside of the catheter.

13. An imaging system comprising:

a catheter having a lumen;

a distal rotatable imaging probe within the catheter lumen including a first transducer, first and second conductors coupled to the first transducer, a second transducer, and third and fourth conductors coupled to the second transducer;

a rotary capacitive coupler that couples the rotatable first and second conductors to non-rotatable fifth and sixth conductors, respectively; and

a rotary inductive coupler that couples the rotatable third and fourth conductors to non-rotatable seventh and eighth conductors, respectively.

14. The system of claim 13, wherein the rotary capacitive coupler comprises a parallel plate capacitor.

15. The system of claim 13, wherein the rotary capacitive coupler comprises a first parallel plate

capacitor that couples the first conductor to the third conductor and a second parallel plate capacitor that couples the second conductor to the fourth conductor.

16. The system of claim 13, wherein the rotary capacitive coupler comprises a parallel plate capacitor that couples the first conductor to the third conductor and a cylindrical surface concentric capacitor that couples the second conductor to the fourth conductor.

17. The system of claim 13, wherein the rotary capacitive coupler comprises a cylindrical surface concentric capacitor.

18. The system of claim 13, wherein the rotary capacitive coupler comprises a first cylindrical surface concentric capacitor that couples the first conductor to the third conductor and a second cylindrical surface concentric capacitor that couples the second conductor to the fourth conductor.

19. The system of claim 13, wherein the rotary capacitive coupler comprises a conical surface concentric capacitor.

20. The system of claim 13, wherein the rotary capacitive coupler comprises a conical surface concentric capacitor that couples the first conductor to the third conductor and a parallel plate capacitor that couples the second conductor to the fourth conductor.

21. The system of claim 13, wherein the rotary capacitive coupler comprises a conical surface concentric capacitor that couples the first conductor to the third conductor and a cylindrical surface concentric capacitor that couples the second conductor to the fourth conductor.

22. The system of claim 13, wherein the rotary capacitive coupler comprises a first conical surface concentric capacitor that couples the first conductor to the third conductor and a second conical surface concentric

capacitor that couples the second conductor to the fourth conductor.

23. An imaging system comprising:

a catheter having a lumen;

a rotatable imaging probe within the catheter lumen including a distal transducer; and

a coupler including a rotary capacitive coupler that couples the rotatable transducer to non-rotatable first and second conductors and a rotary inductive coupler that couples the rotatable transducer to third and fourth non-rotatable conductors.

FIG. 1

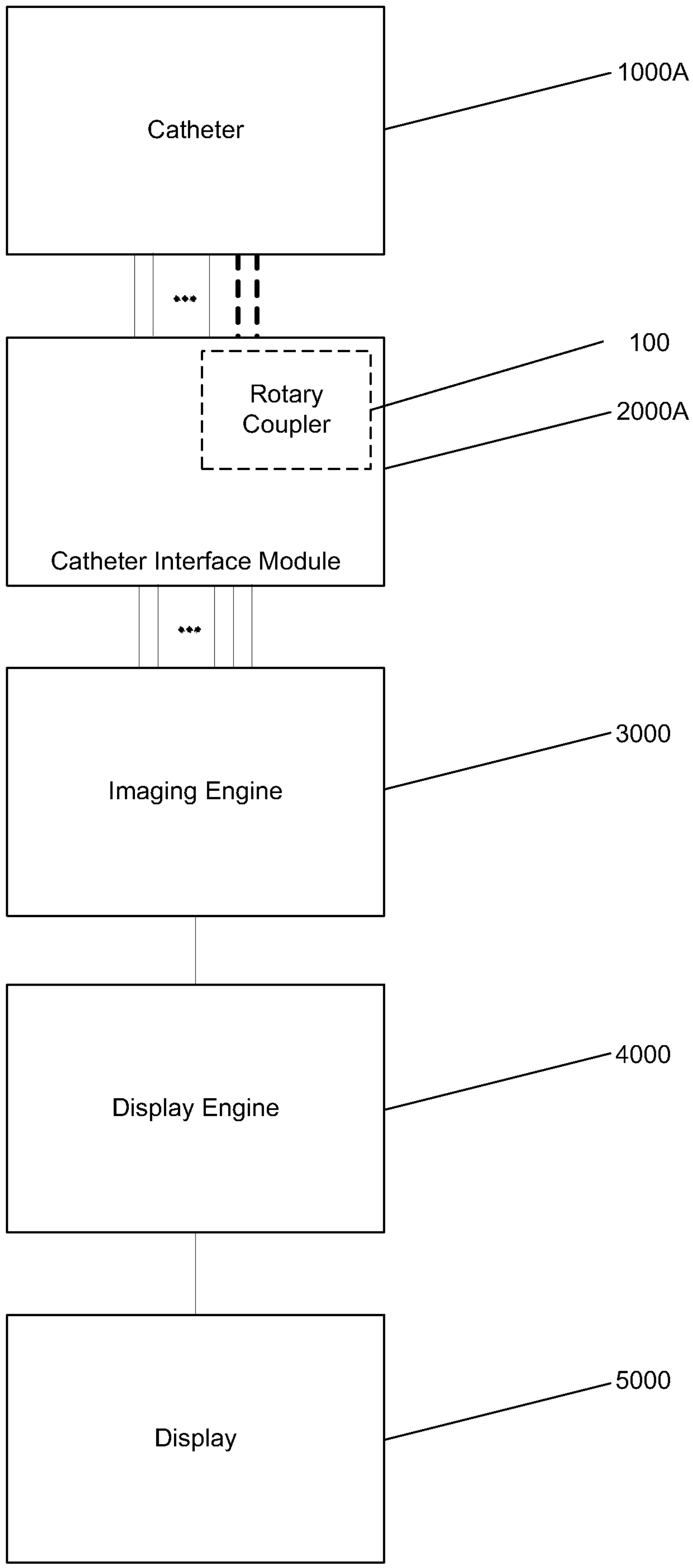
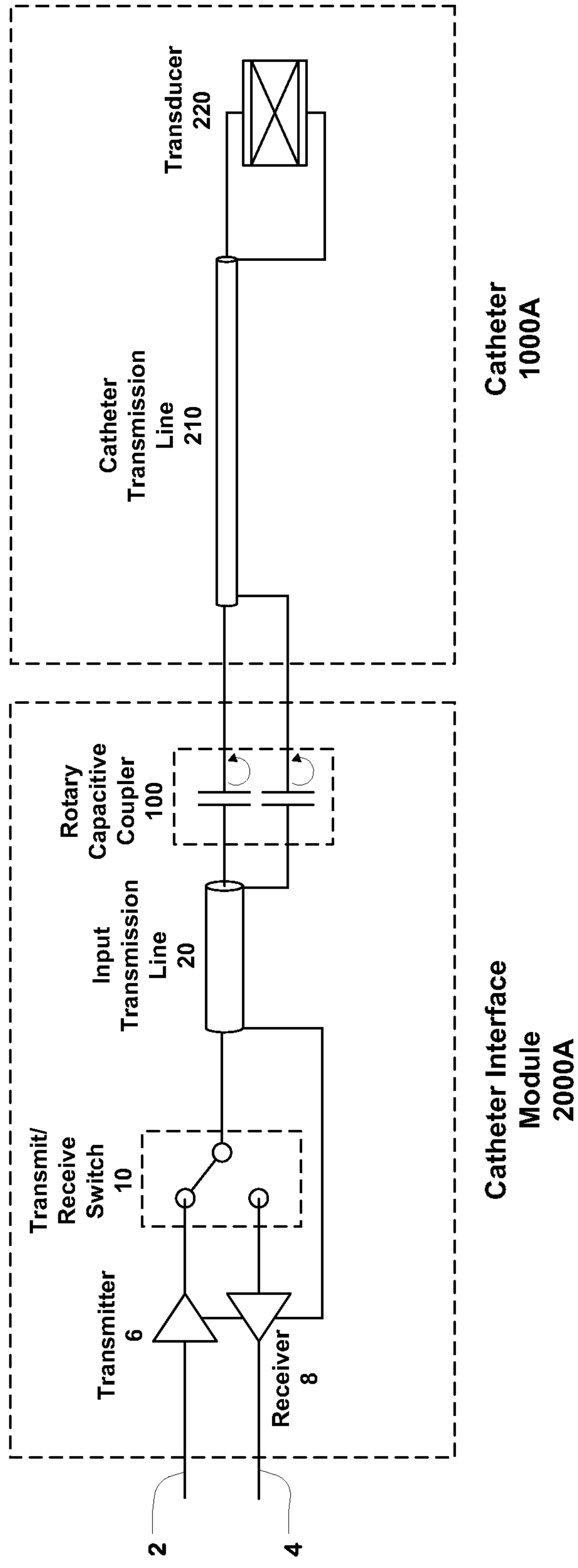
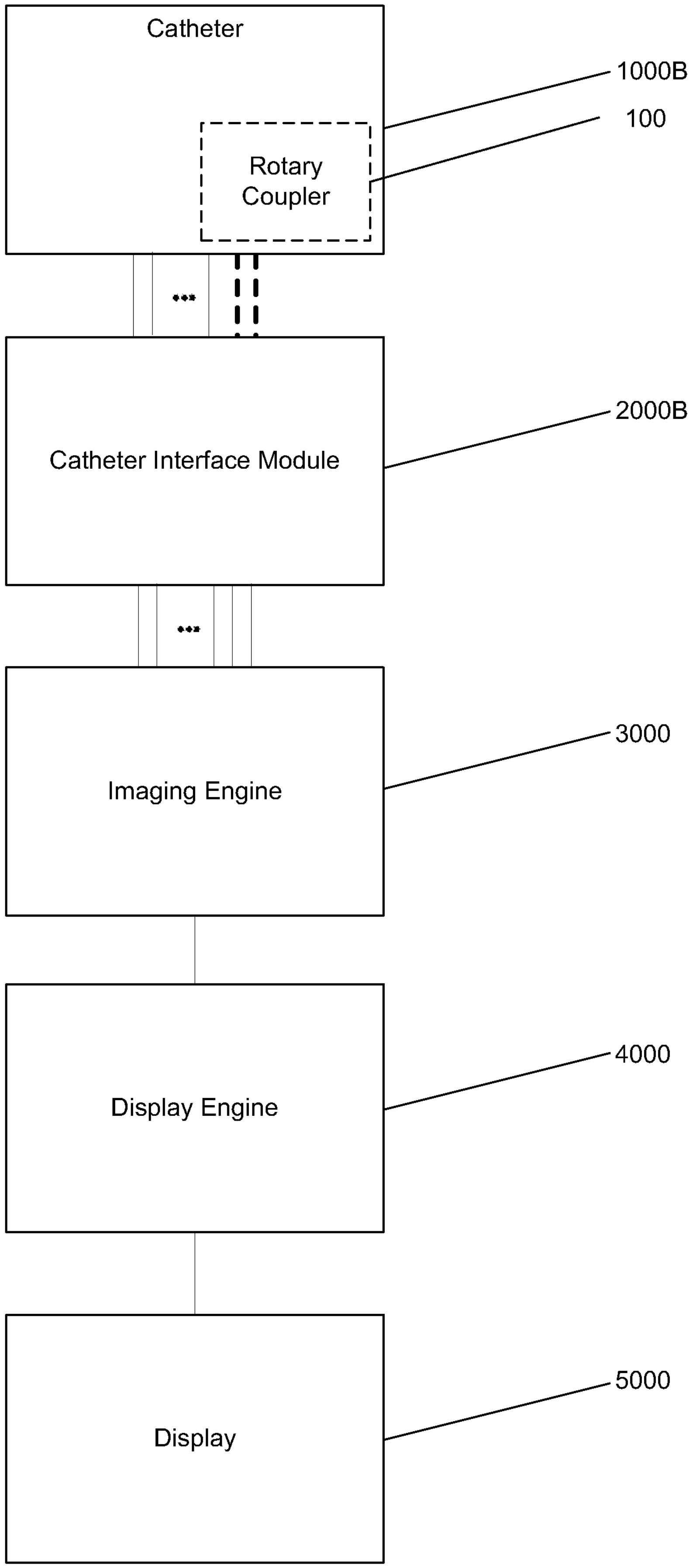

Catheter
1000A
100
Rotary Coupler
2000A
Catheter Interface Module
Imaging Engine
3000
Display Engine
4000
Display
5000

FIG. 2



Transducer
220
Catheter
Transmission
Line
210
Catheter
1000A
Rotary
Capacitive
Coupler
100
Input
Transmission
Line
20
Transmit/
Receive
Switch
10
Transmitter
6
Receiver
8
Catheter Interface
Module
2000A
2
4

FIG. 3


Catheter
Rotary Coupler
1000B
100
Catheter Interface Module
2000B
Imaging Engine
3000
Display Engine
4000
Display
5000

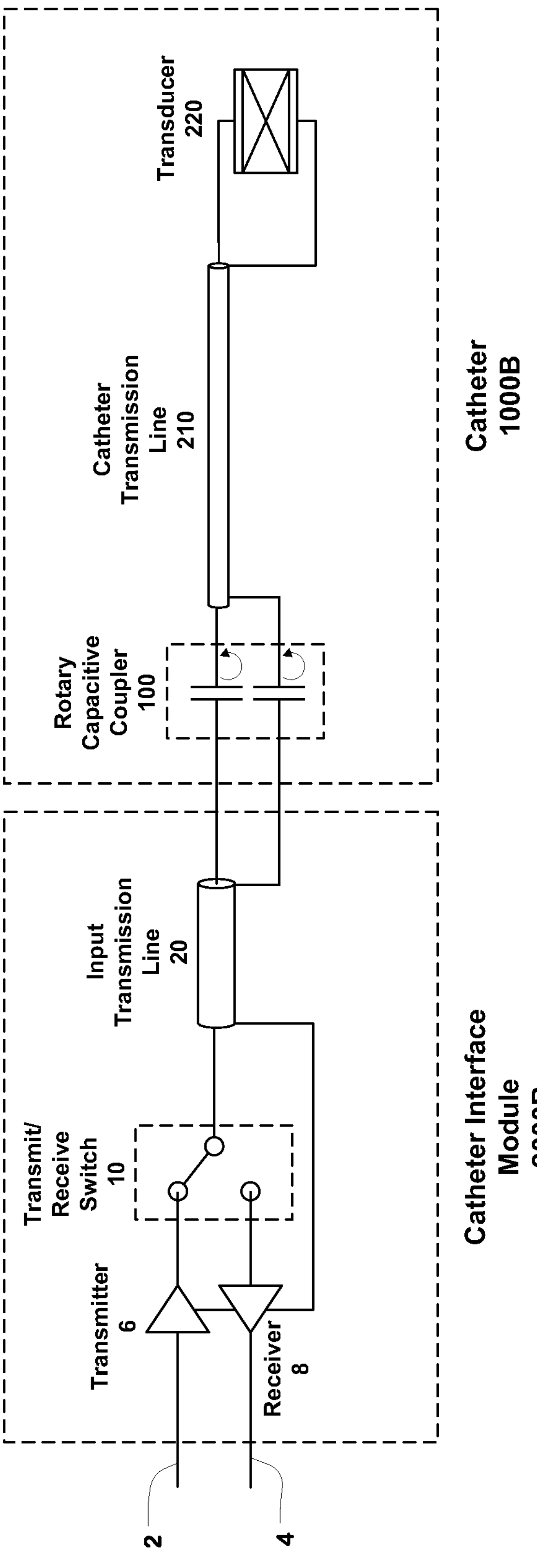

Transducer
220
Catheter
Transmission
Line
210
Rotary
Capacitive
Coupler
100
Catheter
1000B
Input
Transmission
Line
20
Transmit/
Receive
Switch
10
Transmitter
6
Receiver
8
Catheter Interface
Module
2000B
2
4

FIG. 4

FIG. 5

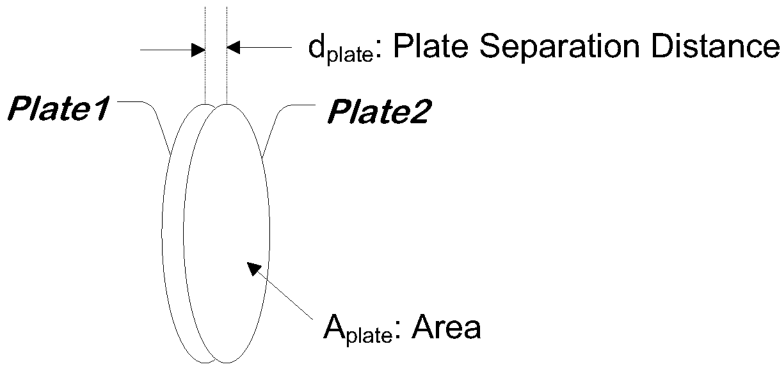

d_{plate}: Plate Separation Distance
Plate1
Plate2
A_{plate}: Area

FIG. 6

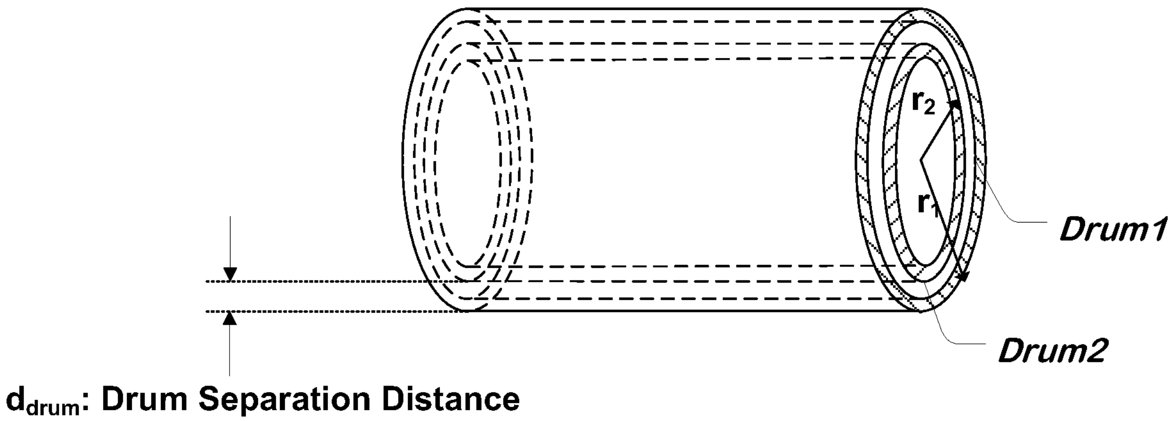


FIG. 7

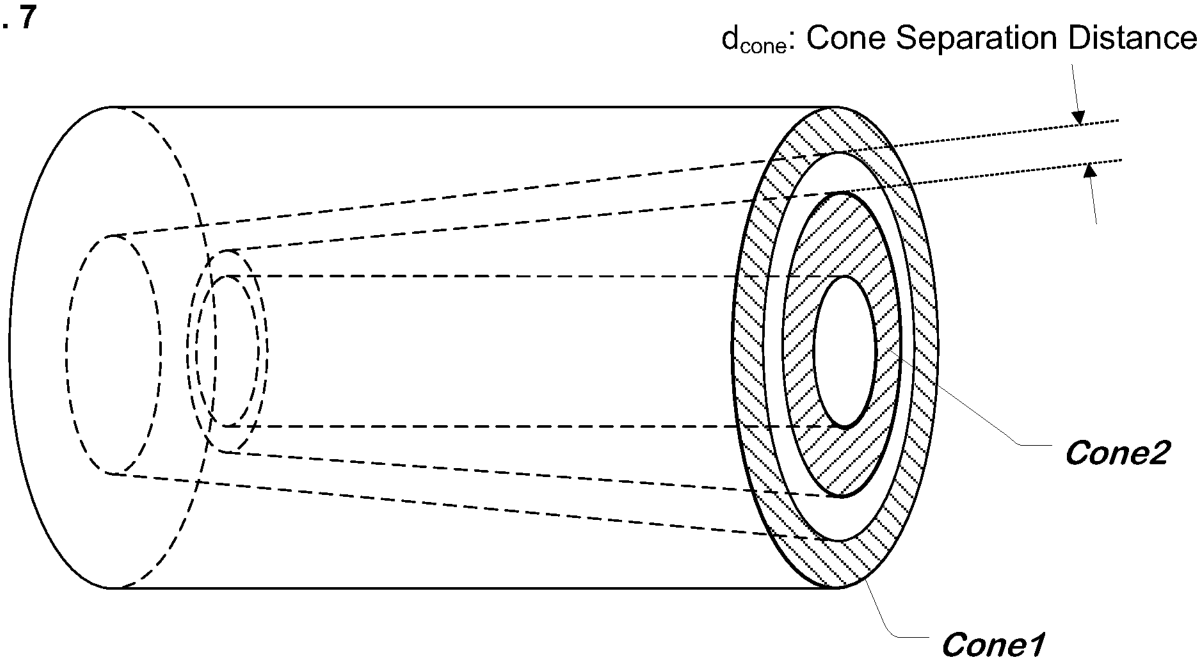


FIG. 8

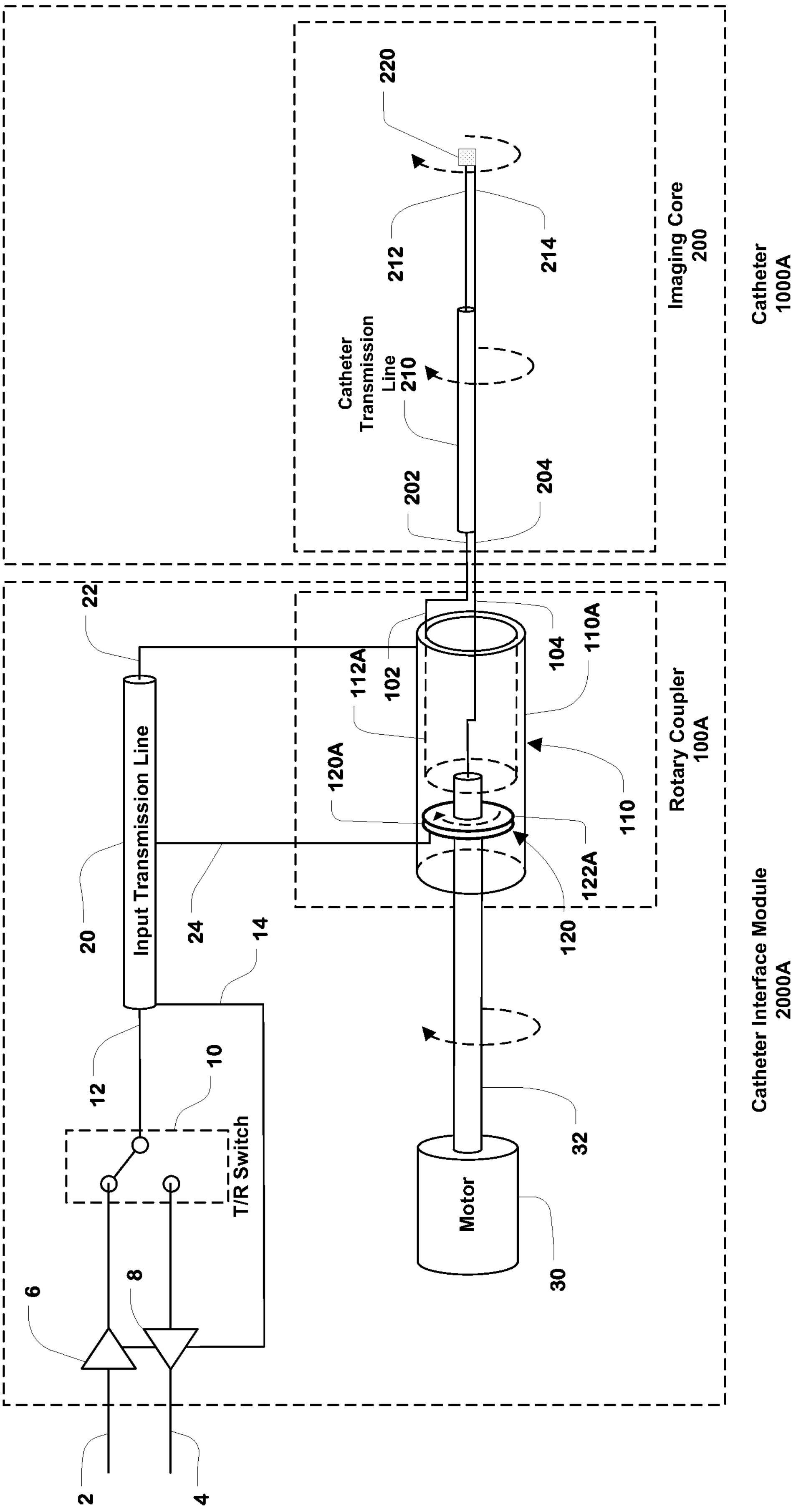

Input Transmission Line
T/R Switch
Motor
Rotary Coupler
100A
Catheter Interface Module
2000A
Catheter Transmission Line
210
Imaging Core
200
Catheter
1000A
2
4
6
8
10
12
14
20
22
24
30
32
102
104
110
110A
112A
120
120A
122A
202
204
212
214
220

FIG. 9

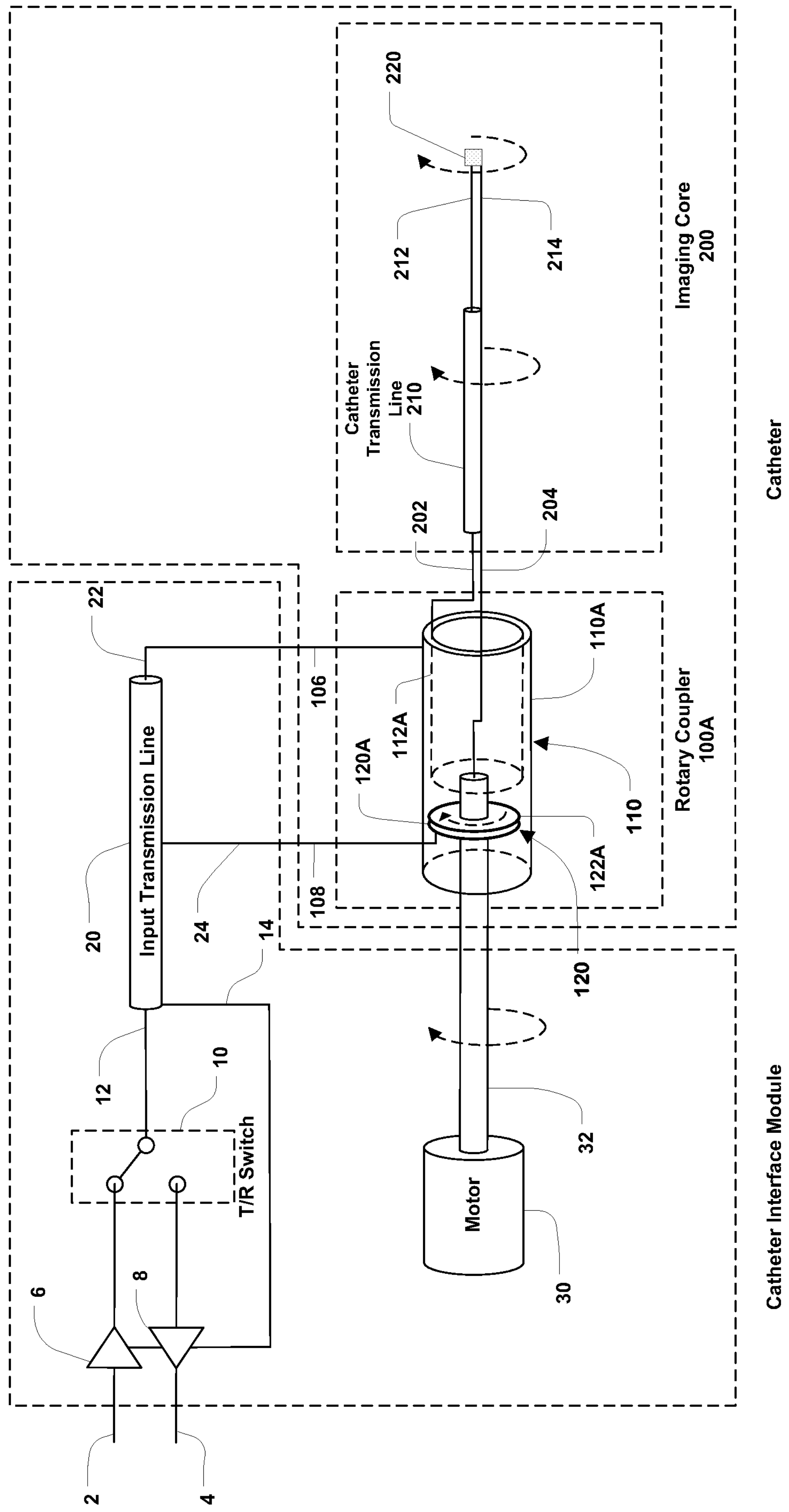
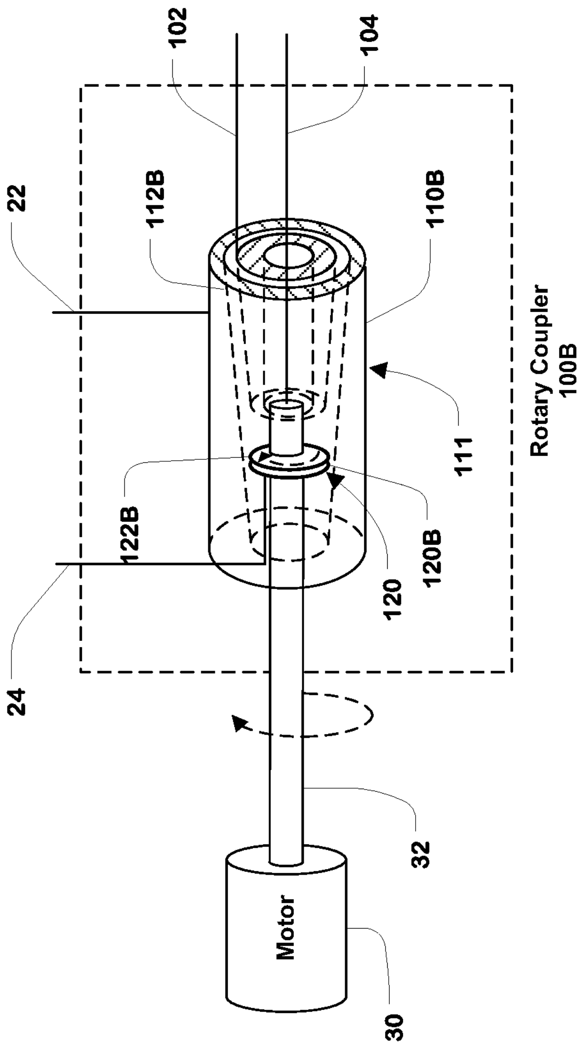

Catheter Interface Module
2000B
Catheter
1000B
Imaging Core
200
Rotary Coupler
100A
Catheter
Transmission
Line
210
Input Transmission Line
T/R Switch
Motor
2
4
6
8
10
12
14
20
22
24
30
32
106
108
110
110A
112A
120
120A
122A
202
204
212
214
220

FIG. 10


102
104
22
112B
110B
Rotary Coupler
100B
111
122B
120B
120
24
32
Motor
30

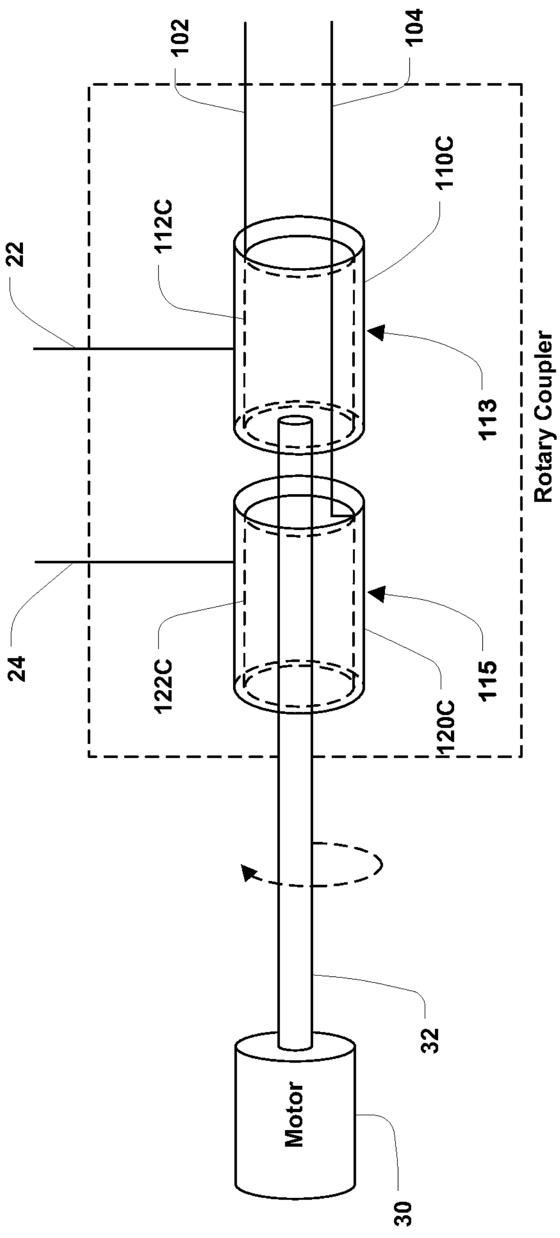

102
104
22
112C
110C
113
Rotary Coupler
100C
24
122C
120C
115
32
Motor
30

FIG. 11

FIG. 12

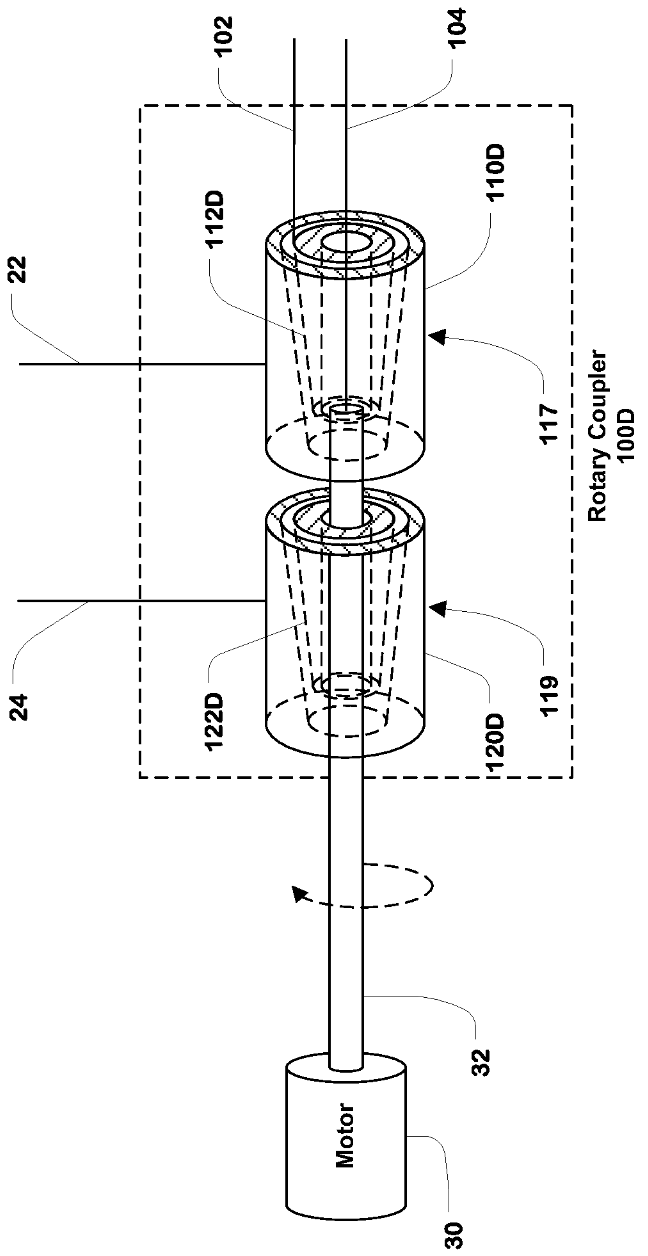

102
104
22
112D
110D
117
Rotary Coupler
100D
24
122D
120D
119
32
Motor
30

FIG. 13

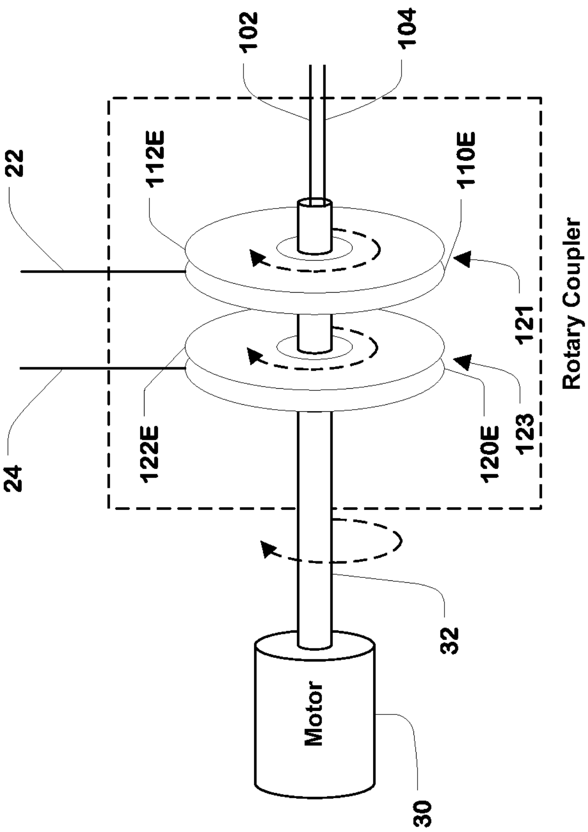
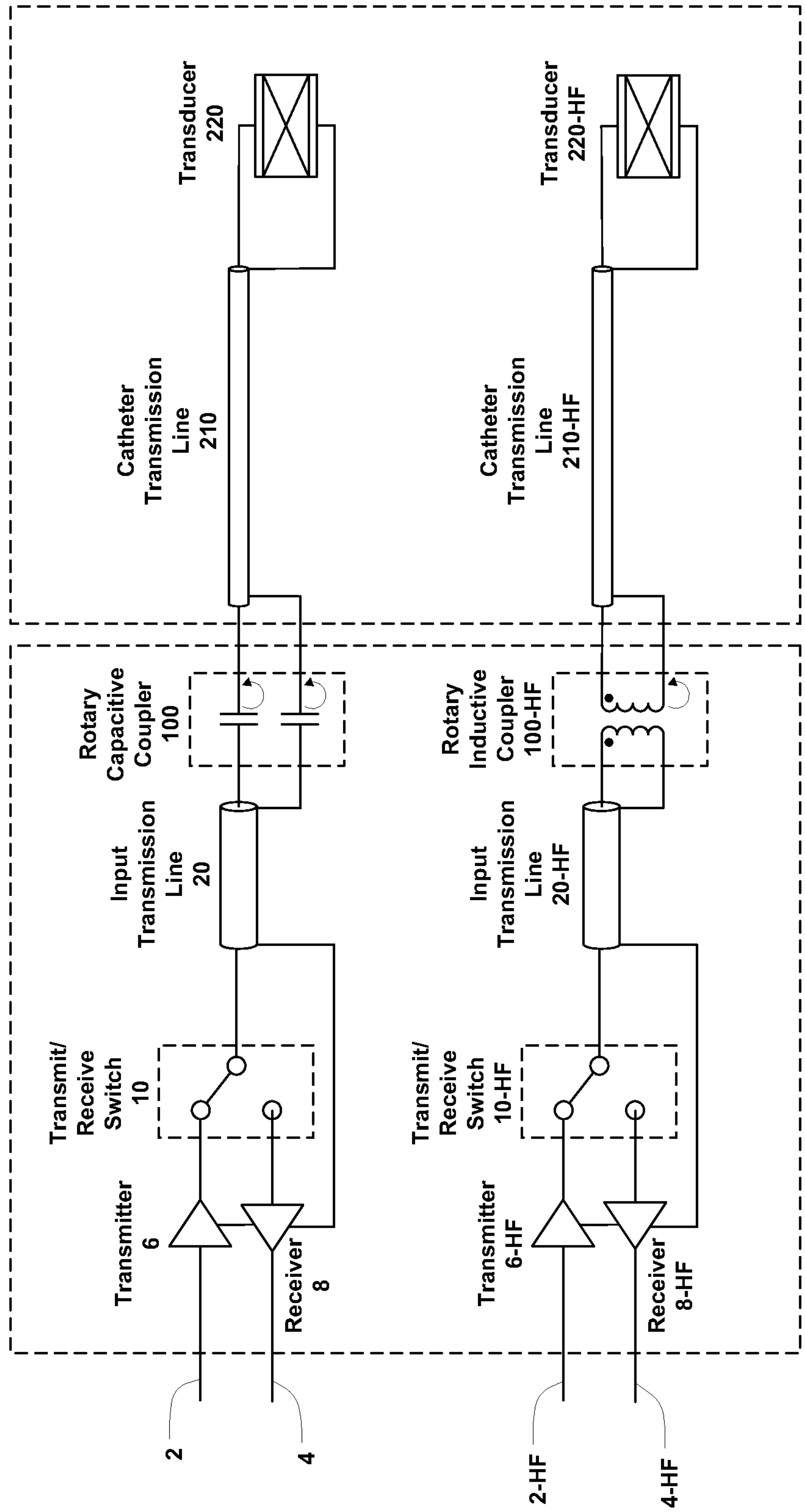

102
104
22
112E
110E
Rotary Coupler
100E
121
123
120E
122E
24
32
Motor
30

FIG. 14


Transducer 220
Catheter Transmission Line 210
Transducer 220-HF
Catheter Transmission Line 210-HF
Catheter 1000C
Rotary Capacitive Coupler 100
Input Transmission Line 20
Transmit/ Receive Switch 10
Transmitter 6
Receiver 8
Rotary Inductive Coupler 100-HF
Input Transmission Line 20-HF
Transmit/ Receive Switch 10-HF
Transmitter 6-HF
Receiver 8-HF
Catheter Interface Module 2000C
2
4
2-HF
4-HF