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(54) **ABLATION CATHETER WITH ULTRASONIC LESION MONITORING CAPABILITY**

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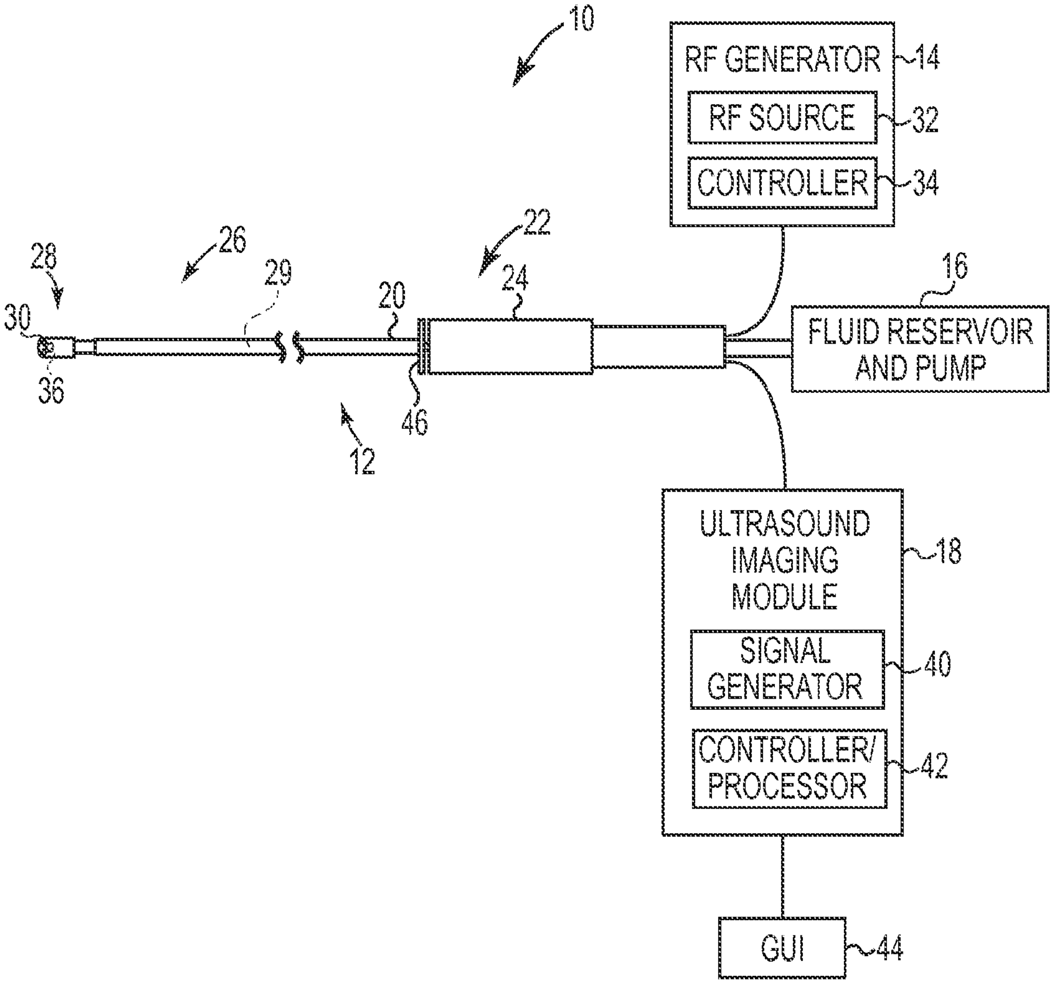
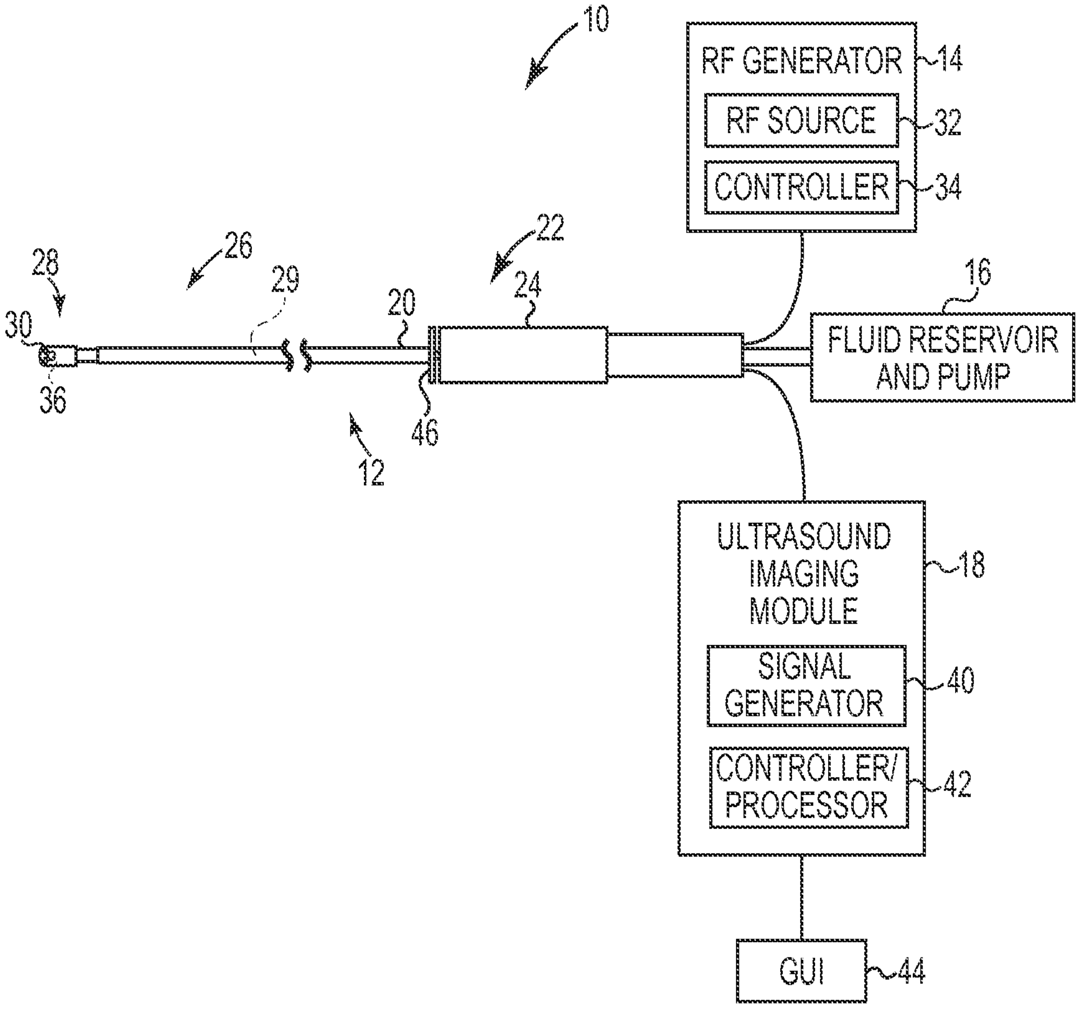
USPC **600/439**

(57) **ABSTRACT**

An ablation probe for treating and imaging body tissue includes an ablation electrode tip including an ablation electrode configured for delivering ablation energy to body tissue. A plurality of acoustic openings are disposed through the ablation electrode tip. A plurality of ultrasonic imaging sensors are positioned inside the ablation electrode tip. The ultrasonic imaging sensors are configured to transmit ultrasonic waves through the acoustic openings. A plurality of flex circuits are each electrically connected to one of the plurality of ultrasonic imaging sensors.

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RF GENERATOR
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RF SOURCE
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CONTROLLER
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FLUID RESERVOIR AND PUMP
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ULTRASOUND IMAGING MODULE
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SIGNAL GENERATOR
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CONTROLLER/ PROCESSOR
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GUI
44

Fig. 1

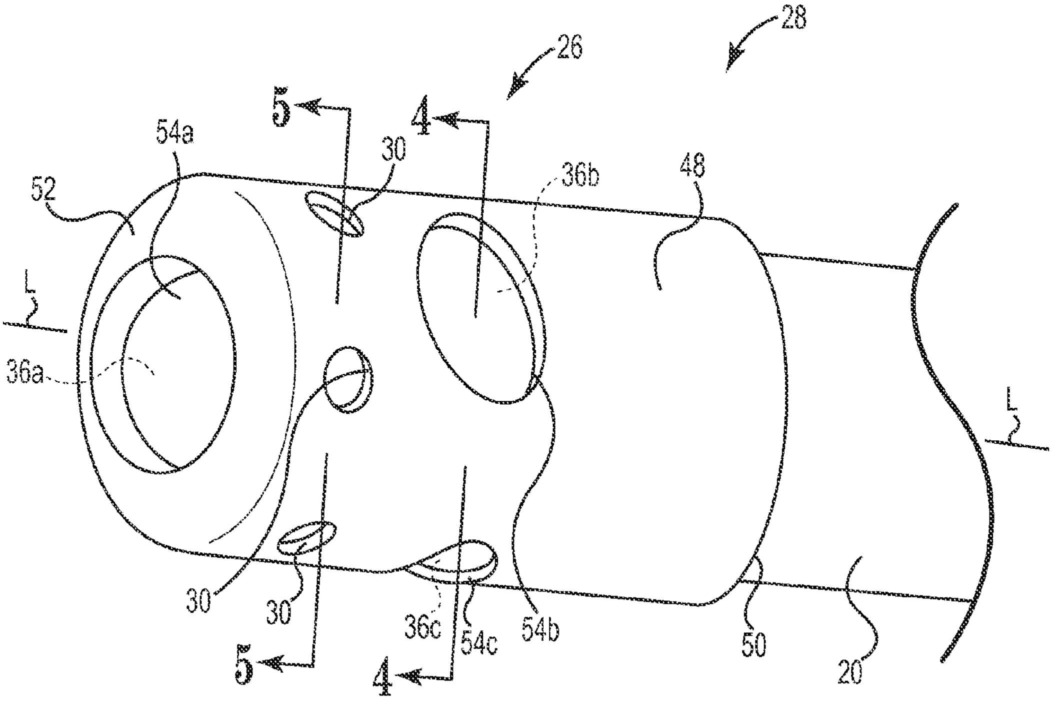

Fig. 2

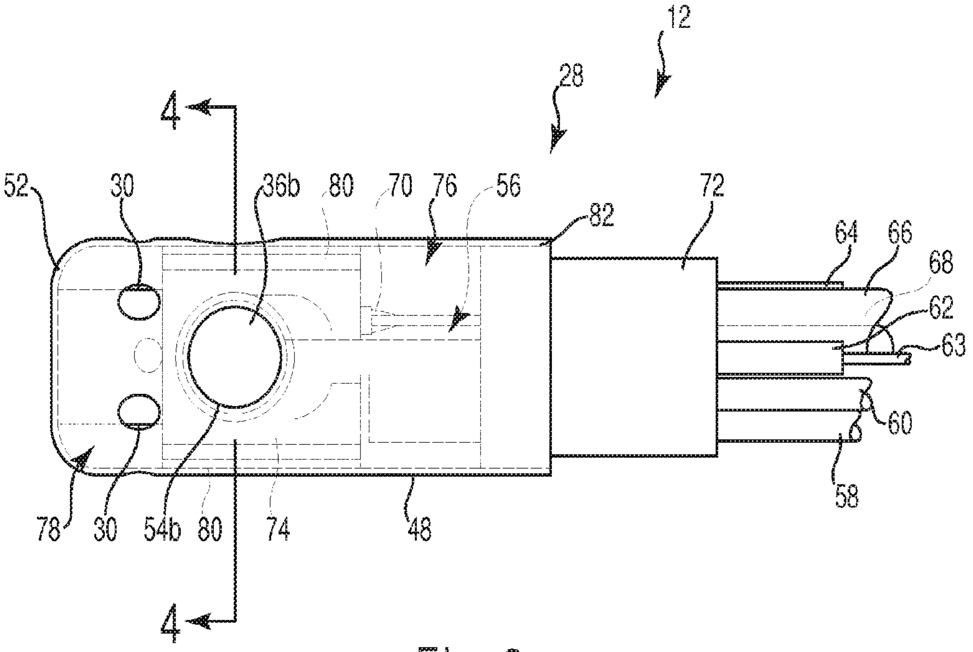
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Fig. 3

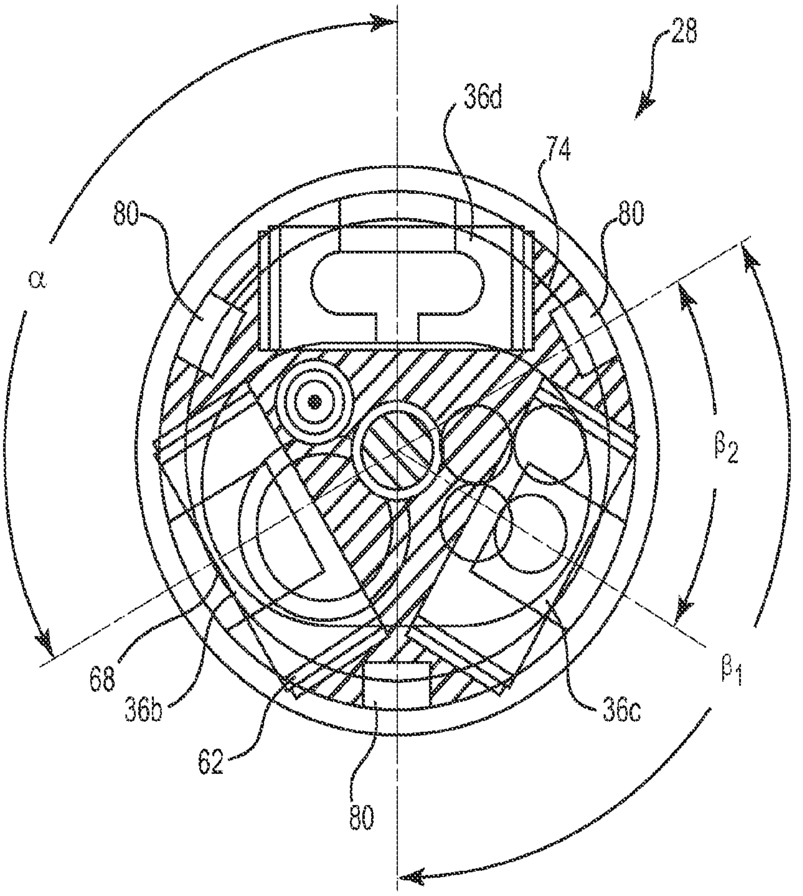


Fig. 4

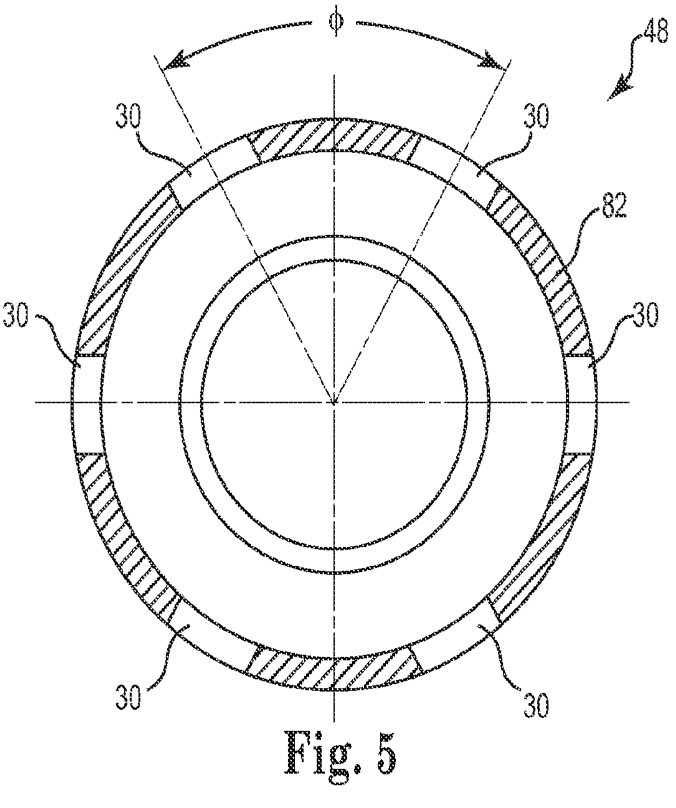


Fig. 5

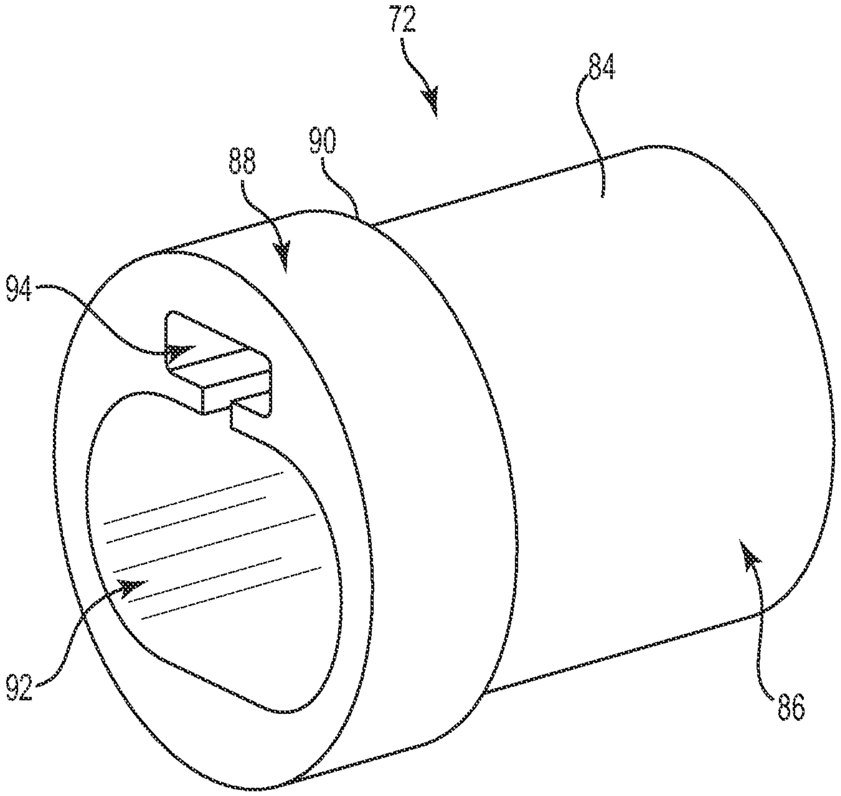


Fig. 6

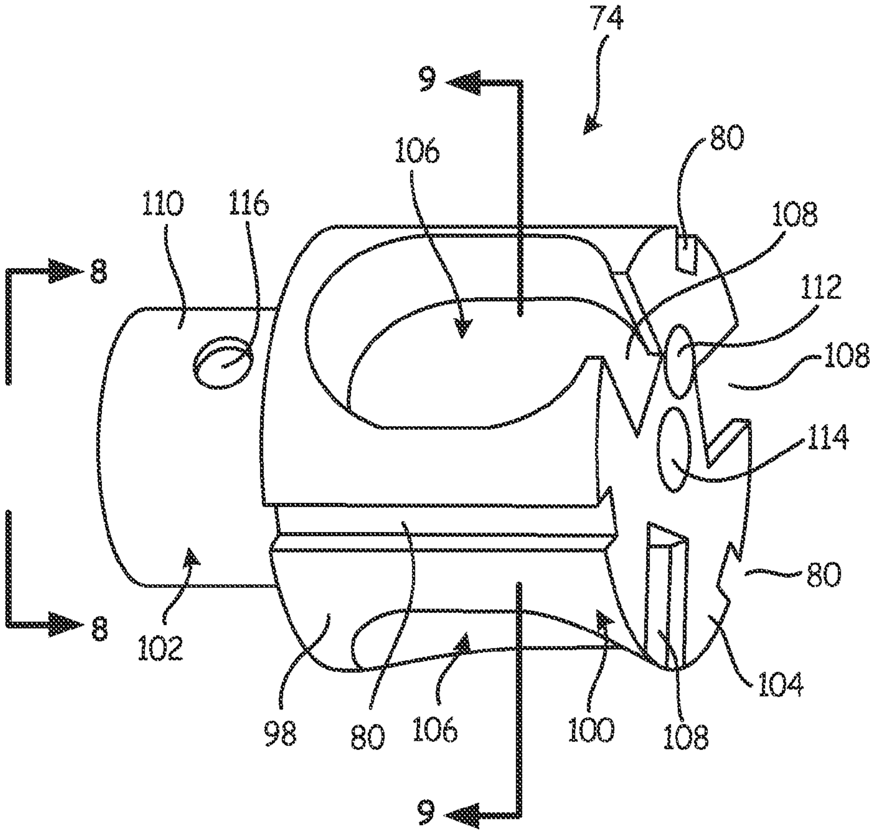


Fig. 7

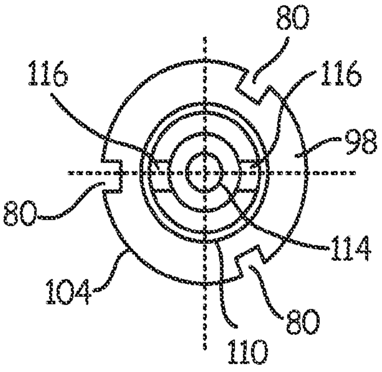


Fig. 8

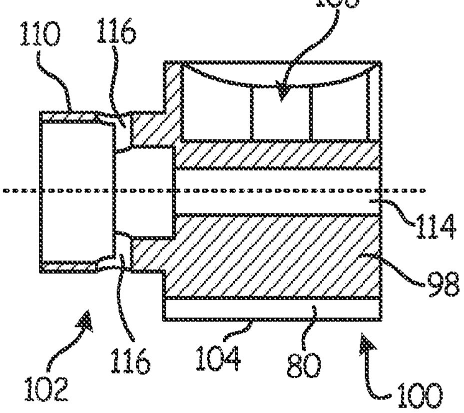
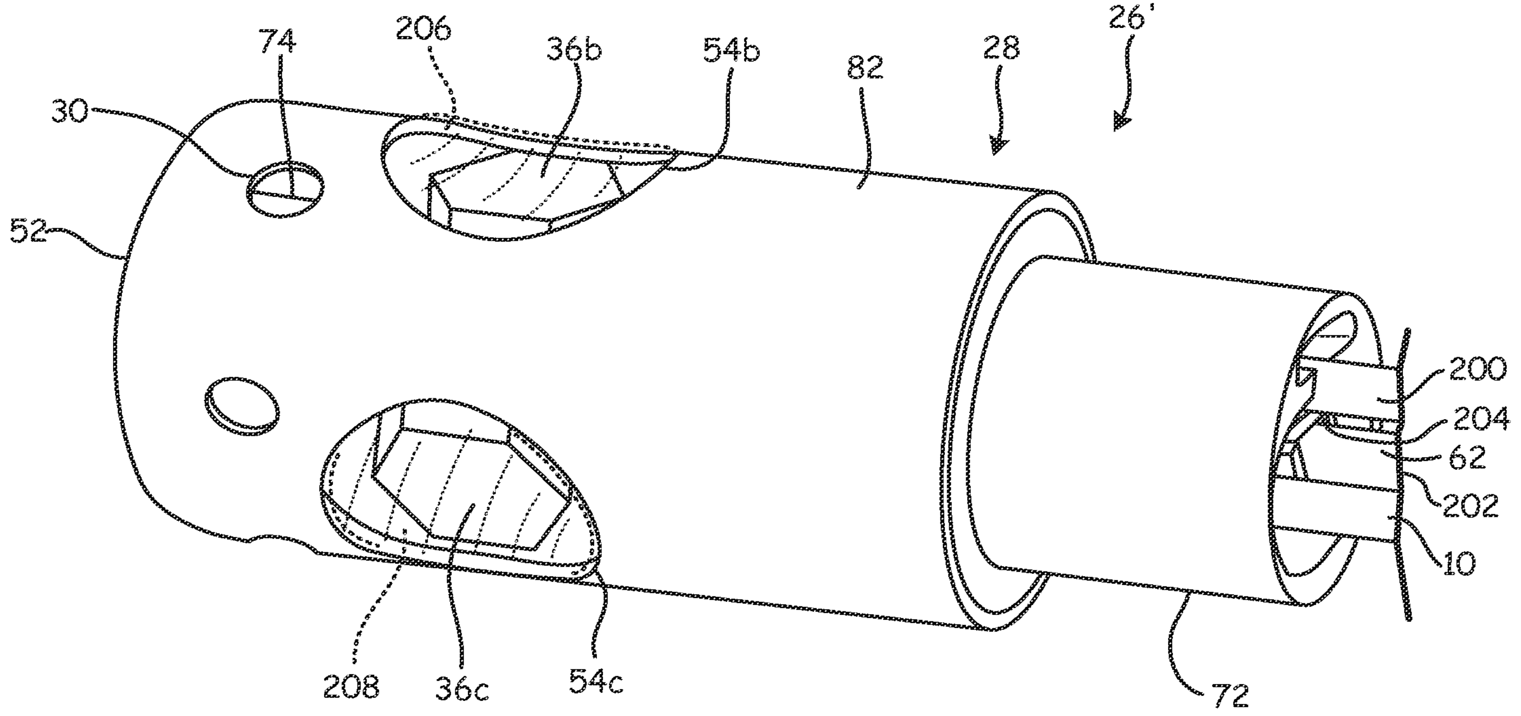


Fig. 9



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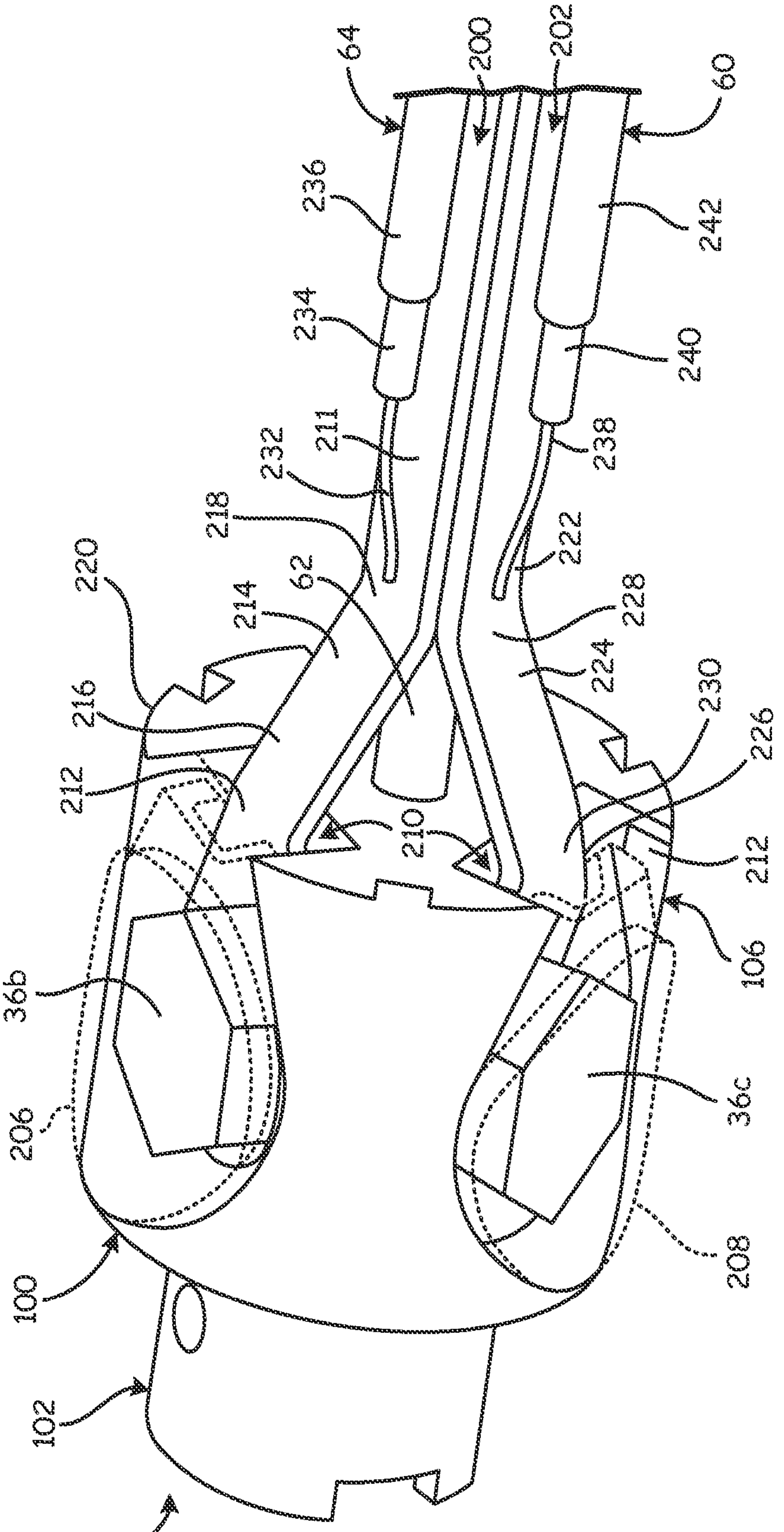
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Fig. 11

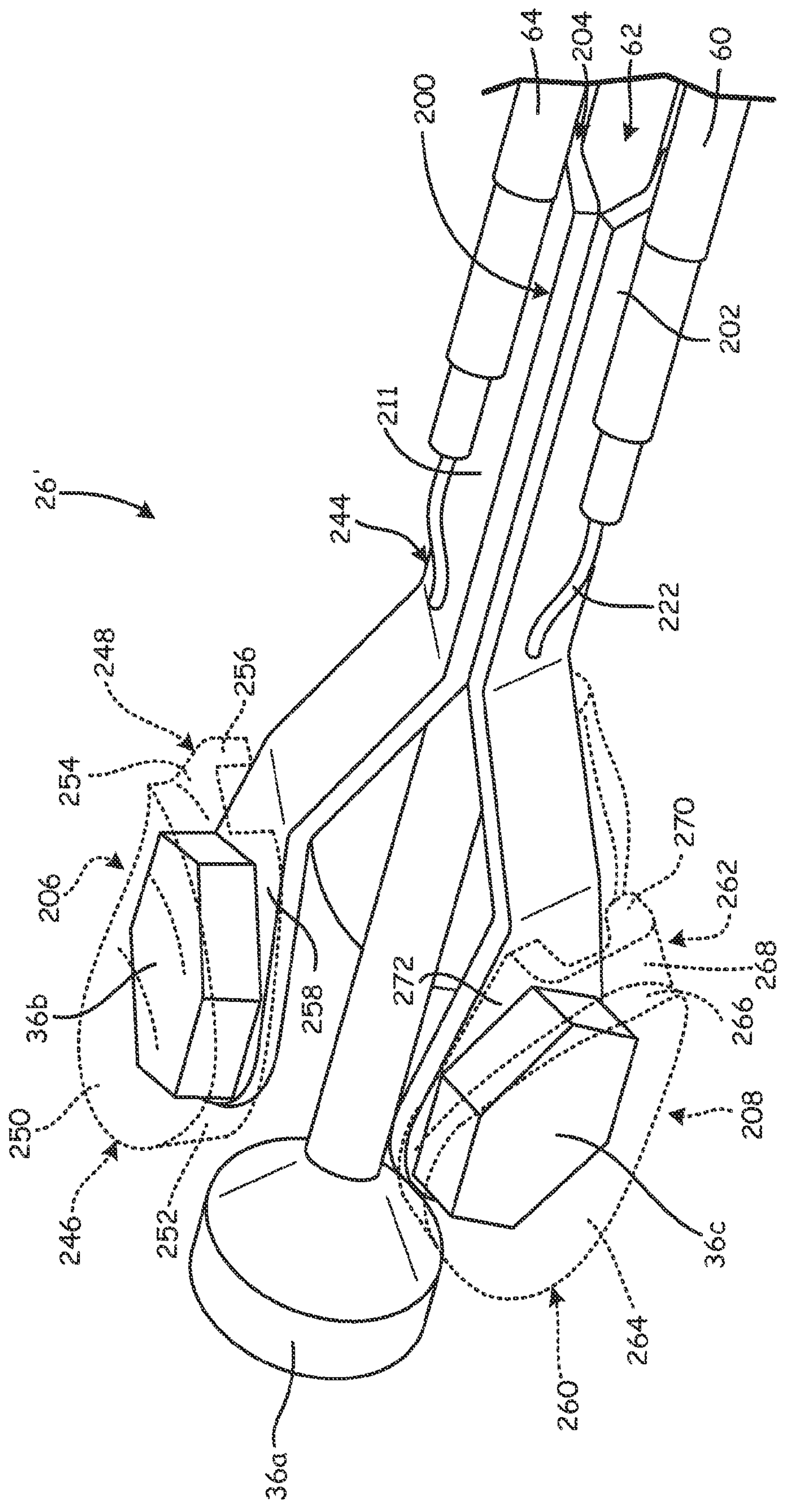
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Fig. 12

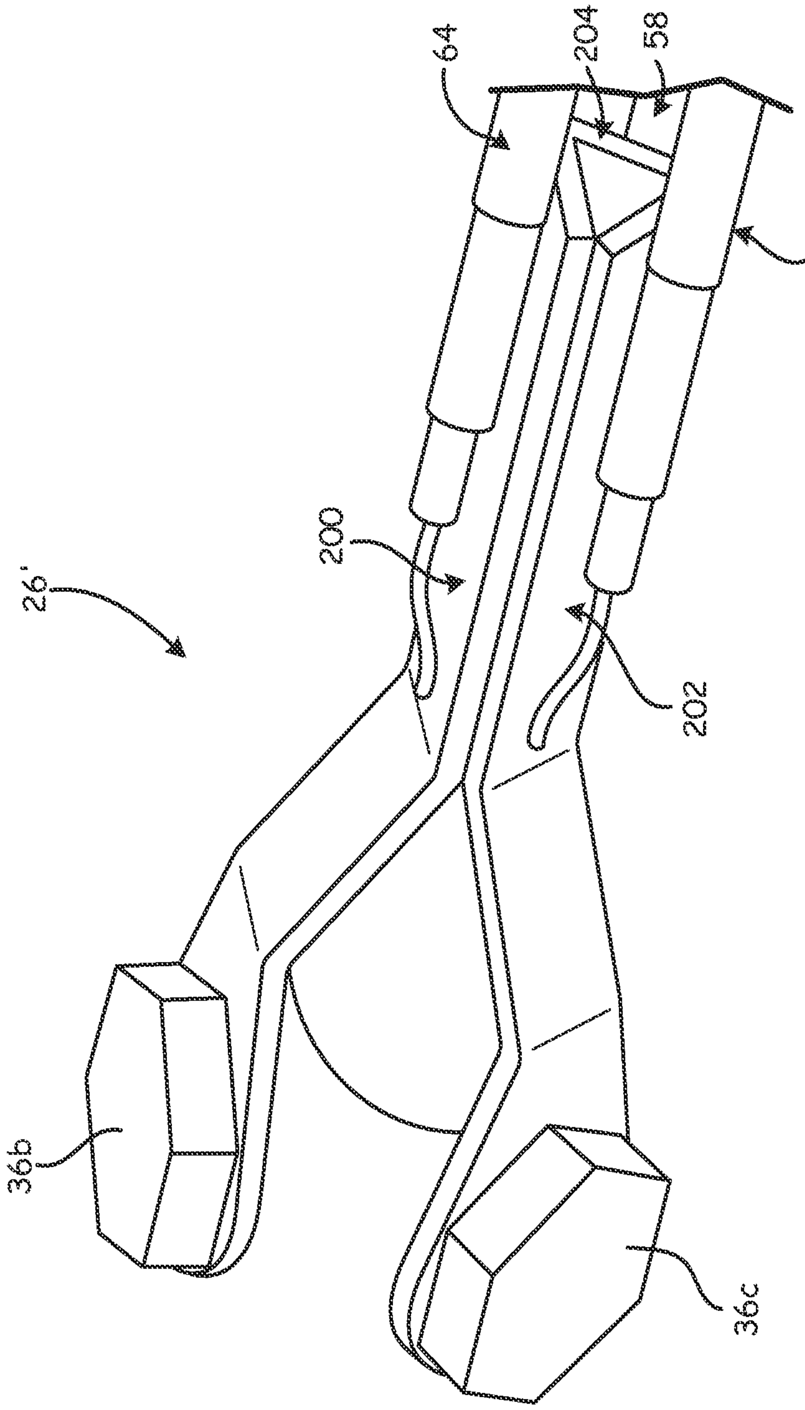


Fig. 13

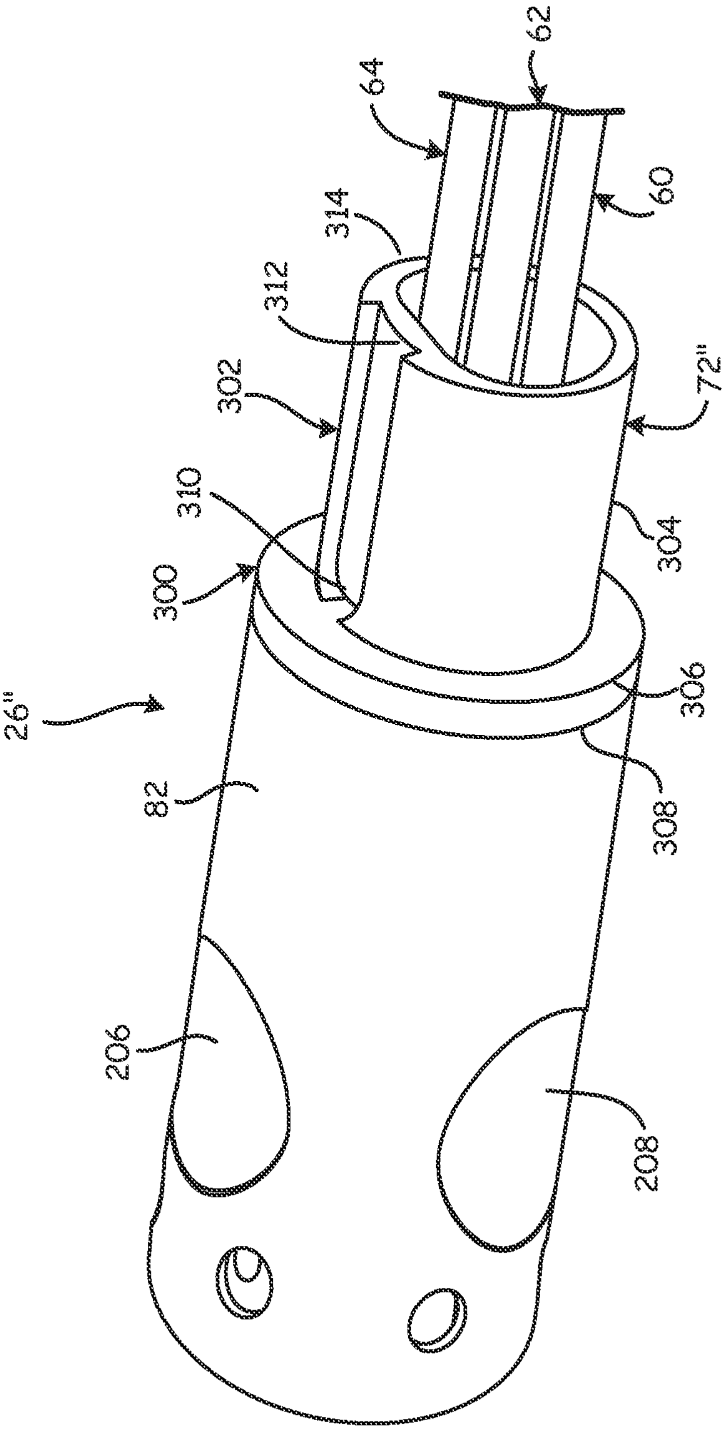
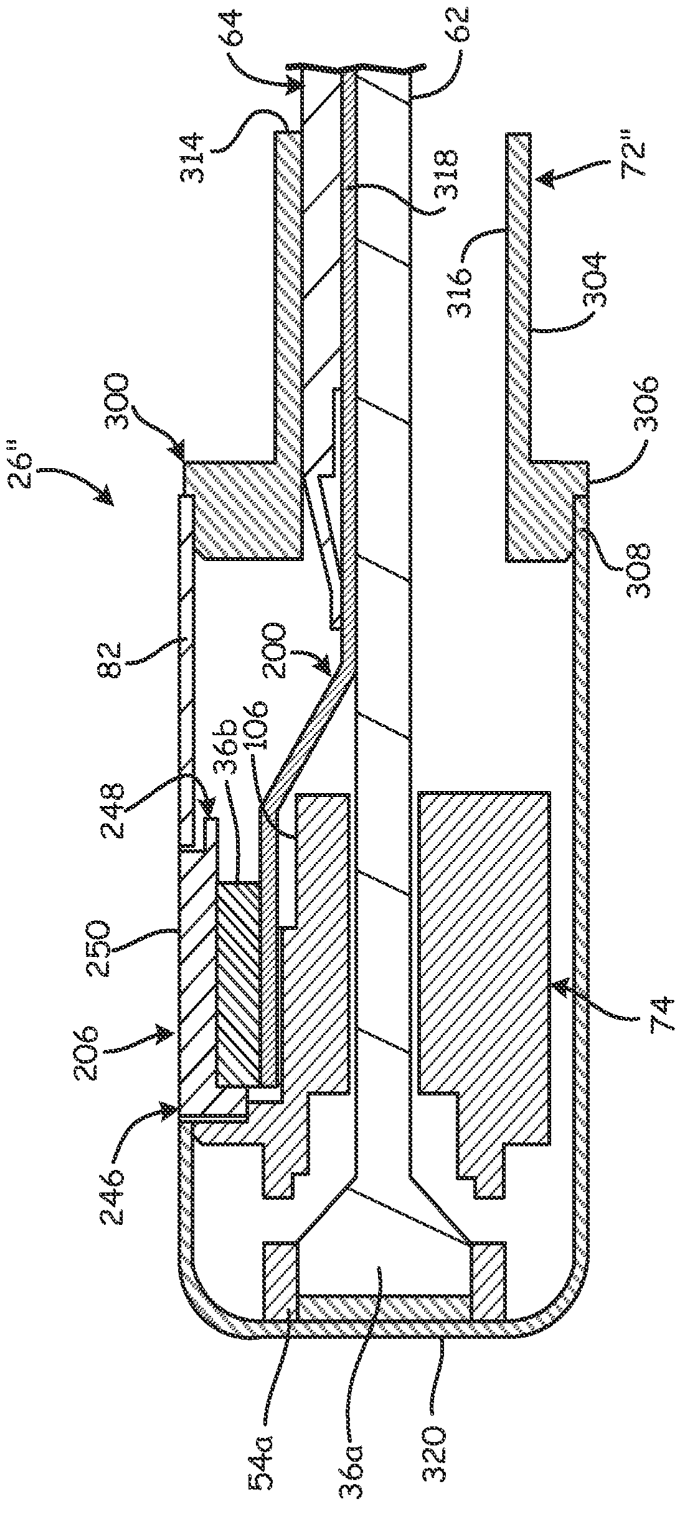


Fig. 14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54a
36a
320

Fig. 15

ABLATION CATHETER WITH ULTRASONIC LESION MONITORING CAPABILITY

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to U.S. Provisional Application 61/852,459, filed Mar. 15, 2013, which is herein incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates generally to devices and systems for imaging tissue within the body during an ablation procedure. More specifically, the present disclosure relates to an ablation probe with ultrasonic imaging capabilities.

BACKGROUND

[0003] In ablation therapy, it is often necessary to determine various characteristics of body tissue at a target ablation site within the body. In interventional cardiac electrophysiology (EP) procedures, for example, it is often necessary for the physician to determine the condition of cardiac tissue at a target ablation site in or near the heart. During some EP procedures, the physician may deliver a mapping catheter through a main vein or artery into an interior region of the heart to be treated. Using the mapping catheter, the physician may then determine the source of a cardiac rhythm disturbance or abnormality by placing a number of mapping elements carried by the catheter into contact with the adjacent cardiac tissue and then operate the catheter to generate an electrophysiology map of the interior region of the heart. Once a map of the heart is generated, the physician may then advance an ablation catheter into the heart, and position an ablation electrode carried by the catheter tip near the targeted cardiac tissue to ablate the tissue and form a lesion, thereby treating the cardiac rhythm disturbance or abnormality. In some techniques, the ablation catheter itself may include a number of mapping electrodes, allowing the same device to be used for both mapping and ablation.

[0004] Various ultrasound-based imaging catheters and probes have been developed for directly visualizing body tissue in applications such as interventional cardiology, interventional radiology, and electrophysiology. For interventional cardiac electrophysiology procedures, for example, ultrasound imaging devices have been developed that permit the visualization of anatomical structures of the heart directly and in real-time. In some electrophysiology procedures, for example, ultrasound catheters may be used to image the intraatrial septum, to guide transseptal crossing of the atrial septum, to locate and image the pulmonary veins, and to monitor the atrial chambers of the heart for signs of a perforation and pericardial effusion.

[0005] Many ultrasound-based imaging systems comprise an imaging probe that is separate from the mapping and ablation catheters used to perform therapy on the patient. As a result, a position tracking system is sometimes used to track the location of each device within the body. In some procedures, it may be difficult for the physician to quickly and accurately determine the condition of tissue to be ablated. Moreover, the images obtained using many ultrasound-based imaging systems are often difficult to read and understand without reference to images obtained from a separate imaging system such as a fluoroscopic imaging system.

SUMMARY

[0006] The present disclosure relates generally to devices and systems for imaging anatomical structures within the body during an ablation procedure.

[0007] In Example 1, an ablation probe for treating and imaging body tissue, the ablation probe comprising an ablation electrode tip, an ultrasonic imaging sensor, and a flex circuit. The ablation electrode tip includes an ablation electrode configured for delivering ablation energy to body tissue. The ultrasonic imaging sensor is disposed within the ablation electrode tip and is configured to transmit and receive ultrasonic waves. The flex circuit is mechanically and electrically connected to the ultrasonic imaging sensor.

[0008] In Example 2, the ablation probe of Example 1, further comprising a plurality of ultrasonic imaging sensors and a plurality of flex circuits. The plurality of ultrasonic imaging sensors is disposed within the ablation electrode tip, and each of the plurality of ultrasonic imaging sensors is configured to transmit and receive ultrasonic waves. The plurality of flex circuits are each mechanically and electrically connected to one of the plurality of ultrasonic imaging sensors.

[0009] In Example 3, the ablation probe of Example 2, and further comprising a plurality of electrical conduits, each electrically connected to one of the plurality of ultrasonic imaging sensors via one of the plurality of flex circuits.

[0010] In Example 4, the ablation probe of either of Examples 2 or 3, wherein the plurality of ultrasonic imaging sensors comprises at least three ultrasonic imaging sensors, wherein the plurality of flex circuits comprises at least three separate and distinct flex circuits each connected to one of the ultrasonic imaging sensors.

[0011] In Example 5, the ablation probe of any of Examples 2-4, wherein the plurality of ultrasonic imaging sensors are each mounted on one of the plurality of flex circuits within the ablation electrode tip.

[0012] In Example 6, the ablation probe of any of Examples 2-5, wherein each of the plurality of flex circuits has a proximal end terminating within a central bore of the ablation electrode tip.

[0013] In Example 7, the ablation probe of any of Examples 2-6, wherein the ablation electrode tip has a tubular electrode shell and a plurality of acoustic openings disposed therein, and wherein each of the ultrasonic imaging sensors is aligned with a respective one of the acoustic openings.

[0014] In Example 8, the ablation probe of any of Examples 2-7, wherein the plurality of ultrasonic imaging sensors includes three ultrasonic imaging transducers oriented circumferentially about the ablation electrode tip.

[0015] In Example 9, the ablation probe of Example 7, wherein the ablation tip further comprises a plurality of irrigation ports formed in the tubular electrode shell distally of the acoustic openings.

[0016] In Example 10, an ablation probe for treating and imaging body tissue, the ablation probe comprising an ablation electrode tip, a plurality of acoustic openings in the tip, a plurality of ultrasonic imaging sensors, and a plurality of acoustic cups. The ablation electrode tip includes an ablation electrode configured for delivering ablation energy to body tissue, and the plurality of acoustic openings are disposed through the ablation electrode tip. The plurality of ultrasonic imaging sensors are positioned inside the ablation electrode tip, each aligned with one of the acoustic openings. Each of the plurality of acoustic cups covers one of the ultrasonic imaging sensors.

[0017] In Example 11, the ablation probe of Example 10, wherein each of the acoustic cups comprises a main cup section, a back step extending from a side of the main cup section.

[0018] In Example 12, the ablation probe of Example 11, wherein the main cup section is positioned in one of the acoustic openings with an interference fit.

[0019] In Example 13, the ablation probe of either of Examples 10 or 11, wherein the main cup section is positioned in one of the acoustic openings with the back step extending in a distal direction to provide mechanical retention of the acoustic cup.

[0020] In Example 14, the ablation probe of any of Examples 10-13, and further comprising a tip insert having a plurality of recesses each configured for receiving one of the ultrasonic imaging sensors and for partially receiving one of the acoustic cups, wherein each of the plurality of recesses has a recess shoulder upon which the respective acoustic cup rests.

[0021] In Example 15, the ablation probe of any of Examples 10-14, wherein the acoustic cups are molded of a polyether block amide.

[0022] In Example 16, an ablation probe for treating and imaging body tissue, the ablation probe comprising an ablation electrode tip and a plurality of ultrasonic imaging sensors. The ablation electrode tip includes an ablation electrode configured for delivering ablation energy to body tissue, and further comprises an electrode shell, a proximal tip insert connected to a proximal end of the electrode shell, a distal tip insert and a plurality of acoustic openings. The distal tip insert is disposed within the electrode shell distally of the proximal tip insert, and the plurality of acoustic openings are disposed through the ablation electrode tip. The plurality of ultrasonic imaging sensors are positioned inside the ablation electrode tip and mounted to the distal tip insert, and are configured to transmit ultrasonic waves through the acoustic openings.

[0023] In Example 17, the ablation probe of Example 16, wherein the proximal tip insert has a shoulder extending radially outward from and circumferentially around an outer perimeter of the proximal tip insert and wherein the shoulder abuts a rear edge of the electrode shell.

[0024] In Example 18, the ablation probe of either of Examples 16 or 17, wherein the proximal tip insert has a recess on an outer perimeter of the proximal tip insert for receiving a distal end of a steering mechanism for deflecting and steering the ablation probe.

[0025] In Example 19, the ablation probe of any of Examples 16-18, wherein the proximal tip insert has a central bore passing through the proximal tip insert that is sized and configured to receive electrical and fluid conduits extending into the ablation electrode tip.

[0026] In Example 20, the ablation probe of any of Examples 16-19, further comprising a plurality of acoustic cups each coupled to the ablation electrode tip, each acoustic cup positioned at a location corresponding to one of the acoustic imaging sensors.

[0027] While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] FIG. **1** is a schematic view of a combined ablation and imaging system in accordance with an illustrative embodiment;

[0029] FIG. **2** is a perspective view showing the distal section of a first embodiment of the combined ablation and ultrasonic imaging probe of FIG. **1** in greater detail;

[0030] FIG. **3** is a cross-sectional view of the ablation electrode tip;

[0031] FIG. **4** is a cross-sectional view of the ablation electrode tip along line **4-4** in FIG. **2**;

[0032] FIG. **5** is a cross-sectional view of the RF electrode along line **5-5** in FIG. **2**;

[0033] FIG. **6** is a perspective view of the proximal tip insert of FIG. **3**;

[0034] FIG. **7** is a perspective view of the distal tip insert of FIG. **3**;

[0035] FIG. **8** is an end view of the distal tip insert of FIG. **7** along line **8-8** in FIG. **7**;

[0036] FIG. **9** is a cross-sectional view of the distal tip insert along line **9-9** in FIG. **7**;

[0037] FIG. **10** is a perspective view showing the distal section of a second embodiment of the combined ablation and ultrasonic imaging probe of FIG. **1** in greater detail;

[0038] FIG. **11** is a perspective view of the distal section of the combined ablation and ultrasonic imaging probe of FIG. **10**, with the proximal tip insert and the electrode tip removed;

[0039] FIG. **12** is a perspective view of the distal section of the combined ablation and ultrasonic imaging probe of FIG. **10**, with the proximal tip insert, the distal tip insert, and the electrode tip removed;

[0040] FIG. **13** is a perspective view of the distal section of the combined ablation and ultrasonic imaging probe of FIG. **10**, with the proximal tip insert, the distal tip insert, the electrode tip, the acoustic cups, and distal-facing ultrasonic imaging sensor removed;

[0041] FIG. **14** is a perspective view showing the distal section of a third embodiment of the combined ablation and ultrasonic imaging probe of FIG. **1** in greater detail; and

[0042] FIG. **15** is a schematic side sectional view of the distal section of the combined ablation and ultrasonic imaging probe of FIG. **14**.

[0043] While the invention is amenable to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and are described in detail below. The intention, however, is not to limit the invention to the particular embodiments described. On the contrary, the invention is intended to cover all modifications, equivalents, and alternatives falling within the scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

[0044] FIG. **1** is a schematic view of a combined ablation and imaging system **10** in accordance with an illustrative embodiment. As shown in FIG. **1**, the system **10** includes a combined ablation and ultrasonic imaging probe **12**, an RF generator **14**, a fluid reservoir and pump **16**, and an ultrasonic imaging module **18**. The probe **12** comprises an elongate probe body **20** having a proximal section **22** equipped with a handle assembly **24**, and a deflectable distal section **26** including an ablation electrode tip **28**. The probe body **20** includes an internal cooling fluid lumen **29** fluidly coupled to the fluid reservoir and pump **16**, which supplies a cooling fluid, such as saline, through the probe body **20** to a number of irrigation ports **30** in the ablation electrode tip **28**. The probe body **20** may further include additional lumens or other tubular elements for supporting electrical conductors, additional fluid lumens, a thermocouple, an insertable stylet, as well as other components. In some embodiments, the probe body **20** comprises flexible plastic tubing with a braided metal mesh to increase the rotational stiffness of the body **20**.

[0045] In various embodiments, the probe **12** includes one or more pacing/sensing electrodes (e.g., circumferential ring electrodes, not shown) on the probe body **20** near the ablation electrode tip **28** for sensing intrinsic cardiac electrical activity and for providing pacing stimuli. In such embodiments, the system **10** may also include additional equipment (not shown) operatively coupled to the pacing/sensing electrodes for recording electrocardiograms and for generating the aforementioned pacing stimuli. Such pacing/sensing components are not critical to the various embodiments, however, and are therefore need not be described in greater detail herein.

[0046] The RF generator **14** is configured for generating RF energy for performing ablation procedures using the ablation electrode tip **28**. The RF generator **14** includes an RF energy source **32** and a controller **34** for controlling the timing and level of the RF energy delivered by the ablation electrode tip **28**. During an ablation procedure, the RF generator **14** is configured to deliver ablation energy to the ablation electrode tip **28** in a controlled manner to ablate any sites identified or targeted for ablation. Other types of ablation sources in addition to or in lieu of the RF generator **14** can also be used for ablating target sites. Examples of other types of ablation sources can include, but are not limited to, microwave generators, acoustic generators, cryoablation generators, and laser/optical generators.

[0047] The ultrasonic imaging module **18** is configured for generating high resolution ultrasonic images (e.g., A, M, or B-mode images) of anatomical structures within the body based on signals received from several ultrasonic imaging sensors **36** located within the ablation electrode tip **28**. In the embodiment of FIG. **1**, the ultrasonic imaging module **18** includes an ultrasonic signal generator **40** and an image processor **42**. The ultrasonic signal generator **40** is configured to provide electrical signals for controlling each of the ultrasonic sensors **36**. The imaging signals received back from the ultrasonic imaging sensors **36**, in turn, are fed to the image processor **42**, which processes the signals and generates images that can be displayed on a graphical user interface (GUI) **44**. In certain embodiments, for example, the ultrasonic images displayed on the GUI **44** can be used to assist the physician with advancing the probe **12** through the body and to perform an ablation procedure. In cardiac ablation procedures, for example, the ultrasonic images generated from the ultrasound signals can be used to confirm tissue contact of the probe **12** within the heart or surrounding anatomy, to determine the orientation of the probe **12** within the body, to determine the tissue depth of the tissue at a target ablation site, and/or to visualize the progression of a lesion being formed in the tissue.

[0048] Various characteristics associated with the ultrasonic imaging sensors **36** as well as the circuitry within the ultrasonic imaging module **18** can be controlled to permit the sensors **36** to accurately detect tissue boundaries (e.g., blood or other bodily fluids), lesion formation and progression, as well as other characteristics of the tissue before, during, and/or after the ablation procedure. Example tissue characteristics that can be visualized using the probe **12** include, but are not limited to, the presence of fluid vaporization inside the tissue, the existence of a prior scar, the size and shape of a lesion being formed, as well as structures adjacent to heart tissue (e.g., lungs, esophagus). The depth at which the ultrasonic imaging sensors **36** can visualize anatomical structures within the body is dependent on the mechanical characteristics of the sensors **36**, the electrical characteristics of the sensor circuitry including the drive frequency of the signal generator **40**, the boundary conditions and degree of attenuation between the sensors **36** and the surrounding anatomy, as well as other factors.

[0049] In some embodiments, the probe **12** further includes a steering mechanism to permit the operator to deflect and steer the probe **12** within the body. In one embodiment, for example, a steering member such as a steering knob **46** rotatably coupled to the handle **24** can be used to deflect the ablation electrode tip **28** in one or multiple directions relative to a longitudinal axis of the probe body **20**. Rotational movement of the steering knob **46** in a first direction relative to the handle **24** causes a steering wire within the probe body **20** to move proximally relative to the probe body **20**, which, in turn, bends the distal section **26** of the probe body **20** into a particular shape such as an arced shape. Rotational movement of the steering knob **46** in the opposite direction, in turn, causes the distal section **26** of the probe body **20** to return to its original shape, as shown. To assist in the deflection, and in some embodiments, the probe body **20** includes one or more regions made of a lower durometer material than the other portions of the probe body **20**.

[0050] Although the system **10** is described in the context of a medical system for use in intracardiac electrophysiology procedures for diagnosing and treating the heart, in other embodiments the system **10** may be used for treating, diagnosing, or otherwise visualizing other anatomical structures such as the prostate, brain, gall bladder, uterus, esophagus, and/or other regions in the body. Moreover, many of the elements in FIG. **1** are functional in nature, and are not meant to limit the structure that performs these functions in any manner. For example, several of the functional blocks can be embodied in a single device or one or more of the functional blocks can be embodied in multiple devices.

[0051] FIG. **2** is a perspective view showing the distal section **26** of the probe **12** of FIG. **1** in greater detail. As can be further seen in FIG. **2**, the ablation electrode tip **28** includes an RF electrode **48** configured for delivering ablation energy to body tissue surrounding the ablation electrode tip **28**. In the embodiment of FIG. **2**, the RF electrode **48** comprises a tubular-shaped metal electrode shell that extends from a distal end **50** of the probe body **20** to a distal end **52** of the ablation electrode tip **28** along longitudinal axis L. A number of exposed openings **54***a*, **54***b*, **54***c* disposed through the ablation electrode tip **28** form acoustic openings that permit ultrasonic waves transmitted by the ultrasonic imaging sensors **36***a*, **36***b*, **36***c*, **36***d* to pass through the ablation electrode tip **28** and into the surrounding tissue. The reflected ultrasonic waves received back from the tissue pass through the acoustic openings **54***a*, **54***b*, **54***c* and are sensed by the ultrasonic imaging sensors **36***a*, **36***b*, **36***c*, **36***d* operating in a receive mode. In some embodiments, the acoustic openings **54***a*, **54***b*, **54***c* comprise exposed openings or apertures formed through the wall of the ablation electrode tip **28**.

[0052] In addition to serving as an ablation electrode, the RF electrode **48** also functions as a housing that contains the ultrasonic imaging sensors **36***a*, **36***b*, **36***c*, **36***d*, the electrical conductors coupling the RF electrode **48** to the RF generator **14**, the electrical conductors coupling the ultrasonic imaging sensors **36***a*, **36***b*, **36***c*, **36***d* to the ultrasonic imaging module **18**, one or more steering wires of the steering mechanism, as well as other components. In certain embodiments, the RF electrode **48** comprises an electrically conductive alloy such as platinum-iridium, which in addition to serving as an electrode for providing ablation therapy, is also used as a fluoroscopic marker to determine the location of the ablation electrode tip **28** within the body using fluoroscopy.

[0053] In the embodiment of FIG. **2**, the probe **12** includes a distal-facing ultrasonic imaging sensor **36***a* located at or near the distal end **52** of the ablation electrode tip **28**. In other embodiments, multiple distal-facing ultrasonic imaging sensors **36***a* are located at or near the distal end **52** of the ablation electrode tip **28**. Each ultrasonic sensor **36***a* is configured to transmit ultrasonic waves primarily in a forward or distal direction away from the distal end **52** of the ablation electrode tip **28**. A second set of ultrasonic imaging sensors **36***b*, **36***c*, **36***d* disposed within the ablation electrode tip **28** at a location proximal to the distal-facing ultrasonic imaging sensor **36***a* are configured to transmit ultrasonic waves primarily in a lateral or side-facing direction away from the side of the ablation electrode tip **28**. The reflected waves received back from the ultrasonic imaging sensors **36***a*, **36***b*, **36***c*, **36***d* produces signals that can be used by the ultrasonic imaging module **18** to generate images of the surrounding body tissue.

[0054] In some embodiments, the ultrasonic imaging sensors **36***a*, **36***b*, **36***c*, **36***d* each comprise piezoelectric transducers formed of a piezoceramic material such as lead zirconate titanate (PZT) or a piezoelectric polymer such as polyvinylidene fluoride (PVDF). In some embodiments, the ablation electrode tip **28** includes three laterally-facing ultrasonic imaging sensors **36***b*, **36***c*, **36***d* each oriented circumferentially at 120° intervals apart from each other about the ablation electrode tip **28** for use in imaging tissue located adjacent to the sides of the ablation electrode tip **28**. In other embodiments, a greater or lesser number of laterally-facing ultrasonic imaging sensors are employed for imaging tissue adjacent to the sides of the ablation electrode tip **28**.

[0055] In the embodiment of FIG. **2**, the ablation electrode tip **28** has an open irrigated configuration including a number of irrigation ports **30** used to deliver cooling fluid to cool the ablation electrode tip **28** and the surrounding tissue. In other embodiments, the ablation electrode tip **28** has a closed irrigation configuration in which the cooling fluid is recirculated through the ablation electrode tip **28** without being ejected into the surrounding tissue. In some embodiments, the ablation electrode tip **28** comprises six irrigation ports **30** each disposed circumferentially at 60° intervals apart from each other about the ablation electrode tip **28** and at a location proximal to the distal-facing ultrasonic sensor **36***a* and distal to the location of the laterally-facing ultrasonic sensors **36***b*, **36***c*, **36***d*. In other embodiments, a greater or lesser number of fluid irrigation ports **30** are employed. In some embodiments, the fluid irrigation ports **30** are circular in shape, and have a diameter in the range of approximately 0.005 inches to 0.02 inches. The size, number, and/or positioning of the irrigation ports **30** can vary, however. In some embodiments, for example, the ablation electrode tip **28** further includes a number of fluid irrigation ports **30** located circumferentially about the ablation electrode tip **28** proximally of the laterally-facing ultrasonic imaging sensors **36***b*, **36***c*, **36***d*. During ablation therapy, the cooling fluid is used to control the temperature and reduce coagulum formation on the ablation electrode tip **28**, thus preventing an impedance rise of the tissue in contact with the ablation electrode tip **28** and increasing the transfer of RF ablation energy delivered from the ablation electrode tip **28** into the tissue.

[0056] FIG. **3** is a cross-sectional view of the ablation electrode tip **28**. As can be further seen in FIG. **3**, the ablation electrode tip **28** includes an interior lumen **56** that houses the ultrasonic imaging sensors **36***a*, **36***b*, **36***c*, **36***d*, electrical conduits **58**, **60**, **62**, **63** for transmitting power to and receiving signals back from the sensors **36***a*, **36***b*, **36***c*, **36***d*, and an electrical conduit **64** for supplying RF ablation energy to the RF electrode **48**. A fluid conduit **66** extending through the probe **12** supplies cooling fluid from the fluid reservoir and pump **16** to the interior lumen **56** of the ablation electrode tip **28**, which is then transmitted into the surrounding tissue through the irrigation ports **30**. A thermocouple lead **68** extending through the probe **12** terminates distally at a thermocouple **70** located within the interior lumen **56** for sensing the temperature of the ablation electrode tip **28** during the ablation procedure.

[0057] A proximal tip insert **72** is used for coupling the ablation electrode tip **28** to the distal end **50** of the probe body **20**. A distal tip insert **74** is configured to support the laterally-facing ultrasonic imaging sensors **36***b*, **36***c*, **36***d* within the ablation electrode tip **28**, and divides the interior lumen **56** into a proximal fluid chamber **76** and a distal fluid chamber **78**. A number of fluid channels **80** extending lengthwise along the length of the distal tip insert **74** fluidly connect the proximal fluid chamber **76** to the distal fluid chamber **78**. During ablation, the presence of the distal tip insert **74** within the ablation electrode tip **28** creates a back pressure as the cooling fluid enters the proximal fluid chamber **76**, causing the fluid to circulate before being forced through the channels **80** and into the distal fluid chamber **78**.

[0058] FIG. **4** is a cross-sectional view of the ablation electrode tip **28** along line **4-4** in FIG. **3**. As can be further seen in conjunction with FIG. **4**, and in some embodiments, the distal tip insert **74** includes three fluid channels **80** for supplying cooling fluid from the proximal fluid chamber **76** to the distal fluid chamber **78**. As can be further seen in FIG. **4**, and in some embodiments, the ablation electrode tip **28** includes three laterally-facing ultrasonic imaging sensors **36***b*, **36***c*, **36***d* equally spaced from each other at an angle α of 120° about the circumference of the distal tip insert **74**. Although three laterally-facing ultrasonic sensors **36***b*, **36***c*, **36***d* are shown in the embodiment of FIG. **4**, a greater or lesser number of ultrasonic imaging sensors may be employed. By way of example and not limitation, four ultrasonic imaging sensors may be disposed at equidistant angles α of 90° about the circumference of the distal tip insert **74**. During imaging, the use of multiple laterally-facing ultrasonic imaging sensors **36***b*, **36***c*, **36***d* spaced about the circumference of the distal tip insert **74** ensures that the field of view of at least one of the sensors **36***b*, **36***c*, **36***d* is in close proximity to the target tissue irrespective of the tip orientation relative to the target tissue. Such configuration also permits the physician to easily visualize the target tissue without having to rotate the probe **12** once the probe **12** is in contact with the tissue.

[0059] To conserve space within the ablation electrode tip **28**, the fluid channels **80** are each circumferentially offset from the ultrasonic imaging sensors **36***b*, **36***c*, **36***d*. In the embodiment shown in which three laterally-facing ultrasonic imaging sensors **36***b*, **36***c*, **36***d* are employed, each of the fluid channels **80** are disposed circumferentially at equidistant angles β_1 of 120° about the circumference of the distal tip insert **74**, and are circumferentially offset from each adjacent ultrasonic imaging sensor by an angle β_2 of approximately 60°. The angle β_1 between each of the fluid channels **80** and the angle **62** between each fluid channel **80** and adjacent ultrasonic imaging sensors **36***b*, **36***c*, **36***d* can vary in other embodiments depending on the number of fluid channels and/or ultrasonic imaging sensors provided. In some embodiments, the fluid channels **80** each have an equal cross-sectional area and are equally positioned around the center of the distal tip insert **74**. The number and configuration of the fluid channels can vary.

[0060] FIG. **5** is a cross-sectional view of the RF electrode **48** along line **5-5** in FIG. **2**. As can be further seen in FIG. **5**, the RF electrode **48** comprises a tubular-shaped electrode shell **82** including six irrigation ports **30** equally spaced from each other at an angle ϕ of 60° about the circumference of the electrode shell **82**. The number, size, and angle ϕ between each of the irrigation ports **30** can vary in other embodiments. To minimize interference of the irrigation fluid with the transmission of ultrasonic waves from the ultrasonic imaging sensors **36**, and in some embodiments, the centers of the irrigation ports **30** are offset circumferentially from the centers of the side-facing acoustic openings **54***b*, **54***c*. In those embodiments in which the ablation electrode tip **28** includes three lateral-facing ultrasonic imaging sensors **36***b*, **36***c*, **36***d* and six irrigation ports **30**, for example, the irrigation ports **30** can be circumferentially offset from each adjacent side acoustic opening **54***b*, **54***c* by an angle of approximately 30°. This circumferential offset may vary in other embodiments depending on the number and configuration of imaging sensors **36** as well as other factors. In some embodiments, the irrigation ports **30** are circular in shape, and have a diameter within a range of approximately 0.005 to 0.02 inches.

[0061] FIG. **6** is a perspective view of the proximal tip insert **72** of FIG. **3**. As can be further seen in FIG. **6**, the proximal tip insert **72** comprises a hollow metal insert body **84** having a proximal section **86** and a distal section **88**. The proximal section **86** is configured to attach to the distal end **50** of the probe body **20**. The distal section **88**, in turn, has an enlarged outer diameter relative to the proximal section **86**, and is configured to attach to the electrode shell **82**. In some embodiments, the proximal tip insert **72** is coupled to both the distal end **50** of the probe body **20** and to the electrode shell **82** via frictional fit, solder, welding (e.g., laser welding), and/or an adhesive attachment. A shoulder **90** at the transition from the proximal section **86** to the distal section **88** serves as a flange to align the distal end **50** of the probe body **20** flush with the electrode shell **82**.

[0062] A first lumen **92** disposed through the proximal tip insert **72** provides a conduit for the electrical and fluid conduits **58**, **60**, **62**, **64**, **66** that supply electrical signals and cooling fluid to the ablation electrode tip **28**. A second lumen **94** disposed through the proximal tip insert **72** provides a conduit for the steering mechanism used for deflecting the probe **12**.

[0063] FIG. **7** is a perspective view of the distal tip insert **74** of FIG. **3**. As shown in FIG. **7**, the distal tip insert **74** comprises a cylindrically-shaped metal body **98** having a proximal section **100** and a distal section **102**. In the embodiment of FIG. **7**, the outer extent **104** of the proximal section **100** is sized to fit within the electrode shell **82** adjacent to the location of the side acoustic openings **54***b*, **54***c*, and includes three fluid channels **80**. The outer extent **104** further includes a number of recesses **106** each configured to receive a corresponding one of the lateral-facing ultrasonic imaging sensors **36***b*, **36***c*, **36***d* therein. In some embodiments, the recesses **106** are sized and shaped to receive the ultrasonic imaging sensors **36***b*, **36***c*, **36***d* such that the sensors **36***b*, **36***c*, **36***d* lie substantially flush with the outer extent **104**. An exposed opening **108** located at the proximal end of the distal tip insert **74** provides a channel to feed the electrical conduits for the ultrasonic imaging sensors **36***b*, **36***c*, **36***d* into the recesses **106**.

[0064] The distal section **102** of the distal tip insert **74** is configured to support the distal-facing ultrasonic imaging sensor **36***a* within the ablation electrode tip **28**. The outer extent **110** of the distal section **102** is reduced in diameter relative to the proximal section **100**. This reduction in diameter creates an annular-shaped distal fluid chamber **78** (see FIG. **3**) that receives cooling fluid via the fluid channels **80**.

[0065] An aperture **112** within the proximal section **100** of the insert body **98** is configured to receive the distal end of a thermocouple used for sensing the temperature of the ablation electrode tip **28**. As can be further seen in FIGS. **8-9**, a second, central bore **114** extending through the proximal and distal sections **108**, **110** of the insert body **104** is configure to receive the distal-facing ultrasonic imaging sensor **36***a* and a portion of the electrical conduit **63** that connects the sensor **36***a* to the ultrasonic imaging module **18**. In some embodiments, a number of side apertures **116** disposed through the distal section **102** are used to permit alignment and mounting of the distal-facing ultrasonic imaging sensor **36***a*.

[0066] FIG. **10** is a perspective view showing a distal section **26'** of the probe **12** of FIG. **1**. The distal section **26'** is an alternative embodiment of the distal section **26** (shown in FIGS. **1** and **2**), which both include the electrode shell **82**, the proximal tip insert **72**, the distal tip insert **74**, and the ultrasonic imaging sensors **36***a*, **36***b*, **36***c*, and **36***d*. The distal section **26'** can be connected to the electrical conduits **60**, **62**, and **64** as shown in FIG. **10** as well as the electrical conduits **58** and **63**, the fluid conduit **66**, and the thermocouple lead **68**, which are omitted from FIG. **10** for clarity.

[0067] The distal section **26'** further includes flex circuits **200**, **202**, and **204**, which are positioned radially inward of and substantially inside the electrode shell **82** and the proximal tip insert **72**. In the illustrated embodiment, the flex circuits **200**, **202**, and **204** terminate inside the proximal tip insert **72** such that the flex circuits **200**, **202**, and **204** do not extend out of the proximal tip insert **72** in a proximal direction. The ultrasonic imaging sensors **36***b*, **36***c*, and **36***d* are each mounted on and structurally supported by the flex circuits **200**, **202**, and **204**, respectively. The ultrasonic imaging sensors **36***b*, **36***c*, and **36***d* are each also electrically connected to the flex circuits **200**, **202**, and **204**, respectively. In the illustrated embodiment, the ultrasonic imaging sensors **36***b*, **36***c*, and **36***d* have a substantially hexagonal shape.

[0068] The distal section **26'** further includes acoustic cups **206** and **208**. The acoustic cup **206** is positioned in the side-facing acoustic opening **54***b* to cover the ultrasonic imaging sensor **36***b*. The acoustic cup **206** is sized and shaped to substantially fill the side-facing acoustic opening **54***b*. The acoustic cup **206** has a contoured outer surface that forms a curve that is substantially continuous with that of the cylindrical outer surface of the electrode shell **82**. The acoustic cup **206** can allow ultrasonic waves to pass to and from the ultrasonic imaging sensor **36***b*.

[0069] Similarly, the acoustic cup **208** is positioned in the side-facing acoustic opening **54***c* to cover the ultrasonic imaging sensor **36***c*. The acoustic cup **208** is sized and shaped to substantially fill the side-facing acoustic opening **54***c*. The acoustic cup **208** has a contoured outer surface that forms a curve that is substantially continuous with that of the cylindrical outer surface of the electrode shell **82**. The acoustic cup **208** can allow ultrasonic waves to pass to and from the ultrasonic imaging sensor **36***c*.

[0070] Although not illustrated in FIG. **10**, an additional acoustic cup is also positioned over the radially-facing ultrasonic imaging sensor **36***d*.

[0071] FIG. **11** is a perspective view showing the distal section **26'** with the electrode shell **82** and the proximal tip insert **72** removed for clarity. The flex circuits **200** and **202** are seated partially in the recesses **106**, with the lateral-facing ultrasonic imaging sensors **36***b* and **36***c* being mounted on and positioned radially outward of the flex circuits **200** and **202**, respectively. The acoustic cups **206** and **208** are also seated partially in the recesses **106**, on top of and radially outward of both the flex circuits **200** and **202** and the lateral-facing ultrasonic imaging sensors **36***b* and **36***c*.

[0072] The recesses **106** each have a recess bottom **210** and a recess shoulder **212** positioned radially outward from the recess bottom **210**. The flex circuits **200** and **202** each rest on the recess bottoms **210** and the acoustic cups **206** and **208** each rest on the recess shoulders **212**.

[0073] The flex circuit **200** is a flexible printed circuit having a straight section **211**, a straight section **214**, and a mounting section **216**. A bend **218** is between the straight sections **211** and **214** and another bend **220** is between the straight section **214** and the mounting section **216**. The straight section **212** is substantially parallel to, adjacent, and positioned between the electrical conduits **62** and **64**. The straight section **211** is angled away from the electrical conduit **62**. The mounting section **216** is also substantially parallel to the electrical conduits **62** and **64**, but is spaced from the electrical conduit **62** by the distal tip insert **74**.

[0074] The flex circuit **202** is also a flexible printed circuit having a straight section **222**, a straight section **224**, and a mounting section **226**. A bend **228** is between the straight sections **222** and **224** and another bend **230** is between the straight section **224** and the mounting section **226**. The straight section **222** is substantially parallel to, adjacent, and positioned between the electrical conduits **60** and **62**. The straight section **224** is angled away from the electrical conduit **62**. The mounting section **226** is also substantially parallel to the electrical conduits **60** and **62**, but is spaced from the electrical conduit **62** by the distal tip insert **74**.

[0075] As will be appreciated, the flex circuit **204** can have substantially the same configuration as the flex circuits **200**, **202**, and can be electrically coupled to the electrical conduit **58** in a similar fashion.

[0076] In various embodiments, the flex circuits **200**, **202**, **204** can be multi-layer, flexible circuits formed from conventional techniques. In one embodiment, the flex circuits **200**, **202**, **204** each include a structural substrate layer (which can be made of a conductive or non-conductive material) upon which is formed one or more alternating layers of conductive and dielectric layers. In such embodiments, the conductive layer(s) forming one or more conductive traces to facilitate electrical connection of the ultrasonic imaging sensors **36***a*, **36***b*, **36***c* to respective electrical contacts at the proximal end of the probe, and the dielectric layer(s) operate to electrically insulate the conductive trace(s) from one another (if more than one circuit is present) and from other electrically conductive components in the probe.

[0077] As shown, the ultrasonic imaging sensor **36***b* is mounted on the mounting section **216** of the flex circuit **200**. In one embodiment, the electrical conduit **64** is a coaxial cable including a core **232**, a shield **234**, and an insulating sheath **236**. Though not illustrated in FIG. **11**, the core **232** can be electrically connected to a first electrode (not shown) of the ultrasonic imaging sensor **36***b* via an electrical trace (not shown) extending along the flex circuit **200** from the straight section **211** to the ultrasonic imaging sensor **36***b*. The shield **234** can be electrically connected to a second electrode (not shown) of the ultrasonic imaging sensor **36***b*, for example via a conducting layer (not shown) sputtered on top of the flex circuit **200**. Thus, the flex circuit **200** electrically connects the electrical conduit **64** to the ultrasonic imaging sensor **36***b* for transmitting signals to and from the ultrasonic imaging sensor **36***b*.

[0078] In one embodiment, the ultrasonic imaging sensor **36***c* is mounted on the mounting section **226** of the flex circuit **202**. The electrical conduit **60** is also a coaxial cable including a core **238**, a shield **240**, and an insulating sheath **242**. Though not illustrated in FIG. **11**, the core **238** can be electrically connected to a first electrode (not shown) of the ultrasonic imaging sensor **36***c* via an electrical trace (not shown) extending along the flex circuit **202** from the straight section **222** to the ultrasonic imaging sensor **36***c*. The shield **240** can be electrically connected to a second electrode (not shown) of the ultrasonic imaging sensor **36***c*, for example via a conducting layer (not shown) sputtered on top of the flex circuit **202**. Thus, the flex circuit **202** electrically connects the electrical conduit **60** to the ultrasonic imaging sensor **36***c* for transmitting signals to and from the ultrasonic imaging sensor **36***c*.

[0079] FIG. **12** is a perspective view showing the distal section **26'** with the electrode shell **82**, the proximal tip insert **72**, and the distal tip **74** removed for clarity. As shown in FIG. **12**, the flex circuits **200**, **202**, and **204** are three separate and distinct flex circuits that can combine to effectively form an elongated triangular tube **244** along the straight sections **211** and **222**. The triangular tube **244** formed by the flex circuits **200**, **202**, and **204** can create a channel through which the electrical conduit **62** (and or other conduits) can pass, as well as to create structural rigidity for the distal section **26'**.

[0080] In one embodiment, the acoustic cup **206** can be a micro-molded component that includes a main cup section **246** and a back step **248** extending from the side of the main cup section **246**. The main cup section **246** includes a curved outer surface **250**, which faces radially outward from the distal section **26'** with respect to longitudinal axis L (shown in FIG. **2**). A substantially cylindrical rim **252** extends radially inward from the outer surface **250**. The outer surface **250** and the cylindrical rim **252** combine to form a cup shape within which the ultrasonic imaging sensor **36***b* is contained. The back step **248** includes an outer surface **254** and side surfaces **256** and **258** extending radially inward from the outer surface

254. The outer surface **250** of the main cup section **246** is radially outward of and axially distal from the outer surface **254** of the back step **248**.

[0081] Similarly, in one embodiment, the acoustic cup **208** can be a micro-molded component that includes a main cup section **260** and a back step **262** extending from the side of the main cup section **260**. The main cup section **260** includes a curved outer surface **264**, which faces radially outward from the distal section **26'** with respect to longitudinal axis L. A substantially cylindrical rim **266** extends radially inward from the outer surface **264**. The outer surface **264** and the cylindrical rim **266** combine to form a cup shape within which the ultrasonic imaging sensor **36***c* is contained. The back step **262** includes an outer surface **268** and side surfaces **270** and **272** extending radially inward from the outer surface **268**. The outer surface **264** of the main cup section **260** is radially outward of and axially distal from the outer surface **268** of the back step **262**.

[0082] An acoustic window (not shown) can be used with the ultrasonic imaging sensor **36***a*, and may or may not be cup-shaped.

[0083] FIG. **13** is a perspective view of the distal section **26'**, showing only the ultrasonic imaging sensors **36***b* and **36***c*, the flex circuits **200**, **202**, and **204**, and the electrical conduits **58**, **60**, and **64**. Although the ultrasonic imaging sensors **36***b* and **36***c* are shown in FIG. **13** as mounted on the flex circuits **200** and **202** without the distal tip insert **74** or the electrode shell **82** for illustration purposes, such components can be assembled in a different order.

[0084] In one embodiment, the ultrasonic imaging sensors **36***b*, **36***c*, **36***d* can be pre-assembled and mounted to the respective flex circuits **200**, **202**, **204** and the respective electrical conduits **64**, **60**, **58** can further be pre-assembled to the flex circuits and ultrasonic imaging sensors for subsequent mounting to the distal tip insert **74**.

[0085] In one embodiment, the flex circuits **200** and **202** (as well as **204**) can be installed inside the electrode shell **82** initially without the ultrasonic imaging sensors **36***b* and **36***c*. The ultrasonic imaging sensors **36***b* and **36***c* can then be inserted through the side-facing acoustic openings **54***b* and **54***c* and soldered onto the flex circuits **200** and **202**, respectively.

[0086] The acoustic cups **206** and **208** can then be inserted through the respective side-facing acoustic openings **54***b* and **54***c* by first inserting the back steps **248** and **262**, and then pressing in the main cup sections **246** and **260**. The main cup sections **246** and **260** can be configured to be sufficiently resilient to allow it to be press-fit into the side-facing acoustic openings **54***b* and **54***c* and thereby held in place via an interference fit, and the back steps **248** and **262** can provide further mechanical retention for the acoustic cups **206** and **208**.

[0087] An adhesive can be applied between the acoustic cups **206** and **208** and their respective ultrasonic imaging sensors **36***b* and **36***c*. The adhesive used to attach the acoustic cups **206** and **208** to the ultrasonic imaging sensors **36***b* and **36***c* can be a multipurpose catheter adhesive capable of bonding plastics to metals and capable of transmitting ultrasound, such as an adhesive known as Dymax **209**. The acoustic cups **206** and **208** can be transparent or translucent, allowing the adhesive to be cured by ultraviolet light, for example. The acoustic cups **206** and **208** can be made of a material that is suitable for transmitting ultrasound with minimal losses. In various embodiments, the acoustic cups **206**, **208** may be made of a material that has an acoustic impedance comparable to that of the surrounding blood or other fluid. In various embodiments, the material of the acoustic cups **206**, **208** may have a relatively low hardness such that it can be molded relatively easily. In various embodiments, the material of the acoustic cups **206**, **208** may be a polymeric material such as a polyether block amide material, such as those sold under the brand name PEBAX. In various embodiments, a suitable material is a plasticizer-free thermoplastic elastomer such as a PEBAX 5533. In other embodiments, other materials having desired acoustic, mechanical and manufacturability characteristics may be utilized for the acoustic cups **206**, **208**.

[0088] The materials used for the adhesive and the acoustic cups **206** and **208** can facilitate suitable transmission of acoustic waves to and from the ultrasonic imaging sensors **36***b* and **36***c*. In alternative embodiments, the acoustic cups **206** and **208** and the adhesive can be made of alternative materials suitable for the application.

[0089] FIG. **14** is a perspective view showing a distal section **26"** of the probe **12** of FIG. **1**. The distal section **26"** is an alternative embodiment of the distal section **26** (shown in FIGS. **1** and **2**) and the distal section **26'** (shown in FIG. **10**). The distal section **26"** is similar to the distal section **26'** of FIG. **10** except the distal section **26"** has a proximal tip insert **72"** with a shoulder **300** and a recess **302**, both on an outer perimeter **304** of the proximal tip insert **72"**.

[0090] The shoulder **300** extends radially outward from and circumferentially around the outer perimeter **304** of the proximal tip insert **72"**. The shoulder **300** has a diameter substantially equal to that of the electrode shell **82** such that the shoulder **300** abuts a rear edge **308** of the electrode shell **82** when the distal section **26"** is assembled. The shoulder **300** can be attached to the RF electrode shell **82** via an adhesive, solder, or welding.

[0091] The recess **302** is an elongated depression on an outer perimeter of the proximal tip insert **72"**. The recess **302** has a curved distal end **310** that is positioned proximate the shoulder **300** and has an open proximal end **312** at a proximal edge **314** of the proximal tip insert **72"**. The recess **302** is sized and shaped for receiving a steering mechanism (not shown) used to deflect and steer the probe **12** (shown in FIG. **1**). The steering mechanism can be attached to the proximal tip insert **72"** at the recess **302** to rigidly connect a distal end of the steering mechanism for deflecting and steering the probe **12**.

[0092] FIG. **15** is a schematic side sectional view of the distal section **26"**. FIG. **15** shows the shoulder **300** abutting the rear edge **308** of the electrode shell **82**, as described above. FIG. **15** also shows the ultrasonic imaging sensor **36***b* and the flex circuit **200** seated in the recess **106**. The acoustic cup **206** covers the ultrasonic imaging sensor **36***b*, with the main cup section **246** having a relatively tight fit inside the side-facing acoustic opening **54***b*. The back step **248** extends from the main cup section **246** in the distal direction to help retain the acoustic cup **206** in the electrode shell **82**.

[0093] Although the sectional view of FIG. **15** illustrates only the flex circuit **200** and the electrical conduits **62** and **64** passing through a central bore **316** of the proximal tip insert **72"**, the central bore **316** is sized such that all electrical and fluid conduits can be centrally located and pass through the central bore **316**. This can provide an electromagnetic shielding function for such conduits, thereby minimizing interference caused by the RF energy supplied during the ablation operation. The flex circuit **200** is shown as having its proximal end **318** terminating within the central bore **316**. The flex circuits **202** and **204** (not shown in FIG. **15**) can also have their proximal ends terminate within the central bore **316**. By terminating the flex circuits **200**, **202**, and **204** within the central bore **316**, exposure to acoustic noise can be reduced.

[0094] An acoustic window **320** is positioned in the acoustic opening **54***a*, adjacent the ultrasonic imaging sensor **36***a*. The acoustic window **320** can have similar properties and be made of similar materials to those of the acoustic cups **206** and **208**.

[0095] Various modifications and additions can be made to the exemplary embodiments discussed without departing from the scope of the present invention. For example, while the embodiments described above refer to particular features, the scope of this invention also includes embodiments having different combinations of features and embodiments that do not include all of the described features. Accordingly, the scope of the present invention is intended to embrace all such alternatives, modifications, and variations as fall within the scope of the claims, together with all equivalents thereof.

We claim:

1. An ablation probe for treating and imaging body tissue, the ablation probe comprising:
- an ablation electrode tip including an ablation electrode configured for delivering ablation energy to body tissue;
- an ultrasonic imaging sensor disposed within the ablation electrode tip, the ultrasonic imaging sensor configured to transmit and receive ultrasonic waves; and
- a flex circuit mechanically and electrically connected to the ultrasonic imaging sensor.

2. The ablation probe of claim **1**, further comprising:
- a plurality of ultrasonic imaging sensors disposed within the ablation electrode tip, each of the plurality of ultrasonic imaging sensors configured to transmit and receive ultrasonic waves; and
- a plurality of flex circuits, each being mechanically and electrically connected to one of the plurality of ultrasonic imaging sensors.

3. The ablation probe of claim **2**, and further comprising:
- a plurality of electrical conduits, each electrically connected to one of the plurality of ultrasonic imaging sensors via one of the plurality of flex circuits.

4. The ablation probe of claim **2**, wherein the plurality of ultrasonic imaging sensors comprises at least three ultrasonic imaging sensors, wherein the plurality of flex circuits comprises at least three separate and distinct flex circuits each connected to one of the ultrasonic imaging sensors.

5. The ablation probe of claim **2**, wherein the plurality of ultrasonic imaging sensors are each mounted on one of the plurality of flex circuits.

6. The ablation probe of claim **2**, wherein each of the plurality of flex circuits has a proximal end terminating within a central bore of the ablation electrode tip.

7. The ablation probe of claim **2**, wherein the ablation electrode tip has a tubular electrode shell and a plurality of acoustic openings disposed therein, and wherein each of the ultrasonic imaging sensors is aligned with a respective one of the acoustic openings.

8. The ablation probe of claim **7**, wherein the plurality of ultrasonic imaging sensors includes three ultrasonic imaging transducers oriented circumferentially about the ablation electrode tip.

9. The ablation probe of claim **7**, wherein the ablation tip further comprises a plurality of irrigation ports formed in the tubular electrode shell distally of the acoustic openings.

10. An ablation probe for treating and imaging body tissue, the ablation probe comprising:
- an ablation electrode tip including an ablation electrode configured for delivering ablation energy to body tissue;
- a plurality of acoustic openings disposed through the ablation electrode tip;
- a plurality of ultrasonic imaging sensors positioned inside the ablation electrode tip, each aligned with one of the acoustic openings; and
- a plurality of acoustic cups covering each of the ultrasonic imaging sensors.

11. The ablation probe of claim **10**, wherein each of the acoustic cups comprises:
- a main cup section; and
- a back step extending from a side of the main cup section.

12. The ablation probe of claim **11**, wherein the main cup section is positioned in one of the acoustic openings with an interference fit.

13. The ablation probe of claim **11**, wherein the main cup section is positioned in one of the acoustic openings with the back step extending in a distal direction to provide mechanical retention of the acoustic cup.

14. The ablation probe of claim **10**, and further comprising:
- a tip insert having a plurality of recesses each configured for receiving one of the ultrasonic imaging sensors and for partially receiving one of the acoustic cups, wherein each of the plurality of recesses has a recess shoulder upon which the respective acoustic cup rests.

15. The ablation probe of claim **10**, wherein the acoustic cups are molded of a polyether block amide.

16. An ablation probe for treating and imaging body tissue, the ablation probe comprising:
- an ablation electrode tip including an ablation electrode configured for delivering ablation energy to body tissue, the ablation electrode tip comprising:
  - an electrode shell;
  - a proximal tip insert connected to a proximal end of the electrode shell;
  - a distal tip insert disposed within the electrode shell distally of the proximal tip insert; and
  - a plurality of acoustic openings disposed through the ablation electrode tip; and
- a plurality of ultrasonic imaging sensors positioned inside the ablation electrode tip and mounted to the distal tip insert, the ultrasonic imaging sensors configured to transmit ultrasonic waves through the acoustic openings.

17. The ablation probe of claim **16**, wherein the proximal tip insert has a shoulder extending radially outward from and circumferentially around an outer perimeter of the proximal tip insert and wherein the shoulder abuts a rear edge of the electrode shell.

18. The ablation probe of claim **16**, wherein the proximal tip insert has a recess on an outer perimeter of the proximal tip insert for receiving a distal end of a steering mechanism for deflecting and steering the ablation probe.

19. The ablation probe of claim **16**, wherein the proximal tip insert has a central bore passing through the proximal tip insert that is sized and configured to receive electrical and fluid conduits extending into the ablation electrode tip.

20. The ablation probe of claim **16**, further comprising a plurality of acoustic cups each coupled to the ablation electrode tip, each acoustic cup positioned at a location corresponding to one of the acoustic imaging sensors.

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专利名称(译)	消融导管具有超声波病变监测能力		
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摘要(译)

用于治疗和成像身体组织的消融探针包括消融电极尖端，该消融电极尖端包括消融电极，该消融电极被配置用于将消融能量传递到身体组织。穿过消融电极尖端设置多个声学开口。多个超声成像传感器位于消融电极尖端内。超声成像传感器配置成通过声学开口发射超声波。多个柔性电路均电连接到多个超声成像传感器中的一个。