US008419464B2

(12) United States Patent
Montena et al.

(10) Patent No.: US 8,419,464 B2
(45) Date of Patent: *Apr. 16, 2013

(54) **COAXIAL CONNECTOR WITH INTEGRATED MOLDED SUBSTRATE AND METHOD OF USE THEREOF**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 140 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/966,113**

(22) Filed: **Dec. 13, 2010**

(65) **Prior Publication Data**

US 2011/0130034 A1 Jun. 2, 2011

Related U.S. Application Data

(63) Continuation-in-part of application No. 12/271,999, filed on Nov. 17, 2008, now Pat. No. 7,850,482.

(51) **Int. Cl.**
H01R 9/05 (2006.01)

(52) **U.S. Cl.**
USPC **439/489**; 439/913; 439/620.03

(58) **Field of Classification Search** 439/578, 439/489, 620.03, 913; 340/635
See application file for complete search history.

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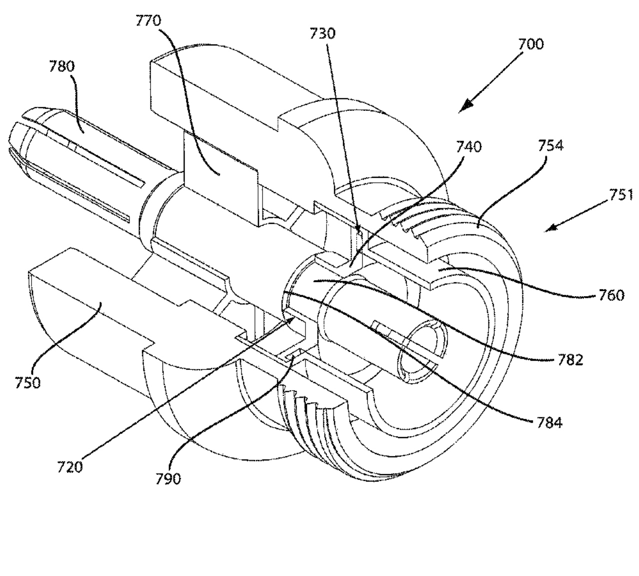
(57) **ABSTRACT**

A substrate structure is provided, the substrate structure comprising: a molded substrate located within a connector body of a coaxial cable connector and an electrical structure mechanically connected to the molded substrate. The electrical structure is located in a position that is external to a signal path of a radio frequency (RF) signal flowing through the coaxial cable connector. The electrical structure may form a sensing circuit configured to sense physical parameters such as a condition of the RF electrical signal flowing through the connector or a presence of moisture in the connector.

22 Claims, 10 Drawing Sheets



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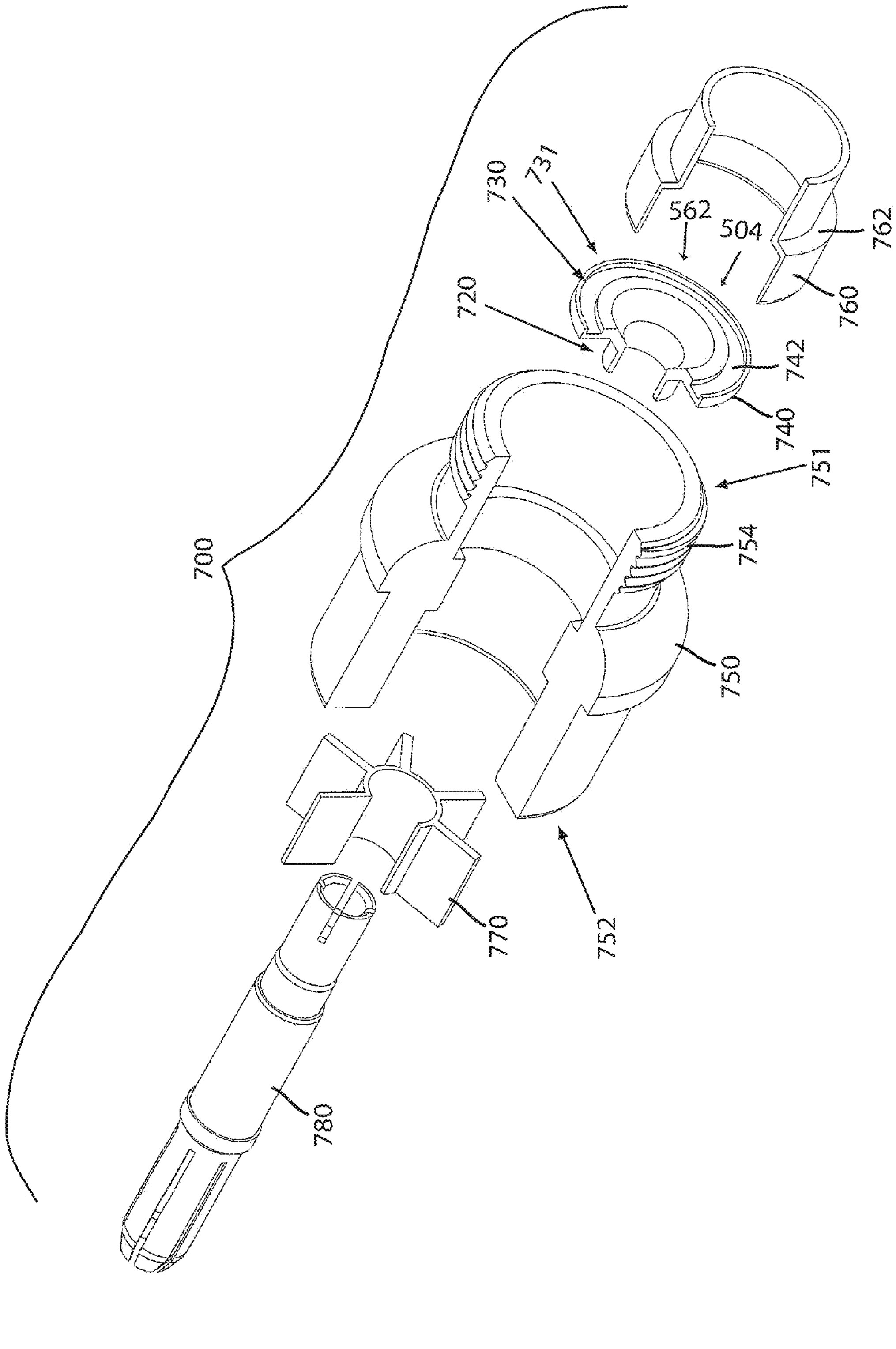


FIG. 1

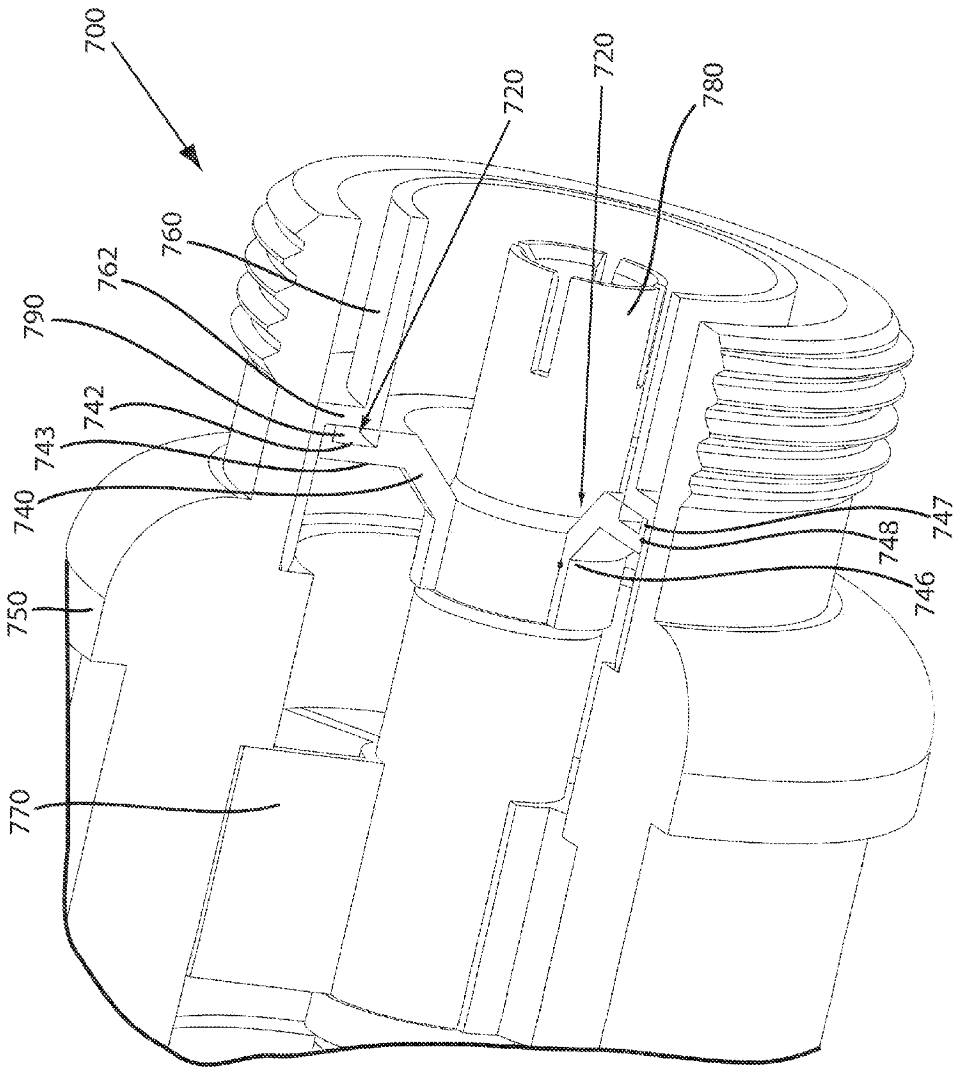


FIG. 2

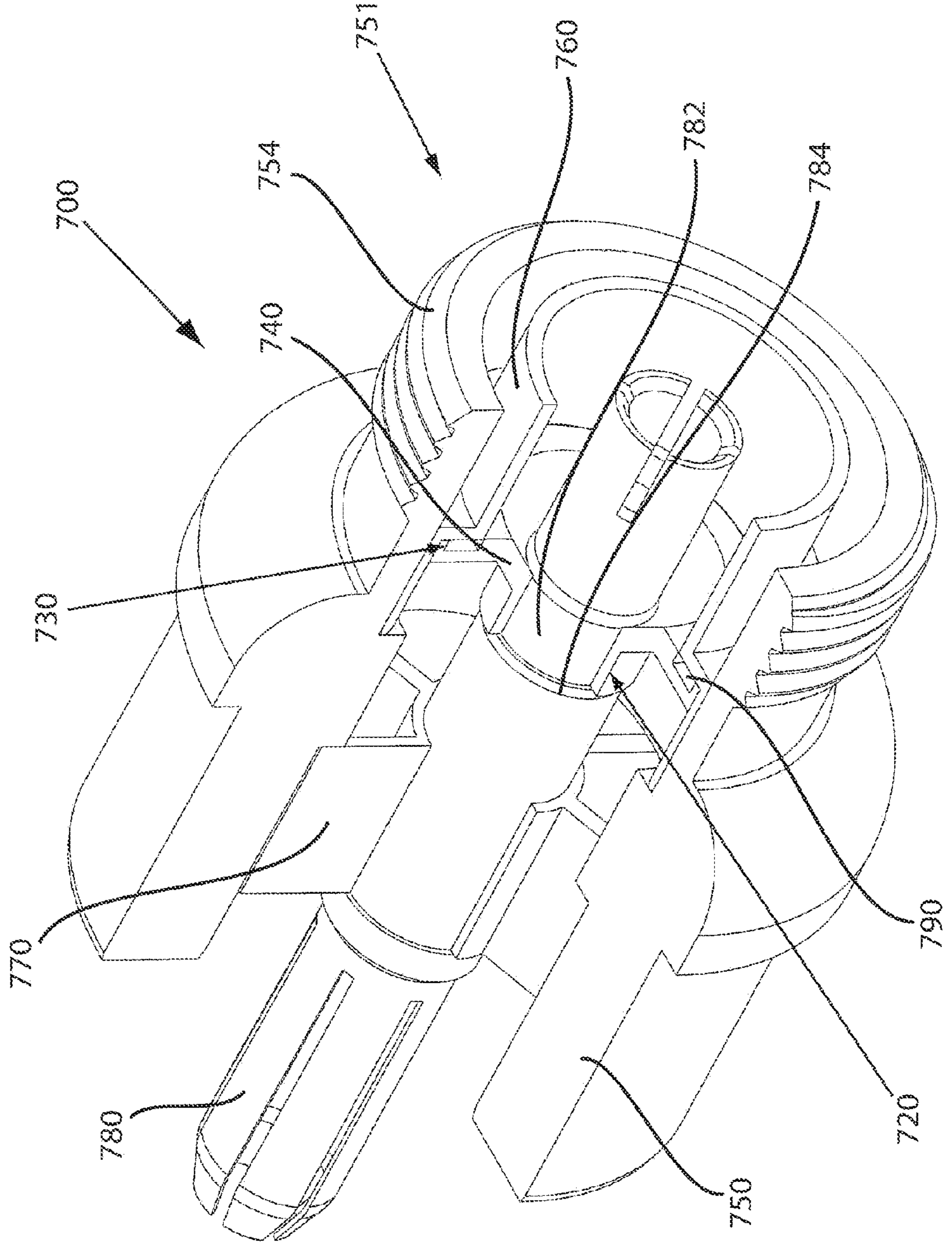


FIG. 3

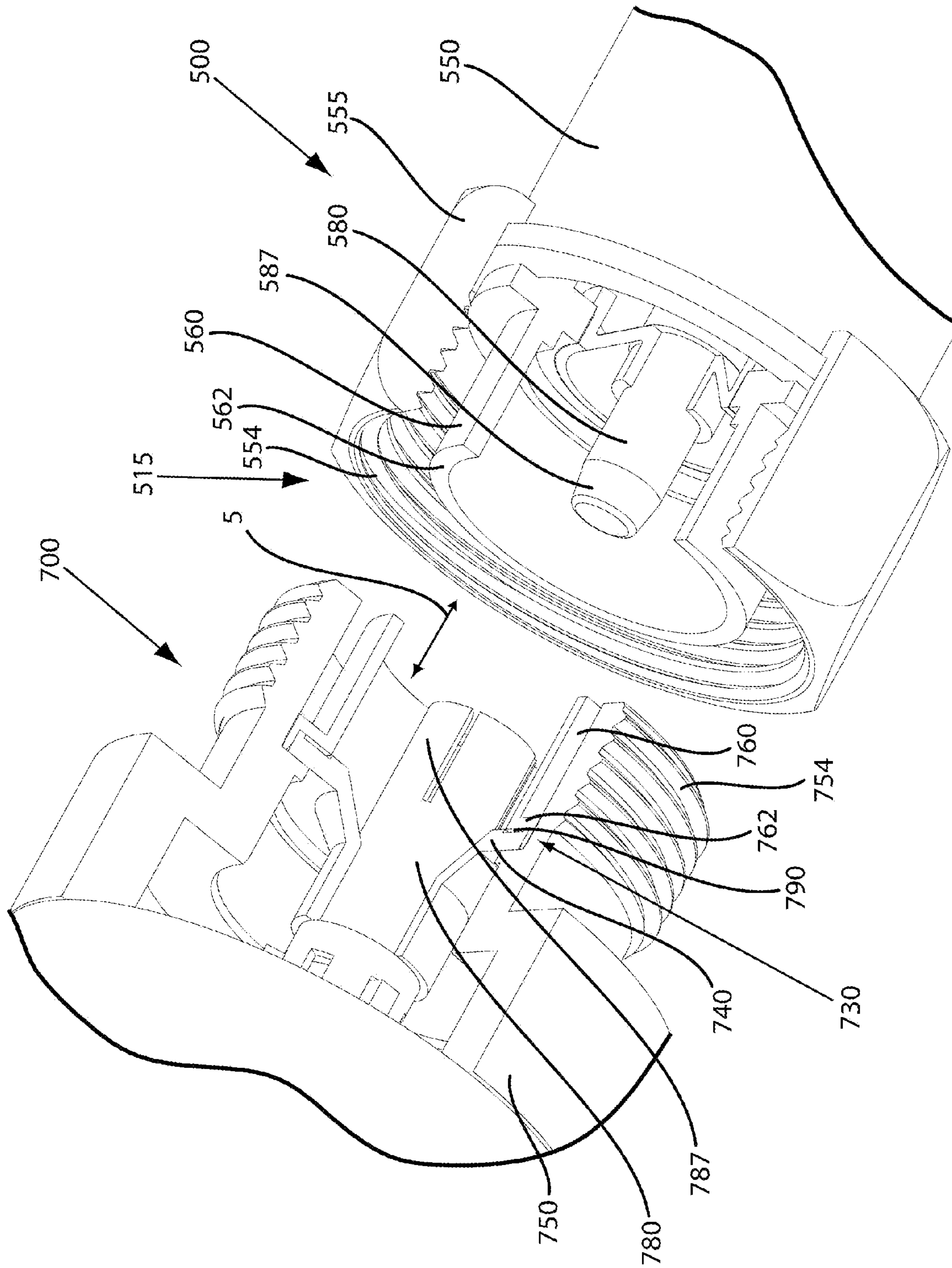

500
550
555
580
587
560
562
554
515
5
700
760
754
762
790
740
730
750
780
787

FIG. 4

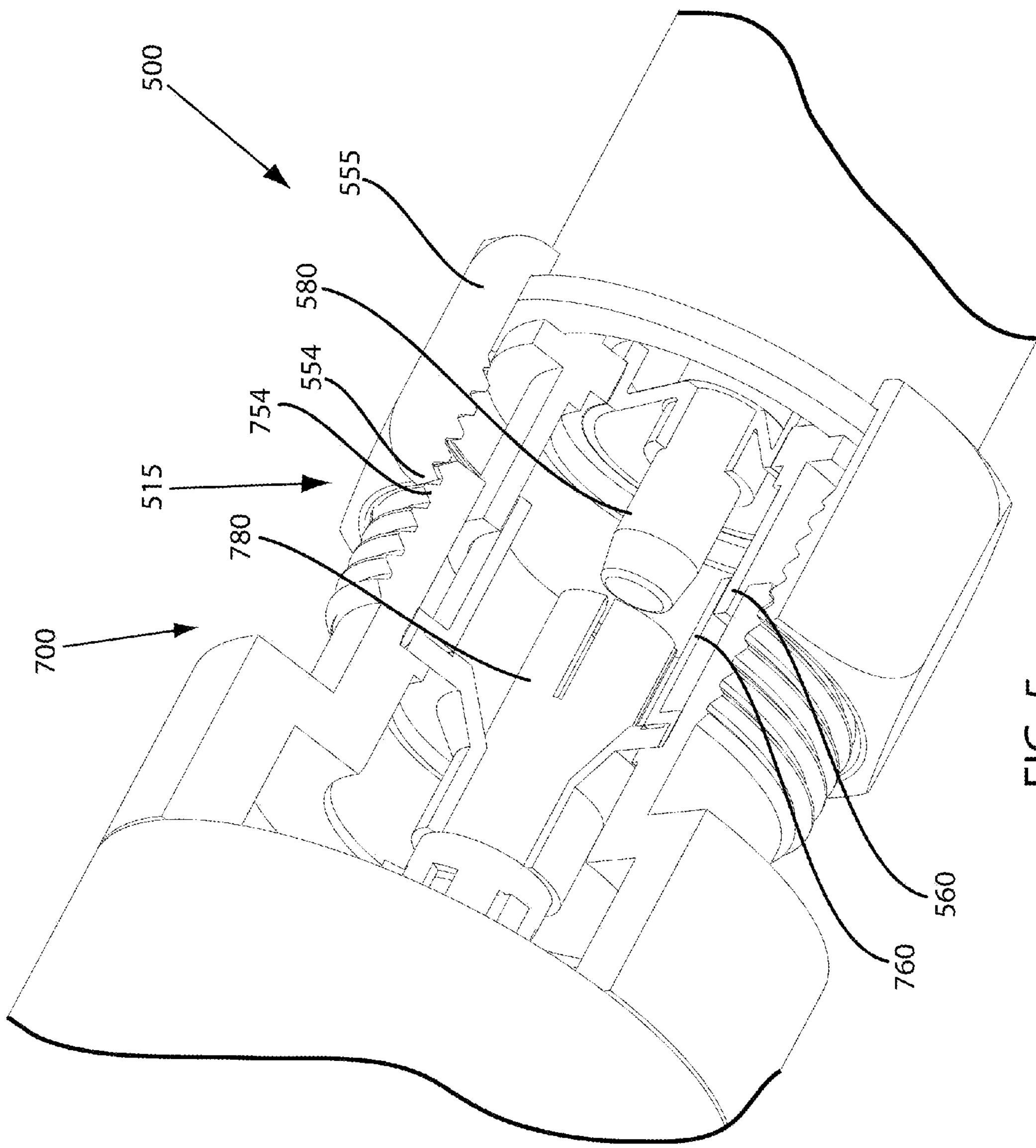


FIG. 5

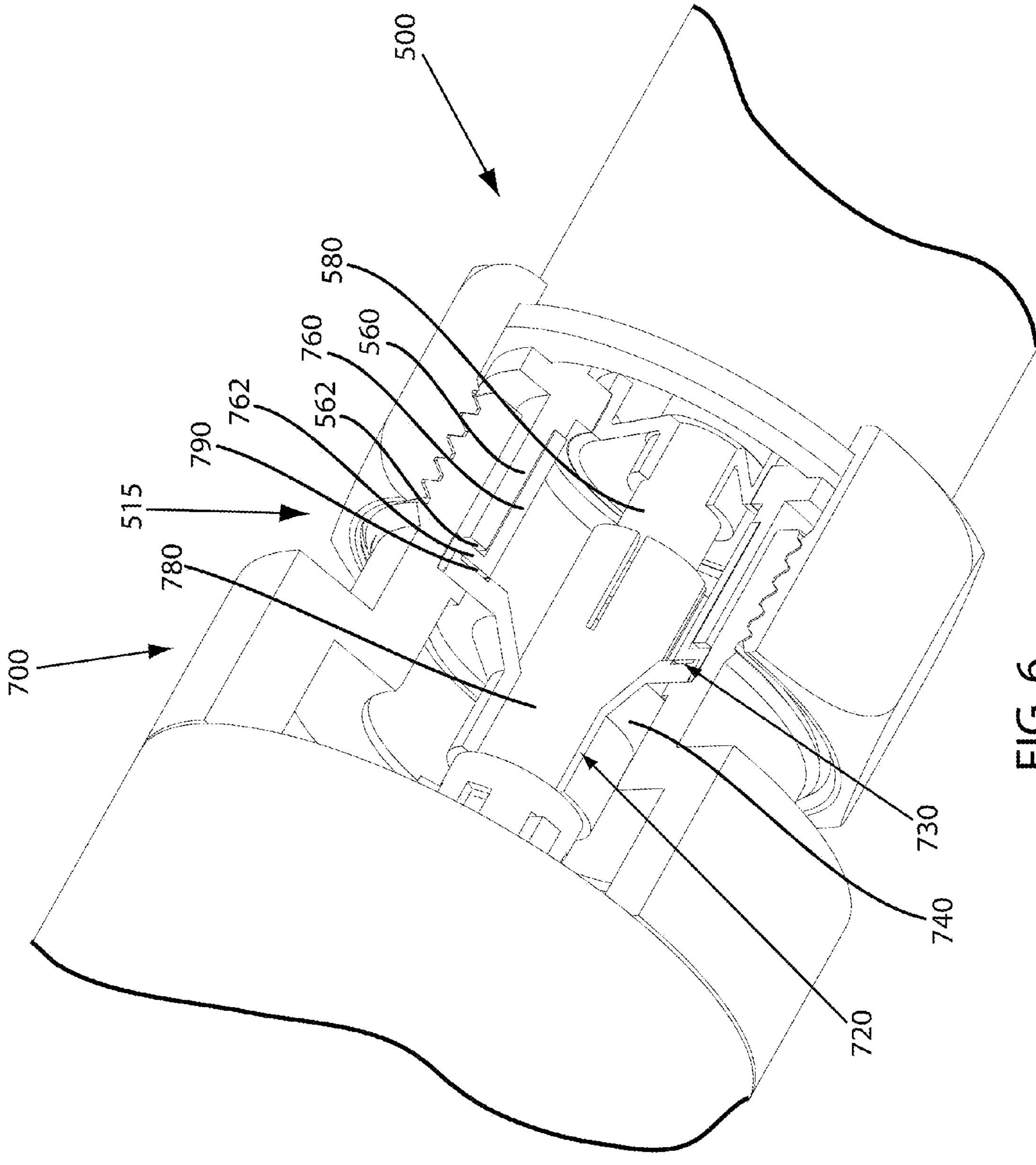


FIG. 6

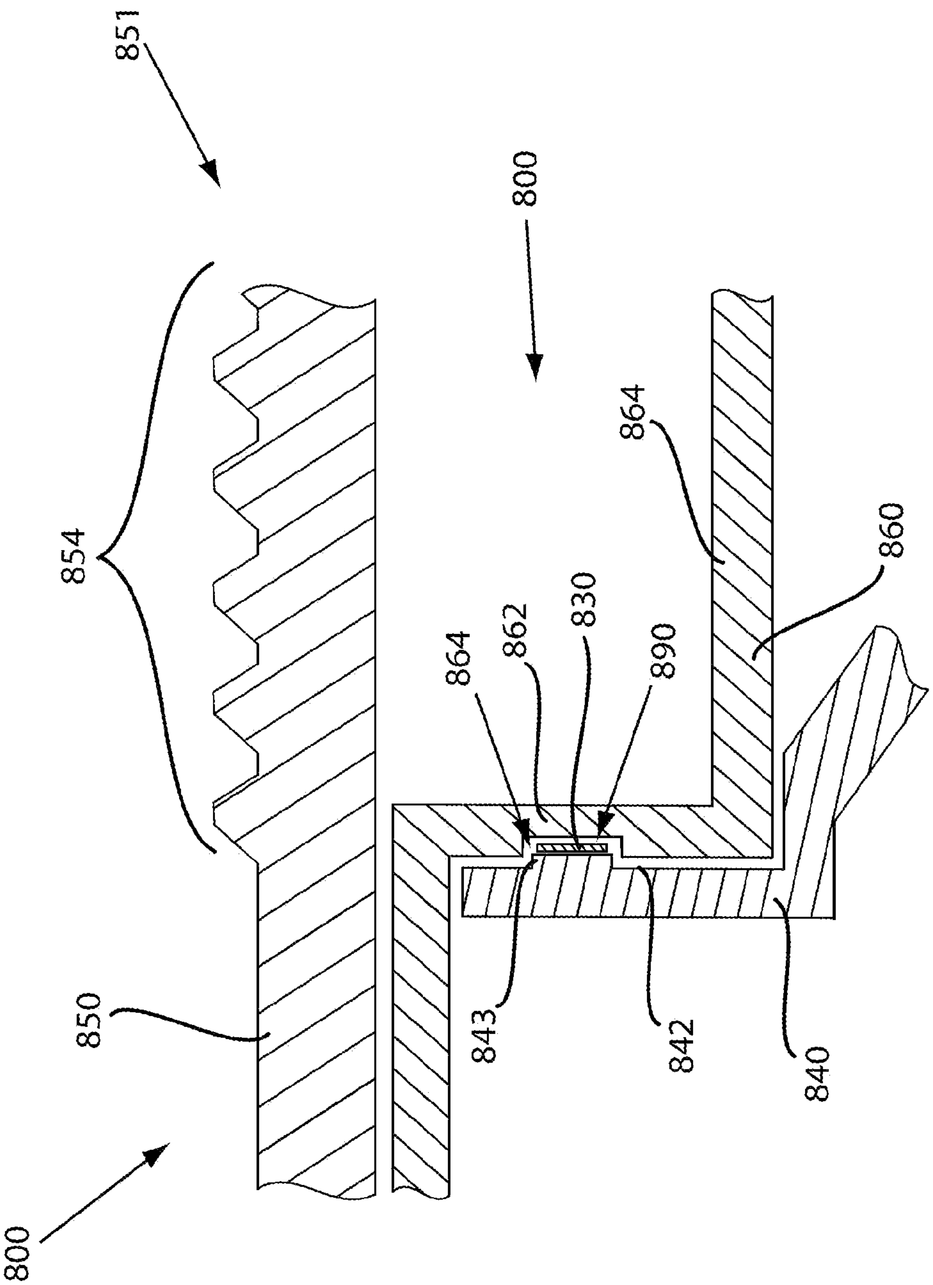


FIG. 7

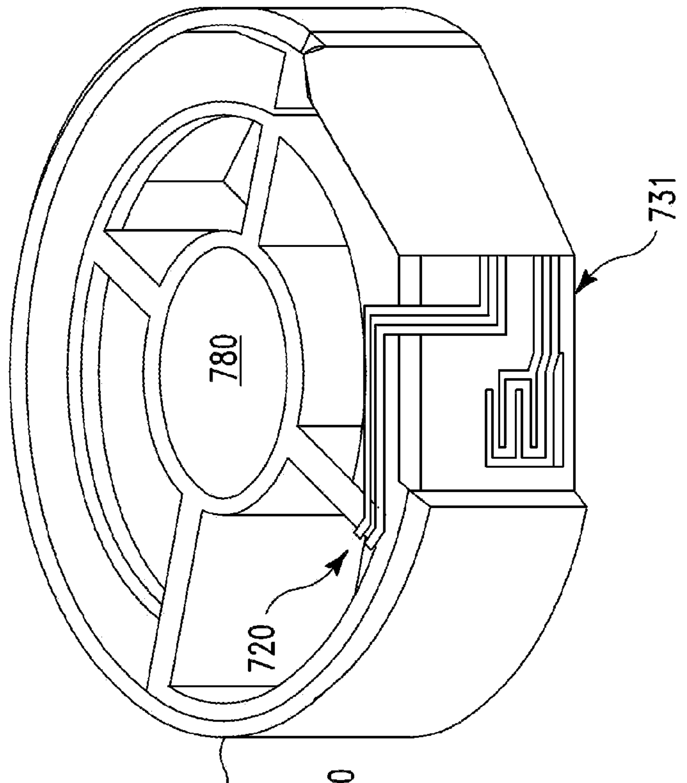


FIG. 8B

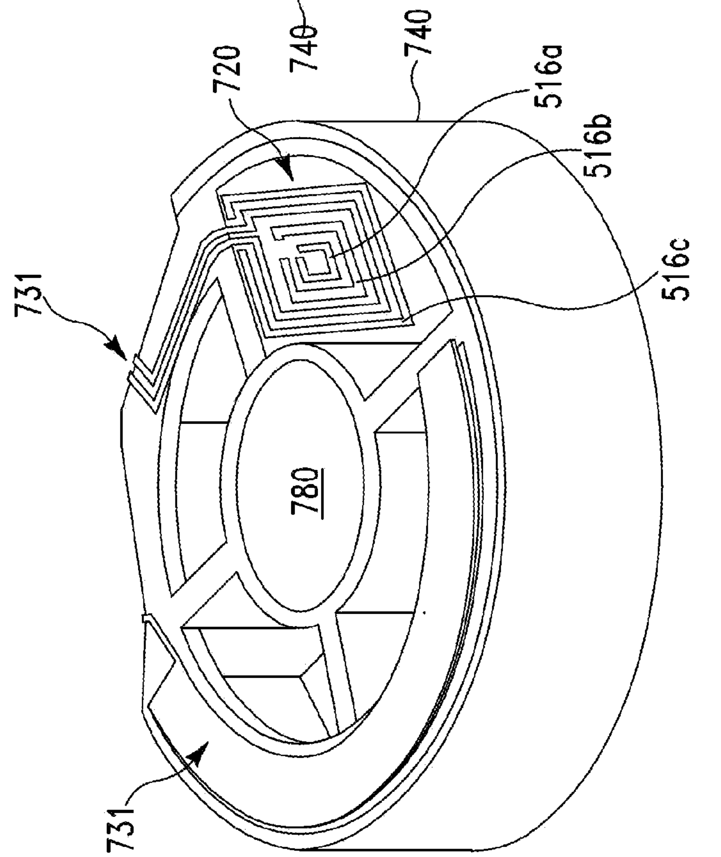
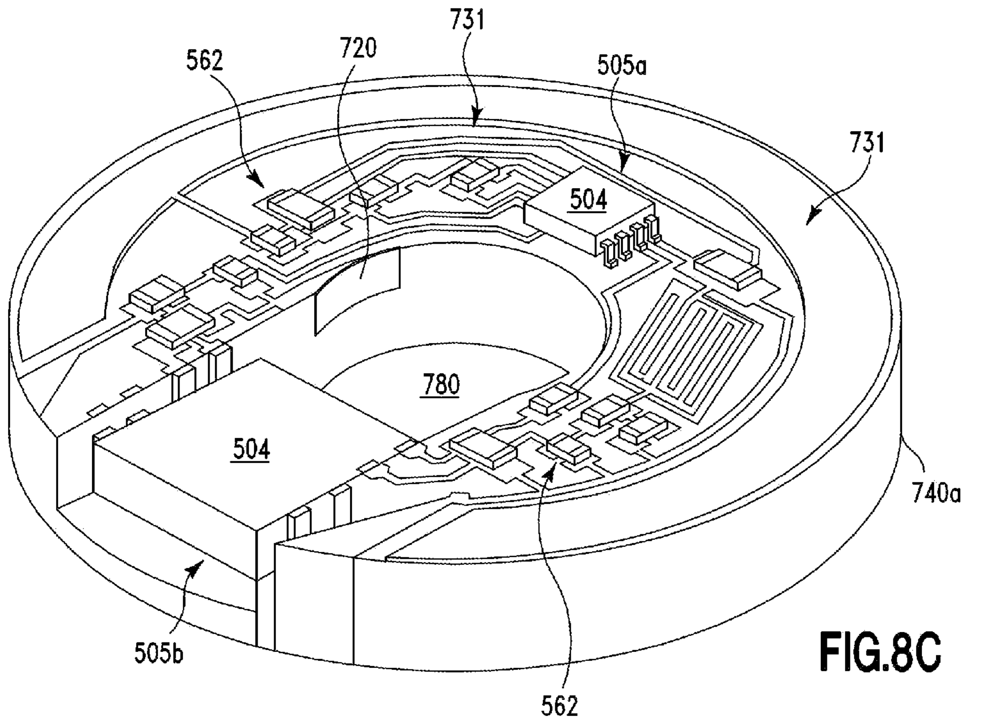


FIG. 8A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562
720
505a
731
504
780
504
740a
505b
562

FIG.8C

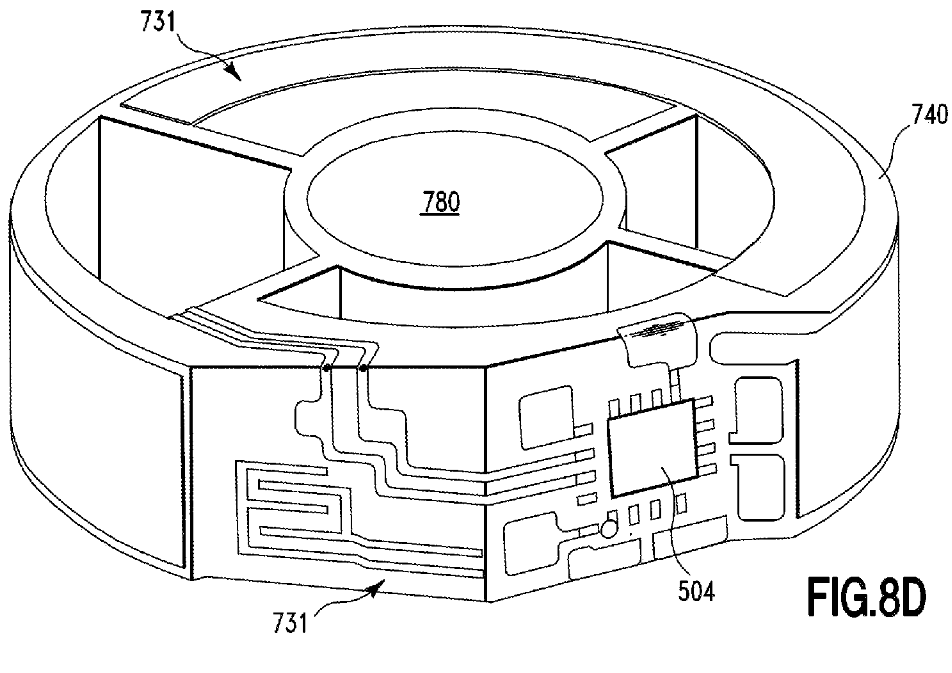
731
740
780
504
731

FIG.8D

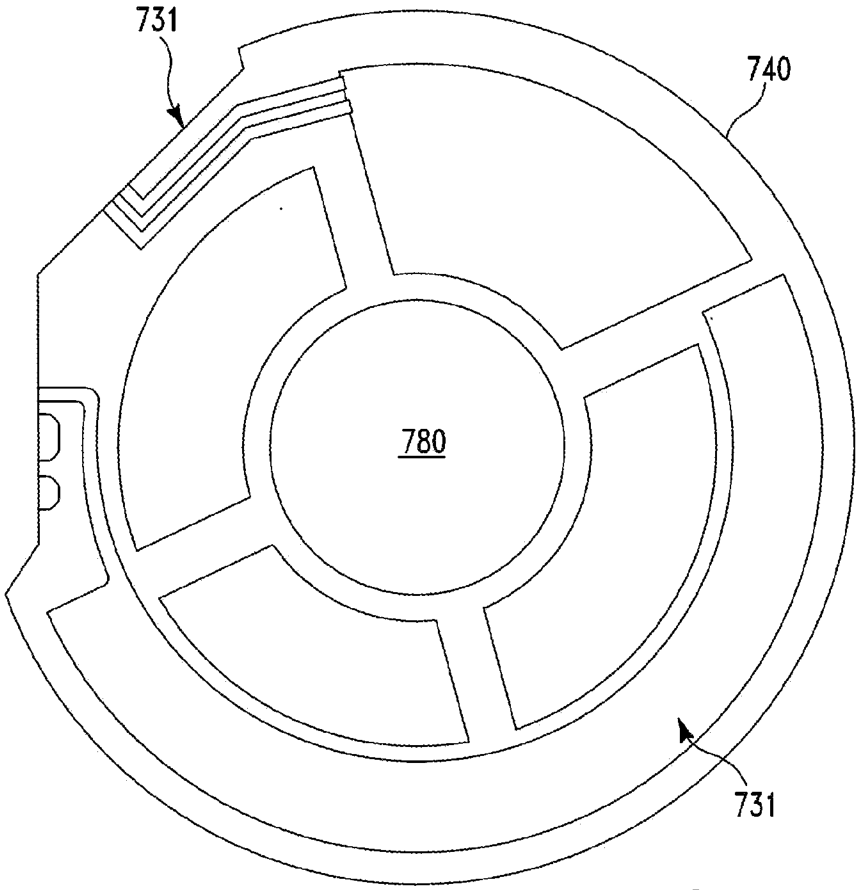

FIG.8E

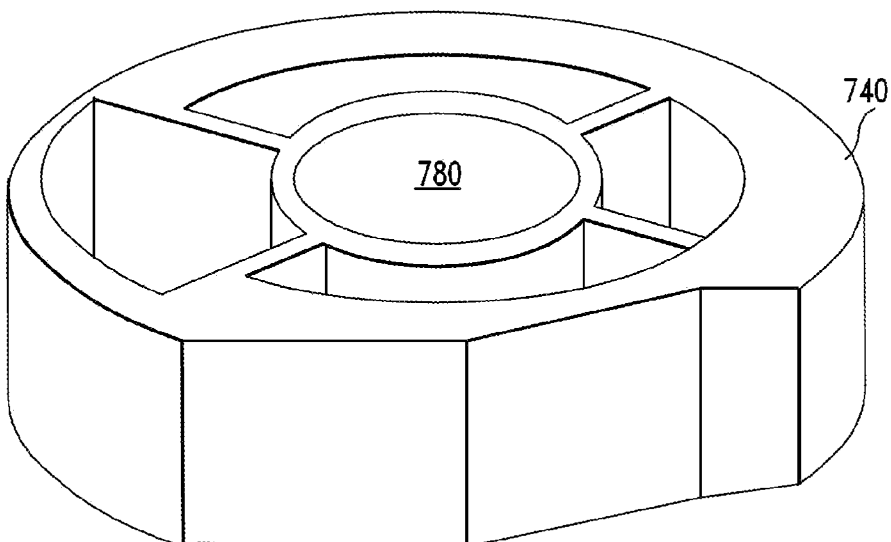

FIG.8F

COAXIAL CONNECTOR WITH INTEGRATED MOLDED SUBSTRATE AND METHOD OF USE THEREOF

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of and claims priority from co-pending U.S. application Ser. No. 12/271,999 filed Nov. 17, 2008, and entitled COAXIAL CONNECTOR WITH INTEGRATED MATING FORCE SENSOR AND METHOD OF USE THEREOF.

BACKGROUND

1. Technical Field

The present invention relates generally to coaxial connectors. More particularly, the present invention relates to a coaxial connector having an integrated interconnect device and related method of use.

2. Related Art

Cable communications have become an increasingly prevalent form of electromagnetic information exchange and coaxial cables are common conduits for transmission of electromagnetic communications. In addition, various coaxial cable connectors are provided to facilitate connection of cables to various devices. It is important that a coaxial cable connector be properly connected or mated to an interface port of a device for cable communications to be exchanged accurately. One way to help verify whether a proper connection of a coaxial cable connector is made is to determine and report mating force in the connection. However, common coaxial cable connectors have not been provided, whereby mating force can be efficiently determined by the coaxial cable connectors. Ordinary attempts at determining mating force have generally been inefficient, costly, and impractical involving multiple devices and complex applications. Accordingly, there is a need for an improved connector for determining mating force. The present invention addresses the abovementioned deficiencies and provides numerous other advantages.

SUMMARY

The present invention provides an apparatus for use with coaxial cable connections that offers improved reliability.

A first aspect of the present invention provides A coaxial cable connector for connecting a coaxial cable to a mating component, the mating component having a conductive interface sleeve, the coaxial cable connector comprising: a connector body having an internal passageway defined therein; a first insulator component disposed within the internal passageway of the connector body; a capacitive circuit positioned on a face of the first insulator component, the first insulator component at least partially defining a first plate of a capacitor; and a flexible member in immediate proximity with the face of the first insulator component, the flexible member at least partially defining a capacitive space between the face of the first insulator and the flexible member, wherein the flexible member is movable upon the application of mating forces created as the conductive interface sleeve interacts with the flexible member.

A second aspect of the present invention provides a coaxial cable connector comprising: a connector body; a capacitive circuit positioned on a face of a first insulator component, the first insulator component located within the connector body; a flexible member located proximate the face of the first insulator component, the flexible member being movable due

to mating forces when the connector is connected to a mating component; and a capacitive space located between the face of the first insulator component and the flexible member; wherein the flexible member forms at least one boundary surface of the capacitive space, and the face of the first insulator forms at least another boundary surface of the capacitive space.

A third aspect of the present invention provides a mating force sensing coaxial cable connector comprising: a sensing circuit printed on the face of a first spacer component positioned to rigidly suspend a center conductor contact within an outer conducting housing; and a capacitive space in immediate proximity with the sensing circuit, said capacitive space having at least one defining wall configured to undergo elastic deformation as a result of mating forces.

A fourth aspect of the present invention provides a coaxial cable connector comprising: a connector body; an insulator component and an interface sleeve housed by a connector body; a capacitive space formed between the insulator component and the interface sleeve; and means for sensing proper mating by determining a change in size of the capacitive space due to mating forces.

A fifth aspect of the present invention provides a method for detecting mating force of a mated coaxial cable connector, said method comprising: providing a coaxial cable connector including: a sensing circuit positioned on a face of a spacer component located within a connector body; a capacitive space in immediate proximity with the sensing circuit; and an interface component having a flexible member forming at least one boundary surface of the capacitive, said flexible member being movable due to mating forces; mating the connector with a connecting device; bending the flexible member of the interface component due to contact with the connecting device during mating, thereby reducing the size of capacitive space; and detecting mating force by sensing the reduction of size of the capacitive space by the sensing circuit.

A sixth aspect of the present invention provides a connector body having a first end and a second end, the first end having a first bore; a first insulator located within the first bore, the first insulator having a first face; a mount portion defined on the first face; a capacitive circuit positioned on the mount portion; and, an interface member, having a first section and a second section, the interface member located within the first bore in immediate proximity to the mount portion to define a capacitive space, the first section having a first section bore, the first and second sections being movable between a first position and a second position upon the application of an axial force on the first section.

A seventh aspect of the present invention provides a substrate structure comprising: a molded substrate located within a connector body of a coaxial cable connector; and an electrical structure mechanically connected to the molded substrate, wherein the electrical structure is located in a position that is external to a signal path of a radio frequency (RF) signal flowing through the coaxial cable connector.

An eighth aspect of the present invention provides a coaxial cable connector for connection to a coaxial cable, the connector comprising: a connector body; and a molded substrate structure located within the connector body, wherein the molded substrate structure comprises an electrical structure mechanically connected to the molded substrate structure, wherein the electrical structure is located in a position that is external to a signal path of a radio frequency (RF) signal flowing through the coaxial cable connector.

A ninth aspect of the present invention provides a method comprising:

providing substrate structure comprising a molded substrate located within a connector body of a coaxial cable connector and an electrical structure mechanically connected to the molded substrate, wherein the electrical structure is located in a position that is external to a signal path of a radio frequency (RF) signal flowing through the coaxial cable connector; and sensing, by the electrical structure, the RF signal flowing through the coaxial cable connector.

The foregoing and other features of the invention will be apparent from the following more particular description of various embodiments of the invention.

DESCRIPTION OF THE DRAWINGS

Some of the embodiments of this invention will be described in detail, with reference to the following figures, wherein like designations denote like members, wherein:

FIG. **1** depicts an exploded cut-away perspective view of an embodiment of a coaxial cable connector with a molded substrate, in accordance with the present invention;

FIG. **2** depicts a close-up cut-away perspective view of a first end of an embodiment of a coaxial cable connector with a molded substrate, in accordance with the present invention;

FIG. **3** depicts a cut-away perspective view of an embodiment of an assembled coaxial cable connector with a molded substrate, in accordance with the present invention;

FIG. **4** depicts a cut-away perspective view of an embodiment of a coaxial cable connector just prior to mating with an embodiment of a male connector, in accordance with the present invention;

FIG. **5** depicts a cut-away perspective view of an embodiment of a cable connector during mating with an embodiment of a male connector, in accordance with the present invention;

FIG. **6** depicts a cut-away perspective view of an embodiment of a mating force sensing coaxial cable connector mated with an embodiment of a male connector, in accordance with the present invention;

FIG. **7** depicts a partial cross-sectional view of a further embodiment of a coaxial cable connector with integrated force mating force sensing circuit, in accordance with the present invention;

FIGS. **8**A and **8**B depict perspective views of an embodiment of the molded substrate of FIG. **1**, in accordance with the present invention;

FIG. **8**C depicts a perspective view of an alternative embodiment of a molded substrate **740**, in accordance with the present invention;

FIG. **8**D depicts a perspective view of an embodiment of a molded substrate comprising an integrated circuit **504**, in accordance with the present invention;

FIG. **8**E depicts a top view of an embodiment of a molded substrate, in accordance with the present invention; and

FIG. **8**F depicts a perspective view of an embodiment of a molded substrate **740** without any components, in accordance with the present invention.

DETAILED DESCRIPTION

Although certain embodiments of the present invention will be shown and described in detail, it should be understood that various changes and modifications may be made without departing from the scope of the appended claims. The scope of the present invention will in no way be limited to the number of constituting components, the materials thereof, the shapes thereof, the relative arrangement thereof, etc., and are disclosed simply as an example of an embodiment. The features and advantages of the present invention are illustrated in detail in the accompanying drawings, wherein like reference numerals refer to like elements throughout the drawings.

As a preface to the detailed description, it should be noted that, as used in this specification and the appended claims, the singular forms "a", "an" and "the" include plural referents, unless the context clearly dictates otherwise.

Referring to the drawings, FIG. **1** depicts an exploded cut-away perspective view of an embodiment of a coaxial cable connector **700**, in accordance with the present invention. The coaxial cable connector **700** may include electrical devices and circuitry including, among other things, a sensing circuit **730** (e.g., an integrated mating force sensing circuit), a coupler **720**, an integrated circuit **504** (illustrated in FIGS. **8**C and **8**D), electrical components **562** (e.g., electrical components), conductive interconnects or traces **731**, etc. A sensing circuit **730** may include, among other things, an integrated mating force sensing circuit, a transducer/sensor (e.g., sensors for generating data regarding a performance, moisture content, temperature, tightness, efficiency, and alarm conditions, etc for the coaxial cable connector **700**), etc. A coupler **720** (e.g., an antenna) is configured to: sense a condition or electrical parameter of a signal flowing through a connector at a given time or over a given time period, harvest power from a signal (e.g., an RF signal) flowing through a coaxial connector. An electrical parameter may comprise, among other things, an electrical signal (RF) power level, wherein the electrical signal power level may be used for discovering, troubleshooting and eliminating interference issues in a transmission line (e.g., a transmission line used in a cellular telephone system). The coaxial cable connector **700** may include internal circuitry that may sense connection conditions, harvest power, store data, and/or determine monitorable variables of physical parameter status such as presence of moisture (humidity detection, as by mechanical, electrical, or chemical means), connection tightness (applied mating force existent between mated components), temperature, pressure, amperage, voltage, signal level, signal frequency, impedance, return path activity, connection location (as to where along a particular signal path a connector **100** is connected), service type, installation date, previous service call date, serial number, etc. Additionally, an insertion of an electrically small low coupling magnetic antenna (e.g., coupler **720**) may used to harvest power from RF signals and measure an integrity of passing RF signals (i.e., using the electromagnetic fields' fundamental RF behavior). The coupler **720** may be designed at a very low coupling efficiency in order to avoid insertion loss. Harvested power may be used to power an on board data acquisition structure (e.g., integrated circuit **504**, circuitry **562**, etc). Sensed RF signal power may be fed to an on board data acquisition structure (e.g., integrated circuit **504**). Data gathered by the integrated circuit **504** is reported back to a data gathering device (e.g., a transmitter, a receiver, a combiner, etc) through a transmission path (i.e., a coaxial cable) or wirelessly.

The connector **700** includes a connector body **750**. The connector body **750** comprises an outer housing surrounding an internal passageway **755** (shown in FIG. **2**) accommodating internal components assembled within the connector **700**. In addition, the connector body **750** may be conductive. The connector **700** comprises a molded substrate **740** being a first insulator component (e.g., as described in detail with respect to FIGS. **8**A-**8**F). A first end **751** of the connector body **750** includes a threaded surface **754**. The first end **751** also includes an axial opening large enough to accommodate the molded substrate **740** and an interface sleeve **760**. Moreover, an opposing second end **752** of the connector body **750** includes an axial opening large enough to accommodate a spacer **770**. The spacer **770** is a second insulator component and is located to operate with an internal surface of the connector body **750** to stabilize a center conductor contact **780** and help retain substantially axial alignment of the center conductor contact **780** with respect to the connector body **750** when the connector **700** is assembled.

The molded substrate **740** is formed of a dielectric material and may be housed within the connector body **750** and positioned to contact and axially align the center conductor **780**. The molded substrate **740** is positioned to rigidly suspend the inner conductor contact **780** within the outer conducting housing or connector body **750**. The molded substrate **740** is an insulator component positioned to help facilitate an operable communication connection of the connector **700**. In addition, the molded substrate **740** may include a face **742** (on or within) which a sensing circuit **730**, coupler **720**, conductive interconnects or traces **731**, electrical components **562**, and/or an integrated circuit **504** (e.g., a semiconductor device such as, among other things, a semiconductor chip) that may include any type of data acquisition/transmission/memory circuitry (e.g., an impedance matching circuit, an RF power sensing circuit, a RF power harvesting/power management circuit, etc) may be positioned. The face **742** may be the bottom of an annular ring-like channel formed into the molded substrate **740** and the sensing circuit **730**, coupler **720**, conductive interconnects or traces **731**, electrical components **562**, and/or an integrated circuit **504** may be printed onto and/or within the face **742**. For example, a capacitive circuit may be printed on the face **742** of the molded substrate **740**, wherein the capacitive circuit is a sensing circuit **730**. Printing the sensing circuit **730** or the aforementioned components onto a face **742** of the molded substrate **740** affords efficient connector **700** fabrication because the sensing circuit **730** can be provided on components, such as the molded substrate **740**. Moreover, assembly of the connector **700** is made efficient because the various connector components, such as the molded substrate **740**, center conductor **780**, interface sleeve **760**, connector body **750** and spacer **770** are assembled in a manner consistent with typical connector assembly. Printing, a sensing circuit **730**, on a typical component can also be more efficient than other means because assembly of small non-printed electronic sensors to the interior surfaces of typical connector housings, possibly wiring those sensors to a circuit board within the housing and calibrating the sensors along with any mechanical elements can be difficult and costly steps. A printed sensing circuit **730** integrated on a typical connector **700** assembly component reduces assembly complexity and cost. Accordingly, it may be desirable to "print" sensing circuits **730** and other associated circuitry in an integrated fashion directly onto structures, such as the face **742** of the molded substrate **740** or other structures already present in a typical connector **700**. Furthermore, printing the sensing circuits **730** onto connector **700** components allows for mass fabrication, such as batch processing of the first spacers **40** being insulator components having sensing circuits **730** printed thereon. Printing the sensing circuit **730** may involve providing conductive pathways, or traces, etched from copper sheets or other conductive materials, laminated or otherwise positioned onto a non-conductive substrate, such as the first spacer insulator component **740**.

An interface sleeve **760** of a connector **700** may include a flexible member **762**. The flexible member **762** is a compliant element of the sleeve **760**. Because the flexible member **762** is compliant, it can bend in response to contact with mechanical elements in the interface of another component, such as a male connector **500** (see FIGS. **4**-**6**). Thus, the flexible member **762** may directly experience mating forces when connected to another component, such as a male connector **500**, and undergo movement as a result, as will be discussed further herein below.

Referring further to the drawings, FIG. **2** depicts a close-up cut-away perspective view of a first end **751** of an embodiment of a coaxial cable connector **700** with (integrated mating force) sensing circuit **730**, in accordance with the present invention. The sensing circuit **730**, coupler **720**, conductive interconnects or traces **731**, electrical components **562**, and/or an integrated circuit **504** may be printed on a face **742** of a molded substrate **740** in proximity with a capacitive space **790**, such as a resonant cavity or chamber in the interface between the molded substrate **740** and the interface sleeve **760**. The sensing circuit **730** may be a capacitive circuit. The capacitive space **790** cavity, such as a cavity or chamber may includes at least one wall or boundary surface movable due to mating forces. For example, a surface of the flexible member **762** of the interface sleeve **760** may comprise a boundary surface of the capacitive space **790**. The flexible member **762** is a compliant portion of the interface sleeve **760** operable to endure motion due to movement from mating forces. Moreover, the flexible member **762** may be resilient and configured such that motions due to mating forces bend the member **762** within its elastic range so that the member **762** can return to its previous non-motivated position once the mating forces are removed. Additionally, the member **762** may also be configured to have some elastic hysteresis in that member **762** may be physically responsive relative to varying motive force and include inherent tendency to return to a previous dynamic physical condition. The flexible member **762** may be formed such that movement due to motive force is resistive to yielding and/or may also be cable of elastic response only within a specific range of movement. Nevertheless, some embodiments of the flexible member **762** may be designed to yield if moved too far by mating forces. The interface sleeve **760** may be formed of metals or metal allows such as brass, copper, titanium, or steel, plastics (wherein the plastics may be formed to be conductive), composite materials, or a combination thereof.

When the connector **700** is assembled, the flexible member **762** is in immediate proximity with the capacitive space **790**. Movements of the flexible member **762** cause changes in the size associated with the capacitive space **790**. The capacitive space **790** size may therefore by dynamic. Changes in the size of the capacitive space **790** may produce changes in the capacitance of the printed sensing circuit **730** and are therefore ascertainable as a physical parameter status. The face **742** of the insulator may be or include a fixed electrode, such as a fixed plate **744**, and the flexible member **762** may be or include a movable electrode. The distance between the electrodes, or the size of the capacitive space between the electrodes, may vary inversely with the applied torque. The closer flexible member **762** gets to the fixed plate **744**, the larger the effective capacitance becomes. The sensing circuit **730** translates the changes in capacitance to connector tightness and determines if the connector **700** is too loose. The capacitive space **790** may be a resonant chamber or capacitive cavity. The dimensional space of the capacitive space **790** can be easily manufactured to very tight tolerances either by forming at least a portion of the space **790** directly into the molded substrate **740**, forming it into portion of the housing **750**, forming it into a portion of the interface sleeve **760**, or a combination of the above. For example, an annular channel may be formed in molded substrate **740**, wherein a capacitive sensing circuit **730** is positioned on the bottom face **742** of the channel to form an annular diaphragm capacitor responsive to resonant variation due to changes in the size of cavity **790**. The capacitive space **790** may be filled with air, wherein the air may function as a dielectric. However, the capacitive space **790** may be filled with some other material such as dielectric grease. Moreover, portions of the cavity capacitive space **790** boundaries, such as surfaces of the spacer **740** or flexible member **760** may be coated with dielectric material. Because the connector **700** assembly creates a sandwich of parts, the capacitive space or resonant cavity **790** and sensing circuit **730** need not be adjusted or calibrated individually for each connector assembly, making assembly of the connector **700** no different from a similar common coaxial cable connector that has no sensing circuit **730** built in.

Power for the sensing circuit **730**, electrical components **562**, and/or an integrated circuit **504** may be provided through indirect (i.e., via coupler **720**) or direct (via traces) electrical contact with the center conductor **780**. As a first example, an indirect coupling device (such as a directional coupler) may be used to retrieve or sample (i.e., indirectly) RF energy propagating along a center coaxial line. As a second example, traces may be printed on the molded substrate **740** and positioned so that the traces make electrical contact with the center conductor contact **780** at a location **746**. Electrical contact with the center conduct contact **780** (via coupler **720** or conductive traces) at location **46** facilitates the ability for the sensing circuit **730**, electrical components **562**, and/or an integrated circuit **504** to draw power from the cable signal(s) passing through the center conductor contact **780**. Traces may also be formed and positioned so as to make contact with grounding components. For example, a ground path may extend through a location **748** between the molded substrate **740** and the interface sleeve **760**. Alternatively, a ground isolation circuit may be provided to generate a negative voltage to be used as a reference signal (i.e., a ground).

The sensing circuit **730** can communicate sensed mating forces. The sensing circuit **730**, such as a capacitive circuit, may be in electrical communication with an output component such as traces or a coupler **720** electrically connected to the center conductor contact **780**. For example, sensed conditions due to mating forces, such as changes in capacitance of the cavity or chamber **790**, may be passed as an output signal from the sensing circuit **730** of the molded substrate **740** through an output component, such as a coupler **720** or traces, electrically linked to the center conductor contact **780**. The outputted signal(s) can then travel along the cable line corresponding to the cable connection applicable to the connector **700**. Hence, the signal(s) from the sensing circuit **730** may be accessed at a point along the cable line. In addition, traces or conductive elements of an output component in communication with a sensing circuit **730** may be in electrical contact with output leads available to facilitate connection of the connector **700** with electronic circuitry that can manipulate the sensing circuit **730** operation.

A portion of the molded substrate **740**, such as a flange **747**, may be compressible or bendable. As the flexible member **762** of the interface sleeve **760** moves due to mating forces, the flange **747** may compress or bend as it interacts with the flexible member **762**. The compressible or bendable nature of a portion of the molded substrate **740**, such as flange **747**, may permit more efficient movement of the flexible member **762**. For instance, the flange **747** may contribute resistance to movement of the flexible member **762**, but still allow some bending of the member. In addition, the molded substrate **740** may bend with respect to a rear wall or surface **743** as the flexible member **762** bends due to mating forces and interacts with the molded substrate **740**.

FIG. **3** depicts an embodiment of an assembled coaxial cable connector **700** with integrated mating force sensing circuit **730**. The threaded surface **754** of the first end of connector body **750** facilitates threadable mating with another coaxial cable component, such as a male connector **500** (see FIGS. **4-6**). However, those in the art should appreciate that the connector **700** may be formed without threads and designed to have a tolerance fit with another coaxial cable component, while the sensing circuit **730** is still able to sense mating forces. As shown, the spacer **770** operates with an internal surface of the connector body **750** to stabilize the center conductor contact **780** and help retain substantially axial alignment of the center conductor contact **780** with respect to the connector **700**. The molded substrate **740** may be seated against an annular ridge **784** located on the center conductor contact **780**. Seating the molded substrate **740** against the annular ridge **784** may help retain the spacer **740** in a substantially fixed position along the axis of connector **700** so that the molded substrate **740** does not axially slip or move due to interaction with the interface sleeve **760** when mating forces are applied. The molded substrate **740** is located on a spacer portion **782** of the center conductor contact **780** and has a close tolerance fit therewith to help prevent wobbling and/or misalignment of the center conductor contact **780**.

Mating of a connector **700** is described and shown with reference to FIGS. **4-6**. A connector **700** can mate with RF ports of other components or coaxial cable communications devices, such as an RF port **515** of a male connector **500**. The RF port **515** of the male connector **500** is brought into axial alignment with the mating force sensing connector **700**. The two components are moved together or apart in a direction **5**, as shown in FIG. **4**. The male connector **500** may include a connector body **550** including an attached nut **555** having internal threads **554**. The male connector **500** includes a conductive interface sleeve **560** having a leading edge **562**. The interface sleeve **760** of the mating force sensing connector **700** may be dimensioned such that during mating the two interface sleeves **760** and **560** slidingly interact. The interface sleeve **760** may be designed to slidingly interact with the inner surface of the male connector **500** interface sleeve **560**, as shown in FIG. **5**. However, other embodiments of a connector **700** may include an interface sleeve **760** designed to slidingly interact with the outside surface of a connector component, such as interface sleeve **560**. The sliding interaction of the interface sleeve **760** with the interface sleeve **560** may be snug, wherein the tolerance between the parts is close when the mating force sensing connector **700** is being mated to the male connector **500**.

The female center conductor contact **780** of the force sensing connector **700** may include segmented portions **787**. The segmented portions **787** may facilitate ease of insertion of a male center conductor contact **580** of the male connector **500**. Additionally, the center conductor contact **580** of the male connector **500** may include a tapered surface **587** that further eases the insertion of the male center conductor contact **580** into the female center conductor contact **780**. Those in the art should appreciate that a mating force sensing connector **700** may include a male center conductor contact **780** configured to mate with a female center conductor contact of another connector component.

FIG. **5** depicts an embodiment of a mating force sensing coaxial cable connector **700** during mating with an embodiment of an RF port **515** of a male connector **500**. When the threaded nut **555** of the male connector **500** is initially threaded onto the threaded surface **754** of connector body **750**, the interface sleeve **760** of the mating force sensing connector **700** may begin to slidingly advance against the inner surface of interface sleeve **560** of the male connector **500**. The male center conductor contact **580** is axially aligned with the female center conductor contact **780** and readied for insertion therein.

When mated, the leading edge **562** of the interface sleeve **560** of the male connector **500** makes contact with the flexible member **762** of the interface sleeve **760** of the mating force sensing connector **700**, as shown in FIG. **6**. Contact between the leading edge **562** and the flexible member **762** facilitates transfer of force from the interface sleeve **560** to the interface sleeve **760**. Mating force may be generated by the threading advancement of the nut **555** onto the threaded surface **754** of mating force sensing connector **700**. However, mating force may be provided by other means, such as by a user gripping the connector body **550** of the male connector **500** and pushing it in a direction **5** (see FIG. **4**) into mating condition with the force sensing connector **700**. The force placed upon the flexible member **762** by the leading edge **562** may cause the flexible member **762** to bend.

Because the cavity or chamber **790** can be designed to have a known volume within a tight tolerance in an assembled mating force sensing connector **700**, the sensing circuit **730** can be calibrated according to the known volume to sense corresponding changes in the volume. For example, if the male connector **500** is not threaded onto the mating force sensing connector **700** enough, then the leading edge **562** of the interface sleeve **560** does not place enough force against the flexible member **762** to bend the flexible member **762** sufficiently enough to create a change in the size of capacitive space **790** that corresponds to a sufficient and appropriate change in capacitance of the space **790**. Hence, the sensing circuit **730**, such as a capacitive circuit on the molded substrate **740**, will not sense a change in capacitance sufficient to produce a signal corresponding to a proper mating force attributable to a correct mated condition. Or, if the male connector **500** is threaded too far and too tightly onto the mating force sensing connector **700**, then the leading edge **562** of the interface sleeve **560** will place too much force against the flexible member **762** and will bend the flexible member **762** more than is sufficient to create a change in the size of capacitive space **790** that corresponds to a sufficient and appropriate change in capacitance of the space **790**. Hence, the sensing circuit **730**, such as a capacitive circuit on the first spacer insulator component **740**, will sense too great a change in capacitance and will produce a signal corresponding to an improper mating force attributable to a too tightly-fitted mated condition.

Proper mating force may be determined when the sensing circuit **730** signals a correct change in electrical capacitance relative to the size of capacitive space **790**. The correct change in size may correspond to a range of volume or distance, which in turn may correspond to a range of capacitance sensed by the sensing circuit **730**. Hence, when the male connector **500** is advanced onto the mating force sensing connector **700** and the interface sleeve **560** exerts a force against the flexible member **762** of the interface sleeve **760**, the force can be determined to be proper if it causes the flexible member to bend within a range that corresponds to the acceptable range of size change of capacitive space **790**. The determination of the range acceptable capacitance change can be determined through testing and then associated with mating force conditions.

Once an appropriate capacitance range is determined, then calibration may be attributable to a multitude of mating force sensing connectors **700** having substantially the same configuration. The size and material make-up of the various components of the multiple connectors **700** can be substantially similar. For example, a multitude of mating force connectors **700** may be fabricated and assembled to have a regularly defined capacitive space **790** in immediate proximity with a bendable wall or boundary surface, such as flexible member **762**, wherein the capacitive space **790** of each of the multiple connectors **700** is substantially the same size. Furthermore, the multiple connectors **700** may include a sensing circuit **730**, such as a capacitive circuit, printed on a molded substrate **740**, the molded substrate **740** being an insulator component. The sensing circuit **730** on each of the molded substrates **740** of the multiple connectors **700** may be substantially similar in electrical layout and function. For instance, the sensing circuit **730** for each of the multiple connectors **700** may sense capacitance substantially similarly. Then, for each of the multitude of connectors **700**, capacitance may predictably change relative to size changes of the capacitive space **790**, attributable to bending of the flexible member **762** corresponding to predictable mating force. Hence, when capacitance falls within a particular range, as sensed by sensing circuit **730**, then mating force can be determined to be proper for each of the multiple connectors **700** having substantially the same design, component make-up, and assembled configuration. Accordingly, each connector **700** of the multiple mating force connectors **700** having substantially the same design, component make-up, and assembled configuration does not need to be individually calibrated. Calibration can be done for an entire similar product line of connectors **700**. Then periodic testing can assure that the calibration is still accurate for the line. Moreover, because the sensing circuit **730** is integrated into existing connector components, the mating force sensing connector **700** can be assembled in substantially the same way as typical connectors and requires very little, if any, mass assembly modifications.

With further reference to the drawings, FIG. **7** depicts a partial cross-sectional view of a further embodiment of a coaxial cable connector **800** with integrated force mating force sensing circuit **830**. The mating force sensing circuit **830** may be a capacitive circuit positioned on a mount portion **843** of a first face **842** of an embodiment of a molded substrate **840**. The capacitive circuit **830** may be printed on the mount portion **843**. The mount portion **843** may protrude somewhat from the first face **842** of the molded substrate **840** to help position the capacitive circuit **830** in immediate proximity with a first section bore **863** of a first section **862** of an interface member **860** to define a capacitive space **890** located between the face **842** and the molded substrate **840**. The interface member **860** also includes a second section **864**. The first section **862** of the interface member **860** may be flexible so that it can move between a first non-bent position and a second bent position upon the application of an axial force by a mating component **860** on the first section **862**. When in a second bent position, the first section **862** of the interface member **860** may move closer to the first surface **842** of the molded substrate **840** thereby decreasing the volume of the capacitive space **890** existent proximate the capacitive circuit **830** on the mount portion **843** immediately proximate the first section bore **863** of the first section **862**. The capacitive circuit **830** can detect the decrease in size of the capacitive space **890** and correlate the change in size with mating force exerted on the interface member **860**.

The connector **800** embodiment may include a connector body **850** having a threaded portion **854** located proximate a first end of the connector body **850**. The first end **751** of the connector **800** may axially oppose a second end **852** of the connector **800** (not shown, but similar to second end **752** of connector **700** depicted in FIG. **1**). In addition, the connector body **850** may include a first bore **856** extending axially from the first end **851**. The first bore **856** may be large enough to accommodate the first spacing insulator **840** and the interface member **860** so that the connector body **850** may house the molded substrate **840** and the interface member **860**. Moreover, the first end **851**, including the first bore **851**, may be sized to mate with another coaxial cable component, such as male connector **500** depicted in FIGS. **4-6**.

An embodiment of a method for detecting an RF signal (or harvesting power) or a mating force of a mated coaxial cable connector **700**, **800** is described with reference to FIGS. **1-7**. One step of the mating force detecting method includes providing a coaxial cable connector, such as connector **700** or **800**. The connector **700**, **800** may include a sensing circuit **730**, **830**, coupler **720**, conductive interconnects or traces **731**, electrical components **562**, and/or an integrated circuit **504** positioned on a face **742**, **842** of a spacer component **740**, **840** located within a connector body **750**, **850**. In addition, the connector **700**, **800** may include a capacitive space **790**, **890** in immediate proximity with the sensing circuit **730**, **830**. Moreover, the connector **700**, **800** may have an interface component **760**, **860** having a flexible member **762**, **862** forming at least one surface or boundary portion of the capacitive space **790**, **890**. The flexible member **762**, **862** may be movable due to mating forces.

Another step of the coaxial cable connector mating force detection method includes mating the connector **700**, **800** with a connecting device, such as the male connector **500**, or any other structurally and functionally compatible coaxial cable communications component. Yet another mating force detection step includes bending the flexible member **762**, **862** of the interface component **760**, **860** due to contact with the connecting device, such as male connector **500**, during mating, thereby reducing the size of the capacitive space **790**, **890**. Still further, the mating force detection methodology includes detecting mating force by sensing the reduction of capacitive space **790**, **890** size by the sensing circuit **730**, **830**. The size change of the space **790**, **890** may then be correlated with the mating force exerted on the interface member **760**, **860**.

FIGS. **8**A and **8**B depict perspective views of an embodiment of the molded substrate **740** comprising the coupler **720**, integrated circuit **504**, electrical components **562**, and conductive interconnects or traces **731** of FIG. **1**. FIGS. **8**A and **8**B illustrate the coupler **720** mounted to or integrated with the molded substrate **740**. Coupler **720** illustrated in FIG. **8**A comprises a loop coupler that includes optional loops **516***a*, **516***b*, and **516***c* for impedance matching, etc. The molded substrate **740** may comprise a molded interconnect device (e.g., a disk) generated using a laser direct structuring process on syndiotactic polystyrene material with an LDS additive and plated with an electro-less plating process. The molded substrate **740** is designed to be inserted into a coaxial cable connector housing and provide an electronic sensing and processing platform (i.e., for the sensor **730**, coupler **720**, integrated circuit **504**, electrical components **562**, conductive interconnects or traces **731**). The molded substrate **740** may be generated using materials and processes including, among other things, a syndiotactic polystyrene with LDS additive, a liquid crystal polymer with additive, an injection molding process, a laser activation process, an electro-less plating process, etc. The molded substrate **740** may include multiple sensors defined on its surface to determine a state of a coaxial cable connector and provide information on a status of the connector and quality of an RF signal. The molded substrate **740** comprises a dielectric material capable of being mechanically inserted into a coaxial cable connector housing without deformation. The molded substrate **740** acts a platform for mounting sensors used to monitor parameters that measure a viability of RF coaxial cable connectors (e.g., mating tightness, moisture, temperature, impedance, etc.). Additionally, the molded substrate **740** provides a surface for placing micro-antenna structures (e.g., coupler **720**) used to couple energy from the coaxial cable, measure both the forward and reverse propagating RF voltage signals on a coaxial cable, and provide a coupling connection to the cable for transmitting and receiving data to and from all components on or within the molded substrate **740**. The molded substrate **740** may be included in passive transponder system intended to monitor information being sent and received through a transmission line, extract energy from near field RF sources, and sense a state of a remote station over a transmission line such as a coaxial cable. The molded substrate **740** allows for real time sensing of an RF connector and coaxial cable system reliability.

FIG. **8**C depicts a perspective view of an embodiment of a molded substrate **740***a* (i.e., an alternative geometry to the geometry of molded substrate **740**) comprising a top mounted and/or recessed integrated circuit **504**, electrical components **562**, and conductive interconnects or traces **731**. The integrated circuit **504** of FIG. **8**C includes two different versions (either version may be used) of the integrated circuit **504**: a top mounted version **505***a* and a recessed mounted version **505***b*. Alternatively, a combination of the top mounted version **505***a* and the recessed mounted version **505***b* of the integrated circuit **504** may be used in accordance with embodiments of the present invention. Additionally, the molded substrate **740***a* may comprise additional electrical components **562** (e.g., transistors, resistors, capacitors, inductors, etc)

FIG. **8**D depicts a perspective view of an embodiment of the molded substrate **740** comprising the integrated circuit **504** mounted to or integrated with a side portion of the molded substrate **740**.

FIG. **8**E depicts a top view of an embodiment of the molded substrate **740** comprising various conductive interconnects or traces **731** (e.g., comprising a metallic material) mounted to or integrated with a top side of the molded substrate **740**.

FIG. **8**F depicts a perspective view of an embodiment of the molded substrate **740** without any components.

While this invention has been described in conjunction with the specific embodiments outlined above, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, the preferred embodiments of the invention as set forth above are intended to be illustrative, not limiting. Various changes may be made without departing from the spirit and scope of the invention as defined in the following claims. The claims provide the scope of the coverage of the invention and should not be limited to the specific examples provided herein.

What is claimed is:

1. A substrate structure comprising:

a molded substrate located between a center conductor contact and an outer conductor contact within a connector body of a coaxial cable connector; and

an electrical structure mechanically connected to the molded substrate, wherein the electrical structure is located in a position that is external to a signal path of a radio frequency (RF) signal flowing through the center conductor contact of the coaxial cable connector, wherein the electrical structure comprises a metallic coupler circuit configured to wirelessly sense the RF signal flowing through the center conductor contact of the coaxial cable connector, wherein the metallic coupler circuit is external to and mechanically isolated from the center conductor contact within the coaxial cable connector, and wherein the metallic coupler circuit is located between the center conductor contact and the outer conductor contact.

2. The substrate structure of claim **1**, further comprising a signal processing circuit mechanically attached to the molded substrate, wherein metallic coupler circuit is configured to extract samples of the RF signal flowing through the coaxial cable connector, and wherein the signal processing circuit is configured to report the samples of said RF signal to a location external to the coaxial cable connector.

3. The substrate structure of claim **1**, wherein metallic coupler circuit is configured to extract an energy signal from the RF signal flowing through the coaxial cable connector, and wherein the energy signal is configured to apply power to an electrical device located within the coaxial cable connector.

4. The substrate structure of claim **3**, wherein the electrical device is mechanically attached to the molded substrate.

5. The substrate structure of claim **1**, wherein the metallic coupler circuit is formed within a surface of the molded substrate structure.

6. The substrate structure of claim **1**, wherein the electrical structure comprises metallic traces for connections between electrical components mechanically attached to the molded substrate.

7. The substrate structure of claim **1**, wherein the molded substrate comprises a disk structure.

8. The substrate structure of claim **7**, wherein the molded substrate is positioned to axially align center conductor contact within the connector body.

9. The substrate structure of claim **1**, wherein the molded substrate comprises a material selected from the group consisting of syndiotactic polystyrene and a liquid crystal polymer.

10. A coaxial cable connector for connection to a coaxial cable, the connector comprising:

a connector body; and

a molded substrate structure located between a center conductor contact and an outer conductor contact within the connector body, wherein the molded substrate structure comprises an electrical structure mechanically connected to the molded substrate structure, wherein the electrical structure is located in a position that is external to a signal path of a radio frequency (RF) signal flowing through the center conductor contact of the coaxial cable connector, wherein the electrical structure comprises a metallic coupler circuit configured to wirelessly sense the RF signal flowing through the center conductor contact of the coaxial cable connector, wherein the metallic coupler circuit is external to and mechanically isolated from the center conductor contact within the coaxial cable connector, and wherein the metallic coupler circuit is located between the center conductor contact and the outer conductor contact.

11. The coaxial cable connector of claim **10**, wherein the center conductor contact is electrically and mechanically connected to a center conductor of the coaxial cable.

12. The coaxial cable connector of claim **11**, wherein the molded substrate structure is positioned to axially align the center conductor contact within the connector body.

13. The coaxial cable connector of claim **11**, wherein the molded substrate structure includes traces positioned at a location to make electrical contact between the center conductor contact and the electrical structure when the connector is assembled.

14. The coaxial cable connector of claim **10**, wherein the metallic coupler circuit is configured to extract samples of the RF signal flowing through the coaxial cable connector.

15. The coaxial cable connector of claim **10**, wherein the metallic coupler circuit is configured to extract an energy signal from the RF signal flowing through the coaxial cable connector, and wherein the energy signal is configured to apply power to an electrical device located within the coaxial cable connector.

16. The coaxial cable connector of claim **10**, wherein the metallic coupler circuit is formed within a surface of the molded substrate structure.

17. The coaxial cable connector of claim **10**, wherein the electrical structure comprises metallic traces for connections between electrical components mechanically attached to the molded substrate structure.

18. A method comprising:

providing substrate structure comprising a molded substrate located between a center conductor contact and an outer conductor contact within a connector body of a coaxial cable connector and an electrical structure mechanically connected to the molded substrate, wherein the electrical structure comprises a metallic coupler circuit, wherein the electrical structure is located in a position that is external to a signal path of a radio frequency (RF) signal flowing through the coaxial cable connector, wherein the metallic coupler circuit is external to and mechanically isolated from the center conductor contact within the coaxial cable connector, and wherein the metallic coupler circuit is located between the center conductor contact and the outer conductor contact; and

wirelessly sensing, by the electrical structure, the RF signal flowing through the center conductor contact of the coaxial cable connector.

19. The method of claim **18**, wherein the substrate structure further comprises a signal processing circuit mechanically attached to the molded substrate and electrically connected to the electrical structure, and wherein the method further comprises:

extracting, by the electrical structure, samples of the RF signal flowing through the coaxial cable connector; and

reporting, by the signal processing circuit, the samples of the RF signal to a location external to the coaxial cable connector.

20. The method of claim **18**, further comprising:

extracting, by the electrical structure, an energy signal from the RF signal flowing through the coaxial cable connector; and

applying, by the energy signal, apply power to an electrical device located within the coaxial cable connector.

21. The method of claim **18**, further comprising:

axially aligning, by the molded substrate, a center conductor contact within the connector body.

22. The method of claim **18**, further comprising:

forming the substrate structure by a process selected from the group consisting of an injection molding process, a laser activation process, and an electro-less plating process.

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