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Flasza et al.

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(54) **PROCESS CONTROL INSTRUMENT INTRINSIC SAFETY BARRIER**

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(22) Filed: **Sep. 30, 2003**

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Related U.S. Application Data

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(51) **Int. Cl.**[7] **H01Q 1/50**
(52) **U.S. Cl.** **343/850**
(58) **Field of Search** .... 343/850, 700 MS, 343/829, 846

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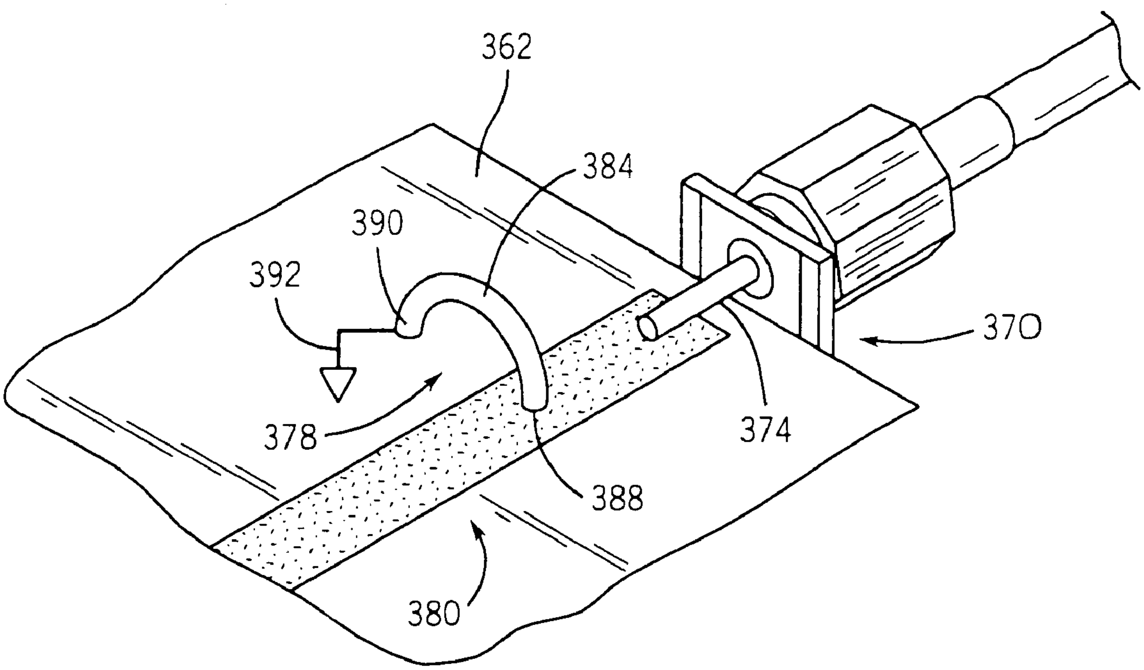
(57) **ABSTRACT**

A process control instrument includes a circuit board having a control circuit for generating or receiving a high frequency signal. An antenna includes an electrical conductor. An intrinsic safety circuit couples the control circuit to the antenna and comprises a microstrip transmission line on the circuit board electrically connecting the control circuit to the electrical conductor. A safety stub has a first end electrically connected to the transmission line proximate the electrical conductor and a second end connected to a ground of the control circuit.

11 Claims, 7 Drawing Sheets



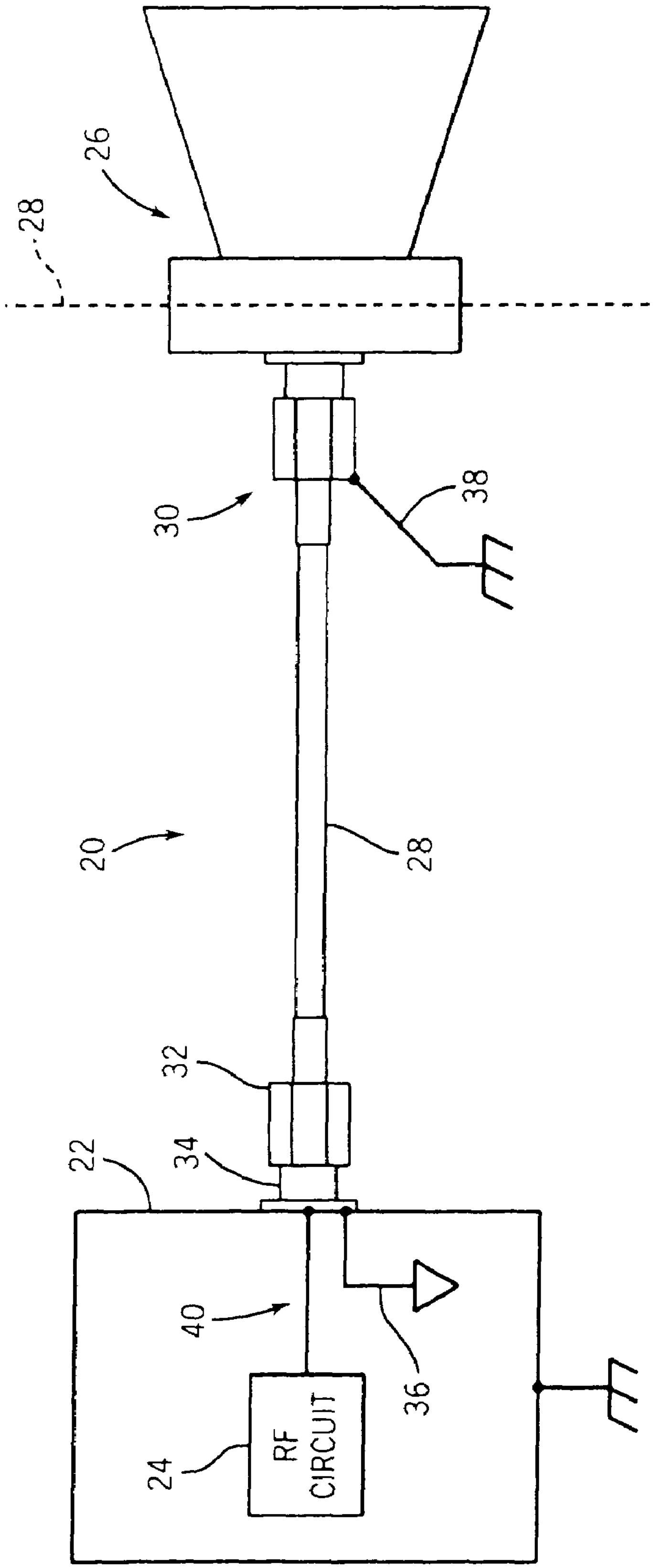
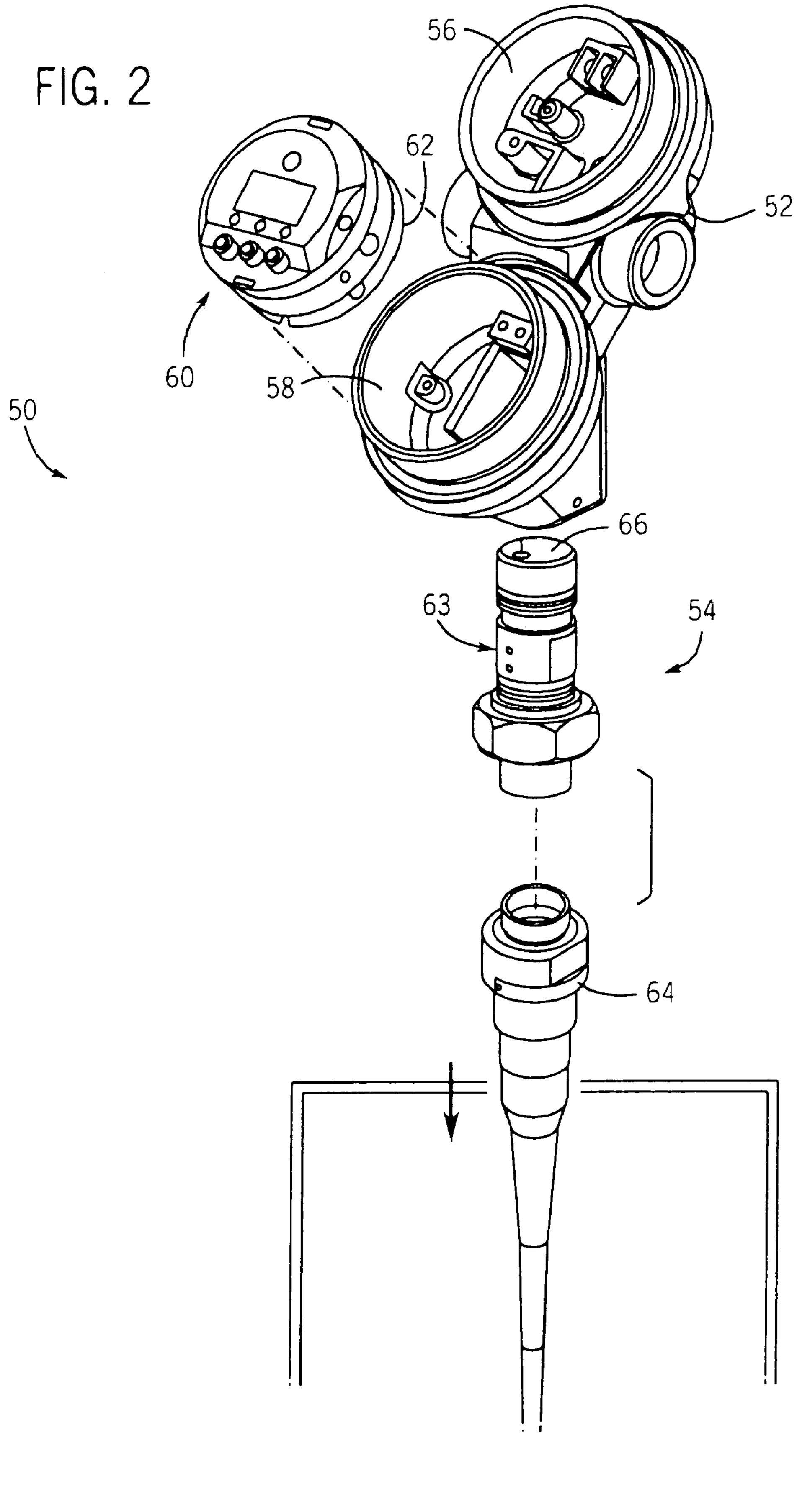


FIG. 1
PRIOR ART

FIG. 2



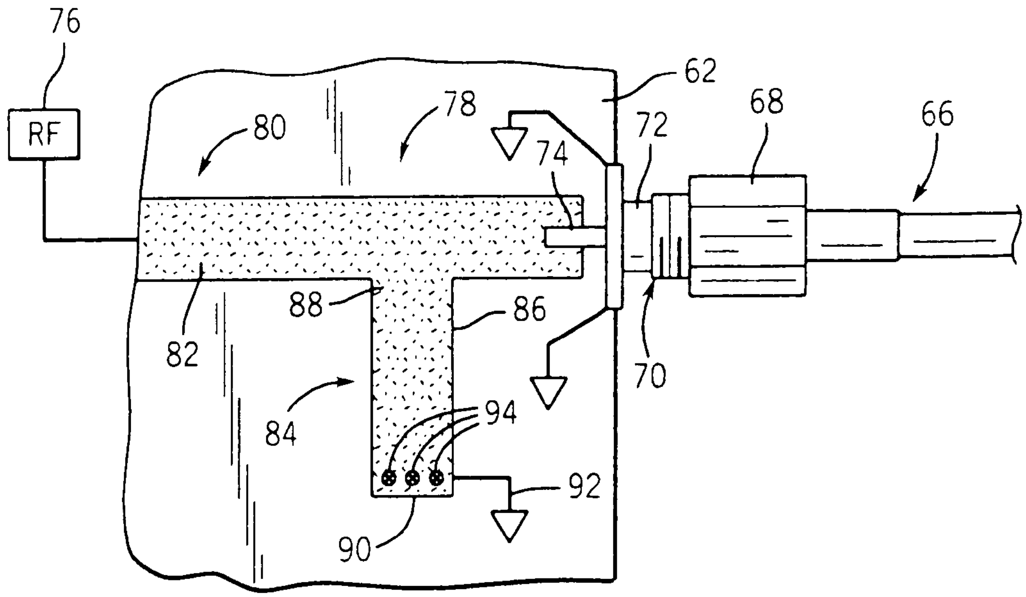

76
RF
80
78
62
72
74
68
66
88
86
82
70
84
94
92
90

FIG. 3

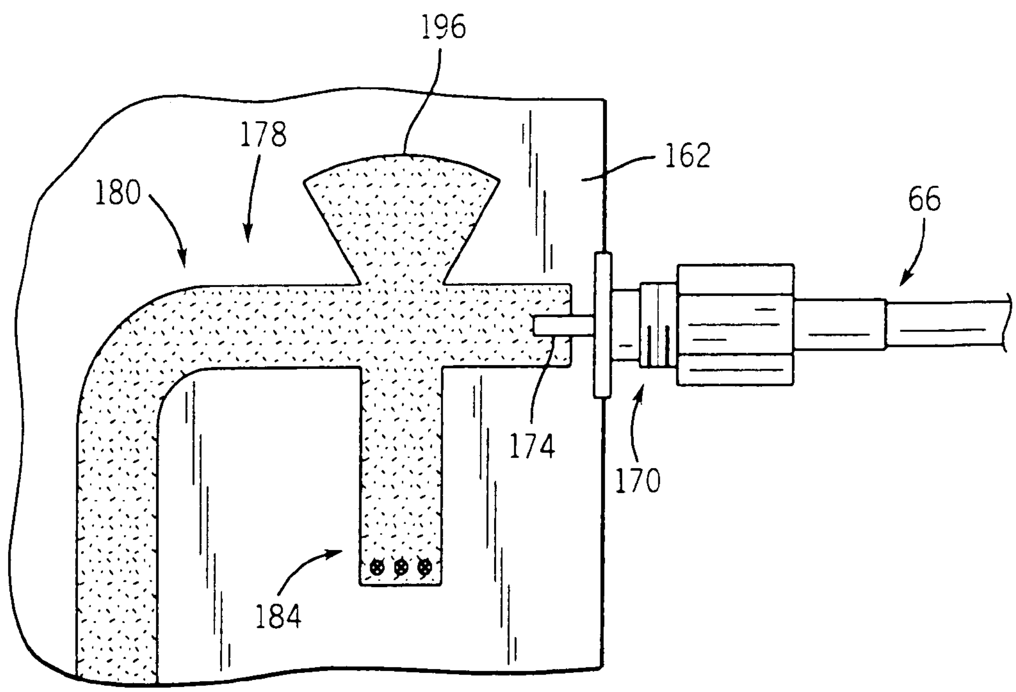

196
178
162
180
66
174
170
184

FIG. 4

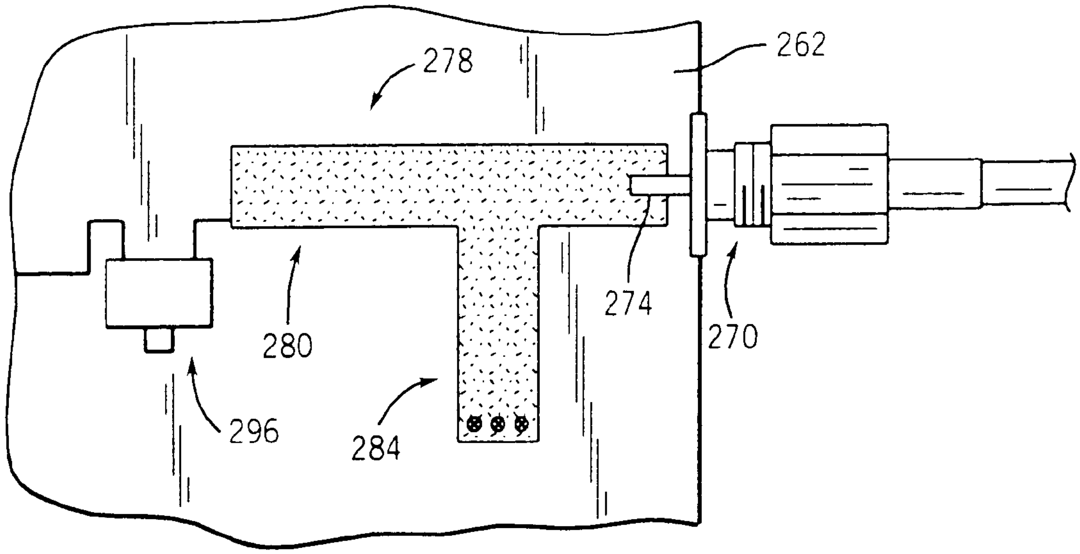


FIG. 5

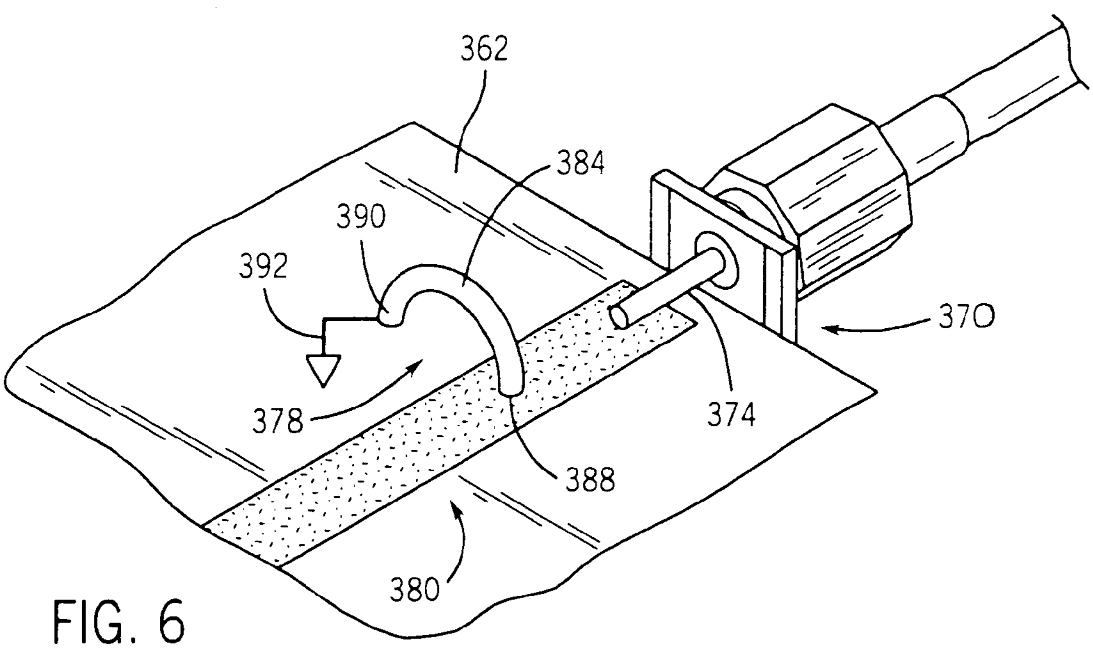


FIG. 6

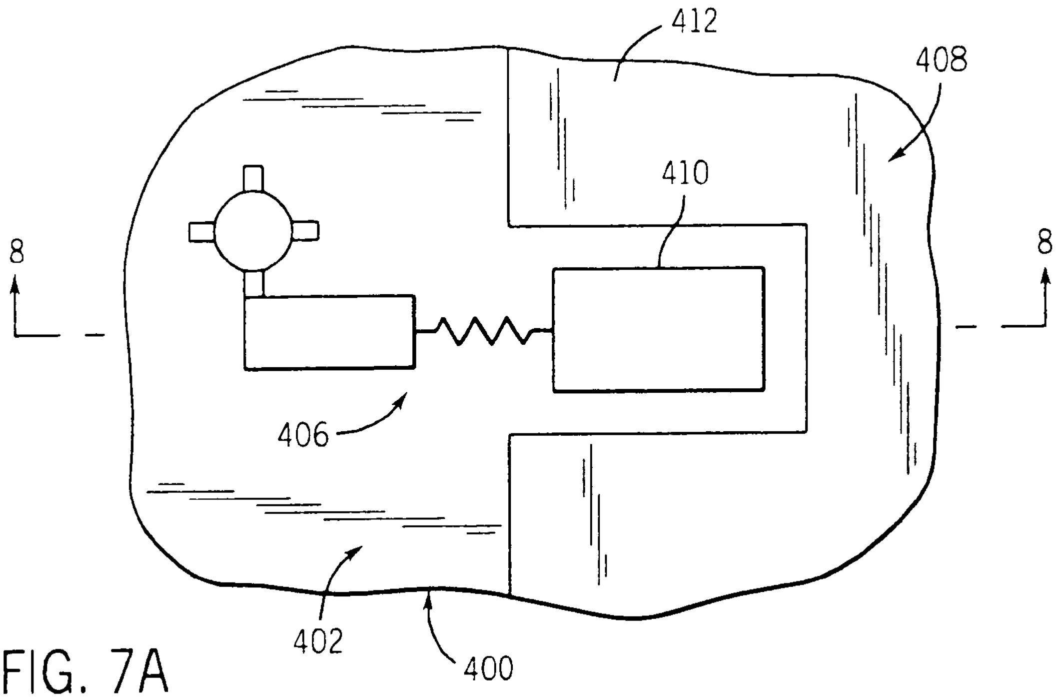


FIG. 7A

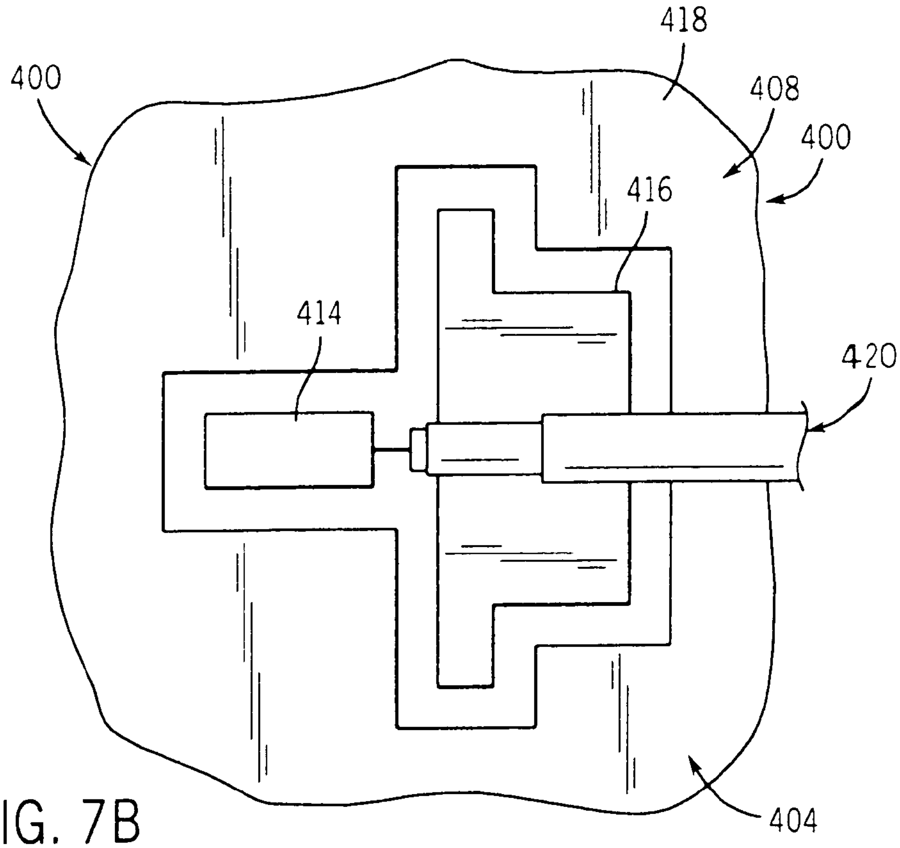


FIG. 7B

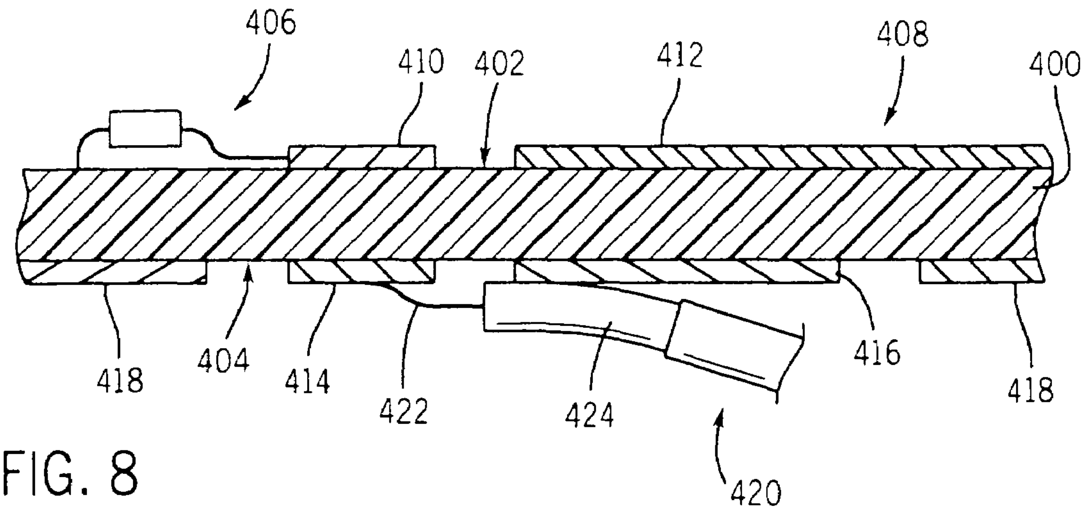


FIG. 8

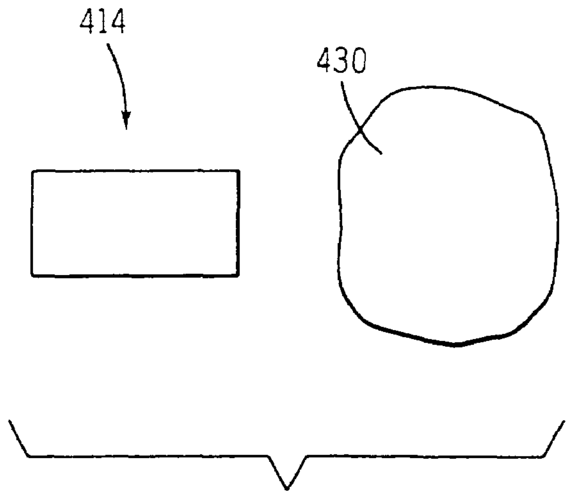


FIG. 9

FIG. 10

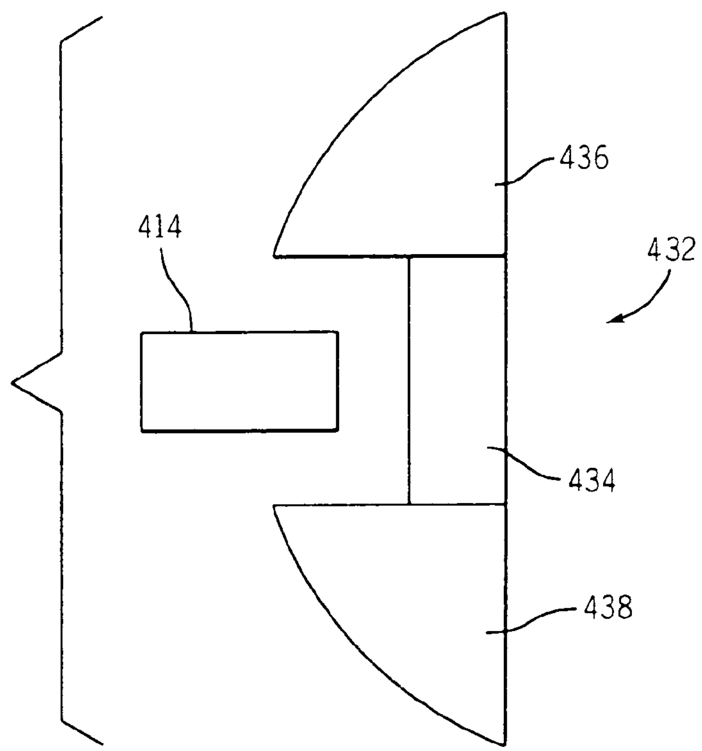
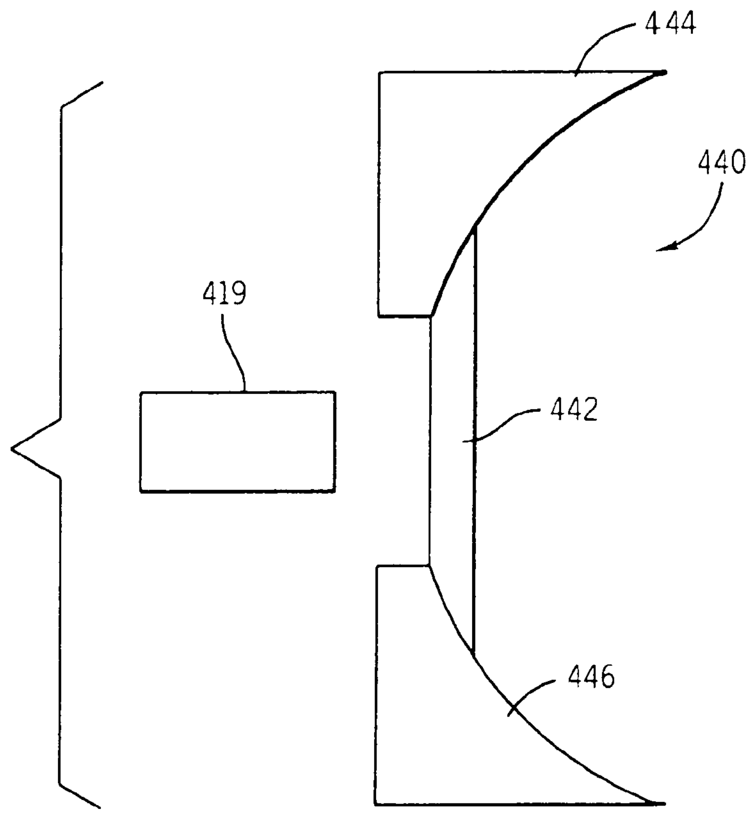


FIG. 11



PROCESS CONTROL INSTRUMENT INTRINSIC SAFETY BARRIER

CROSS REFERENCE

This application claims priority of application No. 60/414,847 filed Sep. 30, 2002 and application No. 60/467,853 filed May 5, 2003.

FIELD OF THE INVENTION

This invention relates to a process control instrument and more particularly, to an intrinsic safety barrier for a process control instrument.

BACKGROUND OF THE INVENTION

Industrial processes often require measuring the level of liquid or other material in a tank. Many technologies are used for level measurement. With contact level measurement some part of the system, such as a probe, must contact the material being measured. With non-contact level measurement the level is measured without contacting the material to be measured. One example is non-contact ultrasound, which uses high-frequency audio waves to detect level. Another example is use of high-frequency or microwave RF energy. Microwave measurement for level generally uses either pulsed or frequency modulated continuous wave (FMCW) signals to make product level measurements. This method is often referred to as through air radar. Through air radar has the advantage that it is non-contact and relatively insensitive to measurement errors from varying process pressure and temperature. Known radar process control instruments operate at frequency bands of approximately 6 Ghz or 24 Ghz.

While tank radar process control instruments measure product level without contact, in most cases part of the instrument must be mounted on the tank and a microwave antenna must be inserted into the tank in order to function. Problems can arise if the medium in the tank is "hazardous", i.e. it is subject to ignition and/or explosion. Any equipment installed in such locations must meet strict requirements in order to assure that any device, including tank level measurement devices, cannot ignite the vapors, etc., that may be present in such a tank. One method for achieving safe operation is to include a so-called intrinsic safety (IS) barrier in the system design. The concept of the IS barrier is to guarantee that sufficient amounts of energy cannot be transferred into the tank, in this case via the antenna, to cause an explosion. The IS, or energy-limiting barrier, may consist of zener diodes, current limiting resistors, and fuses so that energy levels at the antenna remain safely below published, known ignition curves for the particular process. IS barriers are traditionally placed in the input connections of a process control instrument. Doing so may cause loss of loop power and supply voltage due to the protective components, and produce ground loop product problems, which are difficult to overcome in multiple unit installations. An optimum location for the IS barrier is at the antenna connection. However, placing an IS barrier at the RF stages of the instrument could pose problems. Circuit design factors such as output impedance matching, return loss, agency compliance, and others are typical concerns. Radiated spectrum compliance, and in some cases radar receiver performance, can often be aided by filtering at the antenna connection.

An additional requirement for industrial measurements such as radar process control instruments is a dielectric

withstand test. As a measure of reliability, the power connections are shorted together and a relatively high DC voltage is applied between the shorted loop leads and the instrument case (earth ground). To pass the test, the circuit electronics must be able to withstand this voltage from its circuitry to earth ground. An IS barrier placed at the antenna connection may be called upon to withstand this voltage.

The present invention is directed to overcoming one or more of the problems discussed above in a novel and simple manner.

SUMMARY OF THE INVENTION

In accordance with the invention, there is disclosed a process control instrument using distributed elements in the circuit design for intrinsic safety.

Broadly, in accordance with one aspect of the invention, there is disclosed a process control instrument comprising a circuit board having a control circuit for generating or receiving a high frequency signal. An antenna includes an electrical conductor. An intrinsic safety circuit couples the control circuit to the antenna and comprises a microstrip transmission line on the circuit board electrically connecting the control circuit to the electrical conductor. A safety stub has a first end electrically connected to the transmission line proximate the electrical conductor and a second end connected to a ground of the control circuit.

It is a feature of the invention that the safety stub comprises a trace line on the circuit board.

It is another feature of the invention that the second end of the trace line includes conductive vias connected to the ground.

It is still another feature of the invention that the trace line comprises a quarter wavelength trace line.

It is still another feature of the invention that the safety stub comprises a wire element.

It is yet another feature of the invention that the intrinsic safety circuit further comprises a radial stub electrically connected to the transmission line.

It is an additional feature of the invention that the safety stub has a length selected to resonate at a select frequency of interest.

It is yet another feature of the invention that the safety stub comprises a trace line on the circuit board having a width of at least 2.0 mm and may be about 2.5 mm and having a length of about 10 mm.

There is disclosed in accordance with another aspect of the invention a process control instrument comprising a circuit board having first and second sides and a control circuit on the first side for generating or receiving a high frequency signal. An antenna includes a coaxial electrical conductor having a center conductor and a shield. An intrinsic safety circuit couples the control circuit to the antenna comprising the circuit board first side including a first microstrip stub electrically connected to the control circuit and a ground plane proximate the transmission line. The circuit board second side includes a second microstrip stub, directly underlying the first microstrip stub, electrically connected to the center conductor, and a ground pad, underlying the ground plane, electrically connected to the shield.

It is a feature of the invention that the first microstrip stub and the second microstrip stub are each of quarter wavelength.

It is another feature of the invention to provide a second ground plane on the circuit board second side proximate the second microstrip stub and the ground pad. The spacing between the ground plane and the ground pad is at least 2.0 mm.

It is yet another feature of the invention that the ground pad is configured to resonate at an operating frequency.

It is a further feature of the invention that the ground pad comprises a microstrip line connected between opposite radial stubs.

Further features and advantages of the invention will be readily apparent from the specification and from the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a generalized view, partially in block diagram form, of a prior art through air radar process control instrument;

FIG. **2** is an exploded view of a through air radar process control instrument in accordance with the invention;

FIG. **3** is a detailed plan view of an intrinsic safety circuit of the instrument of FIG. **2** according to one embodiment of the invention;

FIG. **4** is a perspective view of a first alternative to the intrinsic safety circuit of FIG. **3**;

FIG. **5** is a perspective view of a second alternative to the intrinsic safety circuit of FIG. **3**;

FIG. **6** is a perspective view of a third alternative to the intrinsic safety circuit of FIG. **3**;

FIGS. **7**A and **7**B comprise a partial top and bottom plan view, respectively, of a circuit board for the process control instrument of FIG. **2** according to a second embodiment of the invention;

FIG. **8** is a sectional view taken along the line **8**—**8** of FIG. **7**A; and

FIGS. **9**, **10** and **11** illustrate variations of distributed elements for circuit structures of the embodiment of FIG. **7**B.

DETAILED DESCRIPTION OF THE INVENTION

Referring initially to FIG. **1**, a typical prior art through air radar process control instrument **20** comprises a conventional housing, represented by a block **22**, housing various control circuits, including radio frequency (RF) circuits **24** for generating or receiving a high frequency microwave signal. An antenna **26** is mounted on a tank, represented by a dashed line **28**, to direct electromagnetic energy toward a material in the tank. A typical circuit to couple a microwave signal between the RF circuit **24** and the antenna **26** uses a coaxial cable **28** having connectors **30** and **32**. The first connector **30** is connected to the antenna **26**. The second connector **32** is connected to a connector **34** operatively located in the housing **22**. The coaxial cable **28** includes a center conductor and an outer shield, as is well known. The coaxial cable outer shield is usually connected to the circuit ground of the electronics, as illustrated at **36**. The outer shield is also usually connected to earth ground, or the so-called intrinsic safe ground, via a separate connection **38** whose safety characteristics are well defined. The center conductor is connected to the RF circuit **24** with a wire or other conductive element **40**.

The antenna may consist of an active element or "launcher" which can have various designs, but which may consist of, for example, a one quarter wavelength dipole inserted into a waveguide. The active element can create safety concerns if it is capable of conducting energy levels into the tank that can cause ignition.

One approach to limiting the energy to the center conductor **40** of the coaxial cable **28** might be to place an intrinsic safety (IS) barrier proximate the antenna connection **34**. This IS barrier might consist of resistors, diodes, fuses, etc., and is intended to limit the energy from the center conductor to levels below the established energy limit curves for the process. However, such an IS barrier must be controlled and optimized at microwave frequencies for several key parameters such as return loss and output impedance. Moreover, with the frequencies involved in microwave radar (5–8 Ghz or 22–25 Ghz) circuit design using discrete components can be extremely difficult.

Safety agencies have various requirements for printed circuit (PC) board layouts that must be followed to satisfy intrinsically safe requirements. A PC board trace must be of a certain minimum width, must be a minimum distance from other traces, and must have a redundant connection into a safe ground to be considered infallible.

The present invention relates to combining concepts of distributed-element microwave design with agency intrinsic safe ground requirements. Particularly, circuit elements such as inductors, capacitors, transmission lines, band pass filters, etc., are constructed for microwave frequencies by using transmission-line (microstrip) elements, which are PC board traces of controlled geometry (width/length, shape, etc.) while satisfying intrinsic safe ground requirements.

Referring to FIG. **2**, a through air radar process control instrument **50** in accordance with the invention is illustrated. The instrument **50** includes a housing **52** and an antenna **54**. The housing **52** includes a wiring compartment **56** and an electronics compartment **58**. The electronics compartment **58** receives a control module **60** including a circuit board **62** having an RF circuit similar to the RF circuit **24** of FIG. **1**. The antenna **54** comprises a connector **63** having an active element or loop launcher (not shown) and a dielectric rod **64**. The loop launcher is connected to a coaxial cable **66** which is electrically coupled, as described below, to the circuit board **62** of the control module **60**. As is conventional, the dielectric rod **64** propagates an electrical magnetic wave from the loop launcher into the air where the electromagnetic energy leaves the dielectric and propagates in free space, in the original direction along the axis of the rod **64**. As is apparent, the dielectric rod antenna **64** could be replaced by a horn antenna, such as illustrated in FIG. **1**.

The present invention is not directed to the particular RF circuit for generating or receiving a high frequency microwave signal or to the antenna, but rather to an intrinsic safety circuit for coupling the RF circuit to the antenna.

Referring to FIG. **3**, the coaxial cable **66** includes an end connector **68**. A portion of the printed circuit board **62** has a coaxial connector **70** having a conductive housing **72** and a center conductor **74**, as is conventional. Particularly, the conductive housing **72** is electrically connected in a conventional manner to the shield of the coaxial cable **66**. The center conductor **74** is electrically connected to the center conductor of the coaxial cable **66**, as is well known.

The printed circuit board **62** includes a control circuit, which may be of conventional nature, and having an RF circuit, illustrated in block form as element **76**. The RF control circuit **76** generates or receives a high frequency microwave signal, as discussed above. The microwave signal may be either a pulsed signal or a frequency modulated continuous wave (FMCW) signal. In accordance with the invention, an intrinsic safety (IS) barrier or circuit **78** couples the RF circuit **76** to the antenna **54**, see FIG. **2**. The intrinsic safety circuit **78** includes a microstrip transmission line **80** comprising a trace **82** on the printed circuit board **62** electrically connecting the RF circuit **76** to the center conductor **74**. A safety stub **84**, comprising a trace **86** on the printed circuit board, has a first end **88** electrically connected to the transmission line **80** proximate the electrical conductor **74** and a second end **90** connected to a control circuit ground **92**.

In the embodiment of FIG. **3**, the safety stub **84** comprises a microstrip stub line **86** of quarter wavelength at the operating frequency. As is well known in the art, such a microstrip appears at its ungrounded end as an open circuit. Therefore, it has little or no effect on the circuit operation at its center frequency. The effect of this connection is that, at low frequencies, the entire circuit, including the antenna center conductor **74**, is at ground potential. If the microstrip is sufficiently wide and is safely grounded, the circuit **78** is intrinsically safe. Particularly, it is capable of conducting high energy levels to the center conductor **74** and is safe from the point of view that its width, spacing and grounding requirements have been met.

For microstrips to have certain characteristic impedance, an important design parameter, the thickness of the PC board **62**, its relative dielectric value, and the geometry of the trace **86** must be known. For PC board materials of thickness 0.062 inches and a relative dielectric value of 4.5, and for a characteristic impedance of 50 Ohms, an approximate trace width is about 2.5 mm. At frequencies of 6 Ghz, a quarter wavelength on the PC board **62** might be about 10 mm. Practical values for the trace widths readily exist that are wide enough to meet agency width requirements of 2 mm. As is apparent, different dimensions would be used for different frequencies. Spacing requirements are satisfied by keeping other circuitry away from the IS ground area. Redundant requirements may be satisfied by triple conductive vias **94** through the printed circuit boards **62** connected to a conventional ground plane, represented schematically at **92**, on an opposite side of the circuit board **62** to satisfy infallible ground requirements. As is apparent, conductive vias are not required for the claimed invention.

As is apparent, other configurations are possible for the distributed element network to be placed at the antenna connector **70** that can be used to meet intrinsic safety ground requirements and not affect the microwave circuit, as in FIG. **3**, or to alter the output characteristic to the circuit for a functional reasons, and still retain the intrinsic safety ground feature. Examples are shown in FIGS. **4** and **5**.

Referring initially to FIG. **4**, a printed circuit board **162** includes an intrinsic safety circuit **178**. For simplicity, elements similar to those of the embodiment of FIG. **3** are illustrated using similar reference numerals in the 100 series (similarly FIG. **5** uses similar reference numerals in the 200 series). Such elements, unless different, are not described in detail.

The intrinsic safety circuit **178** of FIG. **4** differs from the intrinsic safety circuit **78** of FIG. **3** in the addition of a radial stub **196** electrically connected to the transmission line **180** proximate the center conductor **174**. The radial stub **196** forms a broadband short circuit that can reduce emissions into unwanted spectral bands. A quarter wavelength shorted stub **184** provides the infallible ground without affecting the operation of the radial stub **196**. This configuration may be used in applications seeking, for example, some band rejection filtering over a larger bandwidth.

FIG. **5** illustrates an intrinsic safety circuit **278** in which a safety stub **284** is not quarter wavelength. As is known, a length less than quarter wavelength can be used to simulate an inductor. A shorted stub of more than quarter wavelength but less that half wavelength may be used to simulate a capacitor. These configurations are used to match and/or tune the other distributed and discrete circuit elements for the specific needs of the particular circuit. For example, in the illustrated embodiment, distributed inductance may be used to resonate or tune out the parasitic capacitance of a detector diode **296**. Again, the shorted safety stub **284** provides necessary safety ground for the antenna connection.

Referring to FIG. **6**, a printed circuit board **362** for a further embodiment of the invention is illustrated. Again, reference numerals similar to those of FIG. **3** are in a 300 number series. The circuit board **362** includes an intrinsic safety circuit **378**. The intrinsic safety circuit **378** differs from the intrinsic safety circuit **78** of FIG. **3** in using an open air quarter wave stub wire **384** connected at an end **388** to the transmission line **380** and at an opposite end **390** to ground **392**.

While each of the variations of FIGS. **3–6** shows a coaxial connector having a center conductor connected to the transmission line, as is apparent the connectors could be eliminated so that the center conductor in each embodiment comprises the center conductor of the coaxial cable **66** itself soldered or otherwise coupled to the particular transmission line.

As described above, the typical method to couple a microwave signal from its source outside a tank, such as the RF circuit **76** of FIG. **3**, to an antenna inside the tank, such as the antenna **54** of FIG. **2**, is via a coaxial cable, such as the coaxial cable **66** of FIG. **2**. The outer conductor or shield is usually connected to earth ground. Problems can arise if the shield is directly connected to circuit ground of the control module **60**. In accordance with the invention, the through air radar process control instrument **50**, in another embodiment of the invention, has complete DC and AC isolation from the earth ground present at the antenna.

Referring to FIGS. **7**A, **7**B and **8**, a printed circuit board **400** is illustrated. As is apparent, the printed circuit board **400** can be substituted for the printed circuit board **62** of FIG. **2**. The printed circuit board **400** includes a first side **402**, see FIG. **7**A and a second side **404**, see FIG. **7**B. Referring initially to FIG. **7**A, a control circuit including an RF circuit **406** on the first side **402** generates or receives a high frequency microwave signal. An intrinsic safety (IS) circuit **408** comprises a microstrip quarter wavelength first stub **410** on the first side **402** electrically connected to the control circuit **406**. Additional PC board area on the first side **402** around the first stub **410** is filled in as a ground plane **412**.

On the PC boards second side **404**, see FIG. **7**B, the IS circuit **408** further comprises a microstrip quarter wavelength second stub **414** placed directly underneath the first stub **410**, as shown in FIG. **8**, in such a way that the two stubs **410** and **414** couple RF energy efficiently at microwave frequency. As is apparent, there is no galvanic electrical connection between the stubs **410** and **414**. Particularly, the stubs **410** and **414** are separated by the dielectric material of the PC board **400**, which is typically about 0.063 inches thick. Additionally, a larger copper ground pad **416** is placed directly underneath the ground plane **412**. The ground pad **416** likewise has no direct connection to the ground plane **412**. Advantageously, the ground pad **416** is a resonant structure to prevent the propagation of circulating RF currents in the shield. Moreover, the structures **414** and **416** are surrounded by a ground plane **418**, as shown.

A coaxial cable **420**, similar to the coaxial cable **66** of FIG. **2**, has a center conductor **422** and a conductive outer shield **424**. The center conductor **422** is soldered to the second stub **414**. The shield **424** is soldered or otherwise electrically connected to the ground pad **416**. As such, the described structures couple microwaves effectively through the board **400** without a direct electrical connection path in either the center conductor **422** or ground shield **424**. Microwaves can be effectively transmitted and received through this barrier, which uses the entire dielectric isolation afforded by the thickness of the PC board material **400**.

The described intrinsic safety circuit **408** is inexpensive as it only uses distributed PC board traces and no discrete components. Frequencies to be transmitted and received may be tuned via the size and length of the stubs **410** and **414**. Since these quarter wavelength stubs **410** and **414** effectively couple only RF energy at the resonant frequencies, which is determined by the physical size and length as well as thickness and dielectric constant of the PC board material, frequencies below or above the desired microwave frequency are not effectively coupled by the structure, affording a desirable filter characteristic.

Adequate spacing, greater than 2 mm, is maintained between the quarter wavelength stub **414**, ground pad **416** and ground plane **418** to satisfy agency requirements.

The control circuit **406** can be a transmitter, receiver, or any type of circuit that must couple microwave energy to an antenna. The length and width of the stubs **410** and **414** determine the frequency of most efficient coupling (center frequency) and the stubs characteristic impedance for impedance matching purposes. In an exemplary embodiment of the invention, 7 mm by 2.5 mm stubs **410** and **414** are used with atypical PC board thickness of 0.063 inches and dielectric constant of 4.5 to effectively couple signals in the 6 Ghz range. Stub length/width/impedance may be varied for other operating frequencies and/or different substrate materials.

As is apparent, shape of either the second stub **414** or coax ground pad **416** may be different from those shown in FIG. **7**B. Regardless, the design must achieve full galvanic isolation of both cable connections while allowing microwave energy to pass through, while still achieving high dielectric strength, and allowing minimum spacing to be observed between the coax ground pad **416** and circuit ground in accordance with safety requirements.

FIGS. **9**, **10** and **11** illustrate other possible configurations for the coaxial cable connection. FIG. **9** illustrates the quarter wavelength second stub **414** proximate a non-resonant, irregular shaped ground pad **430**. FIG. **10** illustrates a ground pad **432** including a microstrip line **434** connected between radial stubs **436** and **438**. FIG. **10** illustrates a ground pad **440** including a microstrip **442** connected between alternative radial stubs **444** and **446** intended for broadband requirements.

Thus, in accordance with the invention, intrinsic safety circuit is provided for coupling a high frequency microwave signal to an antenna in a through air radar process control instrument.

We claim:

1. A process control instrument comprising:

a circuit board having first and second sides and a control circuit on the first side for generating or receiving a high frequency signal;

an antenna including a coxial electrical conductor having a center conductor and a sheild; and

an intrinsic safety circuit coupling the control circuit to the antenna comprising the circuit board first side including a first microstrip stub electrically connected to the control circuit and a ground plane proximate the first microstrip stub, the circuit board second side including a second microstrip stub, directly underlying the first microstrip stub, electrically connected to the center conductor, and a ground pad, underlying the ground plane, electrically connected to the shield.

2. The process control instrument of claim **1** wherein the first microstrip stub and the second microstrip stub are each of quarter wavelength.

3. The process control instrument of claim **1** further comprising a second ground plane on the circuit board second side proximate the second microstrip stub and the ground pad.

4. The process control instrument of claim **3** wherein spacing between the second ground plane and the ground pad is at least 2.0 mm.

5. The process control instrument of claim **1** wherein the ground pad is configured to resonate at an operating frequency.

6. The process control instrument of claim **1** wherein the ground pad comprises a microstrip line connected between opposite radial stubs.

7. A through air radar process control instrument comprising:

a circuit board having first and second sides and a control circuit on the first side for generating or receiving a high frequency microwave signal;

an antenna including a coaxial electrical conductor having a center conductor and a shield; and

an intrinsic safety circuit coupling the control circuit to the antenna comprising the circuit board first side including a microstrip quarter wavelength first stub electrically connected to the control circuit and a ground plane proximate the first stub, the circuit board second side including a microstrip quarter wavelength second stub galvanically isolated from the first stub and electrically connected to the center conductor, the second stub being positioned to couple microwave energy from the control circuit to the antenna, and a ground pad, underlying the ground plane, electrically connected to the shield.

8. The through air radar process control instrument of claim **7** further comprising a second ground plane on the circuit board second side proximate the second stub and the ground pad.

9. The through air radar process control instrument of claim **8** wherein spacing between the second ground plane and the ground pad is at least 2.0 mm.

10. The through air radar process control instrument of claim **7** wherein the ground pad is configured to resonate at an operating frequency.

11. The through air radar process control instrument of claim **7** wherein the ground pad comprises a microstrip line connected between opposite radial stubs.

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