US007956738B2

(12) **United States Patent**
Karschnia et al.

(10) **Patent No.: US 7,956,738 B2**
(45) **Date of Patent: Jun. 7, 2011**

(54) **PROCESS FIELD DEVICE WITH RADIO FREQUENCY COMMUNICATION**

(75) Inventors: **Robert J. Karschnia**, Chaska, MN (US); **Charles R. Willcox**, Eden Prairie, MN (US); **David A. Broden**, Andover, MN (US); **Brian L. Westfield**, Victoria, MN (US); **Kelly M. Orth**, Apple Valley, MN (US)

(73) Assignee: **Rosemount Inc.**, Eden Prairie, MN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 806 days.

(21) Appl. No.: **11/842,356**

(22) Filed: **Aug. 21, 2007**

(65) **Prior Publication Data**

US 2007/0285224 A1 Dec. 13, 2007

Related U.S. Application Data

(63) Continuation of application No. 10/878,235, filed on Jun. 28, 2004, now Pat. No. 7,262,693.

(51) **Int. Cl.**
H04Q 11/04 (2006.01)
G08B 29/00 (2006.01)
G08B 1/08 (2006.01)

(52) **U.S. Cl.** **340/538**; 340/508; 340/506; 340/539.1; 700/9

(58) **Field of Classification Search** 340/538, 340/508
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,533,339 A	12/1950	Willenborg	177/311
2,883,489 A	4/1959	Eadie, Jr. et al.	335/148
3,012,432 A	12/1961	Moore et al.	73/40
3,218,863 A	11/1965	Calvert	73/398
3,232,712 A	2/1966	Stearns	23/255
3,249,833 A	5/1966	Vosteen	317/246
3,374,112 A	3/1968	Danon	117/226
3,557,621 A	1/1971	Ferran	73/398
3,612,851 A	10/1971	Fowler	362/30
3,697,835 A	10/1972	Satori	317/246
D225,743 S	1/1973	Seltzer	D10/102
3,742,450 A	6/1973	Weller	375/257
3,808,480 A	4/1974	Johnston	317/256
3,924,219 A	12/1975	Braun	338/34
4,008,619 A	2/1977	Alcaide et al.	73/398
4,158,217 A	6/1979	Bell	361/283
4,168,518 A	9/1979	Lee	361/283

(Continued)

FOREIGN PATENT DOCUMENTS

CH 672 368 A5 11/1989

(Continued)

OTHER PUBLICATIONS

Office Action from Russian Patent Office in Russian Serial No. 2006145434.

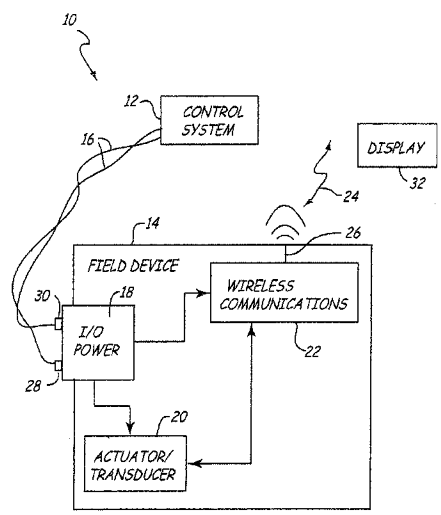
(Continued)

Primary Examiner — Donnie L Crosland
(74) *Attorney, Agent, or Firm* — Westman, Champlin & Kelly, P.A.

(57) **ABSTRACT**

A field device for use in an industrial process control or monitoring system includes terminals configured to connect to a two-wire process control loop. The loop carries data and provides power to the field device. RF circuitry in the field device is provided for radio frequency communication. A power supply powers the RF circuitry using power received from the two-wire process control loop.

97 Claims, 6 Drawing Sheets



U.S. PATENT DOCUMENTS

4,177,496	A	12/1979	Bell et al.	361/283
4,227,419	A	10/1980	Park	73/724
4,287,553	A	9/1981	Braunlich	361/283
4,322,775	A	3/1982	Delatorre	361/283
4,336,567	A	6/1982	Anastasia	361/283
4,358,814	A	11/1982	Lee et al.	361/283
4,370,890	A	2/1983	Frick	73/718
4,383,801	A	5/1983	Pryor	416/17
4,389,895	A	6/1983	Rud, Jr.	73/724
4,422,125	A	12/1983	Antonazzi et al.	361/283
4,422,335	A	12/1983	Ohnesorge et al.	73/724
4,434,451	A	2/1984	Delatorre	361/283
4,455,874	A	6/1984	Paros	73/704
4,458,537	A	7/1984	Bell et al.	73/718
4,475,047	A	10/1984	Ebert	307/66
4,476,853	A	10/1984	Arbogast	126/578
4,490,773	A	12/1984	Moffatt	361/283
4,542,436	A	9/1985	Carusillo	361/283
4,562,742	A	1/1986	Bell	73/718
4,590,466	A	5/1986	Wiklund et al.	340/870.28
4,670,733	A	6/1987	Bell	338/36
4,701,938	A	10/1987	Bell	375/257
4,704,607	A	11/1987	Teather et al.	340/825.07
4,749,993	A	6/1988	Szabo et al.	340/870.31
4,785,669	A	11/1988	Benson et al.	73/718
4,860,232	A	8/1989	Lee et al.	364/571.04
4,875,369	A	10/1989	Delatorre	73/151
4,878,012	A	10/1989	Schulte et al.	324/60
4,926,674	A	5/1990	Fossum et al.	73/4
4,951,174	A	8/1990	Grantham et al.	361/283.1
4,977,480	A	12/1990	Nishihara	73/724
4,982,412	A	1/1991	Gross	377/6
5,025,202	A	6/1991	Ishii et al.	220/101
5,045,963	A	9/1991	Hansen et al.	361/87
5,060,295	A	10/1991	Borras et al.	455/186
5,094,109	A	3/1992	Dean et al.	73/718
D331,370	S	12/1992	Williams	D10/46
5,168,419	A	12/1992	Delatorre	361/283
5,194,819	A	3/1993	Briefer	73/718
5,230,250	A	7/1993	Delatorre	73/733
5,233,875	A	8/1993	Obermeier et al.	73/718
D345,107	S	3/1994	Williams	D10/46
5,329,818	A	7/1994	Frick et al.	73/708
5,492,016	A	2/1996	Pinto et al.	73/724
5,495,769	A	3/1996	Broden et al.	73/18
5,506,757	A	4/1996	Brorby	361/796
5,542,300	A	8/1996	Lee	73/724
5,546,804	A	8/1996	Johnson et al.	73/431
5,554,809	A	9/1996	Tobita et al.	73/700
5,606,513	A	2/1997	Louwagie et al.	702/138
5,610,552	A	3/1997	Schlesinger et al.	327/560
5,637,802	A	6/1997	Frick et al.	73/724
5,642,301	A	6/1997	Warrior et al.	364/571.02
5,656,782	A	8/1997	Powell, II et al.	73/756
5,665,899	A	9/1997	Willcox	731/1.63
5,672,832	A	9/1997	Cucci et al.	73/861.52
5,682,476	A	10/1997	Tapperson et al.	395/200.05
5,705,978	A	1/1998	Frick et al.	340/511
5,710,552	A	1/1998	McCoy et al.	340/870.21
5,757,608	A	5/1998	Bernot et al.	361/283.4
5,787,120	A	7/1998	Louagie et al.	375/257
5,793,963	A	8/1998	Tapperson et al.	395/200.31
5,851,083	A	12/1998	Palan	403/337
5,870,695	A	2/1999	Brown et al.	702/138
5,872,494	A	2/1999	Palan et al.	333/252
5,899,962	A	5/1999	Louwagie et al.	702/138
5,911,162	A	6/1999	Denner	73/718
5,954,526	A	9/1999	Smith	439/136
5,978,658	A	11/1999	Shoji	455/66
5,992,240	A	11/1999	Tsuruoka et al.	73/718
6,038,927	A	3/2000	Karas	73/706
6,062,095	A	5/2000	Mulrooney et al.	73/866.5
6,079,276	A	6/2000	Frick et al.	73/18
6,127,739	A	10/2000	Appa	290/55
D439,177	S	3/2001	Fandrey et al.	D10/46
D439,178	S	3/2001	Fandrey et al.	D10/46
D439,179	S	3/2001	Fandrey et al.	D10/46
D439,180	S	3/2001	Fandrey et al.	D10/85
D439,181	S	3/2001	Fandrey et al.	D10/46
D441,672	S	5/2001	Fandrey et al.	D10/52
6,236,096	B1	5/2001	Chang et al.	257/419
6,236,334	B1	5/2001	Tapperson et al.	340/825.37
6,282,247	B1	8/2001	Shen	375/285
6,295,875	B1	10/2001	Frick et al.	73/718
6,338,283	B1	1/2002	Blazquez Navarro	73/865.8
6,360,277	B1	3/2002	Ruckley et al.	709/250
6,366,436	B1	4/2002	Maier et al.	361/93.9
6,385,972	B1	5/2002	Fellows	60/517
6,405,139	B1	6/2002	Kicinski et al.	702/33
6,429,786	B1	8/2002	Bansemir et al.	340/870.27
6,441,747	B1	8/2002	Khair et al.	340/870.16
6,457,367	B1	10/2002	Behm et al.	73/753
6,484,107	B1	11/2002	Roper et al.	702/50
6,487,912	B1	12/2002	Behm et al.	73/753
6,504,489	B1	1/2003	Westfield et al.	340/870.3
6,508,131	B2	1/2003	Frick	73/756
6,510,740	B1	1/2003	Behm et al.	73/708
6,511,337	B1	1/2003	Fandrey et al.	439/320
D471,829	S	3/2003	Dennis et al.	D10/85
D472,831	S	4/2003	Dennis et al.	D10/85
6,546,805	B2	4/2003	Fandrey et al.	73/753
6,553,076	B1	4/2003	Huang	375/257
6,568,279	B2	5/2003	Behm et al.	73/753
6,571,132	B1	5/2003	Davis et al.	700/2
6,574,515	B1	6/2003	Kirkpatrick et al.	700/19
6,593,857	B1	7/2003	Roper et al.	340/870.3
6,609,427	B1	8/2003	Westfield et al.	73/753
6,662,662	B1	12/2003	Nord et al.	73/715
6,680,690	B1	1/2004	Nilsson et al.	342/124
6,711,446	B2	3/2004	Kirkpatrick et al.	700/19
6,747,573	B1	6/2004	Gerlach et al.	340/870.21
6,765,968	B1	7/2004	Nelson et al.	375/257
6,771,560	B2	8/2004	Lyon et al.	367/13
6,774,814	B2	8/2004	Hilleary	340/870.07
6,778,100	B2	8/2004	Schempf	340/870.07
6,792,259	B1	9/2004	Parise	455/343.1
6,839,546	B2	1/2005	Hedtke	455/67.11
6,891,838	B1	5/2005	Petite et al.	370/401
6,898,980	B2	5/2005	Behm et al.	73/756
6,904,295	B2	6/2005	Yang	455/522
6,907,383	B2	6/2005	Eryurek et al.	702/183
6,910,332	B2	6/2005	Fellows	60/520
6,961,665	B2	11/2005	Slezak	702/61
6,995,685	B2	2/2006	Randall	340/870.39
7,010,294	B1	3/2006	Pyotsia et al.	455/420
7,058,542	B2	6/2006	Hauhia et al.	702/183
7,088,285	B2	8/2006	Smith	342/124
7,109,883	B2	9/2006	Trimble et al.	340/870.16
7,233,745	B2	6/2007	Loechner	398/128
7,262,693	B2	8/2007	Karchnia et al.	340/508
7,271,679	B2	9/2007	Lundberg et al.	333/24
7,301,454	B2	11/2007	Seyfang et al.	340/539.26
7,329,959	B2	2/2008	Kim et al.	290/2
2001/0025349	A1	9/2001	Sharood et al.	713/340
2002/0011115	A1	1/2002	Frick	73/718
2002/0029130	A1	3/2002	Eryurek et al.	702/183
2002/0065631	A1	5/2002	Loechner	702/188
2002/0082799	A1	6/2002	Pramanik	702/130
2002/0095520	A1	7/2002	Wettstein et al.	709/253
2002/0097031	A1	7/2002	Cook et al.	323/273
2002/0105968	A1	8/2002	Pruzan et al.	370/465
2002/0163323	A1	11/2002	Kasai et al.	323/284
2003/0043052	A1	3/2003	Tapperson et al.	340/825.37
2003/0079553	A1	5/2003	Cain et al.	73/861.27
2003/0083038	A1	5/2003	Poon et al.	455/344
2003/0143958	A1	7/2003	Elias et al.	455/73
2003/0171827	A1	9/2003	Keyes, IV et al.	700/19
2003/0204371	A1	10/2003	Sciamanna	702/183
2004/0086021	A1	5/2004	Litwin	374/120
2004/0124854	A1	7/2004	Slezak	324/644
2004/0142733	A1	7/2004	Parise	455/572
2004/0183550	A1	9/2004	Fehrenbach et al.	27/26
2004/0184517	A1	9/2004	Westfield et al.	375/219
2004/0199681	A1	10/2004	Hedtke	710/37
2004/0203434	A1	10/2004	Karschnia et al.	455/67.11
2004/0211456	A1	10/2004	Keyes et al.	136/243
2004/0214543	A1	10/2004	Osone et al.	455/197.2

2004/0218326	A1	11/2004	Duren et al.	361/93.1
2004/0242169	A1	12/2004	Albsmeier et al.	455/91
2004/0259533	A1	12/2004	Nixon et al.	455/414.1
2005/0017602	A1	1/2005	Arms et al.	310/339
2005/0023858	A1	2/2005	Bingle et al.	296/76
2005/0029236	A1	2/2005	Gambino et al.	219/121.69
2005/0040570	A1	2/2005	Asselborn	266/99
2005/0046595	A1	3/2005	Blyth	340/908
2005/0056106	A1	3/2005	Nelson et al.	73/866.3
2005/0072239	A1	4/2005	Longsdorf et al.	73/649
2005/0109395	A1	5/2005	Seberger	137/8
2005/0115601	A1	6/2005	Olsen et al.	136/212
2005/0118468	A1	6/2005	Adams et al.	429/22
2005/0130605	A1	6/2005	Karschnia et al.	455/90.3
2005/0164684	A1	7/2005	Chen et al.	455/414.1
2005/0201349	A1	9/2005	Budampati	370/342
2005/0222698	A1	10/2005	Eryurek et al.	700/90
2005/0228509	A1	10/2005	James	700/19
2005/0245291	A1	11/2005	Brown	455/572
2005/0276233	A1	12/2005	Shepard et al.	370/254
2005/0281215	A1	12/2005	Budampati et al.	370/328
2005/0289276	A1	12/2005	Karschnia et al.	710/305
2006/0002368	A1	1/2006	Budampati et al.	370/351
2006/0028327	A1	2/2006	Amis	340/431
2006/0036404	A1	2/2006	Wiklund et al.	702/183
2006/0063522	A1	3/2006	McFarland	455/423
2006/0092039	A1	5/2006	Saito et al.	340/825.37
2006/0131428	A1	6/2006	Wang et al.	235/492
2006/0148410	A1	7/2006	Nelson et al.	455/67.11
2006/0181406	A1	8/2006	Petite et al.	340/521
2006/0194547	A1	8/2006	Davis	455/69
2006/0227729	A1	10/2006	Budampati et al.	370/278
2006/0274644	A1	12/2006	Budampati et al.	370/216
2006/0274671	A1	12/2006	Budampati et al.	370/254
2006/0287001	A1	12/2006	Budampati et al.	455/552.1
2006/0290328	A1	12/2006	Orth	323/218
2007/0030816	A1	2/2007	Kolavennu	370/252
2007/0030832	A1	2/2007	Gonia et al.	370/338
2007/0054630	A1	3/2007	Scheible et al.	455/90.3
2007/0229255	A1	10/2007	Loechner	340/540
2007/0233283	A1	10/2007	Chen	700/17
2007/0237137	A1	10/2007	McLaughlin	370/389
2007/0275755	A1	11/2007	Chae et al.	455/557
2007/0280144	A1	12/2007	Hodson et al.	370/312
2007/0280178	A1	12/2007	Hodson et al.	370/338
2007/0280286	A1	12/2007	Hodson et al.	370/466
2007/0280287	A1	12/2007	Samundrala et al.	370/466
2007/0282463	A1	12/2007	Hodson et al.	700/20
2007/0285224	A1	12/2007	Karschnia et al.	340/538
2007/0288204	A1	12/2007	Gienke et al.	702/188
2008/0010600	A1	1/2008	Katano	715/748
2008/0280568	A1	11/2008	Kielb et al.	455/74.1
2008/0310195	A1	12/2008	Seberger et al.	363/26
2009/0015216	A1	1/2009	Seberger et al.	323/234
2009/0081957	A1	3/2009	Sinreich	455/68
2009/0146502	A1	6/2009	Sinreich	307/104
2009/0253388	A1	10/2009	Kielb et al.	455/117
2009/0309558	A1	12/2009	Kielb	323/234
2009/0311975	A1	12/2009	Vanderaa et al.	455/90.3
2009/0311976	A1	12/2009	Vanderaa et al.	455/90.3
2009/1311971		12/2009	Kielb et al.	455/74.1
2010/0000316	A1	1/2010	Fehrenbach et al.	73/295

FOREIGN PATENT DOCUMENTS

CN	1 429 354	A	7/2003
CN	1 442 822	A	9/2003
CN	100386602	C	5/2008
DE	2710211		9/1978
DE	3340834	A1	5/1985
DE	38 42 379	A1	6/1990
DE	196 22 295		5/1996
DE	37 11 754	A1	10/1998
DE	201 07 112	U1	7/2001
DE	101 04 582	A1	10/2001
DE	100 41 160		3/2002
DE	102 21 931	A1	5/2002
DE	10 2004 020393		11/2005
EP	0 518 916	B1	2/1991
EP	0 524 550	A1	1/1993
EP	0 895 209	A1	2/1999
EP	0 945 714		9/1999
EP	1 202 145	A1	5/2002
EP	1 192 614		1/2003
EP	1 293 853	A1	3/2003
EP	1879294		1/2008
FI	118699	B	2/2008
GB	1 397 435	A	6/1975
GB	2 300 265	A	10/1996
GB	2 403 043		6/2004
JP	02067794		7/1990
JP	06 199284	A	7/1994
JP	2000-304148		11/2000
JP	2003-070079		11/2000
JP	2003/042881		2/2003
JP	2003051894		2/2003
JP	2003134261		5/2003
JP	2004021877		1/2004
JP	2004146254		5/2004
JP	2004-317593		11/2004
JP	2005-207648		8/2005
RU	2 131 934	C1	6/1999
RU	2342639	C2	8/2003
WO	WO 91/13417		9/1991
WO	WO 95/07522		3/1995
WO	WO 96/12993		5/1996
WO	WO 99/53286		10/1999
WO	WO 01/18723		7/2001
WO	WO 01/76148		10/2001
WO	WO 02/05241		1/2002
WO	WO 03/023536		3/2003
WO	WO 03/089881		10/2003
WO	WO 2004/023423		3/2004
WO	WO 2004/082051		9/2004
WO	WO 2004/094892		11/2004
WO	WO 2005/060482		7/2005
WO	WO 2005/086331		9/2005
WO	WO 2007/002769		1/2007
WO	WO 2009/003146		12/2008
WO	WO 2009/003148		12/2008
WO	WO 2009/063056		5/2009

OTHER PUBLICATIONS

Official Communication in Application No. 2006/145434, filed May 5, 2005.

"Wireless R&D Aims to Boos Traffic," by M. Moore, InTech with Industrial Computing, Feb. 2002, pp. 40-41.

"System Checks Faraway Machines' Health," by J. Strothman, InTech with Industrial Computing, Feb. 2002, pp. 42-43.

Notification of Transmittal of the International Search Report or the Declaration—PCT/US03/10403.

"Wireless Management Toolkit XYR 5000", by Honeywell International Inc., Phoenix, Arizona, 3 pgs., Oct. 2003.

"Wireless Analog Input Transmitters XYR 5000", by Honeywell International Inc., Phoenix, Arizona, 4 pgs., Oct. 2003.

"Quad Analog Output Module Installation and User's Manual", by Honeywell International Inc., Phoenix, Arizona, pp. Ii, iii, iv and 1-12, Dec. 2003.

International Search Report and Written Opinion of Application No. PCT/US2005/015848, file May 5, 2005.

"Wireless Dual Analog Input Interface Transmitter Installation and User's Manual", by Honeywell International Inc., Phoenix, Arizona, pp. Ii-vi and 7-43, Dec. 2003.

"XYR 5000 Wireless Dual Analog Input Interface, Model Selection Guide", by Honeywell International Inc., Phoenix, Arizona, Dec. 2003.

"Wireless Measure, Monitor & Control", by Accutech, 4 pgs. May 2003.

"Wireless Instrumentation, Multi-Input Field Unit", by Accutech, 2 pgs., Dec. 2003.

"Quad Analog Output Module", by Accutech, 1 pg. Dec. 2003.

3 Pages from Website www.chemicalprocessing.com, Apr. 2004.

Notification of Transmittal of the International Search Report and the Written Opinion—PCT/US2005/021757.

International Search Report for International Application No. PCT/US 03/27561, filed Mar. 9, 2003, dated Jun. 15, 2004.

2002 Microchip Technology Inc., "Stand-Alone CAN Controller with SPI™ Interface," pp. 1-75, Mar. 1, 2002.
Rosemount Reference Manual 00809-0100-4022,Rev AA, Jul. 2002, "Model 4600 Oil & Gas Panel Transmitter," 65 pages.
Transmitter Schematic, Sold Jul. 2002, 5 pages.
Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority for International Application No. PCT/US2005/007328 filed Mar. 7, 2005. Date of Mailing: Jan. 12, 2006.
4 Pages from Website http://content.honeywell.com/imc/eznews/eznews0403/news.htm, 2004.
Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority for International Application No. PCT/US2006/025206 filed Jun. 27, 2006.
"Mechatronic Drives in Mobile Hydraulics," Internet Article, Soncebox News. No. 4, Oct. 2004.
International Search Report and Written Opinion in Appln No. PCT/US2005/021757, filed Jun. 21, 2005.
International Search Report and Written Opinion in Application No. PCT/US2006/035728, filed Sep. 13, 2006.
Examination Report of the European Patent Office in Application No. 05724190.3, filed Mar. 2, 2005.
Office Action from U.S. Patent Office in U.S. Appl. No. 11/028,486.
Office Action from U.S. Patent Office in U.S. Appl. No. 11/028,486 dated May 9, 2008.
U.S. Appl. No. 12/485,169, filed Jun. 16, 2009.
U.S. Appl. No. 12/485,189, filed Jun. 16, 2009.
U.S. Appl. No. 12/486,282, filed Jun. 17, 2009.
U.S. Appl. No. 12/486,269, filed Jun. 17, 2009.
U.S. Appl. No. 12/486,253, filed Jun. 17, 2009.
The International Search Report and Written Opinion in Application No. PCT/US2009/003619, dated Sep. 30, 2009.
Office Action from Chinese patent Application No. 2005800142124, dated Mar. 14, 2008.
Office Action from Chinese patent Application No. 200580006438.X, filed Mar. 2, 2005.
Examiner's Consultation from European patent Application No. 05724190.3, dated Jun. 30,2008.
Office Action from European Application No. 05746241.8, dated Aug. 29, 2007.
USA & Metric Thread Standards http://www.carrlane.com/Catalog/index.cfm/29425071F0B221118070C1C513906103E0B05543B0B012009083C3B285357474A2D020609090C0015312A36515F554A5B.
U.S. Appl. No. 61/012,262, filed Dec. 7, 2007.
U.S. Appl. No. 60/937,396, filed Jun. 26, 2007.
U.S. Appl. No. 60/937,397, filed Jun. 26, 2007.
XP 002400076.
Office Action from European Application No. 05853808.3, dated Nov. 6, 2007.
Examination Report of the European Patent Office in Application No. 05724190.3, dated Jun. 30, 2008.
First Office Action from Chinese Patent Application No. 2005800142124, dated Mar. 14, 2008.
Notification of Transmittal of the International Search Report and Written Opinion, PCT/US2009/0036616, dated Jan. 13, 2010.
"Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority" for PCT/US2008/011451 filed Oct. 3, 2008; date mailed Mar. 30, 2009; 16 pages.
The International Search Report and Written Opinion in Application No. PCT/US2009/003636, dated Oct. 6, 2009.
The International Search Report and Written Opinion in Application No. PCT/US2009/003611, dated Nov. 4, 2009.
The International Search Report and Written Opinion in Application No. PCT/US2009/003621, dated Sep. 30, 2009.
Third Office Action for Chinese Application No. 200680015575.4, dated May 11, 2010.
Communication for European Application No. 06774208.0, dated Apr. 16, 2010.
Second Office Action for Chinese Application No. 200680015575.4, dated Sep. 25, 2009.
Official Action for Russian Application No. 2008103014.
First Office Action for Chinese Application No. 200680015575.4, dated 2008.
Communication for European Application No. 06774208.0, dated Feb. 29, 2008.
First Office Action for Japanese Application No. 20008-518521, dated Aug. 24, 2010.
Notification of Transmittal of the International Search Report and the Written Opinion for the international patent application no. PCT/US2010/047463 dated Dec. 1, 2010.

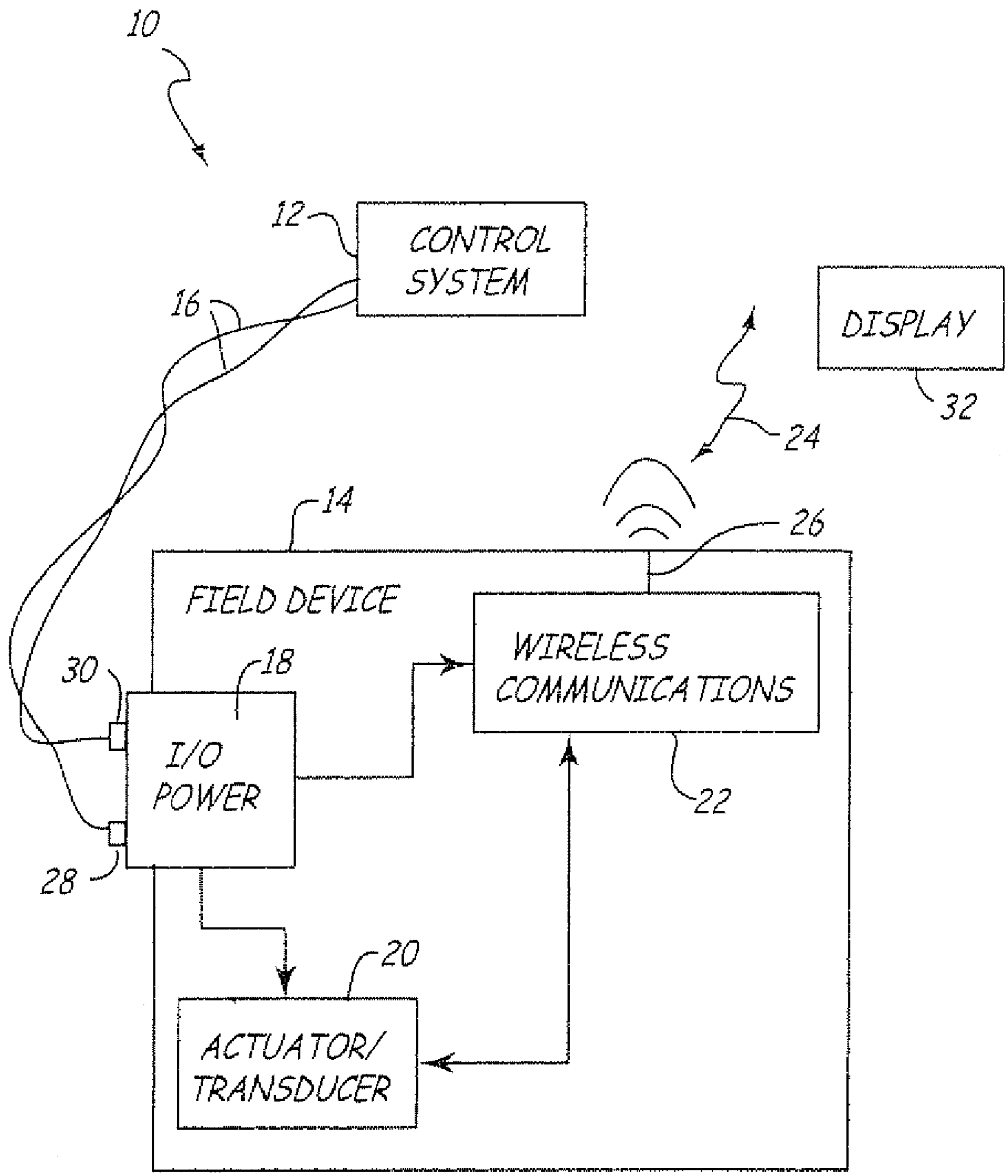

10
12
CONTROL SYSTEM
16
DISPLAY
32
24
14
26
FIELD DEVICE
WIRELESS COMMUNICATIONS
30
18
I/O POWER
22
28
20
ACTUATOR/ TRANSDUCER

Fig. 1

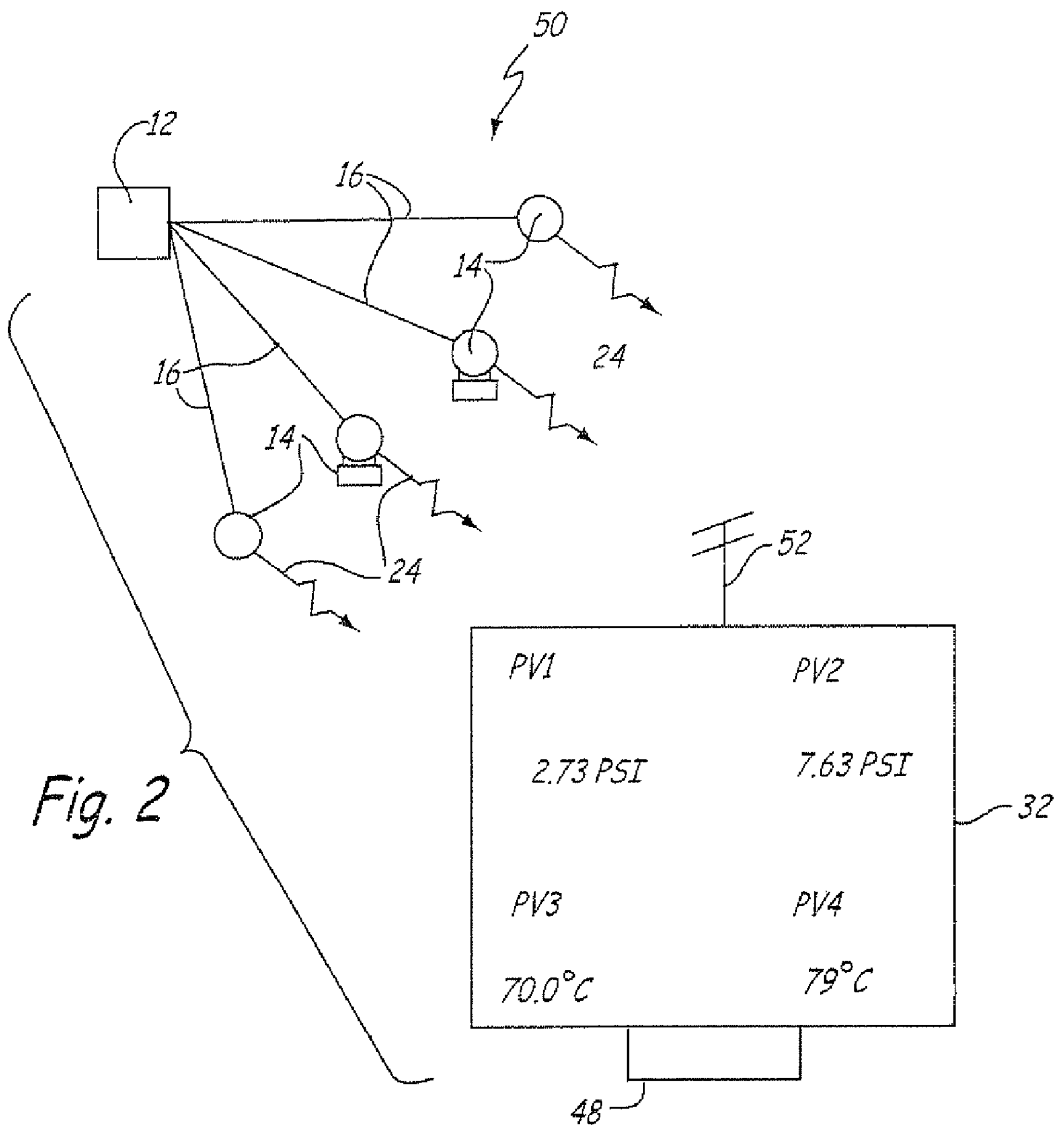
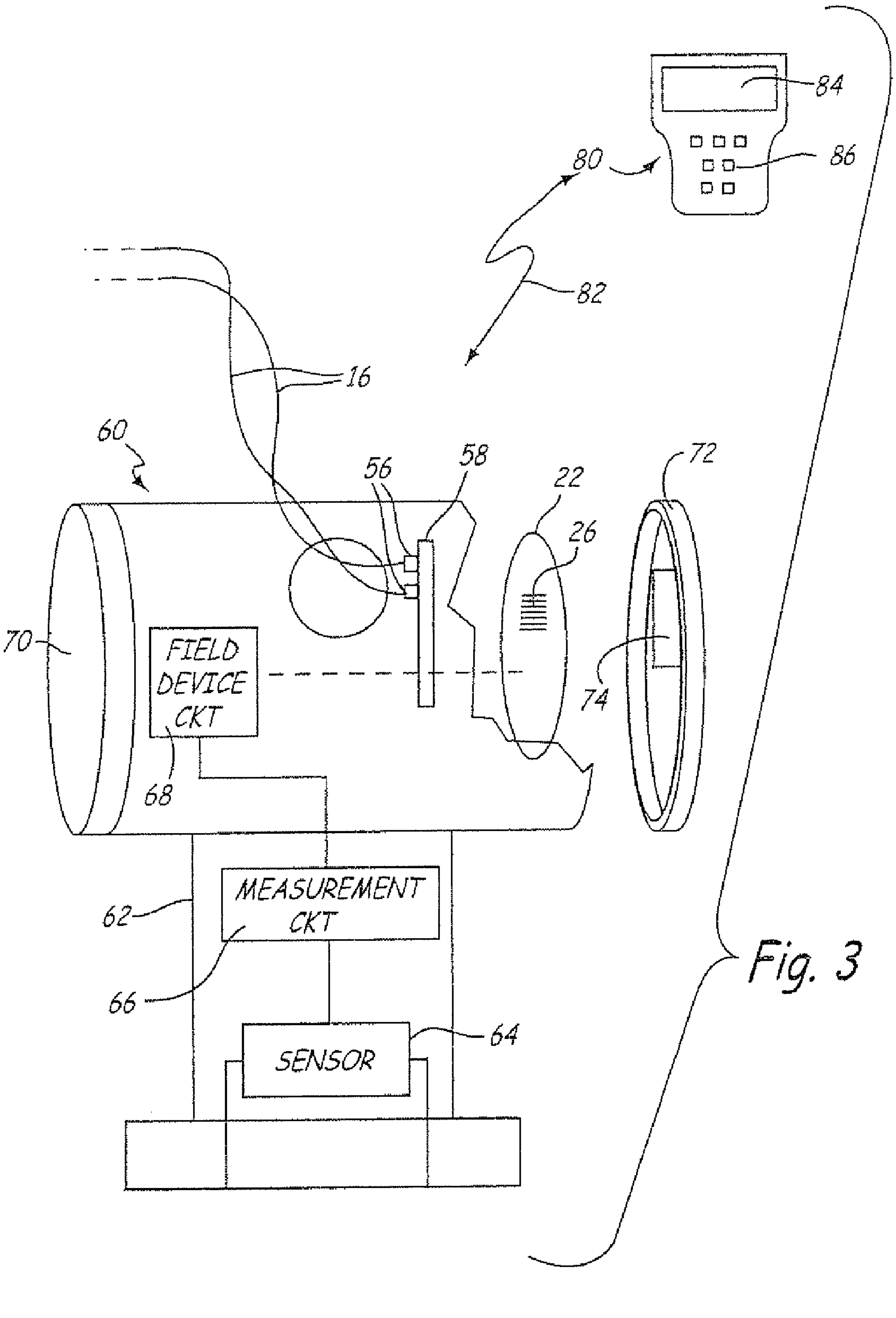

50
12
16
14
24
16
14
24
52
PV1
PV2
2.73 PSI
7.63 PSI
32
PV3
PV4
70.0°C
79°C
48

Fig. 2



84
86
80
82
16
60
56
58
22
26
72
70
FIELD DEVICE CKT
74
68
MEASUREMENT CKT
62
66
SENSOR
64

Fig. 3

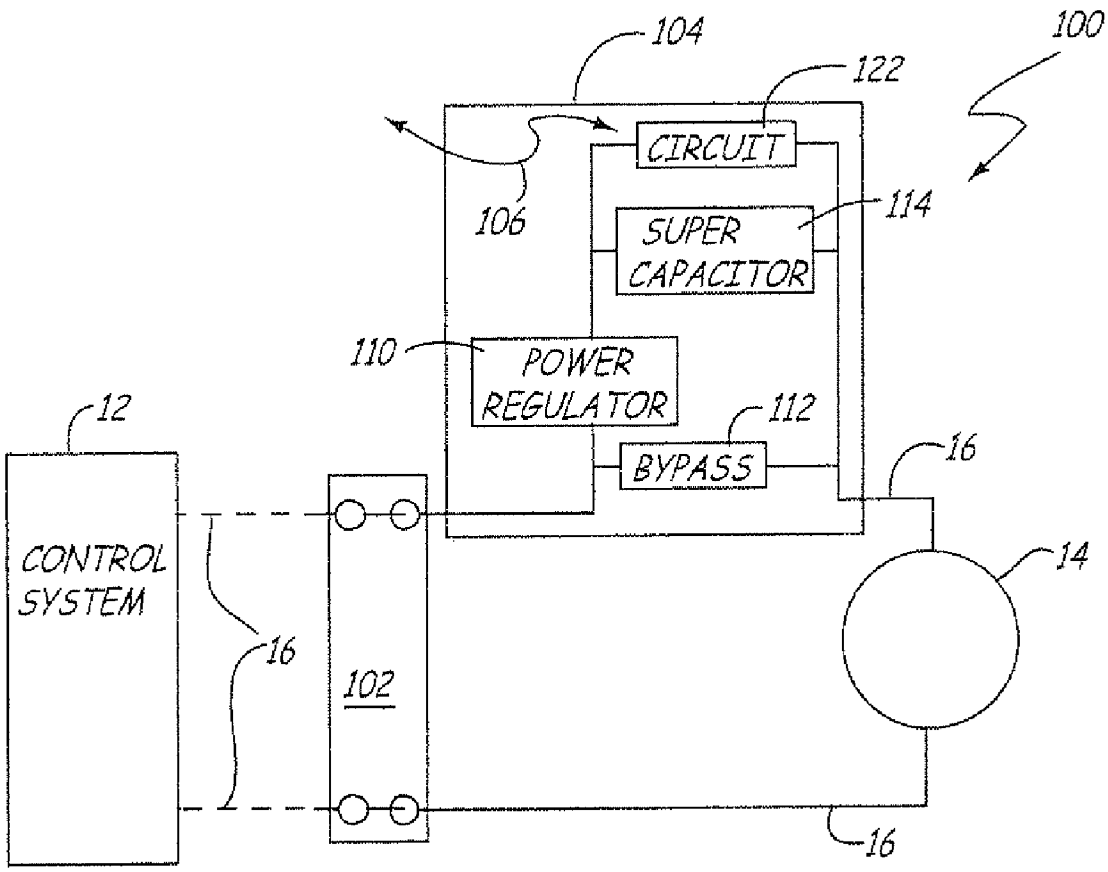

104
100
122
CIRCUIT
106
SUPER
CAPACITOR
114
110
POWER
REGULATOR
112
BYPASS
12
16
CONTROL
SYSTEM
14
16
102
16

Fig. 4

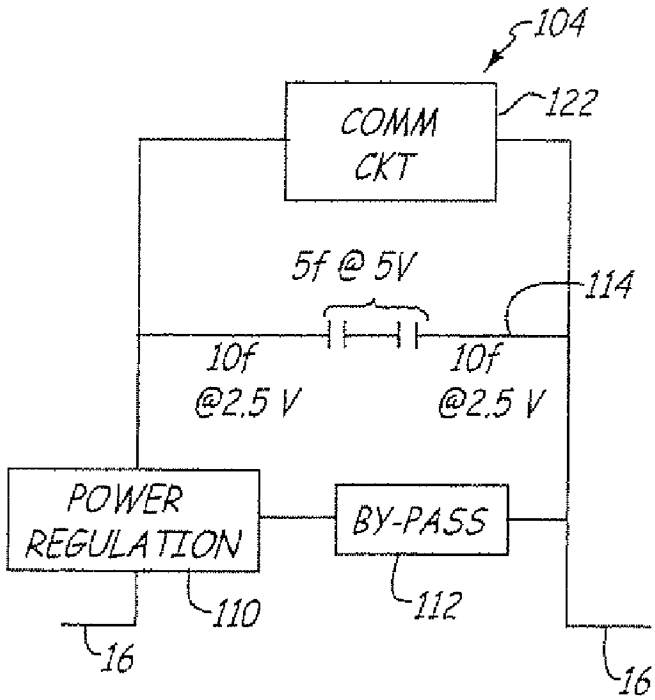

104
COMM
CKT
122
5f @ 5V
114
10f
@2.5 V
10f
@2.5 V
POWER
REGULATION
BY-PASS
110
112
16
16

Fig. 5

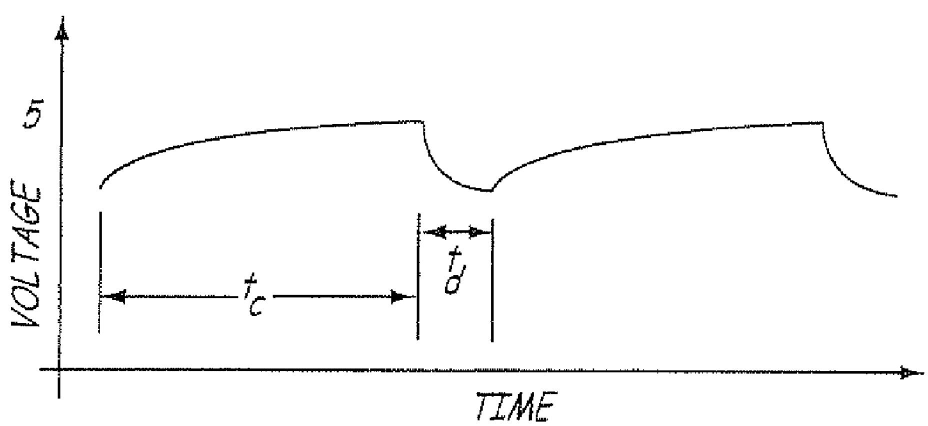

5
VOLTAGE
t_c
t_d
TIME

Fig. 6

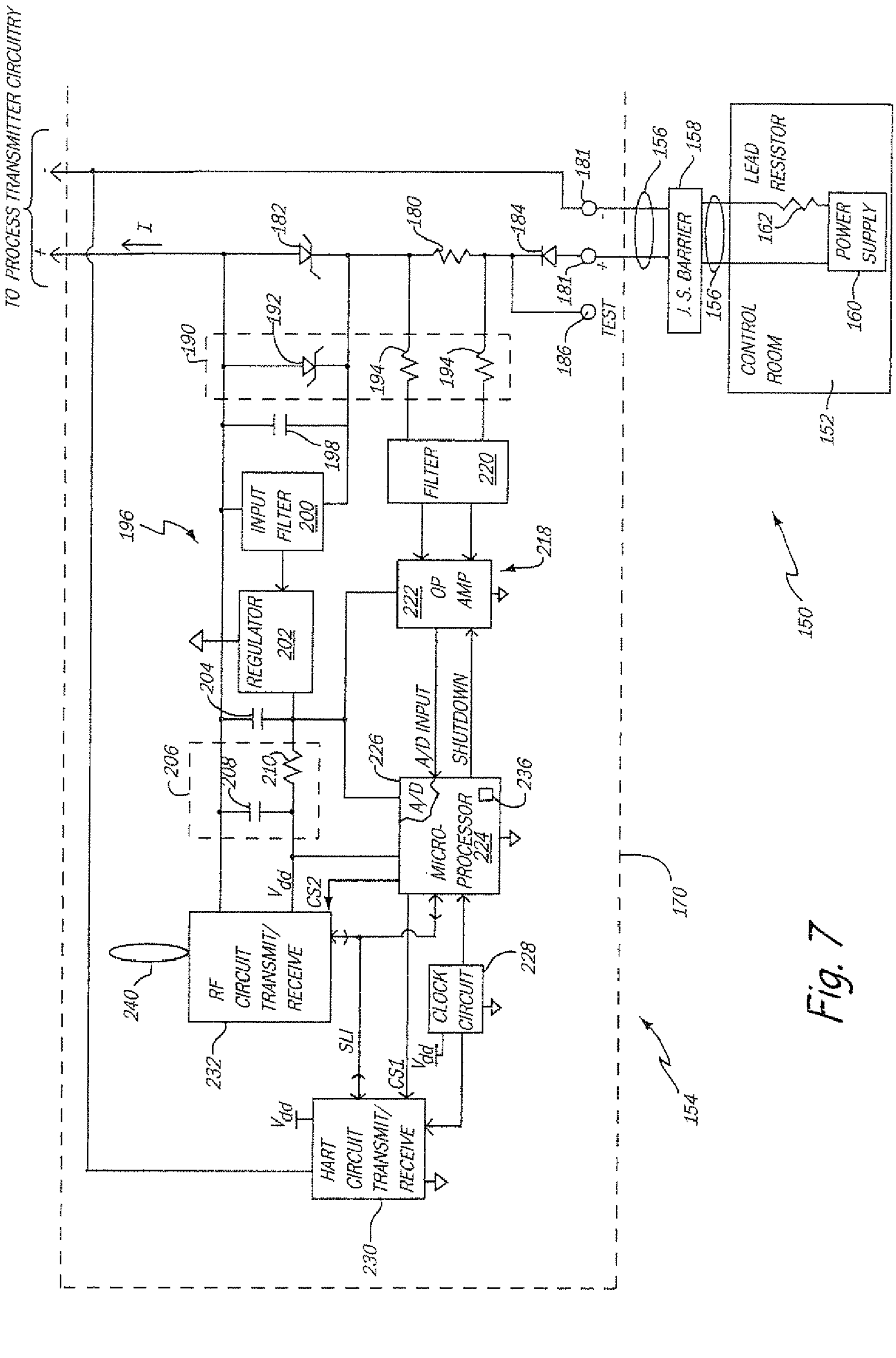

TO PROCESS TRANSMITTER CIRCUITRY
+
-
I
182
180
184
181
181
186
TEST
156
156
158
J. S. BARRIER
LEAD RESISTOR
162
POWER SUPPLY
160
CONTROL ROOM
152
190
192
194
194
198
INPUT FILTER 200
FILTER 220
196
218
222 OP AMP
REGULATOR 202
204
206
208
210
226
A/D INPUT
SHUTDOWN
A/D
MICRO-PROCESSOR 224
236
Vdd
CS2
RF CIRCUIT TRANSMIT/ RECEIVE
240
232
SLI
CS1
Vdd
CLOCK CIRCUIT
228
HART CIRCUIT TRANSMIT/ RECEIVE
Vdd
230
154
170
150

Fig. 7

PROCESS FIELD DEVICE WITH RADIO FREQUENCY COMMUNICATION

The present application is a Continuation of and claims priority of U.S. patent application Ser. No. 10/878,235, filed Jun. 28, 2004 now U.S. Pat. No. 7,262,693, the content of which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

The present invention relates to industrial process control or monitoring systems. More specifically, the present invention relates to field devices in such systems which are capable of Radio Frequency (RF) communication.

In industrial settings, control systems are used to monitor and control inventories of industrial and chemical processes, and the like. Typically, the control system performs these functions using field devices distributed at key locations in the industrial process and coupled to the control circuitry in the control room by a process control loop. The term "field device" refers to any device that performs a function in a distributed control or process monitoring system, including all devices currently known, or yet to be known, used in the measurement, control and monitoring of industrial processes.

Some field devices include a transducer. A transducer is understood to mean either a device that generates an output signal based on a physical input or that generates a physical output based on an input signal. Typically, a transducer transforms an input into an output having a different form. Types of transducers include various analytical equipment, pressure sensors, thermistors, thermocouples, strain gauges, flow transmitters, positioners, actuators, solenoids, indicator lights, and others.

Typically, each field device also includes communication circuitry that is used for communicating with a process control room, or other circuitry, over a process control loop. In some installations, the process control loop is also used to deliver a regulated current and/or voltage to the field device for powering the field device. The process control loop also carries data, either in an analog or digital format.

Traditionally, analog field devices have been connected to the control room by two-wire process control current loops, with each device connected to the control room by a single two-wire control loop. Typically, a voltage differential is maintained between the two wires within a range of voltages from 12-45 volts for analog mode and 9-50 volts for digital mode. Some analog field devices transmit a signal to the control room by modulating the current running through the current loop to a current proportional to the sensed process variable. Other analog field device can perform an action under the control of the control room by controlling the magnitude of the current through the loop. In addition to, or in the alternative, the process control loop can carry digital signals used for communication with field devices.

In some installations, wireless technologies have begun to be used to communicate with field devices. For example, completely wireless installations are used in which the field device uses a battery, solar cell, or other technique to obtain power without any sort of wired connection. However, the majority of field devices are hardwired to a process control room and do not use wireless communication techniques.

SUMMARY

A field device for use in an industrial process control or monitoring system includes terminals configured to connect to a two-wire process control loop configured to carry data and to provide power. RF circuitry in the field device is configured for radio frequency communication. In one embodiment, power supply circuitry powers the RF circuitry using power received completely from the two-wire process control loop. A method is also provided.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified block diagram of a process control monitoring system including a field device configured for wireless communication.

FIG. **2** is a block diagram of a process controller monitoring system in which multiple field devices transmit information to a remote meter.

FIG. **3** is an exploded cut away view of a field device including wireless communication circuitry for communicating with a remote device such as a hand held unit.

FIG. **4** is a diagram of a process controller monitoring system which includes a field device for wireless communication which scavenges power from the process control loop.

FIG. **5** is a more detailed schematic diagram of circuitry shown in FIG. **4**.

FIG. **6** is a graph of voltage versus time as measured across a capacitor shown in FIG. **5**.

FIG. **7** is an electrical block diagram of circuitry for providing wireless communications in a process controller monitoring system.

DETAILED DESCRIPTION

The present invention provides a field device configured to couple to a process control loop which further includes a wireless communication module for one way or bi-directional wireless communication. The wireless communication module can transmit and/or receive an RF signal from a remote device or location. The module can be directly powered with power received from the two-wire process control loop, or can be powered with power received from the process control loop and stored for subsequent use. The module can be a removable module in which the module need only couple to those field devices in which wireless communication is desired.

FIG. **1** is a simplified block diagram of a process control or monitoring system **10** in which a control room or control system **12** couples to a field device **14** over a two-wire process control loop **16**. The field device **14** includes I/O power circuitry **18**, actuator/transducer **20** and wireless communication circuitry **22**. The wireless communication circuitry **22** is configured to send and/or receive an RF signal **24** using an antenna **26**.

Currently, industrial instrumentation often includes a local display or "meter" which can be used for local monitoring of process information. The meter can be quite useful in many installations, however, such a local display configuration does have several limitations. A local display requires direct visual access to the field device. Further, typically an operator can only view a single meter at a time. The instruments which contain the meter are often not at a convenient location or viewing angle. One technique which has been used to address such a configuration is the use of a meter which is wired to a process transmitter. This allows the meter to be mounted at a more convenient location. Another technique is shown and described in U.S. patent application Ser. No. 10/128,769, filed Apr. 22, 2002, entitled PROCESS TRANSMITTER WITH WIRELESS COMMUNICATION LINK.

With the present invention, an RF communication module is included in a field device which can be used in addition to the connection to a process control loop such as loop **16**. The wireless communication module **22** can be configured to be compact and lower power such that it can be easily included in existing field device configurations. The module can be used for wireless transmission of information for use in monitoring control and/or display of data. Such a radio transmitter can make the field device information available in a local area. For example, a single local display such as display **32** can be provided and used to display information from the field device **14**. The display **32** can be configured to display information from several devices, either simultaneously, sequentially, or through commands provided to the display, for example using a manual input such as buttons available to an operator. The display **32** can be placed at a fixed location or can be a portable device such that it can carry throughout the process control system to monitor and observe operation of various field devices. Depending on the strength of the RF signal **24** and the sensitivity of the transmit and receive circuitry, the area covered by the RF transmission can be controlled as desired. For example, FIG. **2** is a simplified diagram of a process control system **50** in which a number of field devices **14** are coupled to the control room **12** through individual process control loops **16**. Each field device **14** transmits an RF signal **24** for receipt by display **32**. In this example, display **32** is capable of displaying four process variables (PV**1**, PV**2**, PV**3** and PV**4**) which are received from the field devices **14** using antenna **52**. As mentioned above, the display **32** can be a fixed display or can be a portable display, such as a hand held unit. In this particular configuration, the display **32** is illustrated as showing two process variables which relate to process pressure and two process variables which relate to process temperature. This allows the field devices **14** to provide information over the RF connection within a desired range, for example, within a local area. For example, if the display **32** is within 40 meters of a field device **14**, it will be capable of receiving an displaying information from that field device. An optional user input **48** can be used to, for example, select the format of the display, the process variable displayed, or used to interrogate a field device **14**.

FIG. **3** is a simplified cutaway partially exploded view of a pressure transmitter **60** which is one example of a field device. Pressure transmitter **60** couples to two-wire process control loop **16** and includes a transmitter housing **62**. Process control loop **16** couples to terminals **56** carried on terminal board **58**. A pressure sensor **64** provides one example of a transducer and is configured to couple to a process fitting to measure a differential pressure occurring in a process fluid. The output from the sensor **64** is provided to measurement circuitry **66** which couples to field device circuit **68**. The field device circuit **68** implements aspects of the I/O power supply **18** shown in FIG. **1**. The wireless communication circuitry **22** couples to field device circuit **68** and may, in some embodiments, couple to process control loop **16**.

The housing **62** includes end caps **70** and **72** which can be screwed into the housing **62**. End cap **72** includes an RF transparent window **74** configured to align generally with an antenna **26** carried on wireless communication circuit **22**. When attached, the end caps provide a intrinsically safe enclosure for circuitry within transmitter **60**. The materials typically used in end caps, for example metal, are not transparent to RF signals. However, RF transparent window **74** allows RF signals to be sent from or received by antenna **26**. One example RF transparent material for use with window **74** is glass or the like. However, any appropriate material can be used. The window and housing configuration can help to meet intrinsic safety requirements and provide flame proof (explosion proof) capability. Further, the cavity within housing **62** can be configured to provide a desired radiation pattern of RF signals generated by antenna **26**. For example, it may be desirable to have the RF transmission be directional in some implementations, or omnidirectional in others. In other implementations, the cover **62** can be lengthened to provide an additional interior cavity for placement of wireless communication circuit **22**.

The wireless communication circuitry **22** can be selected as desired. One example circuit is the “I-Bean” transmitter device available from Millennial Net. However, other circuitry can be used. Analog or digital signals carried on process control loop **16** can be read and transmitted using the wireless communication circuit **22** without disrupting operation of the process control loop **16** or field device circuitry **68**. The circuitry used for wireless transmission should be sufficiently small and low powered to fit within the physical and power constraints of process field devices. Some prior art transmitters are configured to receive an optional display arranged generally in the position shown for wireless communication circuit **22** in FIG. **3**. In such a configuration, the wireless communication circuit **22** can be used in place of the local display. In such a configuration, the communication wireless circuitry **22** simply transmits an RF signal which couples directly to the process control loop **16** and transmits an RF signal which corresponds to any analog and/or digital signals carried on the loop **16**.

In general, the process control loop discussed herein can comprise any type of process control loop for use in industrial process control and monitoring systems. Such loops include 4-20 mA current loops in which a analog current level is varied between 4 and 20 mA to transmit information. The same control loop can be used to provide power to the field device. Another type of process control loop is in accordance with the HART® communication protocol in which digital transmissions are superimposed on the 4-20 mA signal for transmission of additional information. Another example two-wire process control loop uses a protocol set forth by the Instrument Society of America (ISA) which is called the Field Bus SP50 protocol. However, end signaling protocol can be used. Some process control loops are configured to connect to multiple field devices such that the field devices can communication one another or monitor transmissions from another field device. In general, any type of information transmitted on such process control loops, or available or generated internally or received by a field device, or otherwise used to control a field device or other type of information, can be transmitted using the wireless communication techniques of the present invention. In another example, a hand held unit or device used to configure field devices can be carried into the field by an operator. The operator uses the hand held device to send or receive information to a field device when the hand held device is within proximity of the field device. This allows the operator to gather information or program a field device without having to physically couple to the device or the physical process control loop.

In some embodiments, it is also desirable for communications from a field device, or to a field device, to carry addressing information. The addressing information can be indicative of the source of the transmission or the intended recipient of the transmission. The wireless communication circuitry can transmit continuously or on a periodic or intermittent basis, as desired. In another example, the wireless communication circuitry only transmits when activated or “polled”. The activation can be from a source internal to the field device, received through the process control loop, received from a wireless source, or received or generated by another source. In environments in which multiple field devices may transmit simultaneously, the transmission protocol should be selected to avoid or address any type of collisions which might interfere with the transmissions. For example, different frequencies or frequency skipping techniques can be used, random or semi-random transmission windows can be used, repeated transmissions or token based techniques can be implemented or other collision avoidance techniques as desired. If the transmission includes error detection or correction information, this information can be used to detect an error in the transmission and/or correct any errors in the transmissions. If an error is not correctable, the receiving unit can request a re-transmission of the corrupt data or, can indicate an error, or can wait for a subsequent transmission of the data, or take other steps as desired.

FIG. **3** also shows an example hand held device **80** for communication with circuitry **22** over RF connection **82**. Hand held device **80** includes a display **84** and user input **86**. Other types of inputs and outputs can be included in hand held device **80**. Preferably, the hand held device **80** is battery operated and can be carried into the field by an operator for communication with field device **60**. Information from the field device **60**, or from other sources, is displayed on display **84** and the hand held device is controlled using input **86**. Commands or other information can be transmitted by the hand held device **80** to field device **60**.

In one configuration, the wireless communication circuitry requires power which is within the power constraints available in the field device. For example, one display currently used within field devices uses 3.6 volts at 0.5 mA. If a transmitter which is capable of operating an LCD meter is employed, the wireless communication circuitry can replace the LCD meter and use the same power source that is used to drive the LCD meter. In another example, the wireless communication circuitry is powered directly from the process control loop, for example using the voltage developed across a diode drop connected in series with the process control loop. In embodiments in which no battery is used with the communication circuitry, the circuitry can more easily meet intrinsic safety or other safety approval requirements and provide an indefinite field life without battery replacement or maintenance. In configurations in which the wireless configuration is only for sending information, power requirements can be reduced. In another example, if a greater transmission range is desired, a stationary device such as display **32** as illustrated in FIG. **1** can include an RF repeater for re-transmission of data received from, or sent to, a field device. The RF repeater can be loop powered, or can derive its power from other sources. Further, once the RF data is received, it can be reformatted for transmission over other medium, for example an Ethernet connection, into existing data transmission structures used within process control systems, over an extended range RF communication link such as a cell phone, or relaying using another technique.

FIG. **4** is a simplified diagram of a process controller or monitoring system **100** which illustrates another aspect of the present invention. In system **100**, a field device **14** connects to a control system **12** through process control loop **16** through junction box **102**. In the embodiment of FIG. **4**, a field device **104** couples to the process control loop **16** and includes wireless communication circuitry **122**. The wireless communication circuitry **122** is configured to send an RF signal **106** and to be completely powered by power received from the process control loop **16**.

Process device **104** includes a power regulator **110**, a shunt or bypass **112**, and a super capacitor **114**. During operation, the super capacitor **114** is slowly charged (trickle charged) using a power regulator **110** by using excess voltage tapped from the process control loop **16**. The bypass **112** allows loop **16** to operate normally and is connected in series with loop **16**. Communication circuit **122** includes circuitry for receiving information, analog and/or digital information, carried on process control loop **16**. The circuit **122** can responsively transmit an RF signal **106** based upon the received information. If operated as a receiver, circuitry **122** is capable of modulating data onto the electrical current carried in the loop **16**. This can be either analog or digital information. This configuration allows data to be relayed over a wireless communication network. The network can be configured in accordance with any type of topology, including point to point, spoke and hub and mesh topologies. Process device **104** can be positioned at any location along the loop including configured as an individual device such as that illustrated in FIG. **4**. In some installations, the field device **104** should be field hardened and configured for intrinsically safe operation. The device **104** can also be positioned within another field device **14**, as part of a junction box **102**, or even located within the control room which houses control system **12**. The field device **104** can connect to more than one RF circuit **122** and/or more than one process control loop **16**, either simultaneously or through the use of multiplexers or other techniques.

The use of a super capacitor allows the device to operate without internal batteries or other techniques. The use of a capacitor allows quick charging and the storage of sufficiently large energy potentials. When used in a hazardous environment, large energy storage may not be acceptable in order to meet intrinsic safety standards. However, the process device **104** can be moved away from the hazardous environment, such as at the junction box **102**, where intrinsic safety is not required.

FIG. **5** is a simplified schematic diagram of field device **104** showing super capacitor **114** in greater detail. In this example, super capacitor **114** comprises two 10 Farad capacitors configured to each carry a 2.5 volt potential. This yields an equivalent capacitance of 5 farads with a 5 volt potential drop. Assuming that the wireless communication circuit **122** is capable of operating at a voltage of between 4 and 5 volts, the available energy from each of the 5 Farad capacitors is $\frac{1}{2}*C(V_i^2-V_F^2)$ which is $\frac{1}{2}*5*(5^2-4^2)=22.5$J.

FIG. **6** is a graph of voltage versus time measured across super capacitor **114**. In this example, 600 mW wireless transmitter which transmits a burst signal for a period of t_d of 1 second will require 0.6J/S*1s=0.6J of energy. Thus, there is ample energy available for operation of such a communication circuit **122**.

A typical power supply used to provide power to a process control loop provides 24 volts DC. However, in a 4-20 mA system, a transmitter may only require 12 volts to operate. Wiring losses in the process control loop may cause 2 to 4 volts of voltage drop. Assuming only 5 volts is available for charging the super capacitor **114**, and that the process control loop is operating at a low current level (i.e., 4 mA), there is still 20 mW available to charge the super capacitor **114**. Because only 0.6 J was consumed during the transmit cycle, the available 20 mW will charge the super capacitor to full capacity in a time t_c=0.6J/0.02W=30s. Therefore, such a configuration will be capable of transmitting a signal having a 1 second duration every 30 seconds. Assuming that the bandwidth of the communications signal is 200 Kb/s and a packet size of 200 b, the burst time is reduced to one millisecond and the resulting transmit time is 0.03 seconds. In such a configuration, diagnostic data can easily be transmitted because it is not of a time critical nature. However, if sufficiently fast charge times are available, control and process variable signals can also be transmitted wirelessly.

Although a super capacitor is described, any energy storage device can be employed including a battery, or other. The energy that is used to charge the storage device can be electrical or magnetic and can be derived or collected from any source.

FIG. **7** is a simplified diagram of process controller monitoring system **150** which includes a control room **152** coupled to a field device **154** through two-wire process control loop **156**. Process control loop **156** extends across an intrinsic safety barrier **158**. The control room **152** is modeled as including a power supply **160** and a load resistance **162**.

The field device **154** can be of any configuration and is not limited to the specific schematic shown in FIG. **7**. RF communication circuitry **170** is shown coupled in series with loop **156**. Circuitry **170** can be implemented in a terminal block of a field device. For example, circuitry **170** can be configured as an add on module such that the two-wire process control loop **156** can connect to existing transmitter circuitry.

In the configuration illustrated in FIG. **7**, the communication circuitry **170** enables wireless communication abilities to be added to a new or existing process control loop or field device. The circuitry is configured to be powered by the process control loop and can be installed anywhere in the loop ranging from the control room, anywhere along the loop itself, in the intrinsic safety (IS) barrier or junction box **158**, as a stand alone field device, or included in another field device. The circuitry can be configured for any type of communication. However, in one simple configuration, the circuit **170** is configured to measure the current carried in process control loop **156** and transmit an output related to the measured current to a wireless receiver.

Turning now to one specific embodiment of circuitry **170** shown in FIG. **7**, a sense resistance **180** and a power supply diode **182** couple in series with process control loop **156**. The sense resistance **180** can be, for example, 10 ohms and is used in sensing the current level I carried in the process control loop **156**. A test diode **184** is also coupled in series with the loop **156** and provides a test point **186**. This can be used to calibrate or characteristize a field device coupled to circuitry **170**. An intrinsic safety protection circuit **190** is provided which includes diode **192** connected as shown across diode **182** and isolation resistors **194** connected at opposed ends of sense resistance **180**. Diode **182** is part of a power supply **196** which includes capacitor **198**, input filter **200**, regulator **202**, capacitor **204** and secondary filter **206**. Secondary filter **206** includes capacitor **208** and resistor **210**. The power supply circuitry **196** generates a power supply voltage V_{DD} relative to a circuit ground for use by circuitry in measuring the loop current and wirelessly transmitting a resultant signal. Although a specific power supply implementation is shown, any appropriate power supply configuration or embodiment may be used as desired.

In this embodiment, input circuitry **218** includes sense resistance **180** and is configured to measure the current I flowing through loop **156**. Input circuitry **218** also includes a filter **220** which provides a differential connection to an OP amp **222**. The OP amp provides an amplified input signal to an analog to digital converter **226** which is illustrated as part of a microprocessor **224**. A clock circuit **228** is provided and used to provide a clock signal to, for example, microprocessor **222**. Optional HART® transmit and receive circuit **230** connects to microprocessor **224**, loop **156**, clock circuit **228** and an RF transmit/receive circuit **232**. The optional HART® circuit **230** is configured to receive a digital chip select signal (CS**1**) from microprocessor **224**. The RF circuit **232** is configured to receive a separate digital chip select signal (CS**2**) from microprocessor **224**. Both the HART® circuit **230** and the RF circuit **232** are configured to communicate with the microprocessor **224** on an SCI bus, depending on which chip select is active. Microprocessor **224** is also configured to provide a shut down signal to operational amplifier **222**. Microprocessor **224** includes a memory **236** which is used for storing programming instructions, temporary and permanent variables and other information and may include both volatile and non-volatile memory. The memory can include, for example, an EEPROM and can contain addressing information which uniquely identifies circuitry **170**. RF circuit **232** couples to an antenna **240** which can be configured as an internal antenna, external antenna, or combination, as desired. Circuitry **170** is configured to couple across the two-wire process control loop **156** such that the loop **156** can terminate at another field device such as a process transmitter or process controller.

The circuitry **170** illustrated in FIG. **7** can be implemented on a single printed circuit board such that RF antenna **240** is formed integral with the board. This configuration allows the circuitry **170** to be easily implemented in existing field devices and does not require the use of an external antenna. This reduces installation complexity.

The optional HART® transmit/receive circuit **230** can be used to monitor digital signals, such as a process variable, carried on the process control loop **156**. Based upon the sensed digital signal, the HART® circuitry **230** can control operation of the RF transmit/receive circuit **232** for transmission of information related to the sensed process variable, or other information. If the HART® circuitry is implemented in accordance with the complete HART® protocol and appropriate RF protocol stacks, the circuitry can implement gateway level functionality which will allow a HART® master to communication in a bi-directional manner through the RF HART® gateway device with a HART® capable field device on the process control loop **156**. This allows wireless communication with a field device for monitoring, configuration, diagnostics, or exchange of other information or data.

Frequently, in process control or monitoring installations, an operator is required to physically access a field device or the process control loop in order to exchange information with the field device. This allows the operator to repair equipment and do preventive maintenance on the equipment. The wireless communication configuration set forth herein allows the operator to interrogate field devices which may be in locations which are difficult to access. Further, even in configurations in which the field devices are easily accessible, the wireless communication circuitry does not require an operator to remove covers on equipment such as transmitters or junction boxes in order to expose loop wiring for physical connection to the process control loop. This can be particularly beneficial in hazardous locations where explosive gases or vapors may be present. A digital or analog process variable can be sensed by the wireless communication circuitry and transmitted to a wireless meter or hand held device as discussed above.

During operation, circuit **170** is placed in series with the process control loop **156** where it utilizes the 4-20 mA current flowing through the loop to power itself. For field devices that employ a common electrical ground, circuitry **170** can be inserted on the high voltage side of the loop connection. This configuration allows access to other bus circuitry within the field device such as a CAN interface. The configuration includes a test connection **186** for use in measuring loop current during testing. The sense resistance **180** is preferably configured to provide an equivalent of capacitance of zero as measured at terminals **181** which connect to loop **156** in accordance with intrinsic safety standards. Circuitry **170** is configured for nominal operation at between 3 and 4 volts and the zener diode **182** along with sense resistance **180** sets this operating voltage. The excess voltage available on typical 4-20 mA current loop is sufficient to operate circuitry **170**. Further, power management techniques can be employed to limit the current drawn from the loop to about 3 mA. This allows any field device connected to the process control loop to send an alarm level signal of 3.6 mA without collapsing the circuit by drawing more than the available current level.

Zener diode **182** acts as a shunt element which is placed in series with the loop **156** to develop a preregulated voltage on the input filter stage. Any portion of the loop current which is not used by circuitry **170** is shunted through zener diode **182**. The input filter **200** can comprise capacitive, inductive and resistive elements and is used to isolate the loop from any noise or load fluctuation generated by circuitry **170**. This also suppresses noise in the HART® extended frequency band in order to conform with HART® standards.

The voltage regulator **202** can be any appropriate voltage regulator such as, but not limited to linear or switch mode regulators and is used to supply the voltage V_{DD} to the circuitry. Filter **206** is used to store energy and further decouples circuit loads from the regulator **202**. The output voltage of the secondary filter **206** is allowed to sag by several hundred millivolts during circuit load changes. This allows peak current draws by the circuitry **172** to be averaged from the 4-20 mA current loop.

In this embodiment, the microprocessor **224** including A/D converter, along with the RF circuitry **232** and input circuitry **218** can be placed into a sleep mode or low power mode during periods of idle operation in order to reduce power drain. For example, at a selected interval such as every 10 seconds, an internal timer in the microprocessor can enable the measurement of the loop current by the A/D converter. The measurement circuitry is allowed to settle before the A/D conversion occurs. After the A/D conversion is completed, both the loop measurement circuitry and the A/D converter are turned off to conserve power. The microprocessor passes the measured value to the RF circuitry **232** for transmission. Upon completion of the transmission, the microprocessor and RF circuitry return to the low power mode until the next cycle. The microprocessor may even put itself to sleep temporarily to save power. Using these power management techniques, the microprocessor is able to manage overall current requirements of the circuit by staggering the load demands on the regulator stage.

Loop current measurement is achieved using the 10 ohm sense resistor **180** coupled in series with the 4-20 mA current loop **156** to measure the analog current level. The voltage developed across the sense resistor **180** is filtered to remove fluctuations due to HART® digital communications as well as any loop noise. An operational amplifier stage **222** provides further signal conditioning and the signal is passed to the A/D converter **226** of microprocessor **224**.

The RF circuitry **232** can be any appropriate circuitry or configuration as desired. In one simple form, the RF circuitry **232** simply transmits a measured variable to a wireless receiver. The antenna **240** can be used to broadcast the RF signal and can be formed integral with the circuitry **170**, for example in the form of traces routed around an outside edge of a circuit board. The RF circuitry **232** can, in some embodiments, include a wireless receiver such that the circuitry **232** can be configured as a transceiver. The same antenna **240** can be used for both transmission and reception if desired. A typical low powered transceiver may have a communication range of about 200 feet, however other ranges can be achieved using different power requirements, circuit sensitivity, antenna configuration, and the like. If the circuitry **170** is mounted in a metal enclosure, such as a field housing compartment of a transmitter, an RF transparent portion of the housing should be used to allow transmission and reception of signals from antenna **240**. For example, as discussed above, a glass window can be used. Other example materials include any material which is sufficiently transmissive to RF signals including plastic, or other materials.

The addition of the optional HART® circuitry **230** allows the circuitry **170** to selectively listen to a HART® message on the 4-20 mA signal carried on the current loop **156**. Information such as measured process variables, diagnostic information, or other information can be transmitted to a wireless receiver. Further, if the HART® circuitry **230** is configured to modulate a digital signal onto the process control loop, it can be used to remotely command or interrogate a field device coupled to the loop **156**. For example, the HART® circuitry **230** can be configured to act as a secondary master on the 4-20 mA current loop. This, in conjunction with RF circuitry **232** configured as a full transceiver, enables bi-directional communication and configuration of field device from a wireless master unit, for example a hand held device **80** shown in FIG. **3**.

Microprocessor **224** can also preferably be used to implement diagnostics functionality. Microprocessor **224** is configured to monitor the voltage and current characteristics of the process control loop **156**, improper or problematic variations in current and voltage can be identified using diagnostic techniques and can be transmitted to a remote location, either wirelessly, or using the HART® transmission capabilities provided by circuitry **230**, or by setting the current level carried on loop **156** to an alarm value or other pre-determined value.

Circuitry **170** is preferably configured to allow operation in hazardous locations and to meet the appropriate approval and specifications, such as intrinsic safety standards. For example, the intrinsic safety protection **190**, along with intrinsically safety rated resistor **180** is used on the input to the circuitry **170**. Using appropriate components and circuit layout, the addition of a redundant zener diode **192** in parallel with zener **182** provides a level of redundancy and limits the amount of voltage that can enter this circuit in an intrinsic safety protected system. Similarly, the sense resistor **180** can be used to limit the maximum current that can enter the circuit **170** and snub any discharge of stored energy from the circuit through its external terminals. This provides an equivalent capacitance of substantially zero. The loop measurement circuitry is further protected by two intrinsic safety rated high value resistors **194** connected between the two ends of the sense resistor **180** and the filter **220**. Other circuit components can be protected from any outside energy sources by the use of potting material or the like which also prevents hazardous gases and vapors from reaching any internal storage elements and nodes in the circuitry **170**. For other non-hazardous locations, intrinsic safety components may not be required.

The term "field device" as used herein can be any device which is used in a process controller monitoring system and does not necessarily require placement in the "field." The device can be located anywhere in the process control system including in a control room or control circuitry. The terminals used to connect to the process control loop refer to any electrical connection and may not comprise physical or discrete terminals. Any appropriate radio frequency communication circuitry can be used as desired as can any appropriate communication protocol, frequency or communication technique. The power supply circuitry is configured as desired and is not limited to the configurations set forth herein. In some embodiments, the field device includes an address which can be included in any RF transmissions such that the device can be identified. Similarly, such an address can be used to determine if a received signal is intended for that particular device. However, in other embodiments, no address is utilized and data is simply transmitted from the wireless communication circuitry without any addressing information. In such a configuration, if receipt of data is desired, any received data may not include addressing information. In some embodiments, this may be acceptable. In others, other addressing techniques or identification techniques can be used such as assigning a particular frequency or communication protocol to a particular device, assigning a particular time slot or period to a particular device or other techniques. Any appropriate communication protocol and/or networking technique can be employed including token-based techniques in which a token is handed off between devices to thereby allow transmission or reception for the particular device.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. As used herein, Radio Frequency (RF) can comprise electromagnetic transmissions of any frequency and is not limited to a particular group of frequencies, range of frequencies or any other limitation. Any communication protocol can be used, as desired, including IEEE 802.11b, 802.154, or other protocols, including proprietary communication protocols.

What is claimed is:

1. A process control transmitter for monitoring a process variable in an industrial process comprising:
- a process variable sensor configured to sense the process variable;
- I/O circuitry configured to couple to a two wire process control loop and communicate on the process control loop;
- wireless communication circuitry coupled to the two wire process control loop configured to transmit an RF signal; and
- power supply circuitry coupled to the two wire process control loop including a voltage regulator, the power supply circuitry electronically connected in series with the process control loop, the voltage regulator configured to receive a voltage drop and responsively provide a regulated voltage output to power the wireless communication circuitry.

2. The apparatus of claim **1** including a terminal block configured to electronically connect to the two wire process control loop and wherein the wireless communication circuitry couples to the terminal block.

3. The apparatus of claim **1** wherein the wireless communication circuitry is completely powered with power from the two wire process control loop.

4. The apparatus of claim **1** wherein the wireless communication circuitry includes a resistor coupled in series with the two wire process control loop.

5. The apparatus of claim **1** including a battery configured to power the wireless communication circuitry.

6. The apparatus of claim **1** wherein the wireless communication circuitry includes two wire loop communication circuitry configured to communicate on the two wire communications loop.

7. The apparatus of claim **1** wherein the wireless communication circuitry includes HART® communication circuitry.

8. The apparatus of claim **1** wherein the wireless communication circuitry includes intrinsic safety protection circuitry.

9. The apparatus of claim **1** wherein the wireless communication circuitry includes an analog to digital converter configured to provide a digital representation of current flowing through the two wire process control loop.

10. The apparatus of claim **8** wherein the RF signal is based upon the sensed current.

11. The apparatus of claim **1** wherein the wireless communication circuitry includes a microprocessor.

12. The apparatus of claim **1** wherein the wireless communication circuitry includes a memory containing addressing information.

13. The apparatus of claim **1** wherein the wireless communication circuitry includes an antenna.

14. The apparatus of claim **1** wherein the wireless communication circuitry is configured to receive an RF signal and responsively transmit a signal on the two wire process control loop.

15. The apparatus of claim **1** wherein the power supply circuitry includes an electrical element comprises a zener diode configured to couple in series with the two wire process control loop.

16. The apparatus of claim **1** wherein the power supply circuitry includes a wireless communication circuitry is configured to enter a sleep mode during idle periods.

17. The apparatus of claim **1** including:
- an energy storage capacitor configured to store an electrical charge using power received from the two-wire process control loop; and
- wherein the power supply circuitry is configured to use power from the electrical charge stored on the energy storage capacitor.

18. The apparatus of claim **1** wherein the wireless circuitry is carried on a modular circuit board configured to mount in a housing of the process variable transmitter.

19. The apparatus of claim **1** wherein the wireless communication circuitry includes terminals configured to couple in series with the two-wire process control loop.

20. The apparatus of claim **1** including:
- an explosion proof housing configured to enclose the wireless circuitry;
- an integral RF transparent region in the housing configured to allow RF transmission therethrough.

21. The apparatus of claim **20** wherein the RF transparent region comprises glass.

22. The apparatus of claim **20** including an end cap configured to mount to a main housing and wherein the end cap includes the RF transparent region.

23. The apparatus of claim **1** including:
- a circuit board configured to carry the wireless communication circuitry; and
- an RF antenna coupled to the wireless communication circuitry and carried on the wireless communication circuit board.

24. The apparatus of claim **19** wherein the wireless communication circuitry is integral with a terminal block which carries the terminals.

25. The apparatus of claim **1** wherein the wireless communication circuitry is configured to transmit an RF signal related to an analog current level carried through the process loop.

26. The apparatus of claim **1** wherein the wireless communication circuitry is configured to transmit an RF signal related to a digital signal carried by the process control loop.

27. The apparatus of claim **1** including a HART® module coupled to the wireless communication circuitry configured to operate as a bi-directional HART® to RF gateway unit.

28. The apparatus of claim **1** wherein the wireless communication circuitry is configured for periodic communication.

29. The apparatus of claim **1** wherein the wireless communication circuitry is configured to transmit an RF signal related to a process variable.

30. The apparatus of claim **1** wherein the voltage regulator comprises a linear regulator.

31. The apparatus of claim **1** wherein the voltage regulator comprises a switch mode regulator.

32. Radio frequency (RF) communication apparatus configured to couple to a field device in a two-wire process control loop, comprising:

first and second electrical connections configured to couple in series with the two-wire process control loop;

a third electrical connection configured to couple to the two-wire process control loop, wherein the second and third electrical connections are configured to couple in parallel with the field device; and

an RF circuit configured to receive power from the two-wire process control loop through the first and second electrical connections and transmit an RF signal which contains information related to data carried on the two-wire process control loop.

33. The apparatus of claim **32** wherein the RF circuit is configured to receive an RF signal which contains incoming data and further including circuitry configured to responsively transmit the incoming data on the two-wire process control loop.

34. The apparatus of claim **32** including a forth electrical connection and wherein the third and forth electrical connections are electrically coupled together.

35. The apparatus of claim **32** including an electrical element coupled between the first and second electrical connections for use in communication on the two-wire process control loop.

36. The apparatus of claim **32** including an electrical element coupled between the first and second electrical connections for use in providing power to the RF circuit.

37. The apparatus of claim **36** including a voltage regulator coupled to the electrical element which provides a regulated voltage output to the RF.

38. The apparatus of claim **32** including HART® communication circuitry configured to receive information from the two-wire process control loop in accordance with the HART® communication protocol.

39. The apparatus of claim **38** wherein the information contained in the RF signal comprises information received by the HART® communication circuitry.

40. The apparatus of claim **32** including a microprocessor coupled to the RF circuit configured to control the RF signal.

41. The apparatus of claim **32** wherein the RF circuit is configured to be added to an existing field device.

42. The apparatus of claim **32** wherein the RF signal carries information related to an analog current level carried on the two-wire process control loop.

43. The apparatus of claim **32** wherein the RF signal carries information related to a digital signal carried on the two-wire process control loop.

44. The apparatus of claim **32** including a filter configured to couple the RF circuit to the two-wire process control loop.

45. The apparatus of claim **32** including a terminal block configured to electronically connect to the two wire process control loop and wherein the RF circuit couples to the terminal block.

46. The apparatus of claim **32** wherein the RF circuit is completely powered with power from the two wire process control loop.

47. The apparatus of claim **32** including a resistor coupled in series with the two wire process control loop.

48. The apparatus of claim **32** including a battery configured to power the RF circuit.

49. The apparatus of claim **32** including two wire loop communication circuitry configured to communicate on the two wire communications loop.

50. The apparatus of claim **32** including intrinsic safety protection circuitry.

51. The apparatus of claim **32** including an analog to digital converter configured to provide a digital representation of current flowing through the two wire process control loop.

52. The apparatus of claim **32** including a microprocessor.

53. The apparatus of claim **32** including a memory containing addressing information.

54. The apparatus of claim **32** including an antenna.

55. The apparatus of claim **32** wherein the RF circuit is configured to receive an RF signal and responsively transmit a signal on the two wire process control loop.

56. The apparatus of claim **36** wherein the electrical element comprises a zener diode configured to couple in series with the two wire process control loop.

57. The apparatus of claim **32** wherein the RF circuit is configured to enter a sleep mode during idle periods.

58. The apparatus of claim **32** including:

an energy storage capacitor configured to store an electrical charge using power received from the two-wire process control loop; and

power supply circuitry configured to use power from the electrical charge stored on the energy storage capacitor to power the RF circuit.

59. The apparatus of claim **32** wherein the RF circuit is carried on a modular circuit board configured to mount to the field device the process variable transmitter.

60. The apparatus of claim **32** including:

an explosion proof housing configured to enclose the RF circuit.

61. The apparatus of claim **60** wherein the explosion proof housing includes:

an integral RF transparent region in the housing configured to allow RF transmission therethrough.

62. The apparatus of claim **61** wherein the RF transparent region comprises glass.

63. The apparatus of claim **61** wherein the RF transparent region comprises plastic.

64. The apparatus of claim **32** including:

a circuit board configured to carry the RF circuit; and

an RF antenna coupled to the RF circuit and carried on the circuit board.

65. The apparatus of claim **32** including a HART® module coupled to the RF circuit configured to operate as a bi-directional HART® to RF gateway unit.

66. The apparatus of claim **32** wherein the RF circuit is configured to transmit an RF signal related to a process variable.

67. The apparatus of claim **32** including a directional antenna coupled to the RF circuit.

68. The apparatus of claim **32** wherein the RF signal includes error correction information.

69. The apparatus of claim **32** wherein the RF signal is in accordance with a topology selected from the group of topologies consisting of point to point, spoke and hub, and mesh topologies.

70. The apparatus of claim **32** including a digital chip responsive to a chip select signal.

71. The apparatus of claim **32** including a shunt element configured to shunt electrical current from the two-wire process control loop.

72. The apparatus of claim **32** including loop communication circuitry coupled to the third electrical connection.

73. The apparatus of claim **72** including a microprocessor coupled to the loop communication circuitry.

74. The apparatus of claim **73** wherein the microprocessor is coupled to the RF circuit.

75. The apparatus of claim **32** including power supply circuitry connected in series with the first and second electrical connections.

76. The apparatus of claim **75** wherein the power supply circuitry includes a linear voltage regulator.

77. The apparatus of claim **75** wherein the power supply circuitry includes a switch mode voltage regulator.

78. A method for RF communicating with a two-wire process control loop, comprising:

connecting first and second electrical connections in series to the two-wire process control loop and a field device;

connecting a third electrical connection to the field device;

allowing electrical current from the two-wire process control loop to flow from the first connection through the second connection and through the electrical third connection to the field device;

transmitting an RF signal which contains information related to data carried on the two-wire process control loop.

79. The method of claim **78** wherein the transmitting an RF signal comprises transmitting RF data as a function of information received from the two-wire process control loop in accordance with the HART® protocol.

80. The method of claim **78** wherein the transmitting comprises digital communicating.

81. The method of claim **78** wherein the transmitting comprises analog communicating.

82. The method of claim **78** including receiving an RF signal which contains incoming data and responsively transmit the incoming data on the two-wire process control loop.

83. The method of claim **78** wherein the first and third electrical connections are electrically coupled together.

84. The method of claim **78** including using an electrical element coupled between the first and second electrical connections for use in communication on the two-wire process control loop.

85. The method of claim **78** including using an electrical element coupled between the first and second electrical connections for use in providing power to the RF circuit.

86. The method of claim **78** including coupling an RF circuit to an existing field device.

87. The method of claim **78** wherein the RF signal carries information related to an analog current level carried on the two-wire process control loop.

88. The method of claim **78** wherein the RF signal carries information related to a digital signal carried on the two-wire process control loop.

89. The method of claim **78** including completely powering RF circuitry with power from the two wire process control loop.

90. The method of claim **78** including storing addressing information in a memory.

91. The method of claim **78** including placing RF circuitry in a sleep mode during idle periods.

92. The method of claim **78** including providing a bi-directional HART® to RF gateway.

93. The method of claim **78** including transmitting an RF signal related to a process variable.

94. The apparatus of claim **78** wherein the RF signal includes error correction information.

95. The apparatus of claim **78** wherein the RF signal is in accordance with a topology selected from the group of topologies consisting of point to point, spoke and hub, and mesh topologies.

96. The apparatus of claim **78** including providing a shunt element configured to shunt electrical current from the two-wire process control loop.

97. The apparatus of claim **78** including regulating power with a switch mode voltage regulator.

* * * * *