US 20180135285A1

(19) United States
(12) Patent Application Publication
CANFIELD et al.

(10) Pub. No.: US 2018/0135285 A1
(43) Pub. Date: May 17, 2018

(54) TOILET MONITORING AND INTELLIGENT CONTROL

(71) Applicant: **nth Solutions, LLC**, Exton, PA (US)

(72) Inventors: **Eric L. CANFIELD**, Exton, PA (US); **Scott J. SOMA**, Exton, PA (US)

(21) Appl. No.: **15/814,097**

(22) Filed: **Nov. 15, 2017**

Related U.S. Application Data

(60) Provisional application No. 62/423,502, filed on Nov. 17, 2016.

Publication Classification

(51) **Int. Cl.**

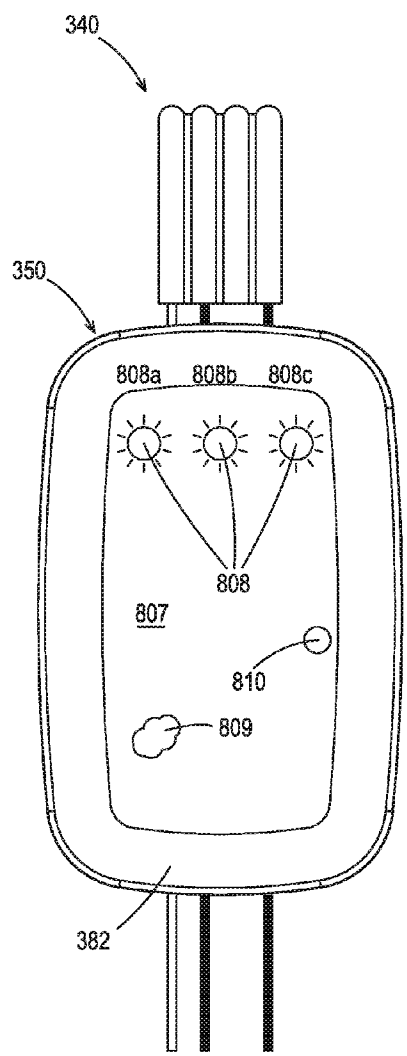
E03D 5/10	(2006.01)
E03D 11/18	(2006.01)
G01F 23/00	(2006.01)

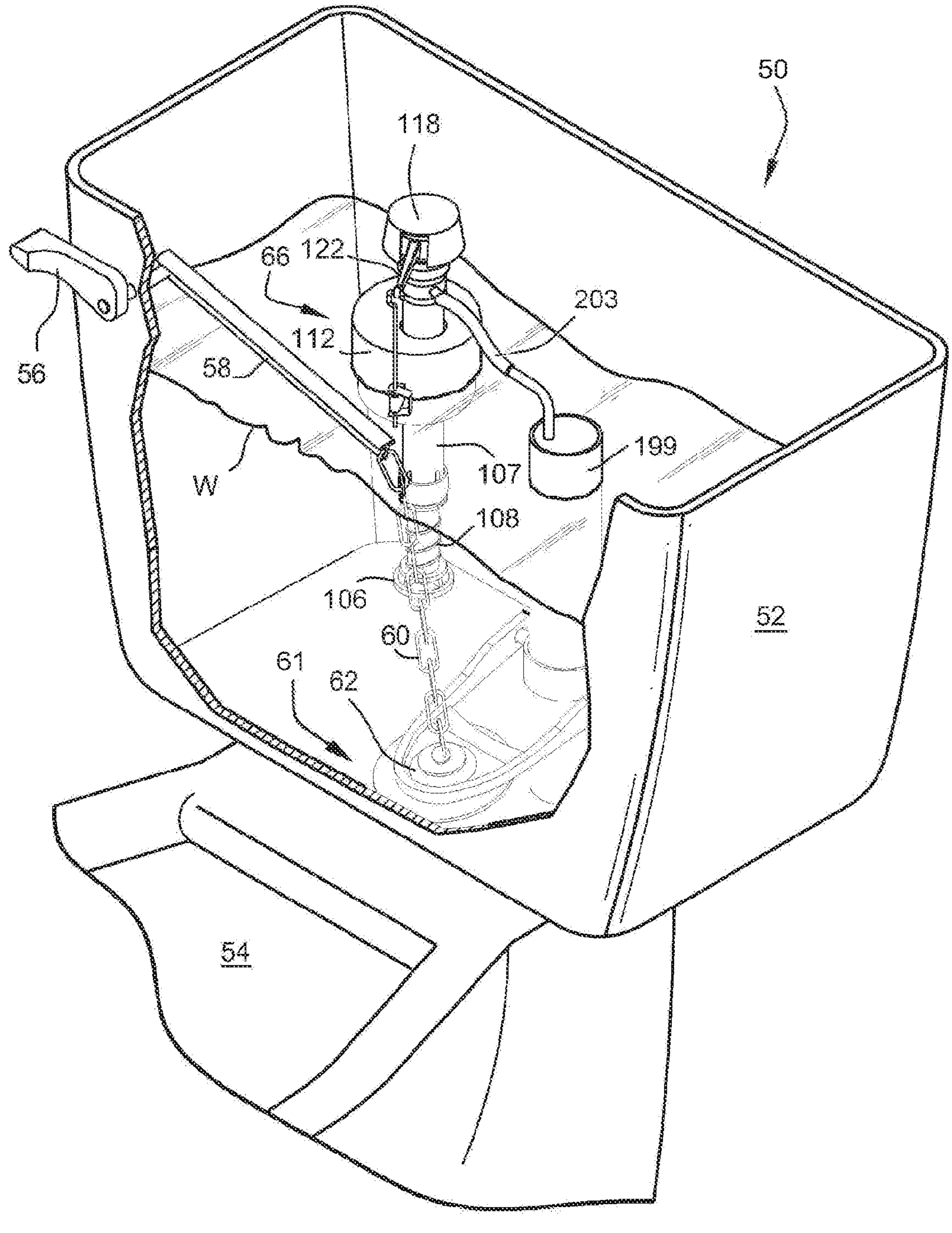
(52) **U.S. Cl.**

CPC ***E03D 5/10*** (2013.01); ***G01F 23/0069*** (2013.01); ***G01F 23/0023*** (2013.01); ***E03D 11/18*** (2013.01)

(57) **ABSTRACT**

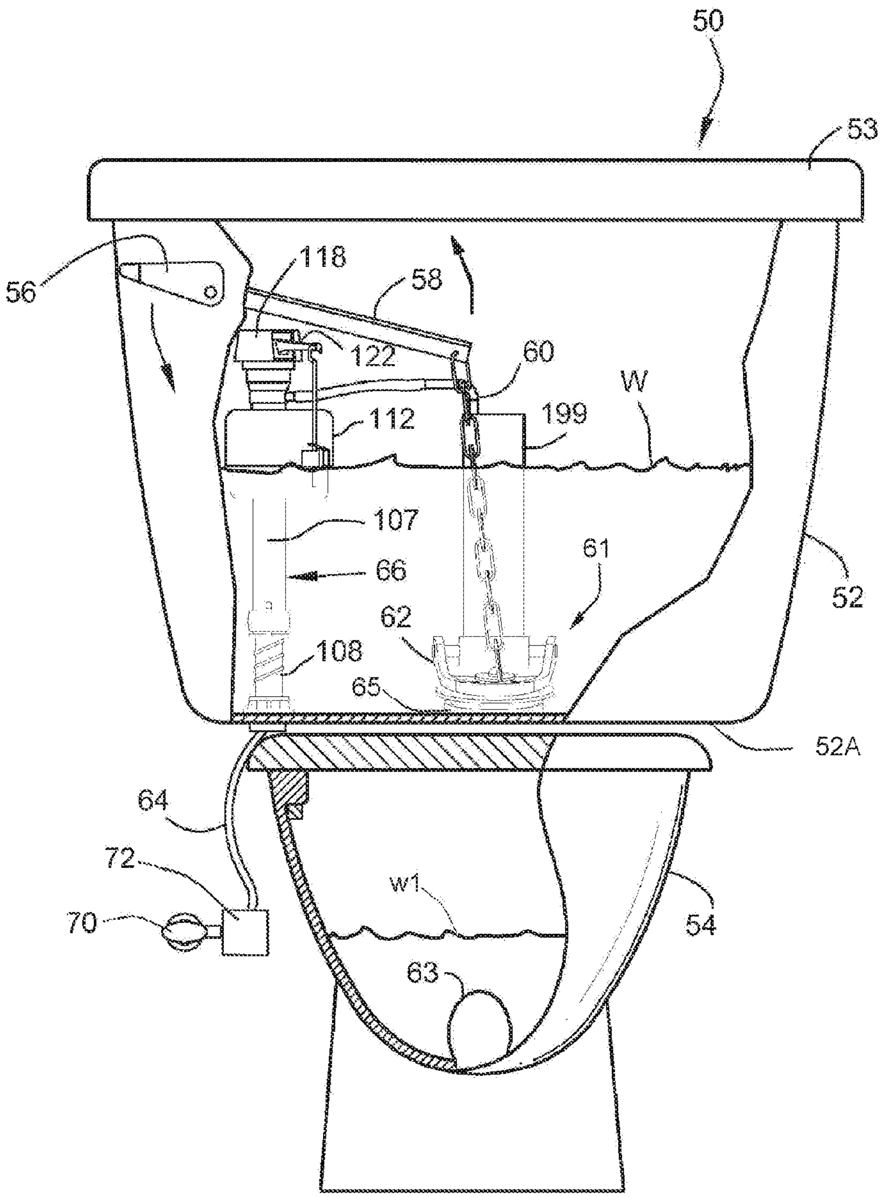
A toilet monitor uses a toilet tank water level sensor producing a toilet tank water level measurement signal. A processor detects rate of change of the measurement signal and conditionally produce a responsive actuation signal in response to the detected rate of change. A transducer connected to receive the actuation signal and transmit information, provide a humanly-perceptible indication, generate a data log and/or control an electronic water supply valve.





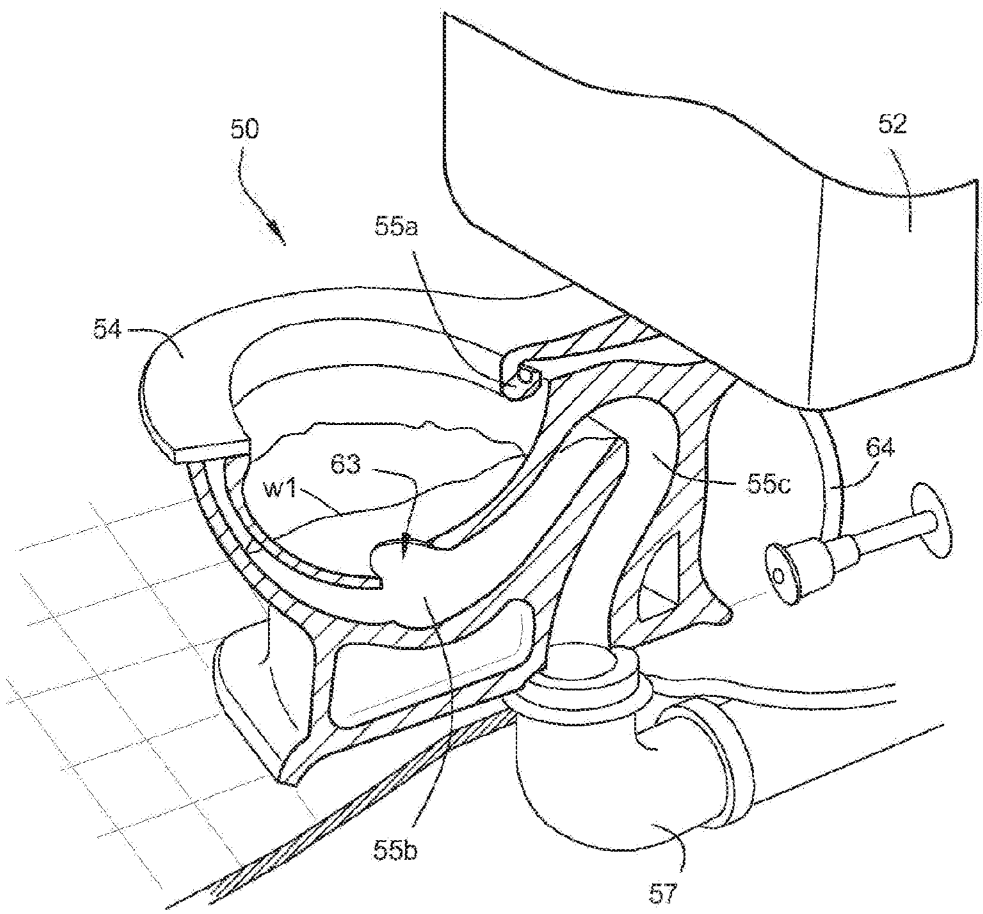
(PRIOR ART)

Fig. 1



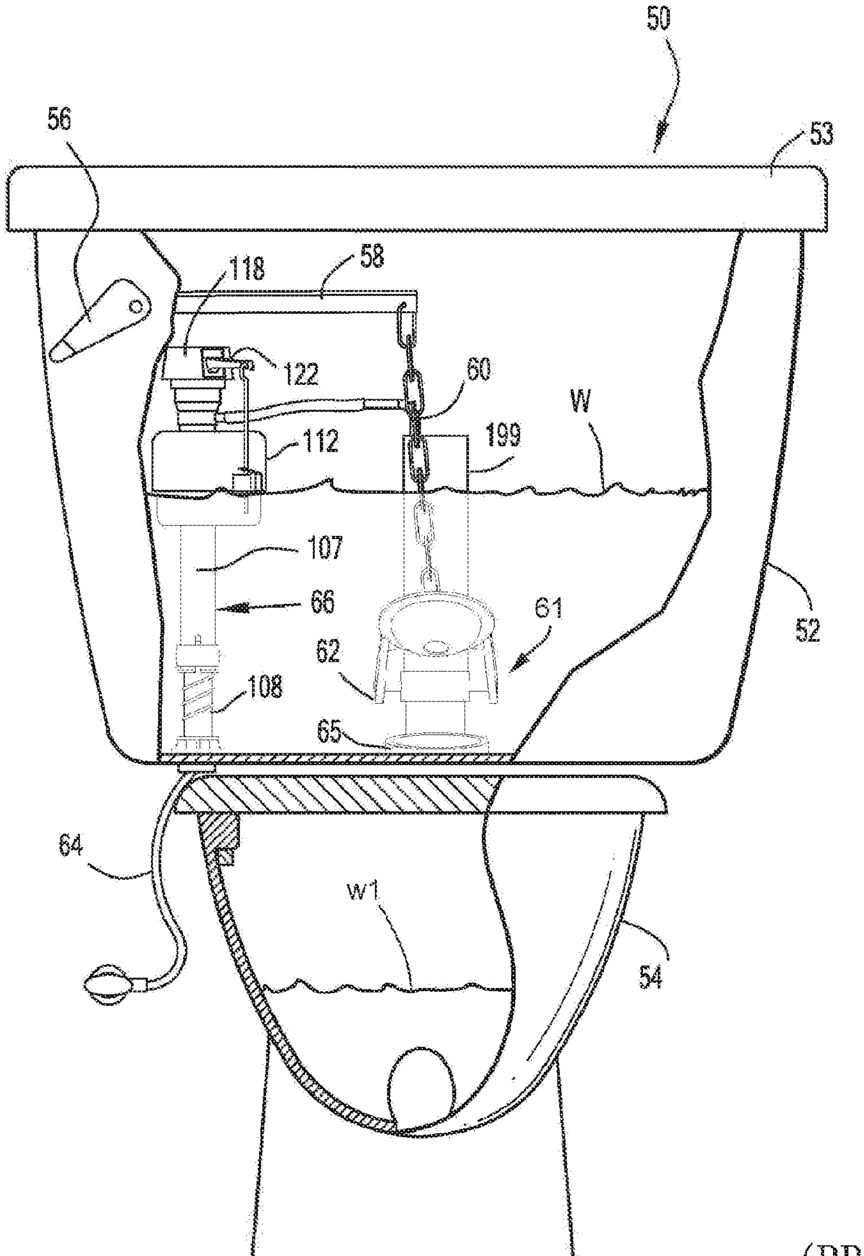
(PRIOR ART)

Fig. 2



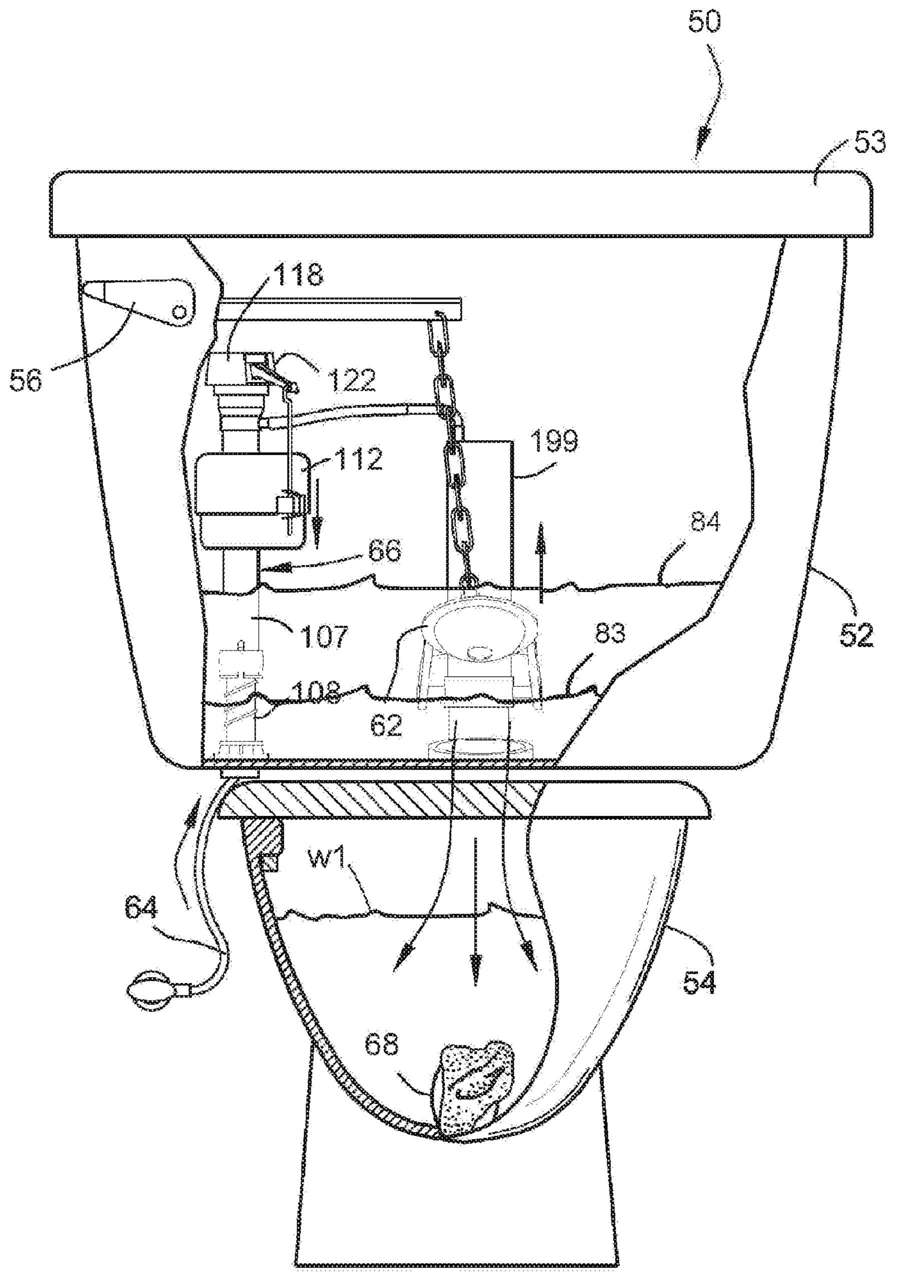
(PRIOR ART)

Fig. 2A



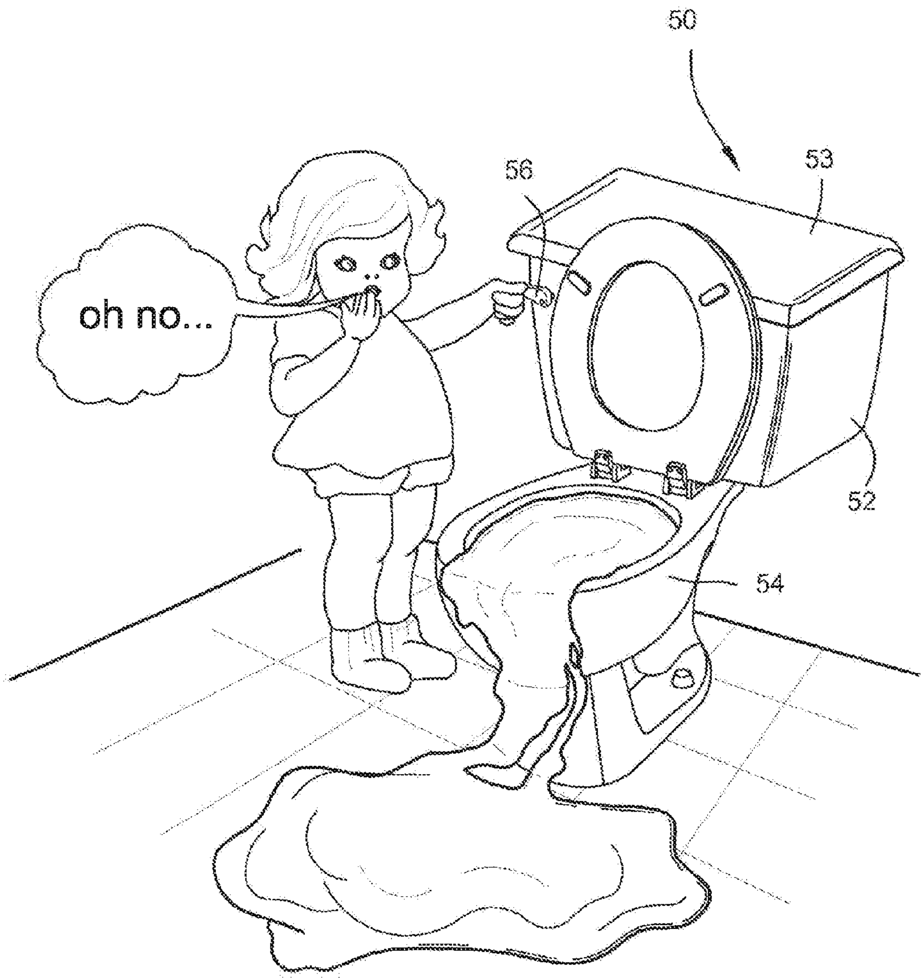
(PRIOR ART)

Fig. 3



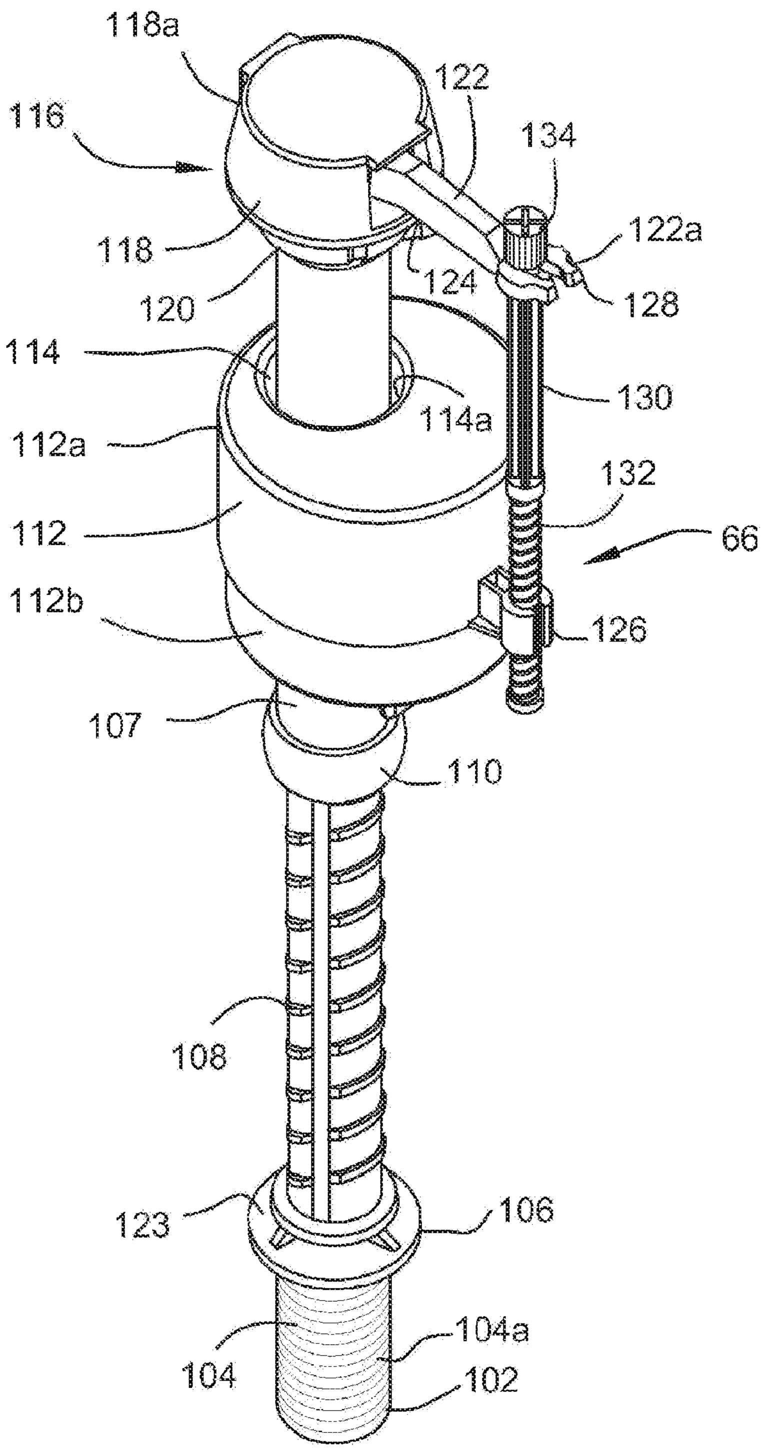
(PRIOR ART)

Fig. 3A



(PRIOR ART)

Fig. 4



(PRIOR ART)

Fig. 5

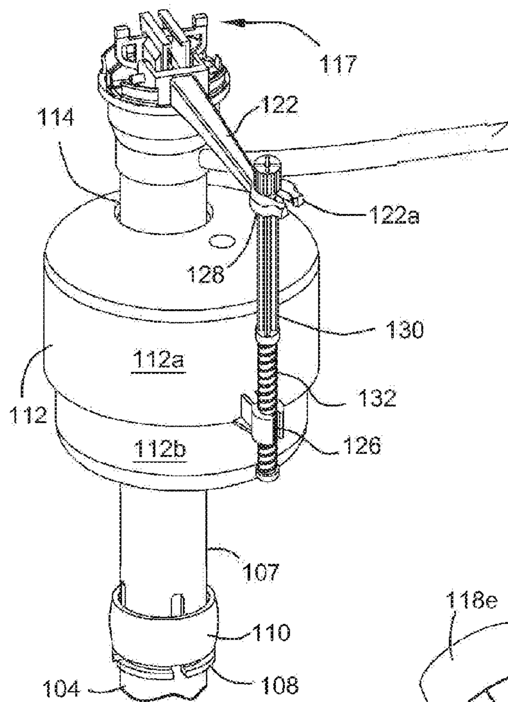


Fig. 5A

(PRIOR ART)

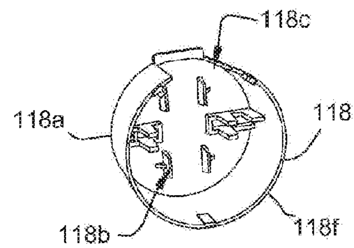


Fig. 5B

(PRIOR ART)

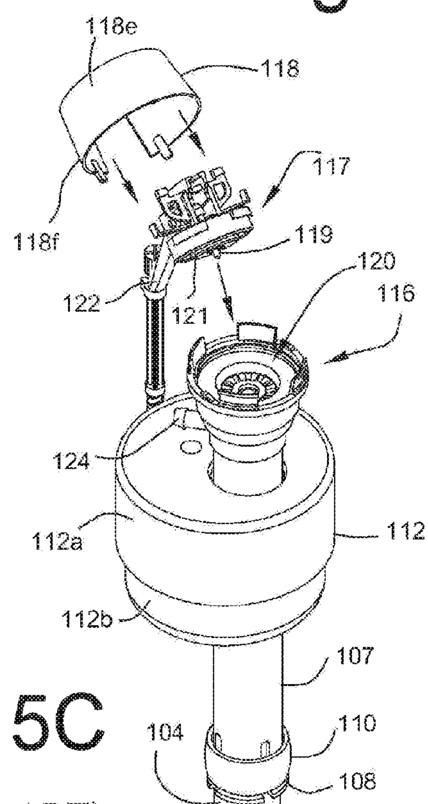
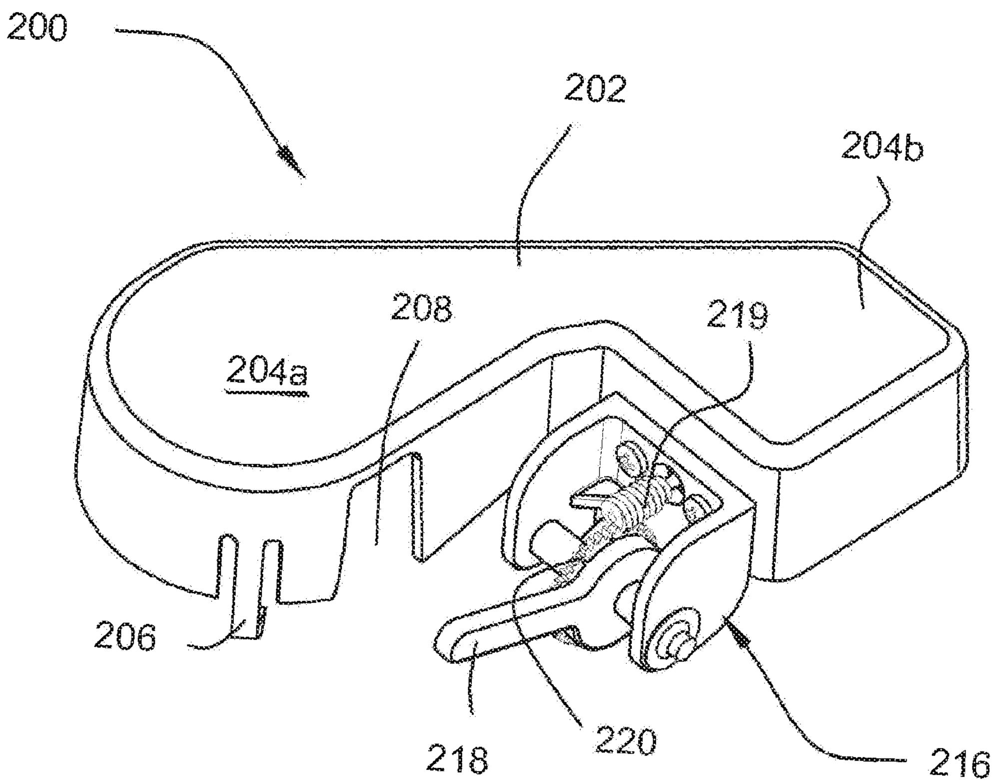


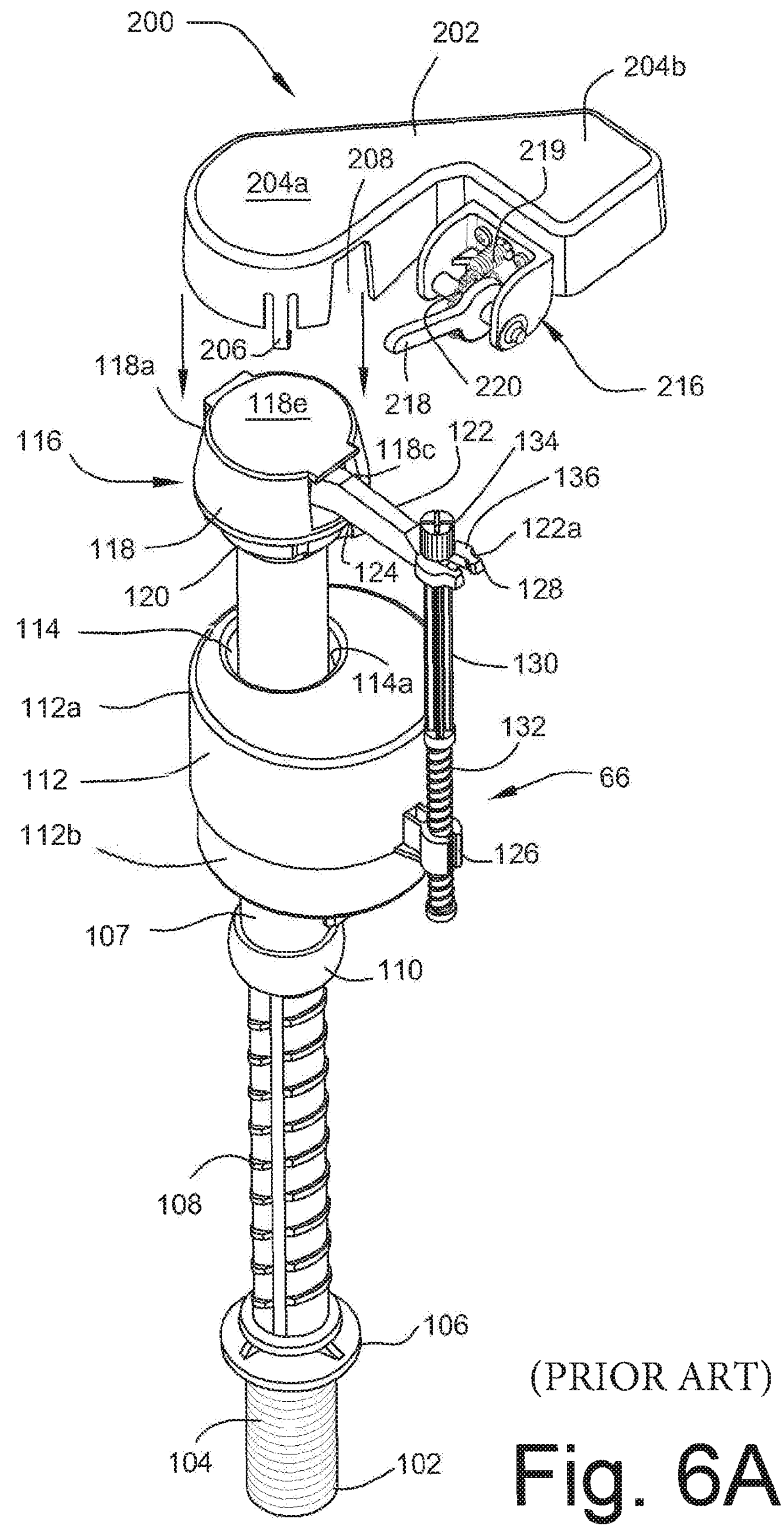
Fig. 5C

(PRIOR ART)



(PRIOR ART)

Fig. 6



(PRIOR ART)

Fig. 6A

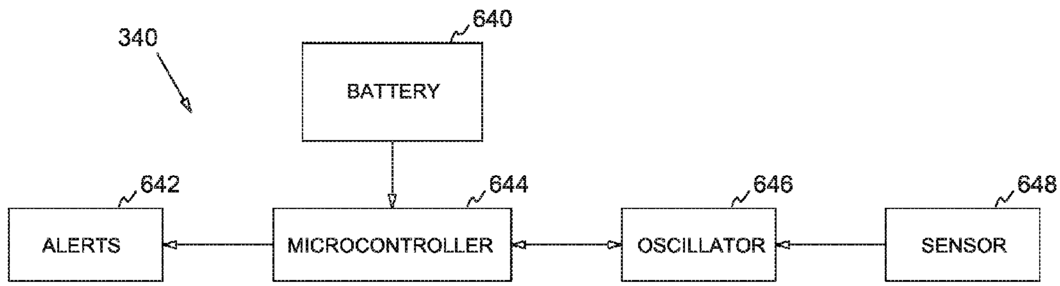


Fig. YA

"OR"

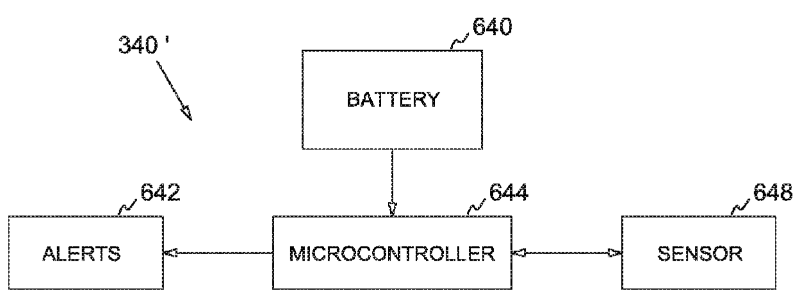


Fig. YB

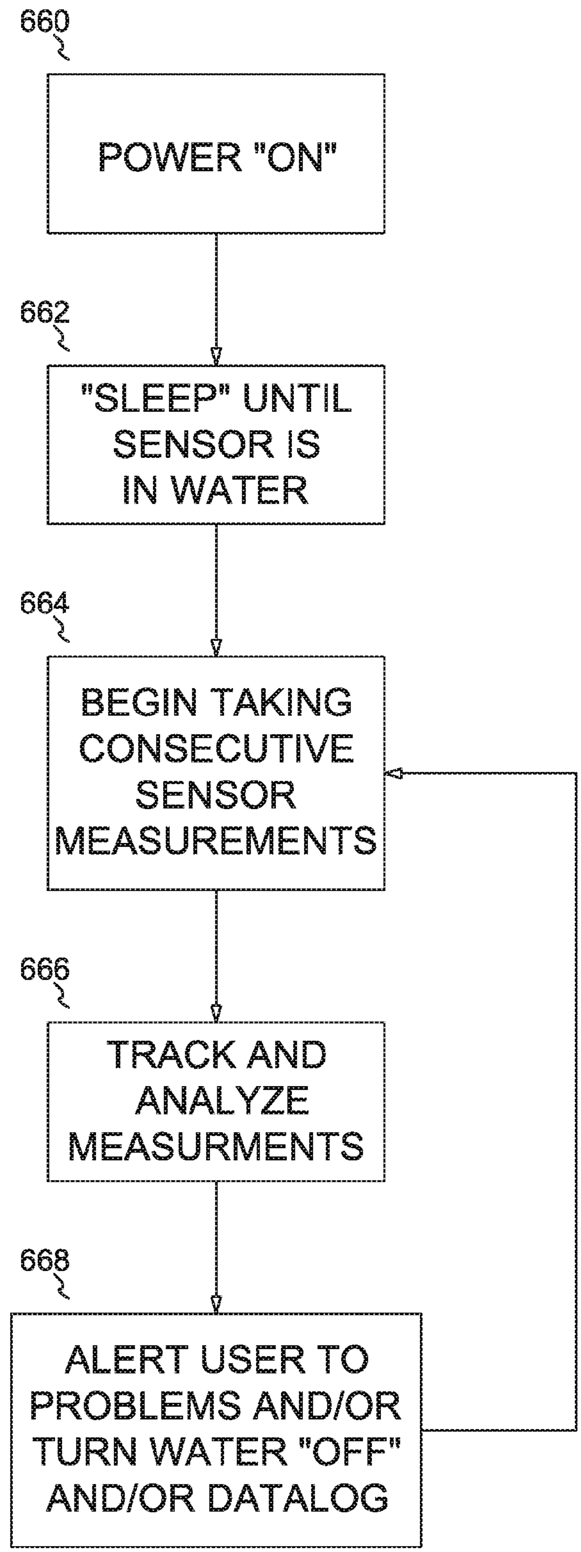

660
POWER "ON"
662
"SLEEP" UNTIL SENSOR IS IN WATER
664
BEGIN TAKING CONSECUTIVE SENSOR MEASUREMENTS
666
TRACK AND ANALYZE MEASURMENTS
668
ALERT USER TO PROBLEMS AND/OR TURN WATER "OFF" AND/OR DATALOG

Fig. Z

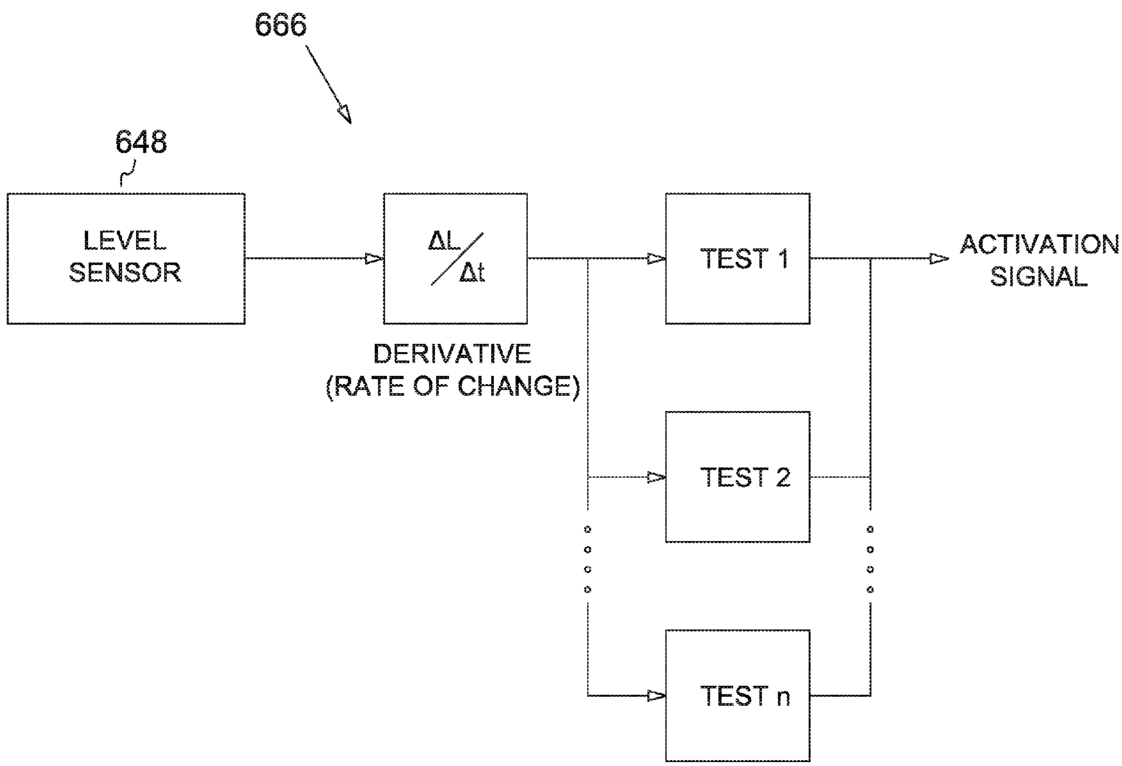

666
648
LEVEL
SENSOR
ΔL
Δt
DERIVATIVE
(RATE OF CHANGE)
TEST 1
TEST 2
TEST n
ACTIVATION
SIGNAL

Fig. Z1

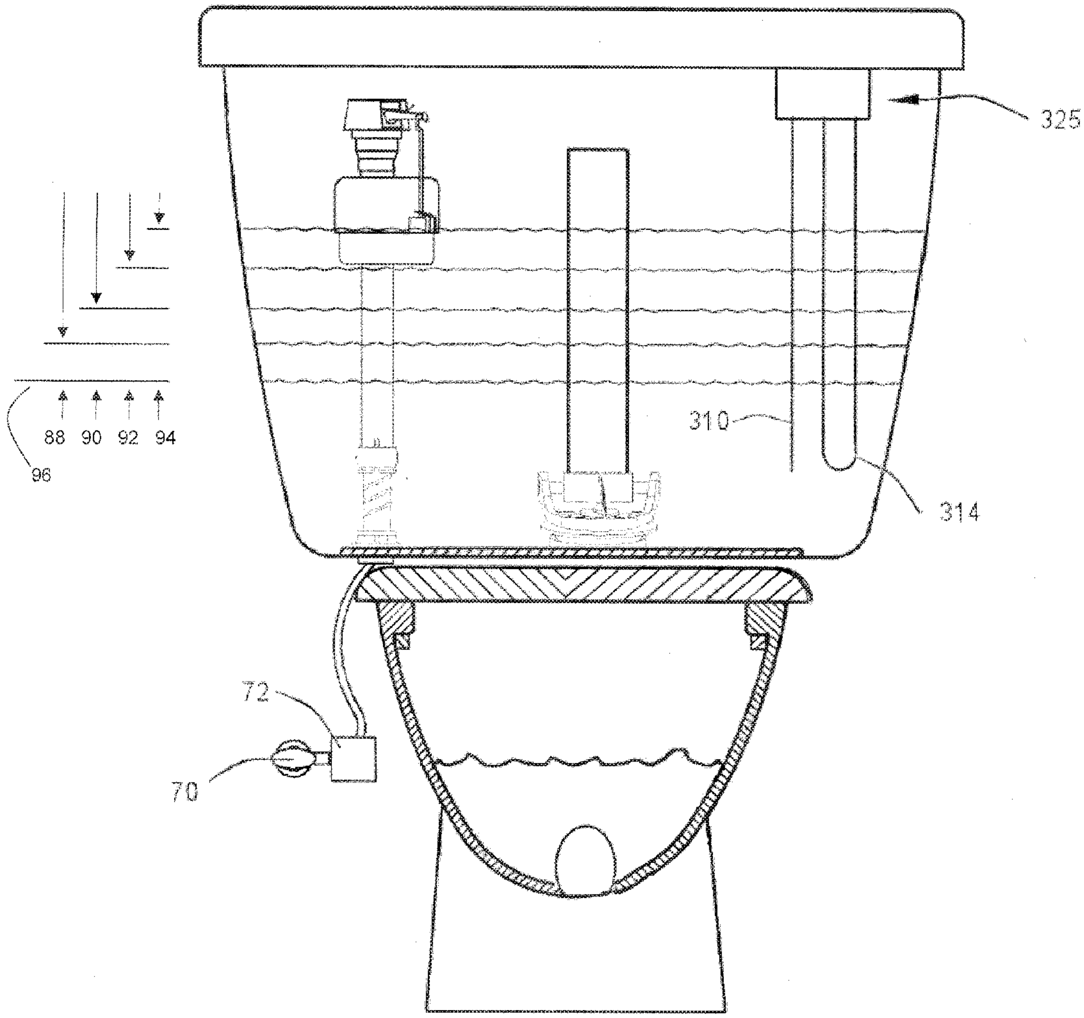


Fig. 7

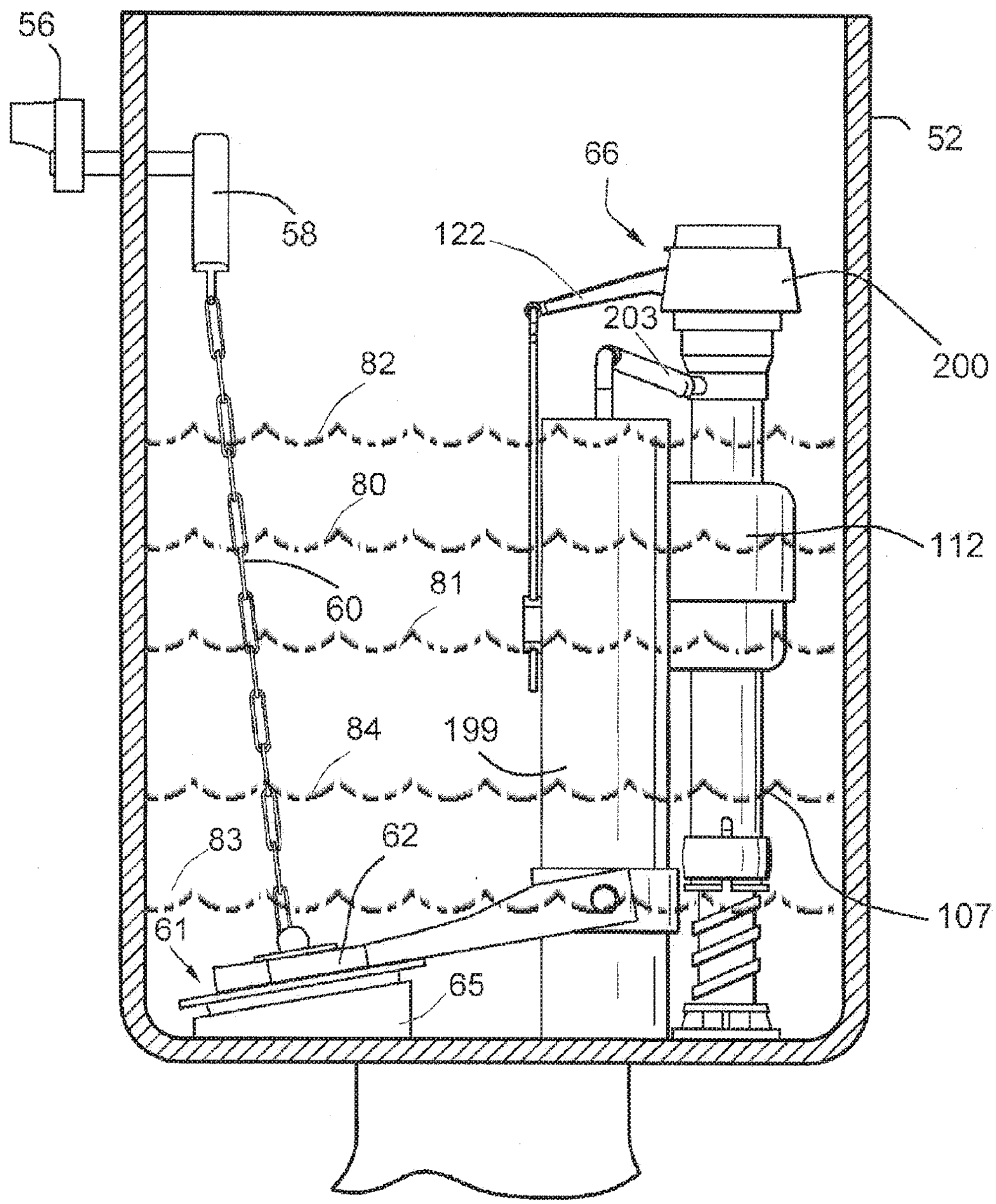


Fig. 8

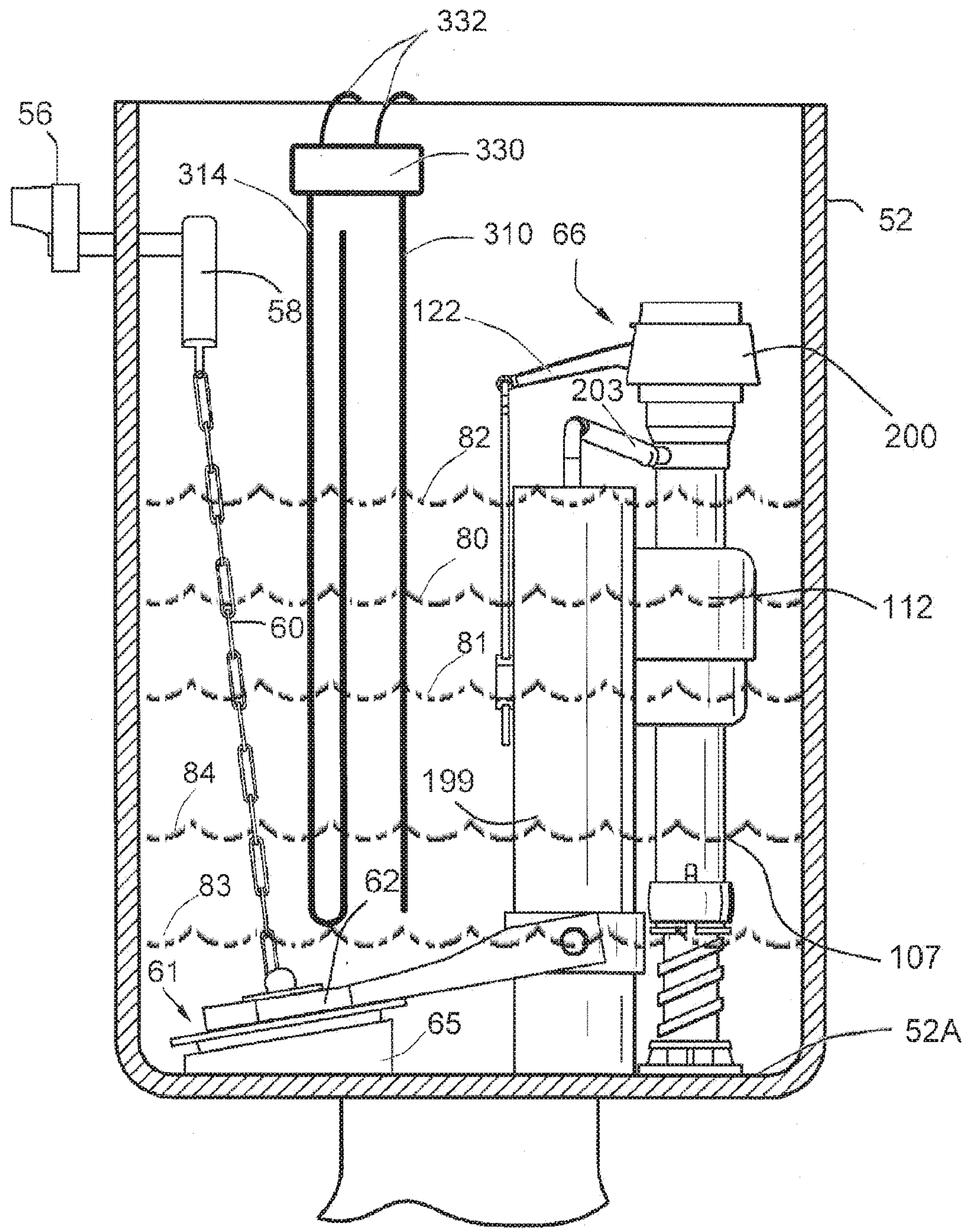

332
56
330
314
52
310
66
58
122
200
203
82
80
112
60
81
84
199
83
62
107
61
65
52A

Fig. 9

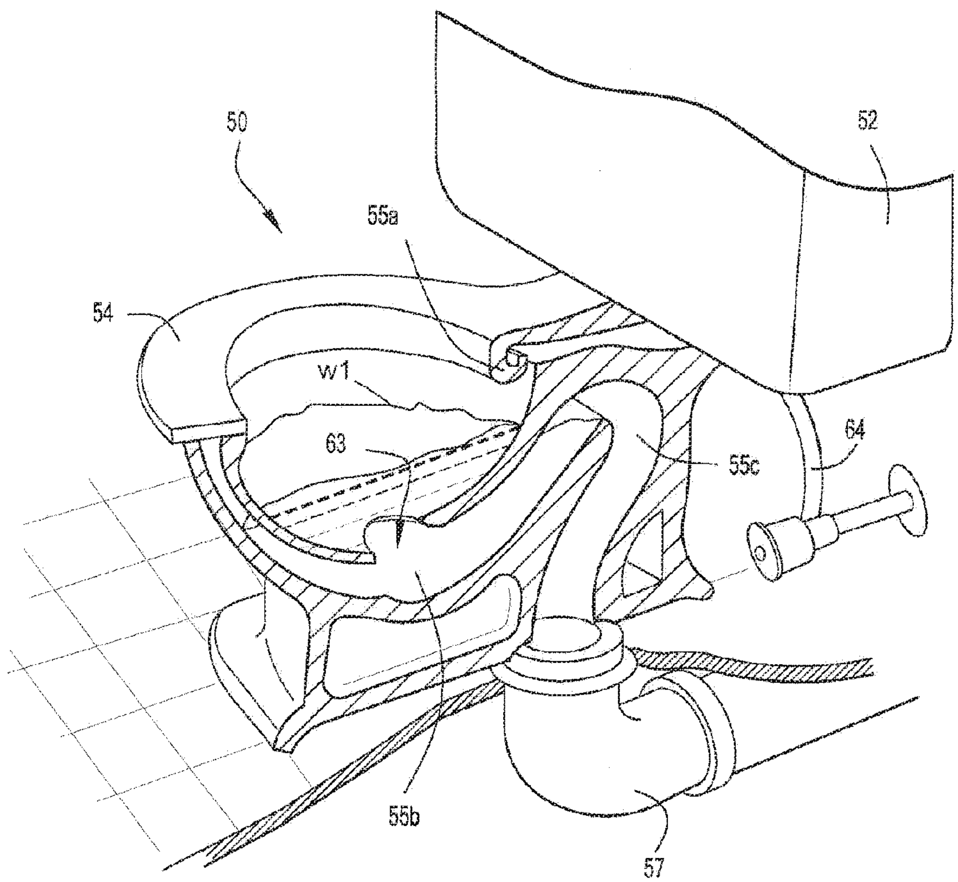


Fig. 10

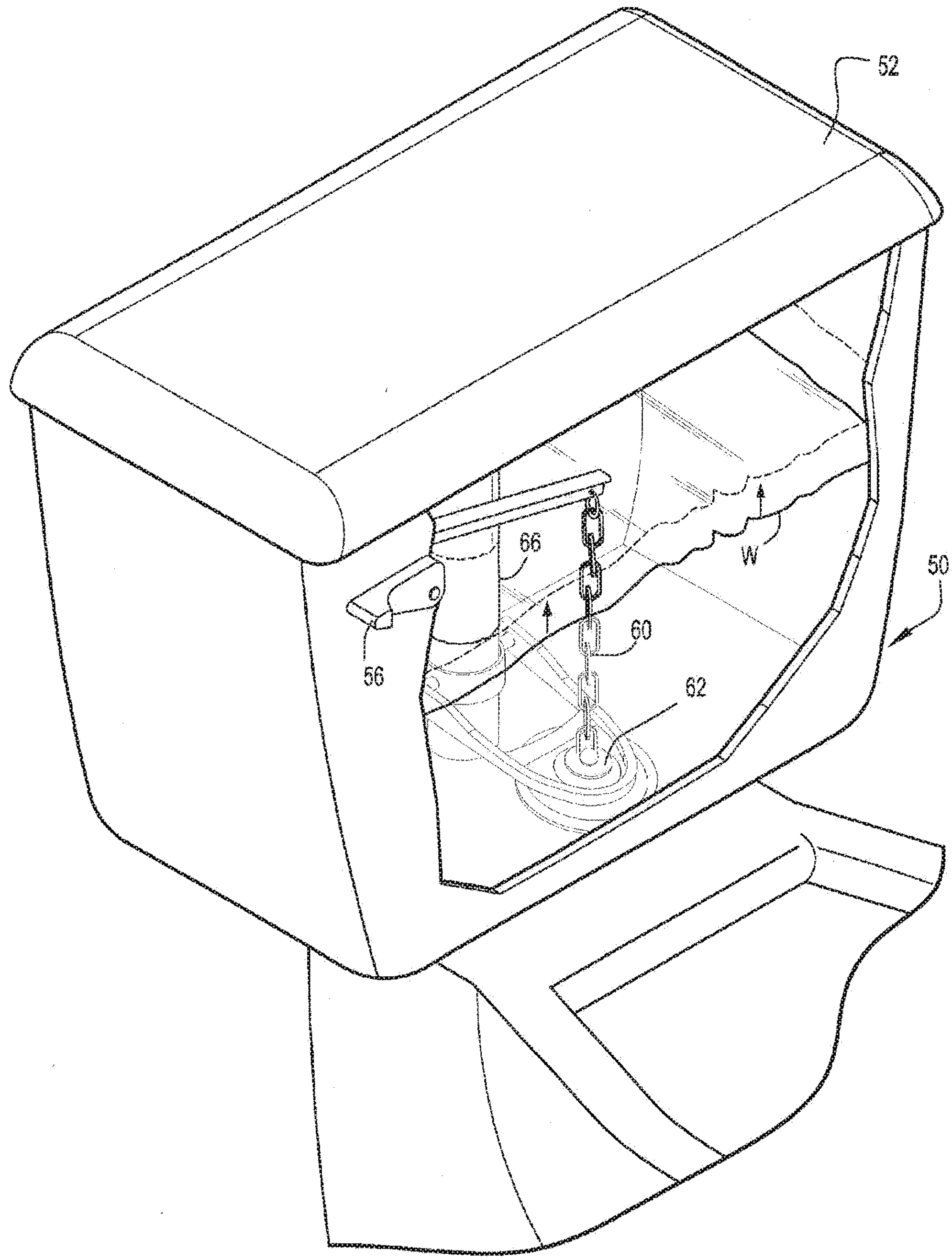


Fig. 11

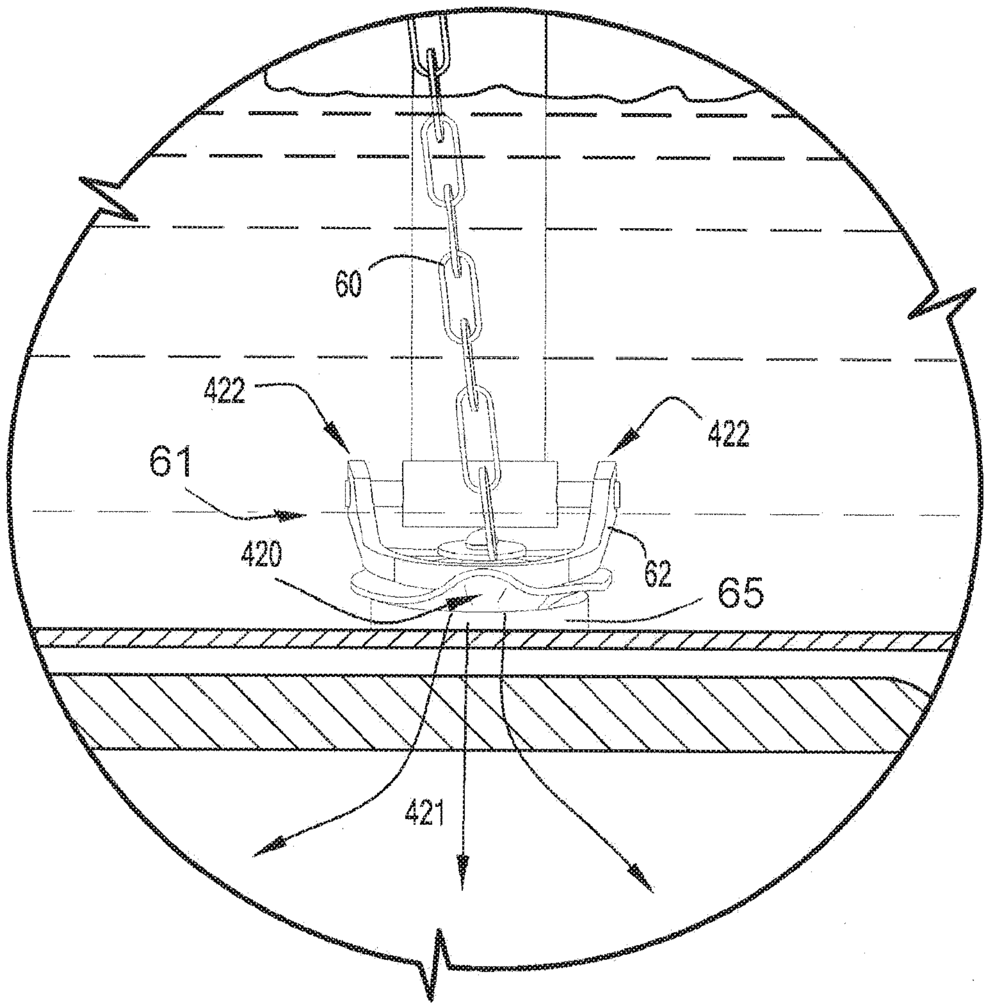


Fig. 12

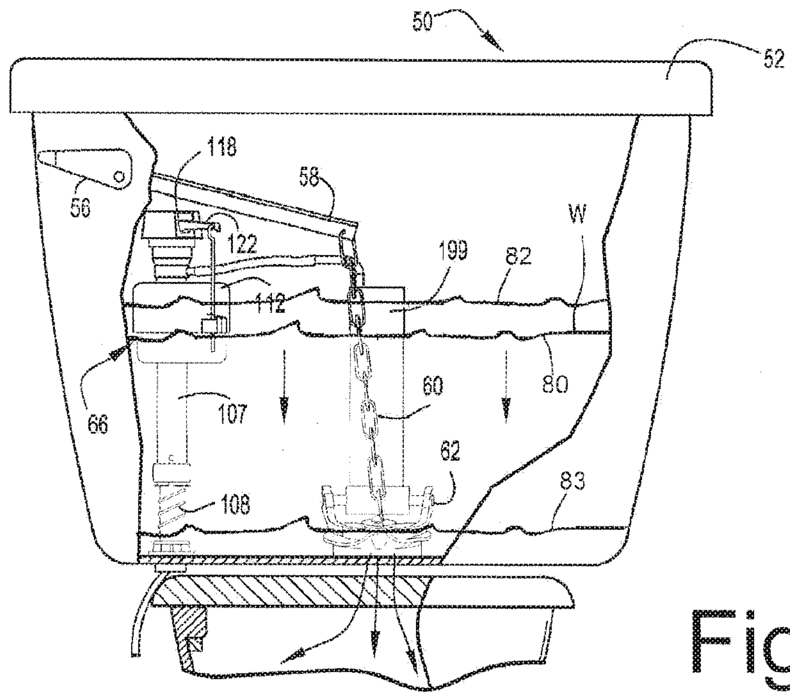


Fig. 13A

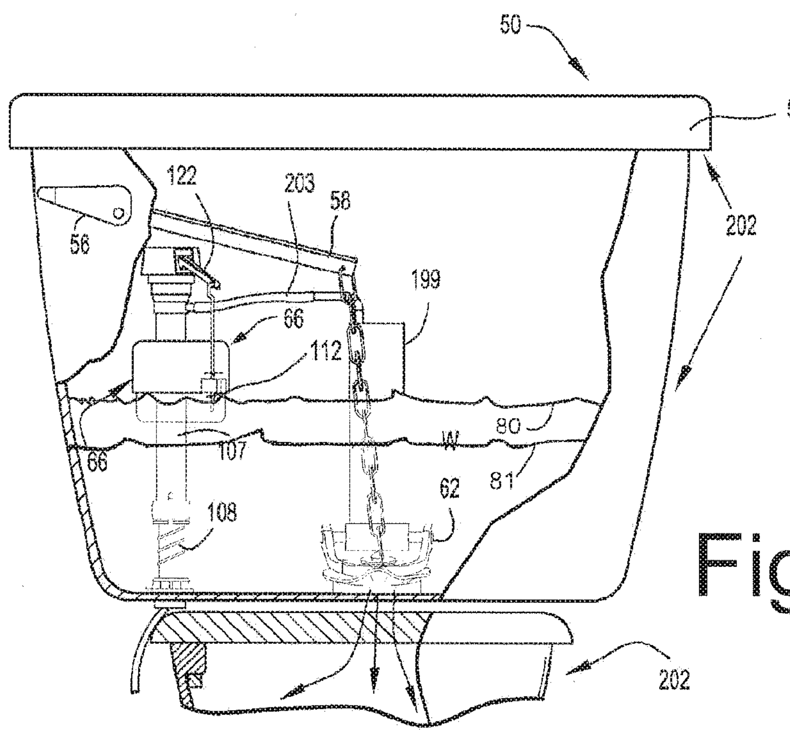


Fig. 13B

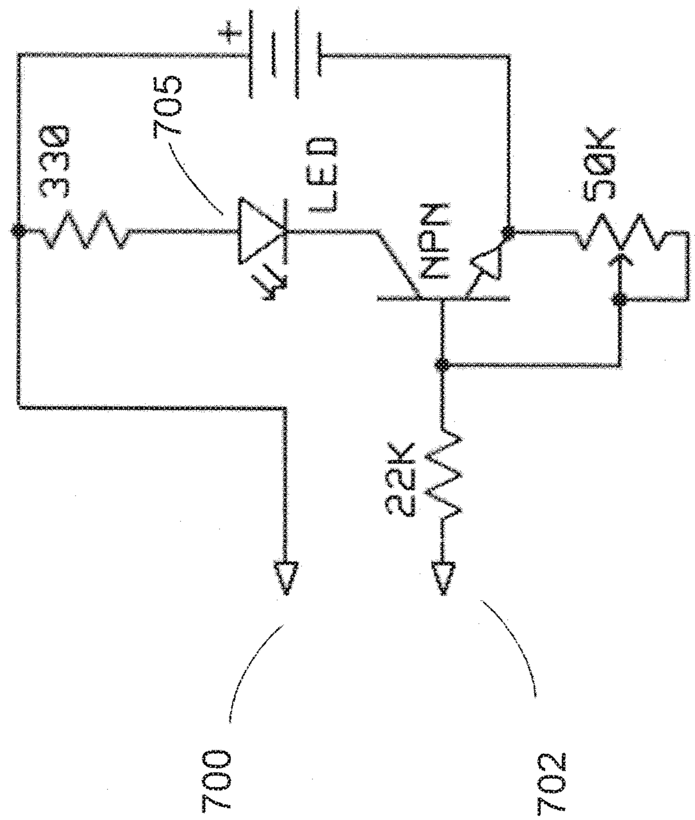


Fig.14

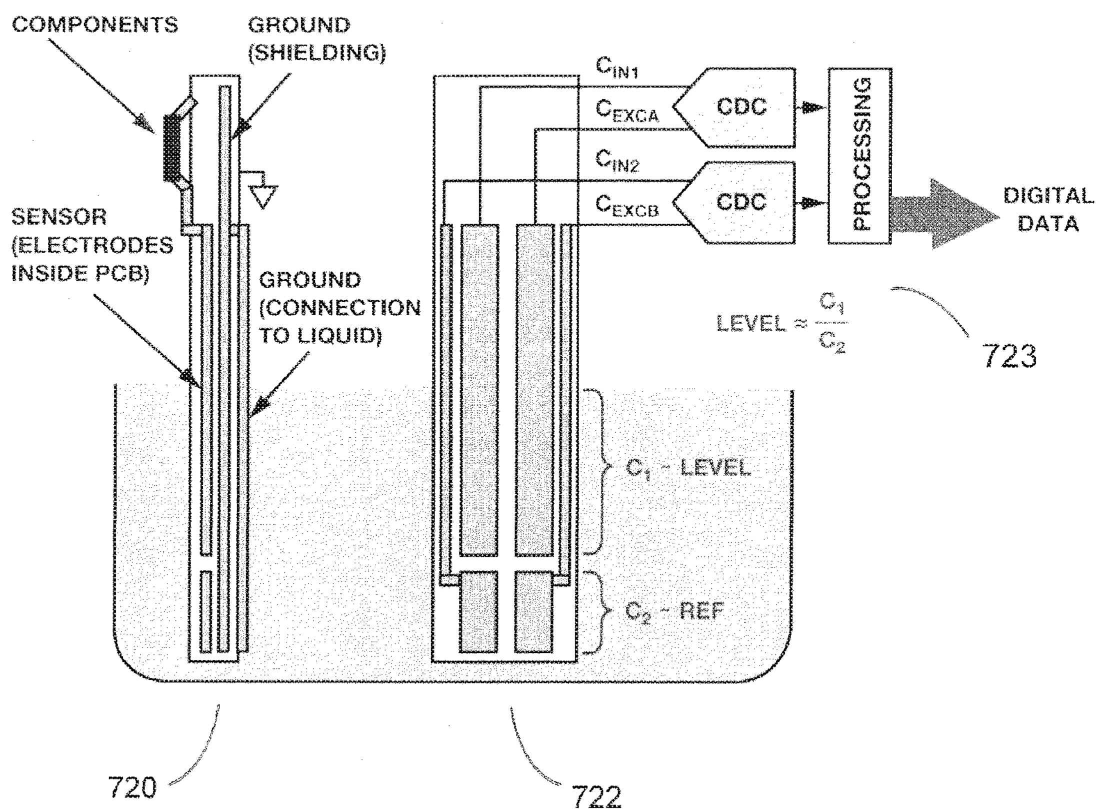

COMPONENTS
GROUND (SHIELDING)
SENSOR (ELECTRODES INSIDE PCB)
GROUND (CONNECTION TO LIQUID)
C_IN1
C_EXCA
C_IN2
C_EXCB
CDC
CDC
PROCESSING
DIGITAL DATA
LEVEL ≈ C1/C2
723
C1 - LEVEL
C2 - REF
720
722

Fig.15

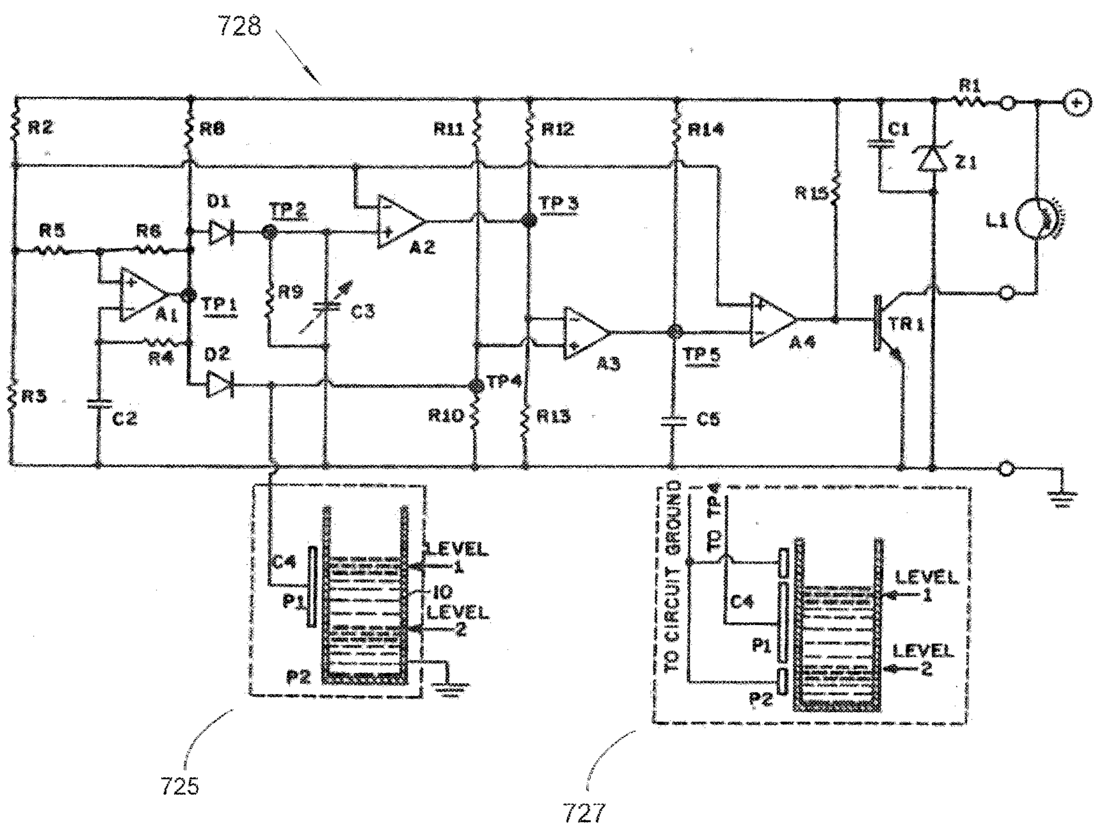

728
R2
R8
R11
R12
R14
R1
C1
Z1
R15
L1
D1
TP2
TP3
A2
R5
R6
TP1
A1
R9
C3
A3
TP5
A4
TR1
R4
D2
TP4
R3
C2
R10
R13
C5
C4
P1
LEVEL 1
10
LEVEL 2
P2
TO CIRCUIT GROUND
TO TP4
725
727

Fig. 15A

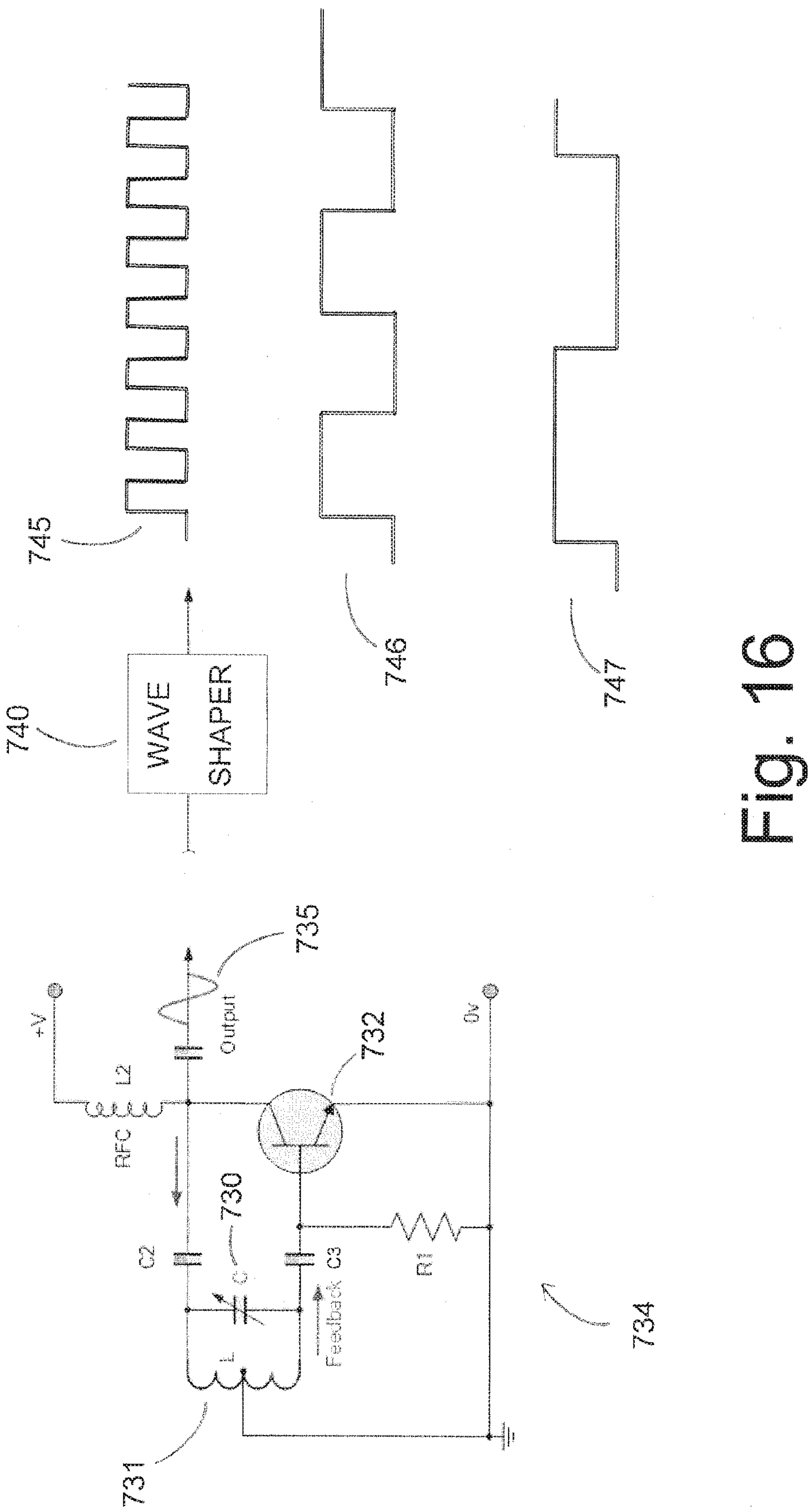

740
WAVE
SHAPER
745
746
747
+V
L2
RFC
Output
735
732
0v
C2
730
C
C3
R
Feedback
L
731
734

Fig. 16

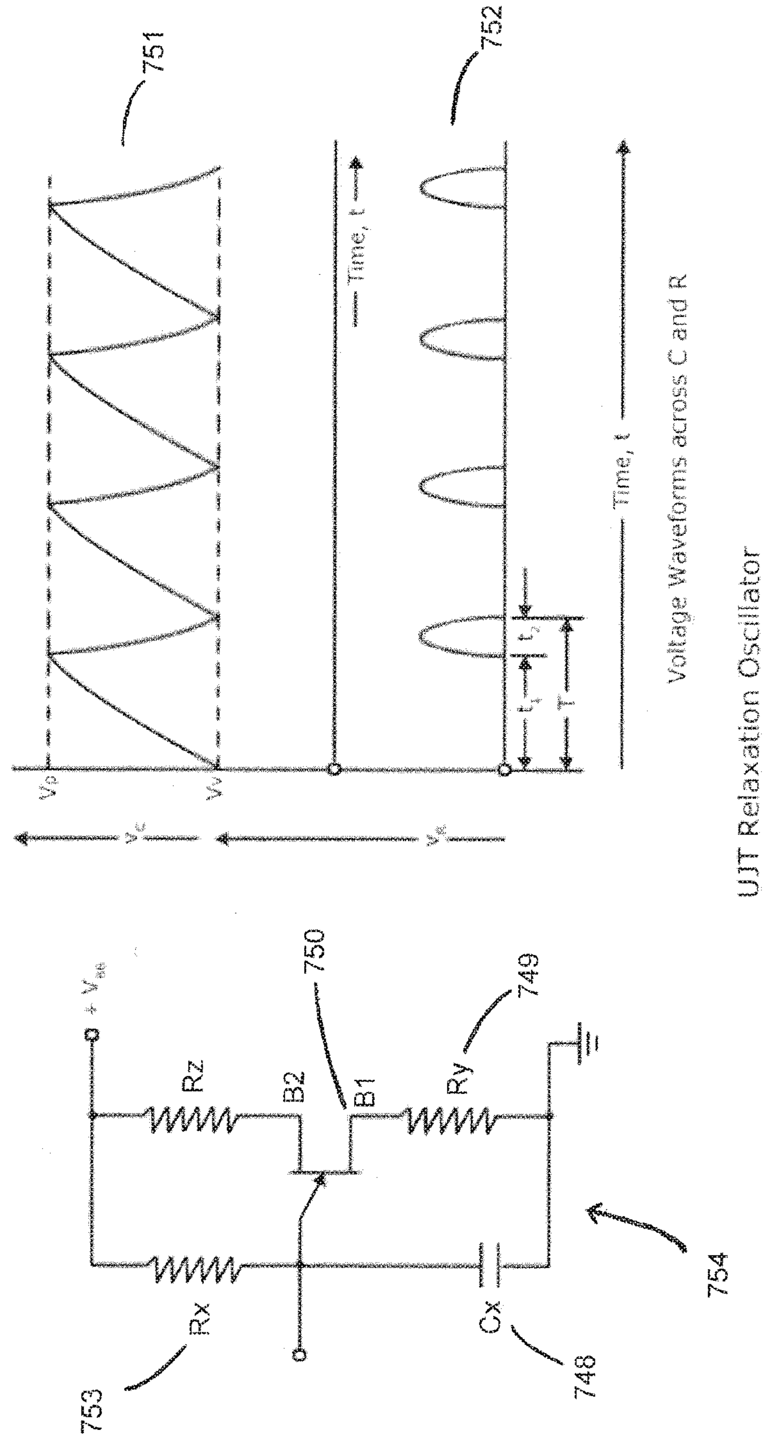

751
752
Time, t
Time, t
Voltage Waveforms across C and R
UJT Relaxation Oscillator
Vp
Vv
T
+ Vbb
Rz
B2
B1
Ry
Rx
Cx
750
749
753
748
754

Fig. 16A

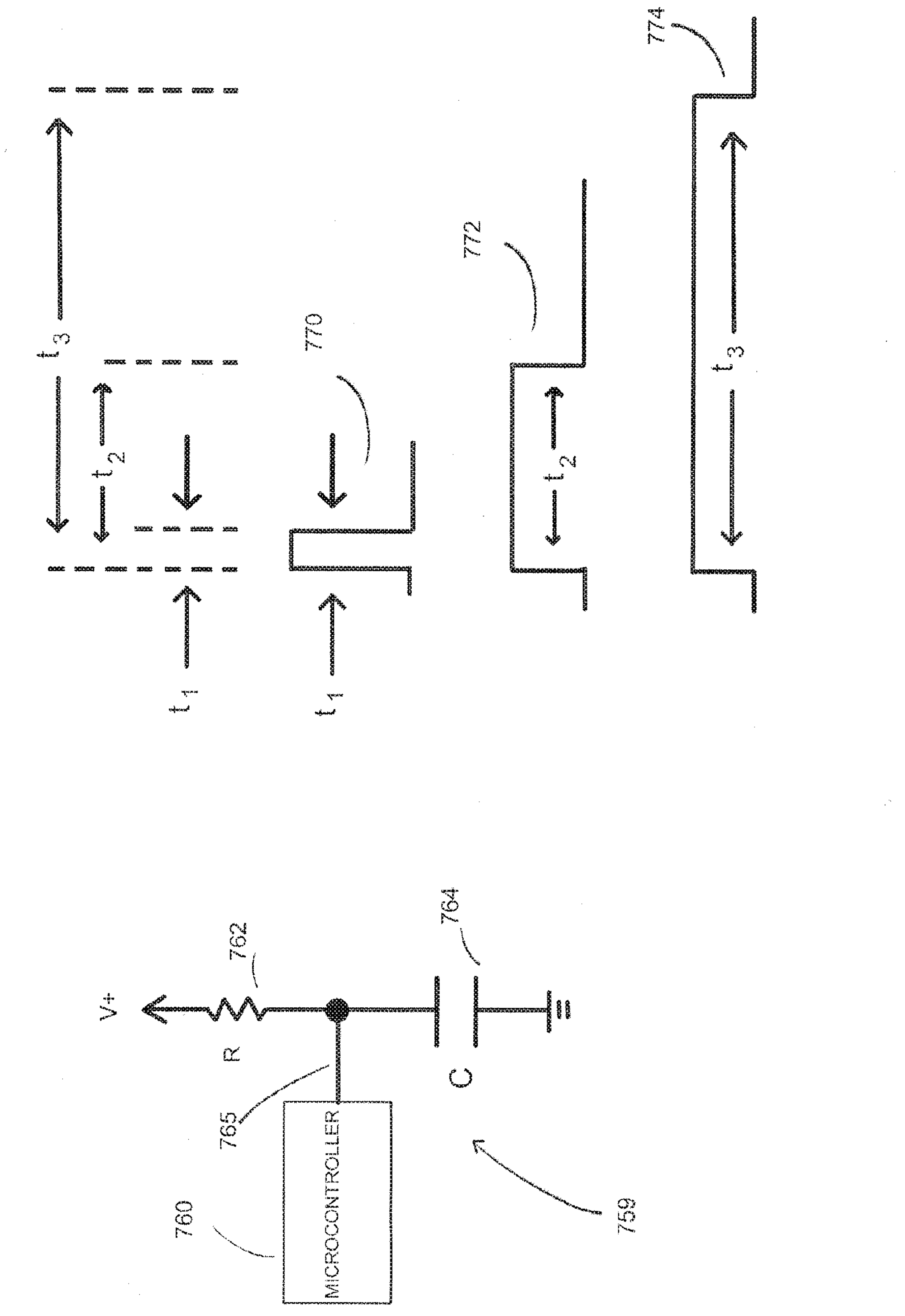

V+
R
762
764
C
765
MICROCONTROLLER
760
759
t_1
t_1
t_2
t_2
t_3
t_3
770
772
774

Fig. 16B

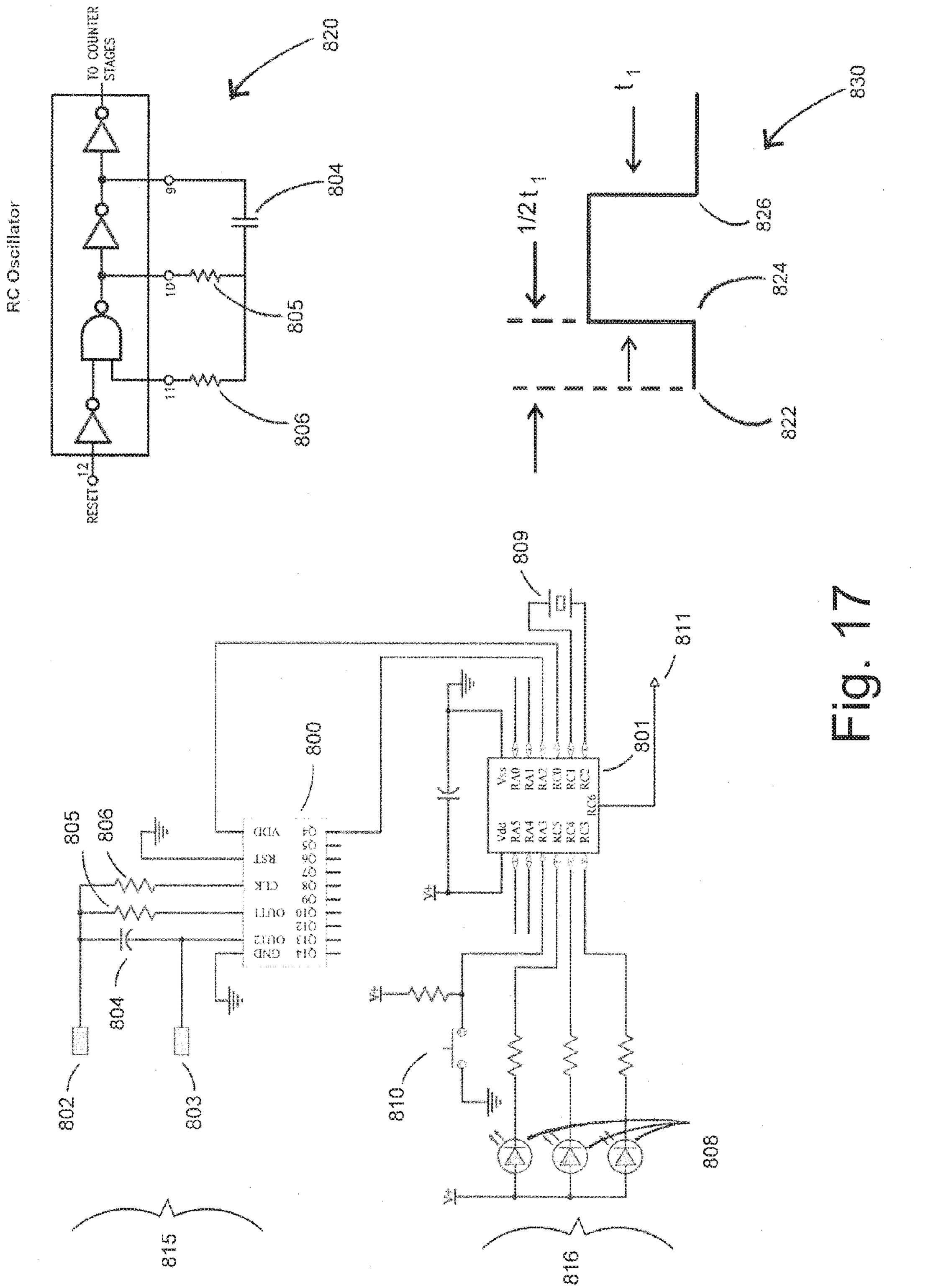

RC Oscillator
TO COUNTER STAGES
RESET
820
830
804
805
806
822
824
826
1/2 t 1
t 1
800
801
802
803
808
809
810
811
815
816
VDD
RST
CLK
OUT1
OUT2
GND
Vdd
Vss
RC6

Fig. 17

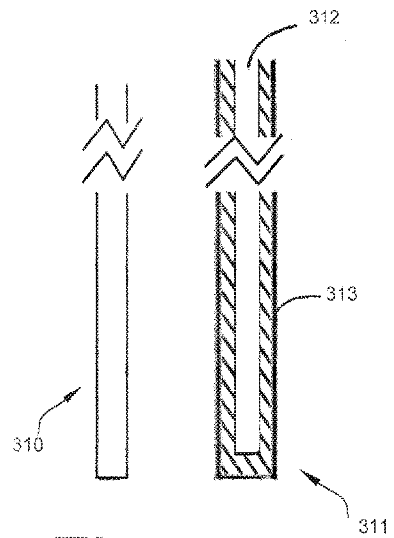


Fig.18A

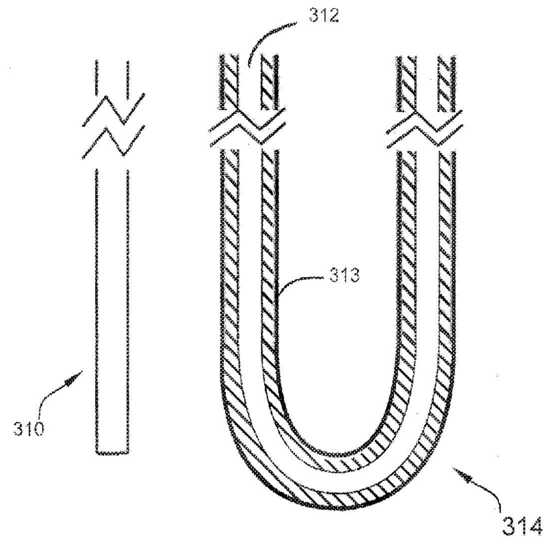


Fig.18B

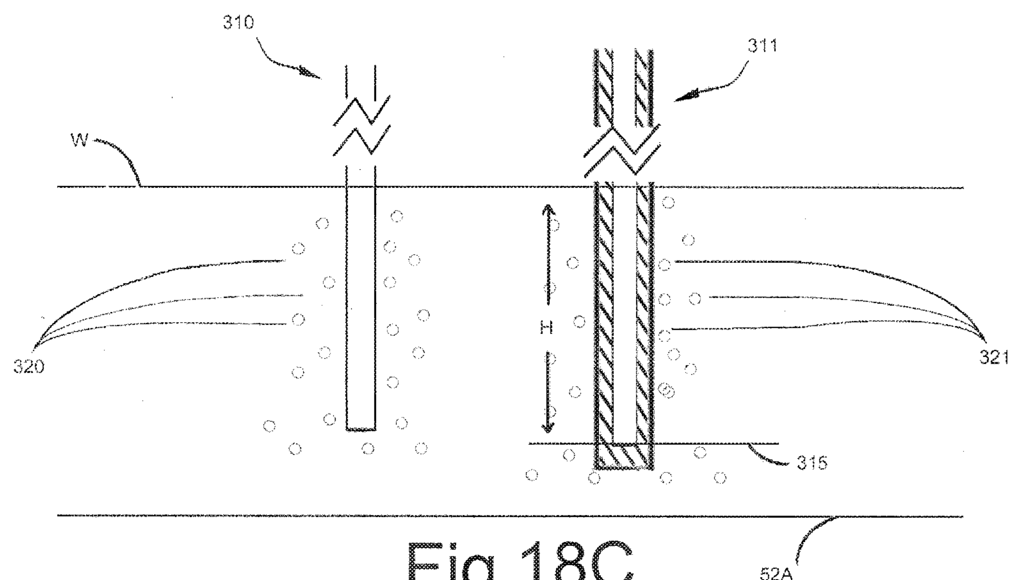


Fig.18C

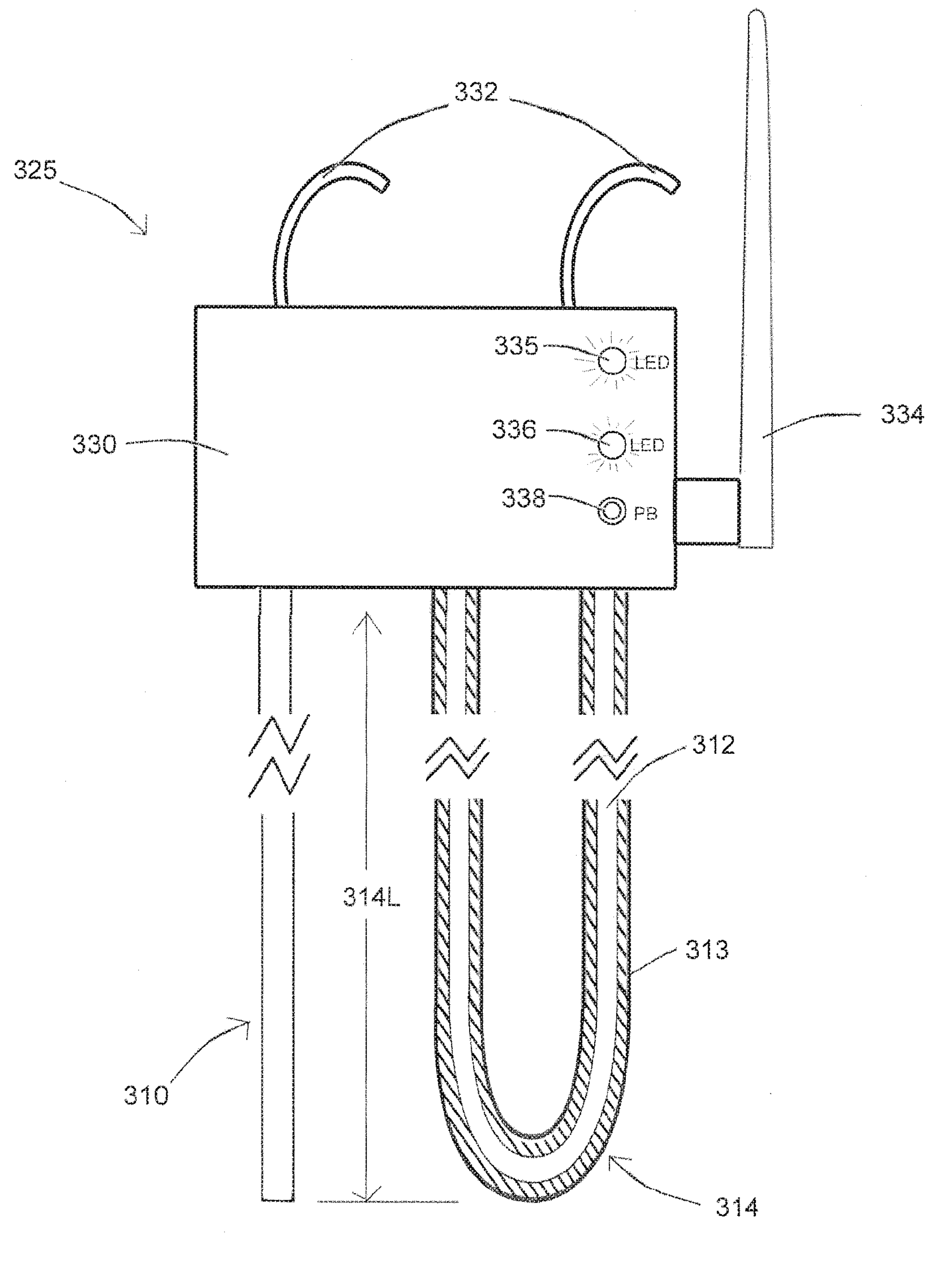


Fig. 19

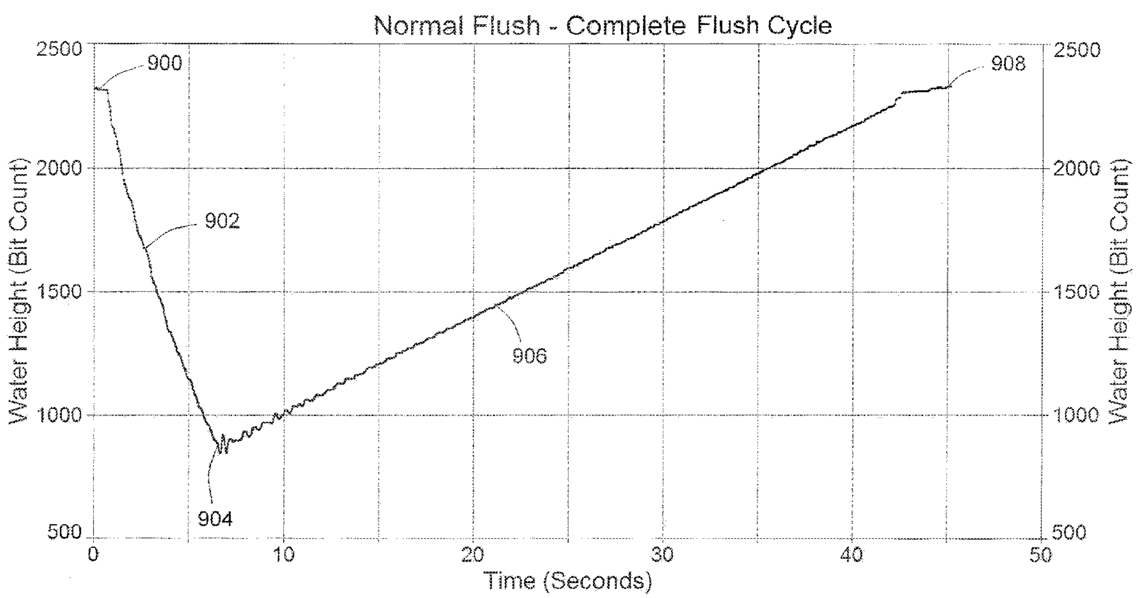
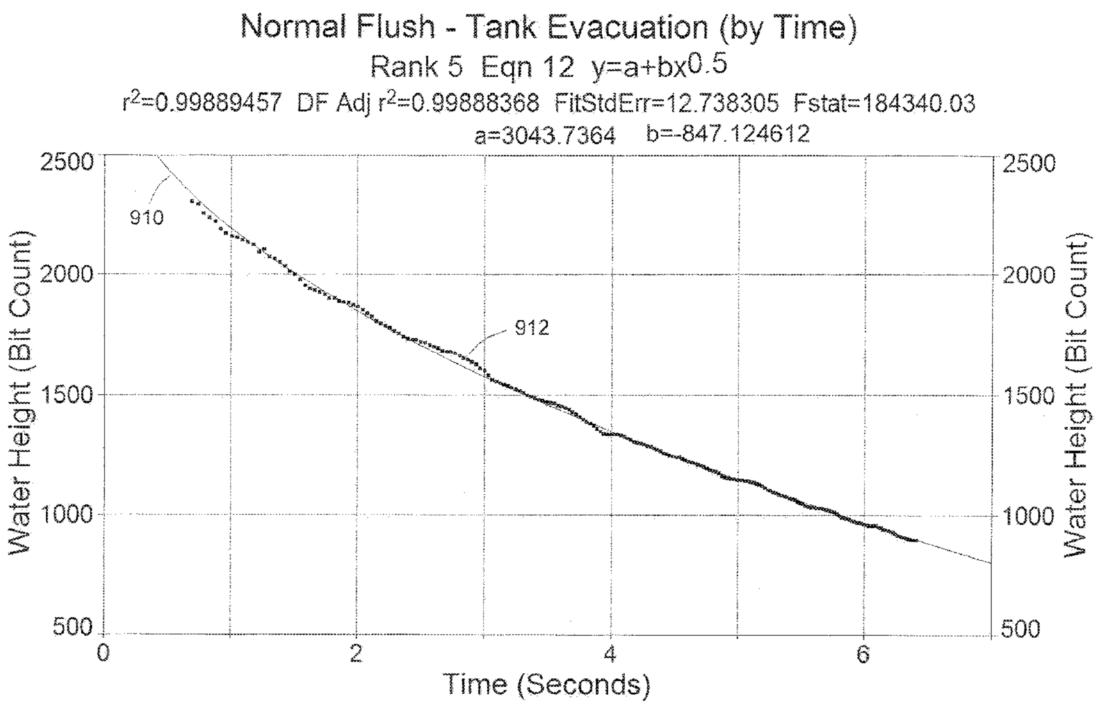
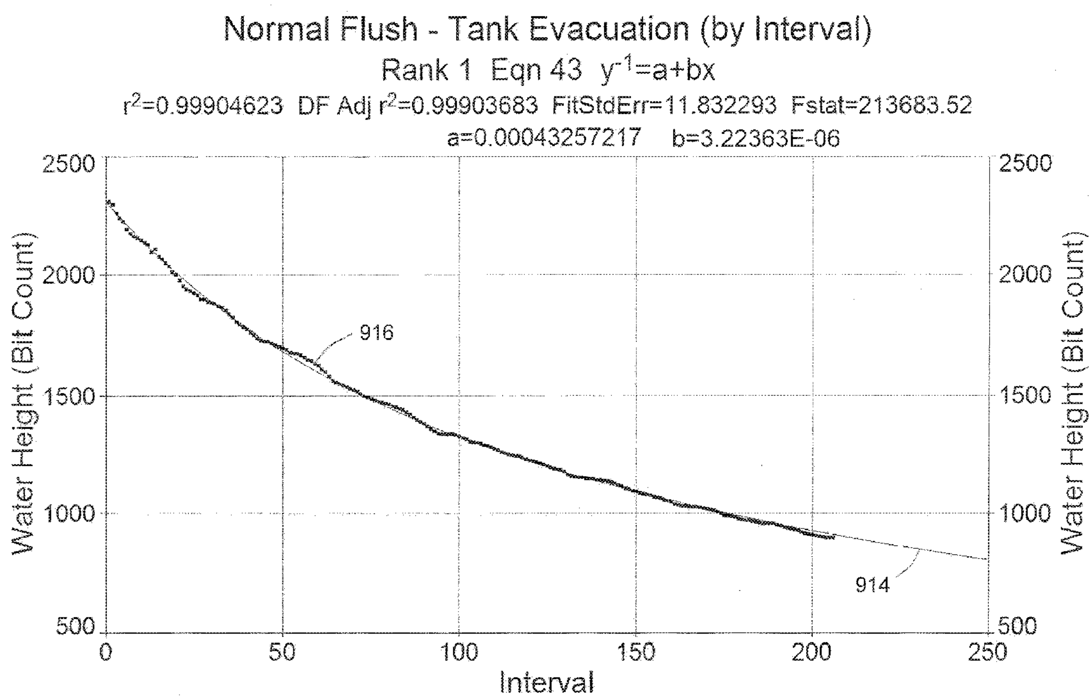

Normal Flush - Complete Flush Cycle
2500
2000
1500
1000
500
Water Height (Bit Count)
900
902
904
906
908
0
10
20
30
40
50
Time (Seconds)

Fig. 20



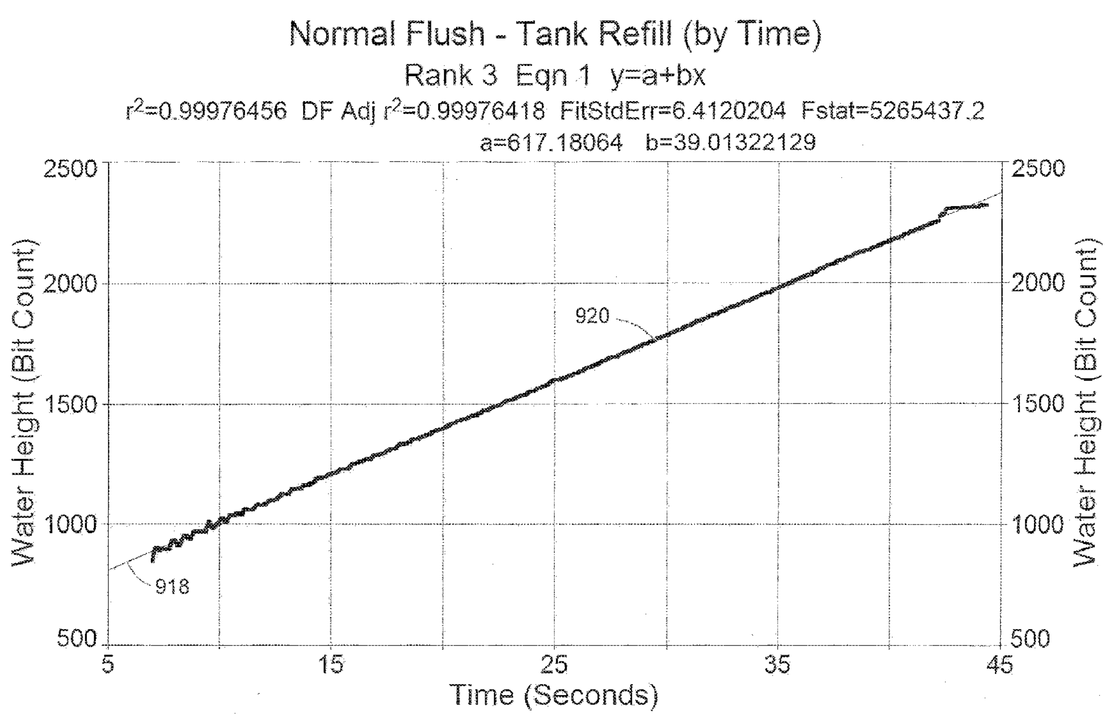
Normal Flush - Tank Evacuation (by Time)
Rank 5 Eqn 12 y=a+bx0.5
r2=0.99889457 DF Adj r2=0.99888368 FitStdErr=12.738305 Fstat=184340.03
a=3043.7364 b=-847.124612
2500
2000
1500
1000
500
910
912
Water Height (Bit Count)
0
2
4
6
Time (Seconds)

Fig. 20A



Normal Flush - Tank Evacuation (by Interval)
Rank 1 Eqn 43 $y^{-1}=a+bx$
r^2=0.99904623 DF Adj r^2=0.99903683 FitStdErr=11.832293 Fstat=213683.52
a=0.00043257217 b=3.22363E-06
2500
2000
1500
1000
500
0
50
100
150
200
250
Water Height (Bit Count)
Interval
916
914

Fig. 20B



Normal Flush - Tank Refill (by Time)
Rank 3 Eqn 1 y=a+bx
r2=0.99976456 DF Adj r2=0.99976418 FitStdErr=6.4120204 Fstat=5265437.2
a=617.18064 b=39.01322129
Water Height (Bit Count)
Time (Seconds)
2500
2000
1500
1000
500
5
15
25
35
45
920
918

Fig. 20C

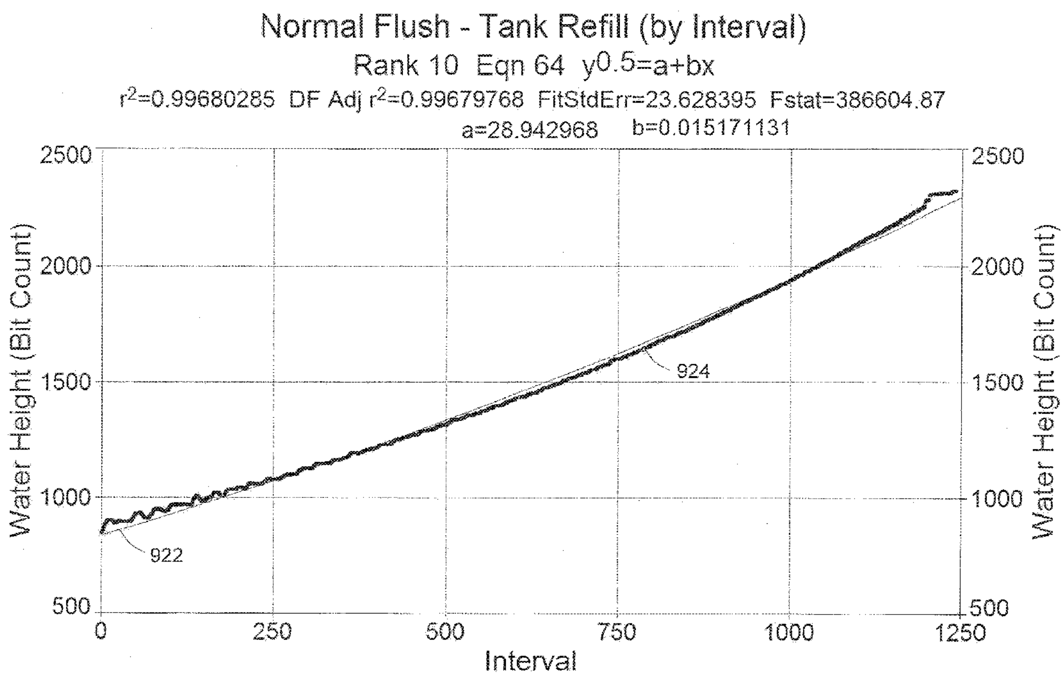

Normal Flush - Tank Refill (by Interval)
Rank 10 Eqn 64 y0.5=a+bx
r2=0.99680285 DF Adj r2=0.99679768 FitStdErr=23.628395 Fstat=386604.87
a=28.942968 b=0.015171131
Water Height (Bit Count)
Interval
2500
2000
1500
1000
500
0
250
500
750
1000
1250
922
924

Fig. 20D

Normal Flush – Complete Cycle

WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time
2320	0.046	1899	1.777	1543	3.155	1292	4.28	1104	5.233	958	6.052	911	6.771	898	7.484	915	8.215	971	8.974
2320	0.093	1898	1.815	1537	3.185	1287	4.306	1100	5.255	957	6.071	921	6.789	898	7.502	917	8.234	970	8.993
2321	0.139	1888	1.853	1532	3.216	1281	4.331	1095	5.277	957	6.09	923	6.808	898	7.52	920	8.252	970	9.013
2316	0.186	1884	1.891	1526	3.247	1274	4.357	1091	5.299	952	6.109	919	6.826	898	7.538	924	8.27	969	9.032
2315	0.232	1879	1.928	1520	3.277	1268	4.382	1085	5.321	948	6.128	914	6.844	897	7.556	928	8.289	969	9.051
2314	0.278	1871	1.966	1509	3.307	1260	4.408	1082	5.342	943	6.147	907	6.863	897	7.574	931	8.308	970	9.071
2314	0.324	1864	2.003	1501	3.337	1255	4.433	1079	5.364	939	6.166	899	6.881	898	7.592	937	8.326	970	9.09
2315	0.371	1851	2.04	1494	3.367	1250	4.458	1074	5.385	936	6.185	892	6.898	898	7.61	941	8.345	969	9.109
2315	0.417	1837	2.077	1488	3.397	1247	4.483	1070	5.407	933	6.203	882	6.916	898	7.628	946	8.364	969	9.129
2315	0.463	1824	2.113	1480	3.426	1243	4.507	1067	5.428	930	6.222	869	6.933	898	7.646	948	8.383	969	9.148
2314	0.51	1804	2.149	1477	3.456	1242	4.532	1062	5.449	923	6.24	859	6.951	899	7.664	949	8.402	971	9.168
2315	0.556	1794	2.185	1472	3.485	1237	4.557	1053	5.47	918	6.259	852	6.968	899	7.682	950	8.421	971	9.187
2315	0.602	1786	2.221	1468	3.515	1232	4.582	1050	5.491	914	6.277	849	6.985	899	7.7	951	8.44	971	9.207
2313	0.648	1776	2.256	1465	3.544	1225	4.606	1047	5.512	911	6.295	849	7.002	899	7.718	951	8.459	971	9.226
2310	0.695	1764	2.292	1456	3.573	1221	4.631	1037	5.533	908	6.313	852	7.019	900	7.736	952	8.478	971	9.245
2298	0.741	1752	2.327	1451	3.602	1217	4.655	1033	5.554	904	6.331	862	7.036	902	7.754	952	8.497	970	9.265
2262	0.786	1741	2.361	1446	3.631	1213	4.679	1032	5.574	902	6.349	872	7.053	905	7.772	951	8.516	968	9.284
2243	0.831	1732	2.396	1439	3.66	1207	4.703	1030	5.595	899	6.367	882	7.071	908	7.79	950	8.535	969	9.303
2225	0.875	1729	2.431	1431	3.689	1201	4.727	1029	5.616	898	6.385	889	7.089	913	7.808	948	8.554	968	9.323
2194	0.919	1727	2.465	1420	3.717	1197	4.751	1028	5.636	898	6.403	895	7.107	917	7.827	947	8.573	967	9.342
2175	0.963	1720	2.5	1409	3.745	1189	4.775	1027	5.657	898	6.421	899	7.125	922	7.845	944	8.592	967	9.362
2164	1.006	1715	2.534	1397	3.773	1187	4.799	1026	5.677	897	6.439	902	7.143	927	7.864	942	8.611	968	9.381
2157	1.049	1707	2.568	1388	3.801	1182	4.822	1022	5.698	895	6.457	903	7.161	932	7.882	941	8.63	969	9.4
2146	1.092	1699	2.602	1382	3.828	1176	4.846	1018	5.718	893	6.475	904	7.179	934	7.901	941	8.648	971	9.42
2138	1.135	1692	2.636	1374	3.856	1164	4.869	1016	5.738	890	6.493	904	7.197	934	7.92	940	8.667	977	9.439
2127	1.177	1680	2.669	1362	3.883	1159	4.892	1011	5.759	887	6.51	905	7.215	934	7.938	940	8.686	983	9.459
2095	1.219	1679	2.703	1350	3.91	1156	4.916	1007	5.779	887	6.528	905	7.233	934	7.957	941	8.705	991	9.479
2107	1.261	1679	2.737	1342	3.937	1152	4.939	1000	5.799	879	6.546	903	7.251	934	7.976	942	8.724	995	9.499
2077	1.303	1672	2.77	1337	3.964	1150	4.962	991	5.819	871	6.563	900	7.269	935	7.994	944	8.743	999	9.519
2067	1.344	1662	2.803	1338	3.991	1148	4.985	989	5.838	863	6.58	897	7.287	934	8.013	946	8.762	1006	9.539
2052	1.385	1651	2.836	1338	4.017	1145	5.007	987	5.858	858	6.598	895	7.305	932	8.032	949	8.781	1008	9.559
2036	1.426	1646	2.869	1337	4.044	1145	5.03	983	5.878	853	6.615	893	7.323	929	8.05	954	8.8	1006	9.579
2014	1.466	1637	2.902	1335	4.071	1142	5.053	978	5.897	849	6.632	893	7.341	925	8.069	958	8.819	1006	9.599
2002	1.506	1626	2.934	1328	4.097	1141	5.076	975	5.917	847	6.649	894	7.359	921	8.087	963	8.838	1002	9.619
1979	1.546	1611	2.967	1323	4.124	1139	5.099	972	5.936	848	6.666	895	7.376	917	8.106	968	8.857	996	9.639
1954	1.585	1603	2.999	1317	4.15	1134	5.121	970	5.956	851	6.683	896	7.394	915	8.124	969	8.877	991	9.659
1940	1.624	1582	3.03	1307	4.176	1131	5.144	968	5.975	856	6.7	897	7.412	914	8.142	969	8.896	987	9.679
1933	1.662	1564	3.062	1304	4.202	1126	5.167	965	5.994	869	6.717	898	7.43	914	8.16	969	8.916	984	9.698
1926	1.701	1558	3.093	1300	4.228	1120	5.189	961	6.014	881	6.735	900	7.448	915	8.179	970	8.935	984	9.718
1915	1.739	1552	3.124	1298	4.254	1113	5.211	959	6.033	897	6.753	899	7.466	914	8.197	971	8.954	983	9.738

Fig. 20E Page #1

Normal Flush – Complete Cycle

WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time
985	9.757	1036	10.57	1058	11.41	1097	12.27	1131	13.16	1166	14.08	1209	15.03	1251	16.01	1287	17.03	1331	18.07
987	9.777	1034	10.59	1059	11.43	1098	12.29	1135	13.18	1166	14.1	1209	15.06	1252	16.04	1288	17.05	1332	18.1
988	9.797	1033	10.61	1059	11.45	1100	12.31	1137	13.2	1167	14.13	1210	15.08	1251	16.06	1287	17.08	1334	18.12
991	9.817	1034	10.63	1059	11.47	1100	12.33	1141	13.23	1169	14.15	1209	15.1	1252	16.09	1289	17.1	1334	18.15
993	9.837	1034	10.65	1060	11.49	1100	12.36	1144	13.25	1169	14.17	1210	15.13	1251	16.11	1289	17.13	1334	18.18
994	9.856	1034	10.67	1061	11.51	1100	12.38	1146	13.27	1170	14.2	1209	15.15	1252	16.14	1290	17.16	1334	18.2
996	9.876	1034	10.69	1062	11.53	1099	12.4	1145	13.3	1171	14.22	1211	15.18	1252	16.16	1290	17.18	1334	18.23
998	9.896	1035	10.71	1063	11.55	1100	12.42	1146	13.32	1173	14.24	1210	15.2	1252	16.19	1290	17.21	1333	18.26
999	9.916	1037	10.73	1067	11.58	1100	12.44	1145	13.34	1173	14.27	1210	15.23	1253	16.21	1291	17.23	1334	18.28
1000	9.936	1039	10.75	1070	11.6	1100	12.47	1146	13.36	1176	14.29	1214	15.25	1257	16.24	1292	17.26	1335	18.31
1000	9.956	1042	10.77	1071	11.62	1100	12.49	1146	13.39	1180	14.31	1216	15.27	1258	16.26	1293	17.28	1334	18.34
1001	9.976	1044	10.8	1074	11.64	1100	12.51	1146	13.41	1185	14.34	1215	15.3	1259	16.29	1293	17.31	1335	18.36
1004	9.996	1044	10.82	1077	11.66	1100	12.53	1145	13.43	1187	14.36	1215	15.32	1260	16.31	1294	17.34	1335	18.39
1006	10.02	1044	10.84	1078	11.68	1101	12.55	1145	13.46	1187	14.39	1217	15.35	1259	16.34	1295	17.36	1337	18.42
1015	10.04	1044	10.86	1080	11.7	1102	12.58	1146	13.48	1189	14.41	1220	15.37	1260	16.36	1295	17.39	1338	18.44
1019	10.06	1043	10.88	1081	11.73	1104	12.6	1146	13.5	1192	14.43	1224	15.4	1261	16.39	1296	17.41	1340	18.47
1020	10.08	1042	10.9	1081	11.75	1108	12.62	1145	13.53	1192	14.46	1226	15.42	1261	16.41	1298	17.44	1342	18.5
1022	10.1	1040	10.92	1080	11.77	1110	12.64	1146	13.55	1192	14.48	1227	15.44	1263	16.44	1301	17.47	1343	18.52
1022	10.12	1037	10.94	1080	11.79	1112	12.66	1147	13.57	1191	14.5	1227	15.47	1265	16.46	1303	17.49	1345	18.55
1022	10.14	1037	10.96	1080	11.81	1114	12.69	1147	13.59	1191	14.53	1228	15.49	1267	16.49	1305	17.52	1347	18.58
1022	10.16	1037	10.98	1080	11.83	1116	12.71	1147	13.62	1191	14.55	1228	15.52	1268	16.52	1306	17.54	1350	18.61
1020	10.18	1037	11	1080	11.86	1118	12.73	1147	13.64	1192	14.58	1229	15.54	1269	16.54	1307	17.57	1351	18.63
1019	10.2	1038	11.02	1080	11.88	1120	12.75	1146	13.66	1191	14.6	1228	15.57	1270	16.57	1308	17.6	1353	18.66
1015	10.22	1041	11.05	1080	11.9	1120	12.78	1147	13.69	1190	14.62	1229	15.59	1271	16.59	1310	17.62	1353	18.69
1011	10.24	1048	11.07	1080	11.92	1122	12.8	1150	13.71	1191	14.65	1229	15.62	1270	16.62	1312	17.65	1353	18.71
1009	10.26	1055	11.09	1080	11.94	1125	12.82	1154	13.73	1191	14.67	1229	15.64	1270	16.64	1312	17.67	1354	18.74
1009	10.28	1059	11.11	1080	11.96	1126	12.84	1159	13.75	1191	14.7	1229	15.67	1271	16.67	1313	17.7	1354	18.77
1007	10.3	1061	11.13	1080	11.99	1127	12.87	1160	13.78	1192	14.72	1229	15.69	1270	16.69	1313	17.73	1354	18.79
1006	10.32	1062	11.15	1081	12.01	1127	12.89	1161	13.8	1193	14.74	1229	15.72	1270	16.72	1313	17.75	1354	18.82
1006	10.34	1062	11.17	1081	12.03	1127	12.91	1161	13.82	1195	14.77	1229	15.74	1270	16.74	1313	17.78	1354	18.85
1009	10.36	1062	11.19	1080	12.05	1127	12.93	1162	13.85	1196	14.79	1229	15.76	1272	16.77	1312	17.81	1354	18.88
1013	10.38	1063	11.21	1081	12.07	1127	12.96	1162	13.87	1198	14.81	1230	15.79	1273	16.8	1313	17.83	1355	18.9
1018	10.4	1061	11.24	1084	12.09	1125	12.98	1161	13.89	1199	14.84	1231	15.81	1276	16.82	1314	17.86	1357	18.93
1024	10.42	1061	11.26	1086	12.11	1125	13	1162	13.92	1202	14.86	1234	15.84	1277	16.85	1315	17.88	1359	18.96
1029	10.44	1061	11.28	1087	12.14	1124	13.02	1162	13.94	1203	14.89	1237	15.86	1281	16.87	1316	17.91	1361	18.98
1035	10.46	1061	11.3	1089	12.16	1124	13.05	1162	13.96	1204	14.91	1239	15.89	1284	16.9	1319	17.94	1363	19.01
1037	10.48	1059	11.32	1091	12.18	1124	13.07	1162	13.99	1205	14.94	1244	15.91	1286	16.92	1322	17.96	1365	19.04
1037	10.51	1059	11.34	1093	12.2	1124	13.09	1163	14.01	1205	14.96	1247	15.94	1288	16.95	1325	17.99	1365	19.07
1036	10.53	1059	11.36	1094	12.22	1124	13.11	1164	14.03	1206	14.98	1249	15.96	1288	16.97	1327	18.02	1366	19.09
1037	10.55	1058	11.38	1096	12.25	1127	13.14	1164	14.06	1206	15.01	1251	15.99	1288	17	1329	18.04	1366	19.12

Fig. 20E Page #2

Normal Flush – Complete Cycle

WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time
1365	19.15	1410	20.26	1454	21.41	1498	22.59	1548	23.81	1600	25.07	1649	26.36	1698	27.7	1751	29.08	1809	30.51
1368	19.18	1412	20.29	1454	21.43	1501	22.62	1550	23.84	1600	25.1	1652	26.4	1698	27.74	1753	29.12	1810	30.55
1368	19.2	1414	20.32	1454	21.46	1503	22.65	1552	23.87	1600	25.13	1653	26.43	1700	27.77	1755	29.15	1811	30.58
1370	19.23	1416	20.34	1455	21.49	1505	22.68	1553	23.9	1602	25.16	1653	26.46	1702	27.81	1757	29.19	1811	30.62
1372	19.26	1417	20.37	1454	21.52	1505	22.71	1554	23.93	1602	25.19	1653	26.5	1704	27.84	1760	29.22	1812	30.65
1373	19.29	1418	20.4	1456	21.55	1506	22.74	1554	23.96	1603	25.23	1654	26.53	1706	27.87	1761	29.26	1815	30.69
1373	19.31	1418	20.43	1459	21.58	1507	22.77	1555	23.99	1605	25.26	1655	26.56	1707	27.91	1763	29.29	1817	30.73
1373	19.34	1419	20.46	1461	21.61	1510	22.8	1554	24.02	1607	25.29	1656	26.59	1707	27.94	1764	29.33	1819	30.76
1373	19.37	1420	20.49	1461	21.64	1513	22.83	1555	24.05	1609	25.32	1658	26.63	1709	27.98	1764	29.37	1821	30.8
1374	19.4	1420	20.51	1462	21.67	1514	22.86	1555	24.09	1610	25.35	1660	26.66	1711	28.01	1765	29.4	1824	30.84
1375	19.42	1421	20.54	1463	21.7	1515	22.89	1556	24.12	1610	25.39	1662	26.69	1712	28.04	1765	29.44	1824	30.87
1376	19.45	1422	20.57	1464	21.73	1515	22.92	1557	24.15	1610	25.42	1663	26.73	1716	28.08	1766	29.47	1824	30.91
1380	19.48	1424	20.6	1469	21.76	1515	22.95	1559	24.18	1611	25.45	1664	26.76	1716	28.11	1769	29.51	1825	30.95
1384	19.51	1429	20.63	1472	21.79	1515	22.98	1563	24.21	1611	25.48	1664	26.79	1716	28.15	1772	29.54	1827	30.98
1386	19.53	1431	20.66	1474	21.81	1515	23.01	1565	24.24	1613	25.52	1665	26.83	1718	28.18	1775	29.58	1828	31.02
1387	19.56	1431	20.69	1475	21.84	1517	23.04	1567	24.27	1616	25.55	1666	26.86	1718	28.22	1776	29.61	1831	31.06
1387	19.59	1431	20.71	1474	21.87	1519	23.07	1567	24.3	1618	25.58	1668	26.89	1719	28.25	1776	29.65	1832	31.09
1387	19.62	1431	20.74	1474	21.9	1520	23.1	1568	24.34	1619	25.61	1671	26.93	1720	28.29	1777	29.68	1833	31.13
1388	19.64	1431	20.77	1475	21.93	1520	23.13	1569	24.37	1620	25.64	1672	26.96	1722	28.32	1777	29.72	1835	31.17
1388	19.67	1431	20.8	1475	21.96	1521	23.16	1570	24.4	1620	25.68	1676	26.99	1722	28.35	1778	29.76	1836	31.2
1389	19.7	1432	20.83	1474	21.99	1523	23.19	1572	24.43	1621	25.71	1679	27.03	1723	28.39	1781	29.79	1836	31.24
1391	19.73	1432	20.86	1475	22.02	1523	23.22	1573	24.46	1622	25.74	1679	27.06	1724	28.42	1783	29.83	1838	31.28
1392	19.76	1434	20.89	1477	22.05	1525	23.25	1575	24.49	1623	25.77	1680	27.1	1726	28.46	1783	29.86	1841	31.31
1393	19.78	1434	20.91	1480	22.08	1528	23.28	1576	24.52	1625	25.81	1681	27.13	1728	28.49	1784	29.9	1844	31.35
1394	19.81	1435	20.94	1482	22.11	1530	23.31	1577	24.56	1628	25.84	1680	27.16	1731	28.53	1785	29.93	1845	31.39
1395	19.84	1436	20.97	1483	22.14	1531	23.34	1577	24.59	1630	25.87	1681	27.2	1732	28.56	1786	29.97	1846	31.42
1394	19.87	1435	21	1483	22.17	1531	23.38	1577	24.62	1630	25.9	1681	27.23	1733	28.6	1788	30.01	1847	31.46
1394	19.89	1435	21.03	1484	22.2	1531	23.41	1578	24.65	1631	25.94	1682	27.26	1734	28.63	1789	30.04	1847	31.5
1394	19.92	1437	21.06	1484	22.23	1532	23.44	1580	24.68	1631	25.97	1683	27.3	1736	28.67	1791	30.08	1848	31.53
1394	19.95	1439	21.09	1486	22.26	1534	23.47	1583	24.71	1631	26	1687	27.33	1738	28.7	1793	30.11	1848	31.57
1395	19.98	1441	21.12	1489	22.29	1536	23.5	1586	24.75	1634	26.04	1688	27.36	1738	28.73	1794	30.15	1851	31.61
1397	20.01	1445	21.14	1491	22.32	1537	23.53	1590	24.78	1636	26.07	1689	27.4	1740	28.77	1794	30.18	1853	31.64
1399	20.03	1446	21.17	1491	22.35	1539	23.56	1592	24.81	1637	26.1	1692	27.43	1740	28.8	1797	30.22	1854	31.68
1400	20.06	1447	21.2	1492	22.38	1539	23.59	1594	24.84	1638	26.13	1693	27.47	1742	28.84	1799	30.26	1855	31.72
1403	20.09	1447	21.23	1492	22.41	1539	23.62	1596	24.87	1638	26.17	1694	27.5	1744	28.87	1802	30.29	1856	31.76
1405	20.12	1449	21.26	1493	22.44	1540	23.65	1598	24.91	1639	26.2	1695	27.53	1747	28.91	1802	30.33	1858	31.79
1405	20.15	1449	21.29	1493	22.47	1540	23.68	1599	24.94	1639	26.23	1696	27.57	1749	28.94	1803	30.36	1862	31.83
1407	20.17	1449	21.32	1493	22.5	1539	23.71	1600	24.97	1641	26.26	1696	27.6	1749	28.98	1804	30.4	1864	31.87
1407	20.2	1451	21.35	1494	22.53	1540	23.74	1600	25	1645	26.3	1697	27.64	1749	29.01	1805	30.44	1863	31.9
1408	20.23	1452	21.38	1496	22.56	1543	23.78	1600	25.03	1647	26.33	1698	27.67	1750	29.05	1806	30.47	1864	31.94

Fig. 20E Page #3

Normal Flush – Complete Cycle

WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time	WH	Time
1865	31.98	1925	33.5	1982	35.06	2043	36.67	2110	38.33	2174	40.05	2241	41.81	2311	43.65
1866	32.02	1976	33.53	1985	35.1	2046	36.71	2114	38.38	2175	40.09	2243	41.86	2311	43.69
1867	32.05	1925	33.57	1986	35.14	2047	36.75	2117	38.42	2178	40.14	2245	41.9	2310	43.74
1870	32.09	1925	33.61	1987	35.18	2050	36.79	2119	38.46	2179	40.18	2245	41.95	2311	43.79
1871	32.13	1926	33.65	1990	35.22	2056	36.83	2121	38.5	2180	40.22	2246	41.99	2311	43.83
1871	32.17	1928	33.69	1992	35.26	2057	36.87	2121	38.55	2181	40.27	2248	42.04	2311	43.88
1872	32.2	1930	33.73	1994	35.3	2057	36.92	2123	38.59	2183	40.31	2250	42.08	2312	43.93
1873	32.24	1932	33.76	1995	35.34	2058	36.96	2125	38.63	2183	40.35	2251	42.13	2315	43.97
1875	32.28	1933	33.8	1995	35.38	2058	37	2126	38.67	2186	40.4	2254	42.17	2317	44.02
1877	32.32	1935	33.84	1998	35.42	2060	37.04	2126	38.72	2187	40.44	2274	42.22	2319	44.06
1879	32.35	1938	33.88	1998	35.46	2064	37.08	2127	38.76	2188	40.48	2279	42.27	2321	44.11
1881	32.39	1941	33.92	2000	35.5	2065	37.12	2129	38.8	2189	40.53	2280	42.31	2321	44.16
1883	32.43	1942	33.96	2001	35.54	2067	37.16	2130	38.84	2192	40.57	2283	42.36	2321	44.2
1883	32.47	1942	34	2001	35.58	2069	37.2	2133	38.89	2196	40.62	2284	42.4	2321	44.25
1885	32.5	1944	34.04	2004	35.62	2071	37.25	2133	38.93	2199	40.66	2284	42.45	2322	44.3
1887	32.54	1945	34.08	2009	35.66	2072	37.29	2134	38.97	2200	40.7	2303	42.49	2323	44.34
1888	32.58	1946	34.11	2010	35.7	2073	37.33	2135	39.01	2201	40.75	2304	42.54	2324	44.39
1889	32.62	1948	34.15	2010	35.74	2073	37.37	2135	39.06	2201	40.79	2305	42.59	2323	44.44
1890	32.66	1950	34.19	2012	35.78	2073	37.41	2138	39.1	2202	40.84	2305	42.63	2324	44.48
1893	32.69	1951	34.23	2012	35.82	2075	37.45	2139	39.14	2206	40.88	2304	42.68	2324	44.53
1895	32.73	1955	34.27	2013	35.86	2078	37.49	2144	39.18	2209	40.92	2305	42.72	2324	44.58
1896	32.77	1957	34.31	2016	35.9	2079	37.54	2145	39.23	2209	40.97	2307	42.77	2324	44.62
1898	32.81	1957	34.35	2018	35.94	2081	37.58	2146	39.27	2210	41.01	2307	42.82	2322	44.67
1899	32.85	1958	34.39	2020	35.98	2087	37.62	2148	39.31	2212	41.06	2307	42.86	2322	44.71
1901	32.88	1959	34.43	2021	36.02	2089	37.66	2148	39.36	2212	41.1	2307	42.91	2322	44.76
1902	32.92	1962	34.47	2022	36.06	2091	37.7	2150	39.4	2216	41.15	2308	42.96	2322	44.81
1904	32.96	1963	34.51	2022	36.1	2091	37.75	2150	39.44	2218	41.19	2309	43	2325	44.85
1904	33	1963	34.54	2022	36.14	2092	37.79	2153	39.49	2219	41.23	2309	43.05	2328	44.9
1905	33.04	1964	34.58	2025	36.18	2092	37.83	2154	39.53	2221	41.28	2309	43.09	2330	44.95
1906	33.07	1964	34.62	2026	36.22	2092	37.87	2155	39.57	2223	41.32	2308	43.14	2330	44.99
1907	33.11	1966	34.66	2028	36.26	2093	37.91	2158	39.62	2223	41.37	2309	43.19	2331	45.04
1909	33.15	1970	34.7	2030	36.3	2095	37.95	2160	39.66	2224	41.41	2310	43.23	2330	45.09
1911	33.19	1974	34.74	2031	36.34	2098	38	2163	39.7	2227	41.46	2309	43.28	2331	45.13
1913	33.23	1974	34.78	2032	36.38	2102	38.04	2165	39.74	2231	41.5	2309	43.32		
1914	33.26	1975	34.82	2034	36.42	2104	38.08	2165	39.79	2232	41.55	2310	43.37		
1916	33.3	1976	34.86	2037	36.47	2105	38.12	2166	39.83	2233	41.59	2310	43.42		
1916	33.34	1978	34.9	2039	36.51	2104	38.16	2167	39.87	2233	41.64	2311	43.46		
1917	33.38	1979	34.94	2041	36.55	2106	38.21	2171	39.92	2235	41.68	2310	43.51		
1920	33.42	1980	34.98	2041	36.59	2107	38.25	2172	39.96	2238	41.73	2310	43.56		
1923	33.46	1982	35.02	2043	36.63	2107	38.29	2172	40.01	2239	41.77	2310	43.6		

Fig. 20E Page #4

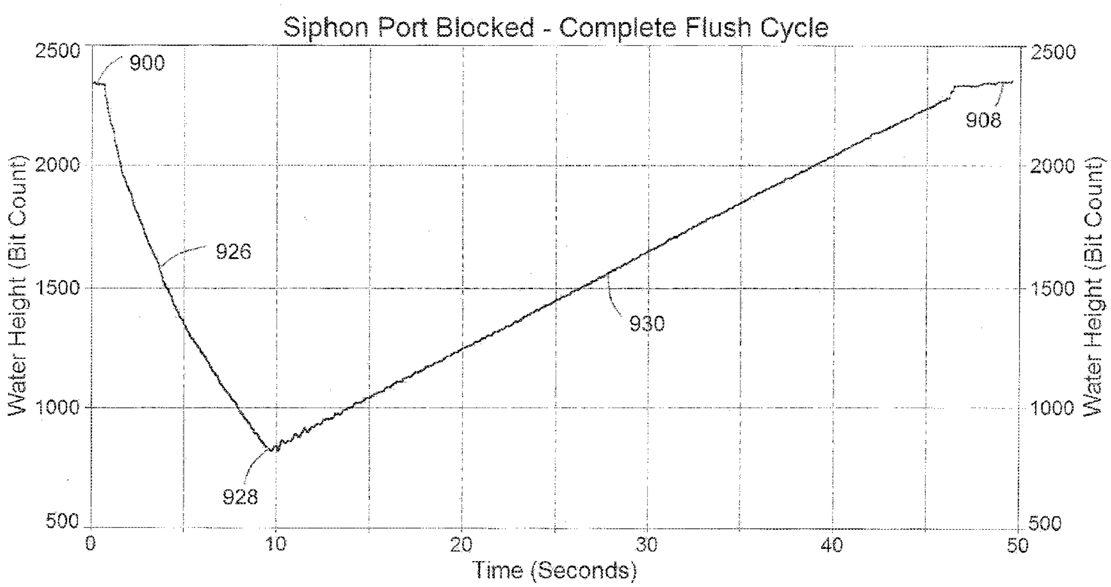

Siphon Port Blocked - Complete Flush Cycle
2500
2000
1500
1000
500
Water Height (Bit Count)
900
926
928
930
908
0
10
20
30
40
50
Time (Seconds)

Fig. 21

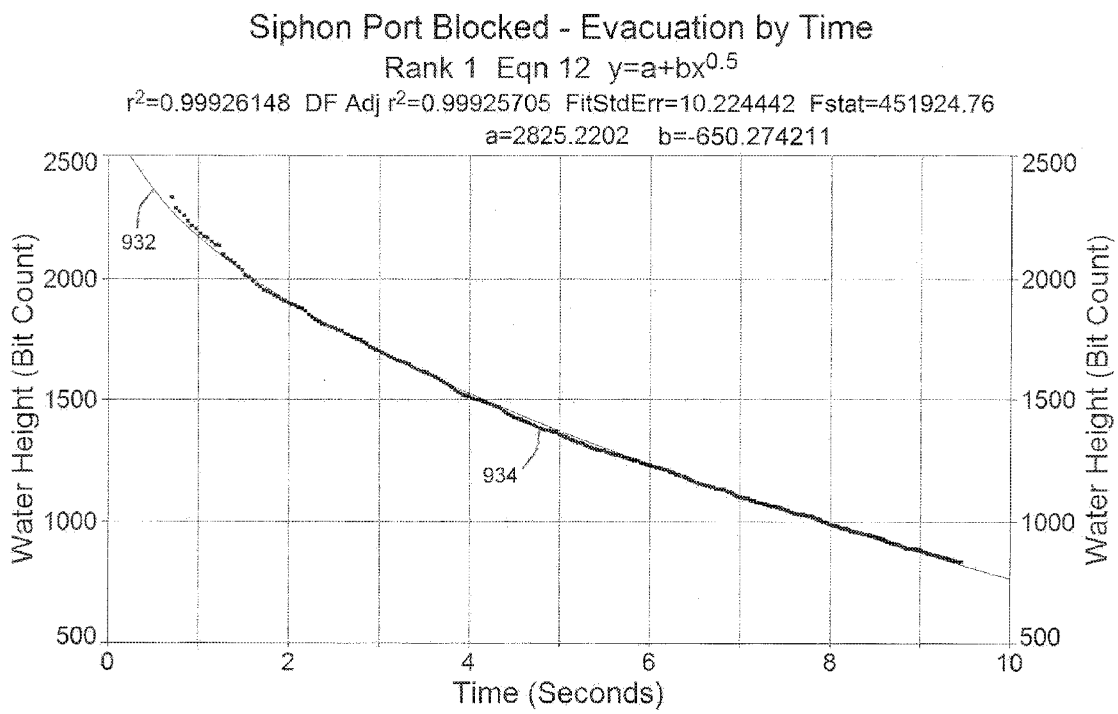

Siphon Port Blocked - Evacuation by Time
Rank 1 Eqn 12 y=a+bx0.5
r2=0.99926148 DF Adj r2=0.99925705 FitStdErr=10.224442 Fstat=451924.76
a=2825.2202 b=-650.274211
Water Height (Bit Count)
Time (Seconds)
932
934
2500
2000
1500
1000
500
0
2
4
6
8
10

Fig. 21A

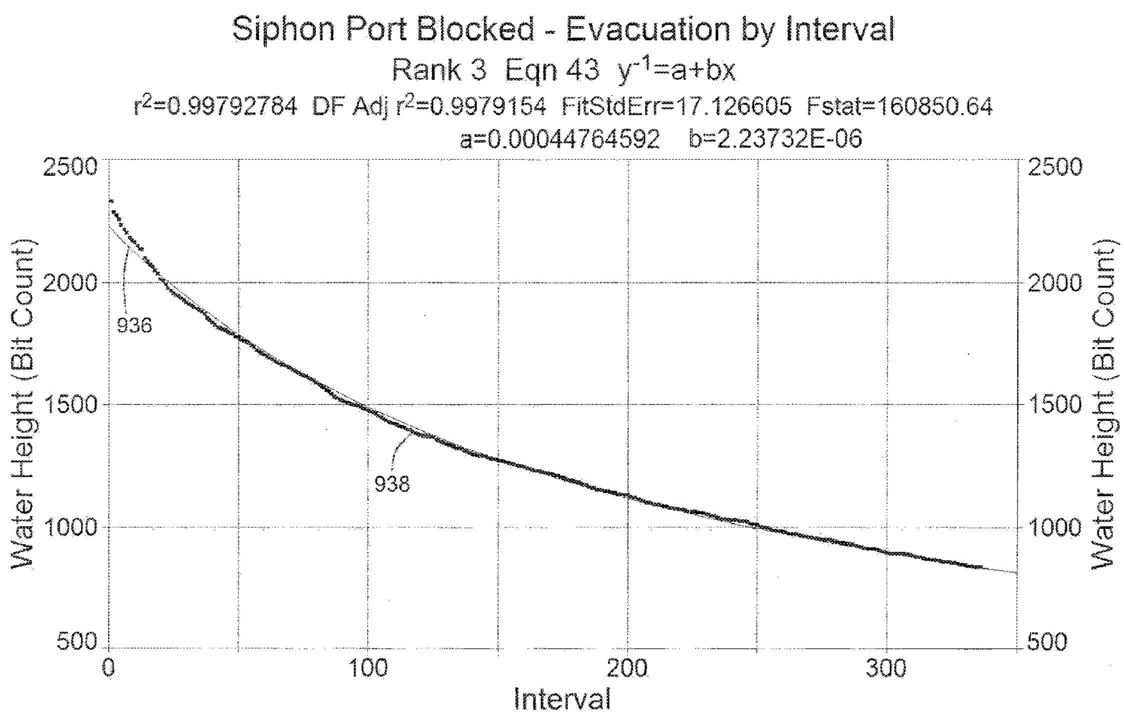

Siphon Port Blocked - Evacuation by Interval
Rank 3 Eqn 43 $y^{-1}=a+bx$
r^2=0.99792784 DF Adj r^2=0.9979154 FitStdErr=17.126605 Fstat=160850.64
a=0.00044764592 b=2.23732E-06
2500
2000
1500
1000
500
0
100
200
300
Interval
Water Height (Bit Count)
936
938

Fig. 21B

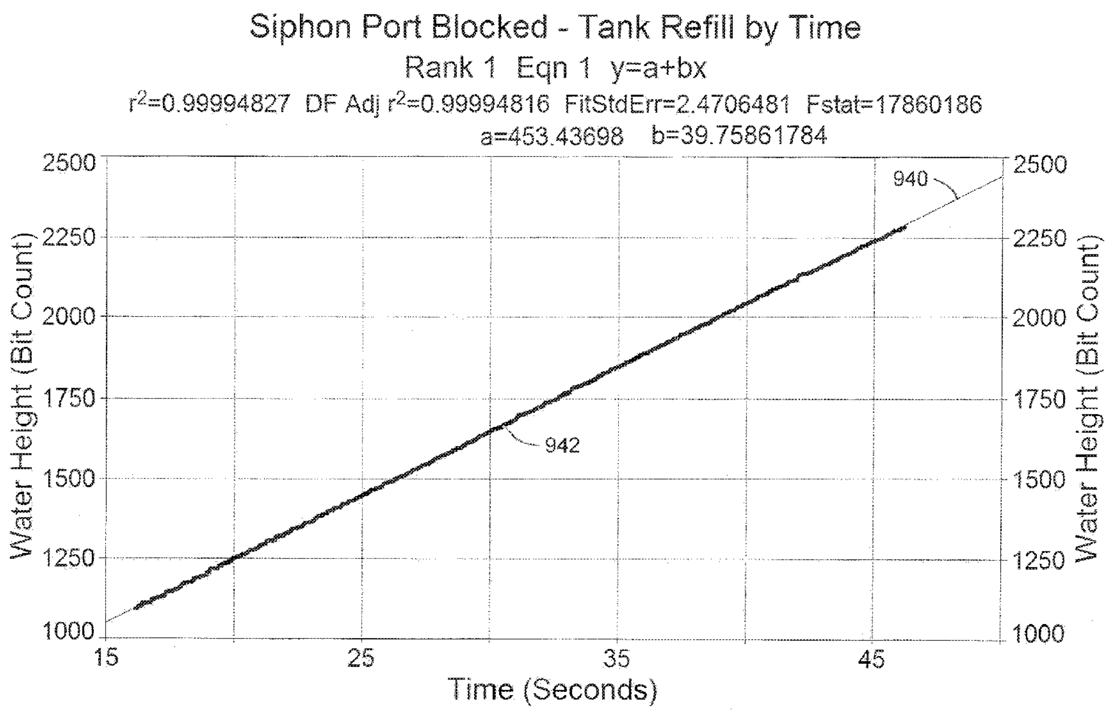

Siphon Port Blocked - Tank Refill by Time
Rank 1 Eqn 1 y=a+bx
r2=0.99994827 DF Adj r2=0.99994816 FitStdErr=2.4706481 Fstat=17860186
a=453.43698 b=39.75861784
Water Height (Bit Count)
2500
2250
2000
1750
1500
1250
1000
940
942
15
25
35
45
Time (Seconds)

Fig. 21C

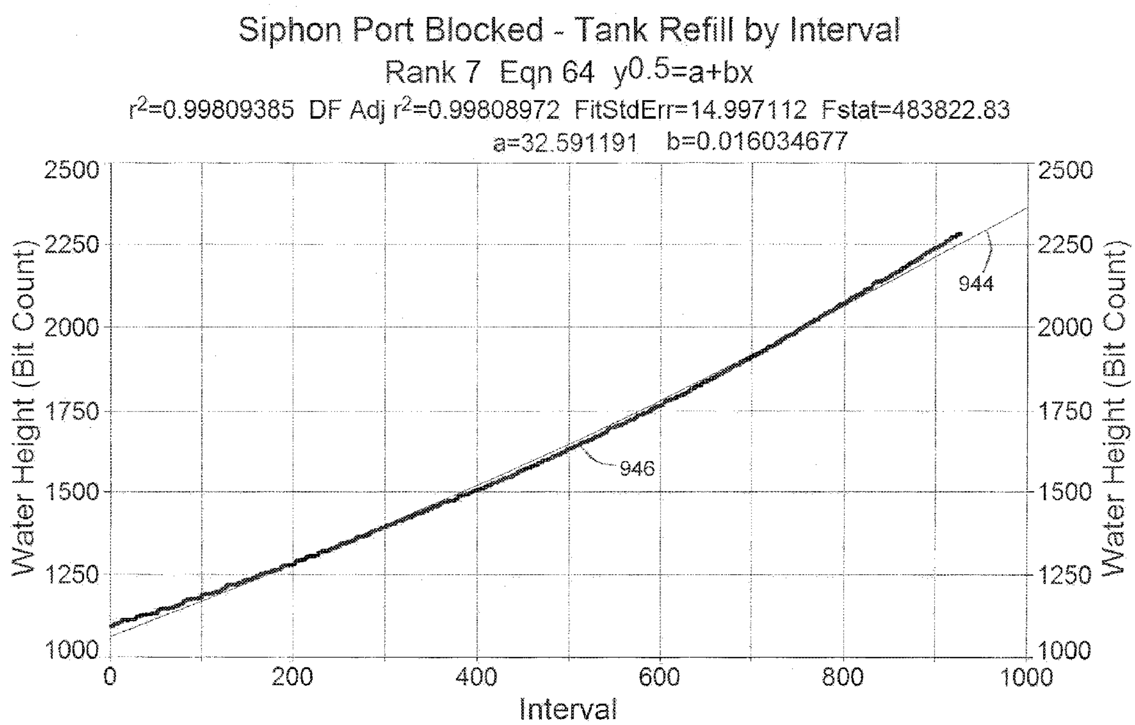

Siphon Port Blocked - Tank Refill by Interval
Rank 7 Eqn 64 y0.5=a+bx
r2=0.99809385 DF Adj r2=0.99808972 FitStdErr=14.997112 Fstat=483822.83
a=32.591191 b=0.016034677
2500
2250
2000
1750
1500
1250
1000
Water Height (Bit Count)
0
200
400
600
800
1000
Interval
944
946

Fig. 21D

Siphon Port Blocked – Complete

WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT
2343	0.047	1943	1.796	1663	3.229	1433	4.463	1281	5.544	1160	6.522	1059	7.406	965	8.216	889	8.955	825	9.636
2344	0.094	1935	1.835	1659	3.262	1427	4.491	1277	5.569	1155	6.545	1058	7.428	962	8.235	888	8.973	823	9.652
2345	0.141	1928	1.873	1653	3.295	1425	4.52	1275	5.595	1154	6.568	1057	7.449	960	8.254	885	8.99	821	9.668
2341	0.187	1919	1.911	1649	3.328	1422	4.548	1272	5.62	1152	6.591	1054	7.47	958	8.273	883	9.008	820	9.685
2340	0.234	1911	1.95	1640	3.361	1417	4.577	1271	5.646	1148	6.614	1050	7.491	957	8.292	880	9.026	820	9.701
2339	0.281	1906	1.988	1633	3.394	1412	4.605	1268	5.671	1149	6.637	1048	7.512	956	8.311	877	9.043	820	9.718
2339	0.328	1899	2.026	1626	3.426	1409	4.633	1264	5.696	1145	6.66	1046	7.533	954	8.33	875	9.061	820	9.734
2339	0.375	1894	2.064	1621	3.459	1404	4.661	1262	5.722	1143	6.683	1041	7.554	951	8.349	872	9.078	820	9.75
2340	0.421	1888	2.101	1617	3.491	1400	4.689	1260	5.747	1142	6.705	1037	7.574	949	8.368	869	9.096	821	9.767
2340	0.468	1880	2.139	1613	3.523	1396	4.717	1257	5.772	1137	6.728	1035	7.595	948	8.387	868	9.113	822	9.783
2340	0.515	1870	2.176	1608	3.556	1388	4.745	1254	5.797	1137	6.751	1035	7.616	948	8.406	866	9.13	823	9.8
2338	0.562	1856	2.214	1602	3.588	1383	4.772	1251	5.822	1136	6.774	1032	7.636	947	8.425	865	9.148	825	9.816
2339	0.609	1846	2.25	1596	3.62	1381	4.8	1250	5.847	1133	6.796	1030	7.657	944	8.444	864	9.165	828	9.833
2339	0.655	1836	2.287	1588	3.651	1376	4.828	1247	5.872	1132	6.819	1029	7.677	941	8.463	862	9.182	831	9.849
2333	0.702	1827	2.324	1580	3.683	1374	4.855	1241	5.897	1127	6.841	1030	7.698	938	8.482	859	9.199	835	9.866
2290	0.748	1818	2.36	1574	3.714	1374	4.883	1238	5.921	1124	6.864	1027	7.719	936	8.5	856	9.216	837	9.883
2276	0.793	1815	2.396	1566	3.746	1371	4.91	1235	5.946	1122	6.886	1025	7.739	935	8.519	856	9.233	838	9.9
2260	0.839	1809	2.433	1558	3.777	1368	4.937	1232	5.971	1115	6.909	1023	7.76	934	8.538	855	9.251	838	9.916
2239	0.883	1805	2.469	1550	3.808	1366	4.965	1230	5.995	1111	6.931	1023	7.78	933	8.557	854	9.268	839	9.933
2219	0.928	1799	2.505	1542	3.839	1358	4.992	1227	6.02	1106	6.953	1021	7.8	930	8.575	852	9.285	839	9.95
2208	0.972	1793	2.54	1531	3.869	1353	5.019	1224	6.044	1101	6.975	1016	7.821	928	8.594	851	9.302	840	9.967
2189	1.016	1787	2.576	1524	3.9	1348	5.046	1221	6.069	1100	6.997	1012	7.841	924	8.612	848	9.319	840	9.984
2175	1.059	1777	2.612	1518	3.93	1344	5.073	1220	6.093	1099	7.019	1011	7.861	920	8.631	846	9.336	839	10
2168	1.102	1772	2.647	1515	3.96	1341	5.099	1217	6.118	1095	7.041	1008	7.881	917	8.649	843	9.352	838	10.02
2152	1.146	1764	2.682	1512	3.991	1334	5.126	1216	6.142	1094	7.063	1003	7.901	915	8.667	842	9.369	833	10.03
2140	1.188	1759	2.718	1505	4.021	1331	5.153	1211	6.166	1093	7.085	1000	7.921	914	8.685	840	9.386	827	10.05
2136	1.231	1755	2.753	1503	4.051	1328	5.179	1210	6.19	1089	7.106	998	7.941	912	8.704	838	9.403	823	10.07
2102	1.273	1749	2.788	1501	4.081	1323	5.206	1206	6.214	1085	7.128	995	7.961	911	8.722	838	9.42	820	10.08
2085	1.315	1741	2.823	1498	4.111	1322	5.232	1202	6.238	1084	7.15	991	7.981	910	8.74	836	9.436	819	10.1
2076	1.356	1733	2.857	1494	4.141	1318	5.259	1198	6.262	1080	7.171	987	8.001	907	8.758	836	9.453	820	10.12
2066	1.398	1722	2.892	1490	4.171	1313	5.285	1194	6.286	1077	7.193	985	8.021	903	8.776	836	9.47	824	10.13
2052	1.439	1714	2.926	1484	4.2	1310	5.311	1191	6.31	1075	7.214	983	8.04	902	8.794	834	9.486	826	10.15
2039	1.479	1708	2.96	1480	4.23	1304	5.337	1188	6.334	1074	7.236	982	8.06	897	8.812	833	9.503	827	10.17
2018	1.52	1703	2.994	1474	4.259	1301	5.363	1187	6.358	1071	7.257	979	8.079	895	8.83	831	9.52	833	10.18
2010	1.56	1698	3.028	1471	4.289	1297	5.389	1182	6.381	1071	7.279	977	8.099	893	8.848	828	9.536	839	10.2
1996	1.6	1691	3.062	1467	4.318	1295	5.415	1181	6.405	1070	7.3	974	8.118	892	8.866	828	9.553	845	10.22
1979	1.639	1685	3.096	1463	4.347	1290	5.441	1174	6.428	1067	7.321	973	8.138	891	8.884	828	9.569	850	10.23
1968	1.679	1678	3.129	1453	4.376	1290	5.467	1171	6.452	1064	7.343	972	8.157	892	8.902	828	9.586	855	10.25
1956	1.718	1671	3.163	1446	4.405	1290	5.492	1167	6.475	1064	7.364	973	8.177	891	8.919	827	9.603	859	10.27
1949	1.757	1666	3.196	1440	4.434	1285	5.518	1162	6.498	1062	7.385	969	8.196	890	8.937	825	9.619	860	10.28

Fig. 21E Page #1

Siphon Port Blocked – Complete Flush

WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT
862	10.3	889	10.99	898	11.71	934	12.44	975	13.21	1000	14	1041	14.81	1069	15.66	1113	16.53	1147	17.43
862	10.32	890	11.01	898	11.72	936	12.46	975	13.23	1000	14.02	1042	14.83	1069	15.68	1112	16.55	1147	17.45
861	10.34	891	11.03	899	11.74	936	12.48	975	13.25	1001	14.04	1042	14.86	1069	15.7	1111	16.57	1148	17.48
861	10.35	890	11.04	903	11.76	940	12.5	975	13.27	1006	14.06	1043	14.88	1071	15.72	1112	16.6	1148	17.5
859	10.37	889	11.06	905	11.78	945	12.52	975	13.29	1006	14.08	1043	14.9	1070	15.74	1112	16.62	1148	17.52
858	10.39	887	11.08	908	11.8	948	12.54	975	13.31	1006	14.1	1043	14.92	1071	15.76	1112	16.64	1148	17.55
856	10.4	885	11.1	911	11.81	950	12.56	974	13.32	1006	14.12	1042	14.94	1075	15.79	1113	16.66	1147	17.57
854	10.42	883	11.12	912	11.83	950	12.58	974	13.34	1008	14.14	1043	14.96	1079	15.81	1113	16.69	1148	17.59
853	10.44	883	11.13	912	11.85	950	12.59	973	13.36	1011	14.16	1041	14.98	1082	15.83	1113	16.71	1149	17.61
853	10.46	881	11.15	914	11.87	951	12.61	972	13.38	1015	14.18	1042	15	1083	15.85	1113	16.73	1150	17.64
853	10.47	879	11.17	916	11.89	951	12.63	971	13.4	1016	14.2	1044	15.02	1085	15.87	1113	16.75	1151	17.66
852	10.49	878	11.19	918	11.91	952	12.65	972	13.42	1016	14.22	1044	15.04	1086	15.89	1118	16.78	1151	17.68
853	10.51	876	11.2	920	11.92	954	12.67	972	13.44	1019	14.24	1043	15.06	1088	15.92	1122	16.8	1152	17.71
852	10.52	876	11.22	920	11.94	953	12.69	973	13.46	1020	14.26	1044	15.08	1088	15.94	1123	16.82	1154	17.73
854	10.54	875	11.24	920	11.96	953	12.71	976	13.48	1020	14.28	1046	15.11	1088	15.96	1122	16.84	1153	17.75
858	10.56	876	11.26	919	11.98	953	12.73	980	13.5	1019	14.3	1050	15.13	1088	15.98	1123	16.86	1155	17.78
859	10.58	877	11.27	919	12	953	12.75	982	13.52	1019	14.32	1050	15.15	1089	16	1124	16.89	1156	17.8
859	10.59	879	11.29	920	12.02	953	12.77	985	13.54	1020	14.34	1050	15.17	1088	16.02	1125	16.91	1156	17.82
860	10.61	882	11.31	920	12.03	952	12.79	987	13.56	1021	14.36	1049	15.19	1089	16.05	1127	16.93	1157	17.85
859	10.63	884	11.33	920	12.05	953	12.8	990	13.58	1020	14.38	1049	15.21	1089	16.07	1128	16.95	1159	17.87
860	10.64	887	11.34	923	12.07	953	12.82	991	13.6	1021	14.4	1055	15.23	1089	16.09	1128	16.98	1160	17.89
860	10.66	891	11.36	925	12.09	953	12.84	991	13.62	1021	14.42	1058	15.25	1088	16.11	1128	17	1161	17.92
860	10.68	895	11.38	927	12.11	953	12.86	991	13.64	1021	14.44	1059	15.27	1089	16.13	1128	17.02	1163	17.94
860	10.7	896	11.4	929	12.13	954	12.88	991	13.66	1021	14.46	1058	15.3	1091	16.15	1129	17.05	1166	17.96
860	10.71	898	11.42	930	12.15	955	12.9	992	13.68	1021	14.48	1058	15.32	1094	16.18	1129	17.07	1169	17.99
859	10.73	899	11.43	931	12.16	955	12.92	992	13.7	1020	14.5	1059	15.34	1095	16.2	1129	17.09	1171	18.01
859	10.75	902	11.45	931	12.18	955	12.94	991	13.72	1021	14.53	1061	15.36	1095	16.22	1130	17.11	1173	18.03
861	10.76	908	11.47	932	12.2	956	12.96	991	13.74	1022	14.55	1061	15.38	1096	16.24	1130	17.14	1173	18.06
860	10.78	911	11.49	932	12.22	956	12.98	992	13.76	1023	14.57	1063	15.4	1098	16.26	1131	17.16	1174	18.08
860	10.8	912	11.51	932	12.24	956	13	994	13.78	1024	14.59	1063	15.42	1100	16.29	1132	17.18	1174	18.1
860	10.82	914	11.52	931	12.26	957	13.01	997	13.8	1026	14.61	1063	15.44	1101	16.31	1131	17.2	1174	18.13
861	10.83	915	11.54	931	12.28	959	13.03	997	13.82	1026	14.63	1063	15.47	1102	16.33	1131	17.23	1174	18.15
868	10.85	912	11.56	931	12.29	961	13.05	997	13.84	1028	14.65	1064	15.49	1104	16.35	1133	17.25	1176	18.17
870	10.87	911	11.58	930	12.31	961	13.07	1000	13.86	1029	14.67	1065	15.51	1104	16.37	1133	17.27	1177	18.2
871	10.89	909	11.6	931	12.33	962	13.09	1000	13.88	1030	14.69	1065	15.53	1105	16.4	1135	17.29	1177	18.22
873	10.9	906	11.62	931	12.35	968	13.11	1000	13.9	1031	14.71	1065	15.55	1106	16.42	1137	17.32	1177	18.24
875	10.92	901	11.63	931	12.37	971	13.13	1000	13.92	1034	14.73	1065	15.57	1110	16.44	1141	17.34	1177	18.27
879	10.94	899	11.65	932	12.39	974	13.15	999	13.94	1036	14.75	1065	15.59	1112	16.46	1145	17.36	1178	18.29
884	10.96	898	11.67	932	12.41	975	13.17	999	13.96	1037	14.77	1068	15.61	1112	16.49	1146	17.39	1177	18.31
887	10.97	897	11.69	933	12.42	974	13.19	1000	13.98	1040	14.79	1069	15.64	1112	16.51	1146	17.41	1178	18.34

Fig. 21E Page #2

Siphon Port Blocked – Complete Flush

WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT
1179	18.36	1219	19.32	1262	20.32	1306	21.34	1344	22.4	1389	23.49	1432	24.62	1477	25.79	1529	26.99	1575	28.23
1180	18.38	1219	19.35	1263	20.34	1306	21.37	1344	22.43	1390	23.52	1433	24.65	1480	25.82	1529	27.02	1578	28.26
1182	18.41	1221	19.37	1263	20.37	1307	21.39	1345	22.45	1391	23.55	1434	24.68	1483	25.85	1530	27.05	1579	28.3
1185	18.43	1225	19.4	1264	20.39	1306	21.42	1346	22.48	1391	23.58	1435	24.71	1486	25.88	1530	27.08	1580	28.33
1188	18.46	1226	19.42	1263	20.42	1307	21.45	1347	22.51	1392	23.61	1436	24.74	1487	25.91	1530	27.11	1581	28.36
1188	18.48	1226	19.44	1264	20.44	1307	21.47	1348	22.54	1395	23.63	1438	24.77	1488	25.94	1532	27.14	1582	28.39
1190	18.5	1227	19.47	1265	20.47	1306	21.5	1348	22.56	1398	23.66	1440	24.8	1488	25.97	1533	27.18	1583	28.42
1191	18.53	1227	19.49	1266	20.49	1307	21.53	1348	22.59	1398	23.69	1442	24.82	1489	26	1534	27.21	1584	28.45
1191	18.55	1230	19.52	1266	20.52	1307	21.55	1349	22.62	1399	23.72	1442	24.85	1490	26.03	1536	27.24	1584	28.49
1192	18.58	1232	19.54	1268	20.54	1308	21.58	1351	22.64	1400	23.74	1444	24.88	1491	26.06	1536	27.27	1587	28.52
1192	18.6	1233	19.57	1271	20.57	1309	21.6	1353	22.67	1400	23.77	1445	24.91	1491	26.09	1539	27.3	1590	28.55
1192	18.62	1234	19.59	1273	20.59	1314	21.63	1356	22.7	1401	23.8	1445	24.94	1491	26.12	1540	27.33	1590	28.58
1192	18.65	1235	19.62	1276	20.62	1317	21.66	1358	22.72	1401	23.83	1446	24.97	1492	26.15	1542	27.36	1590	28.61
1192	18.67	1235	19.64	1278	20.65	1318	21.68	1361	22.75	1403	23.86	1448	25	1493	26.18	1544	27.39	1591	28.64
1192	18.69	1236	19.67	1278	20.67	1320	21.71	1362	22.78	1406	23.89	1451	25.03	1494	26.21	1544	27.42	1595	28.68
1194	18.72	1236	19.69	1279	20.7	1320	21.74	1363	22.81	1407	23.91	1454	25.06	1497	26.24	1545	27.45	1597	28.71
1195	18.74	1237	19.72	1278	20.72	1321	21.76	1363	22.83	1409	23.94	1454	25.09	1498	26.27	1546	27.48	1597	28.74
1195	18.77	1236	19.74	1278	20.75	1320	21.79	1363	22.86	1409	23.97	1455	25.11	1499	26.3	1546	27.51	1597	28.77
1197	18.79	1237	19.77	1279	20.77	1321	21.81	1363	22.89	1411	24	1455	25.14	1500	26.33	1547	27.55	1597	28.8
1198	18.81	1239	19.79	1280	20.8	1321	21.84	1363	22.92	1409	24.03	1454	25.17	1502	26.36	1546	27.58	1598	28.84
1199	18.84	1241	19.82	1280	20.82	1320	21.87	1363	22.94	1410	24.05	1455	25.2	1503	26.39	1547	27.61	1600	28.87
1198	18.86	1241	19.84	1280	20.85	1322	21.89	1364	22.97	1410	24.08	1457	25.23	1506	26.42	1550	27.64	1602	28.9
1198	18.89	1242	19.86	1281	20.88	1323	21.92	1364	23	1411	24.11	1460	25.26	1506	26.45	1552	27.67	1604	28.93
1199	18.91	1243	19.89	1281	20.9	1325	21.95	1366	23.02	1412	24.14	1463	25.29	1507	26.48	1554	27.7	1605	28.96
1202	18.93	1248	19.91	1282	20.93	1328	21.97	1367	23.05	1415	24.17	1464	25.32	1508	26.51	1555	27.73	1606	29
1205	18.96	1248	19.94	1285	20.95	1328	22	1368	23.08	1418	24.2	1466	25.35	1508	26.54	1556	27.76	1608	29.03
1207	18.98	1249	19.96	1289	20.98	1329	22.03	1370	23.11	1419	24.22	1466	25.38	1510	26.57	1558	27.79	1610	29.06
1208	19.01	1251	19.99	1292	21	1329	22.05	1374	23.13	1421	24.25	1466	25.41	1510	26.6	1560	27.82	1611	29.09
1209	19.03	1253	20.01	1293	21.03	1330	22.08	1375	23.16	1421	24.28	1466	25.44	1510	26.63	1563	27.86	1612	29.13
1211	19.05	1253	20.04	1292	21.06	1331	22.11	1376	23.19	1422	24.31	1467	25.46	1511	26.66	1565	27.89	1614	29.16
1214	19.08	1253	20.06	1293	21.08	1331	22.13	1378	23.22	1422	24.34	1467	25.49	1513	26.69	1566	27.92	1614	29.19
1217	19.1	1254	20.09	1293	21.11	1333	22.16	1379	23.24	1422	24.37	1469	25.52	1515	26.72	1567	27.95	1615	29.22
1219	19.13	1255	20.12	1294	21.13	1335	22.19	1381	23.27	1424	24.39	1471	25.55	1516	26.75	1567	27.98	1617	29.25
1219	19.15	1255	20.14	1295	21.16	1337	22.21	1383	23.3	1424	24.42	1472	25.58	1517	26.78	1567	28.01	1618	29.29
1219	19.18	1257	20.17	1295	21.19	1340	22.24	1384	23.33	1427	24.45	1473	25.61	1519	26.81	1570	28.04	1619	29.32
1219	19.2	1256	20.19	1297	21.21	1342	22.27	1384	23.36	1430	24.48	1474	25.64	1520	26.84	1571	28.08	1621	29.35
1219	19.23	1257	20.22	1298	21.24	1344	22.29	1385	23.38	1431	24.51	1473	25.67	1520	26.87	1572	28.11	1622	29.38
1219	19.25	1258	20.24	1301	21.26	1344	22.32	1385	23.41	1431	24.54	1473	25.7	1521	26.9	1573	28.14	1623	29.42
1219	19.27	1259	20.27	1303	21.29	1344	22.35	1386	23.44	1431	24.57	1474	25.73	1523	26.93	1573	28.17	1624	29.45
1219	19.3	1259	20.29	1305	21.32	1344	22.37	1390	23.47	1432	24.59	1476	25.76	1526	26.96	1575	28.2	1626	29.48

Fig. 21E Page #3

Siphon Port Blocked – Complete Flush

WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT	WH	INT
1629	29.51	1681	30.84	1738	32.21	1791	33.62	1849	35.08	1908	36.58	1970	38.13	2034	39.73	2096	41.39	2165	43.09
1632	29.55	1682	30.87	1738	32.24	1793	33.66	1850	35.11	1911	36.62	1972	38.17	2035	39.77	2099	41.43	2166	43.14
1634	29.58	1683	30.91	1738	32.28	1794	33.69	1851	35.15	1912	36.66	1973	38.21	2036	39.81	2099	41.47	2166	43.18
1635	29.61	1684	30.94	1739	32.31	1794	33.73	1852	35.19	1913	36.69	1974	38.25	2039	39.85	2103	41.51	2169	43.22
1637	29.65	1686	30.97	1740	32.35	1796	33.76	1853	35.22	1914	36.73	1977	38.29	2039	39.89	2104	41.55	2171	43.27
1637	29.68	1690	31.01	1743	32.38	1797	33.8	1857	35.26	1915	36.77	1977	38.33	2041	39.94	2109	41.6	2173	43.31
1637	29.71	1694	31.04	1745	32.42	1798	33.83	1859	35.3	1916	36.81	1977	38.37	2042	39.98	2111	41.64	2175	43.35
1638	29.74	1698	31.08	1746	32.45	1799	33.87	1860	35.34	1918	36.85	1979	38.41	2045	40.02	2112	41.68	2177	43.4
1638	29.78	1699	31.11	1746	32.49	1800	33.91	1861	35.37	1920	36.89	1979	38.45	2046	40.06	2113	41.72	2179	43.44
1640	29.81	1699	31.14	1746	32.52	1802	33.94	1861	35.41	1921	36.92	1980	38.49	2048	40.1	2113	41.76	2181	43.48
1642	29.84	1700	31.18	1748	32.56	1802	33.98	1862	35.45	1923	36.96	1982	38.53	2047	40.14	2114	41.81	2181	43.53
1643	29.87	1699	31.21	1750	32.59	1804	34.02	1865	35.48	1925	37	1983	38.57	2050	40.18	2115	41.85	2183	43.57
1644	29.91	1700	31.25	1751	32.63	1806	34.05	1867	35.52	1925	37.04	1987	38.61	2053	40.22	2117	41.89	2186	43.61
1646	29.94	1700	31.28	1754	32.66	1808	34.09	1869	35.56	1927	37.08	1989	38.65	2055	40.26	2117	41.93	2187	43.66
1647	29.97	1702	31.31	1756	32.7	1810	34.12	1870	35.6	1929	37.12	1990	38.69	2055	40.3	2125	41.98	2190	43.7
1650	30.01	1704	31.35	1758	32.73	1811	34.16	1871	35.63	1931	37.16	1992	38.72	2057	40.35	2132	42.02	2191	43.75
1652	30.04	1705	31.38	1759	32.77	1814	34.2	1873	35.67	1932	37.19	1994	38.76	2060	40.39	2133	42.06	2191	43.79
1653	30.07	1707	31.42	1761	32.8	1816	34.23	1873	35.71	1934	37.23	1997	38.8	2064	40.43	2133	42.1	2194	43.83
1655	30.11	1707	31.45	1763	32.84	1818	34.27	1875	35.75	1934	37.27	1998	38.84	2065	40.47	2135	42.15	2195	43.88
1656	30.14	1707	31.48	1764	32.87	1820	34.31	1877	35.78	1935	37.31	2000	38.88	2066	40.51	2137	42.19	2197	43.92
1657	30.17	1707	31.52	1765	32.91	1821	34.34	1880	35.82	1940	37.35	2001	38.92	2067	40.55	2136	42.23	2199	43.97
1657	30.21	1709	31.55	1766	32.94	1823	34.38	1883	35.86	1943	37.39	2001	38.96	2069	40.59	2137	42.28	2199	44.01
1657	30.24	1711	31.59	1766	32.98	1824	34.41	1884	35.9	1946	37.43	2003	39	2069	40.63	2136	42.32	2200	44.05
1658	30.27	1712	31.62	1767	33.01	1825	34.45	1885	35.93	1946	37.47	2007	39.04	2070	40.68	2137	42.36	2203	44.1
1660	30.3	1713	31.66	1768	33.05	1825	34.49	1886	35.97	1946	37.5	2009	39.09	2071	40.72	2139	42.4	2204	44.14
1662	30.34	1714	31.69	1770	33.08	1825	34.52	1887	36.01	1947	37.54	2010	39.13	2072	40.76	2140	42.45	2206	44.19
1662	30.37	1717	31.72	1770	33.12	1827	34.56	1888	36.05	1948	37.58	2011	39.17	2075	40.8	2141	42.49	2208	44.23
1663	30.4	1720	31.76	1775	33.16	1828	34.6	1888	36.09	1948	37.62	2014	39.21	2076	40.84	2142	42.53	2209	44.27
1664	30.44	1720	31.79	1778	33.19	1832	34.63	1888	36.12	1950	37.66	2015	39.25	2081	40.88	2144	42.57	2214	44.32
1665	30.47	1721	31.83	1780	33.23	1835	34.67	1891	36.16	1951	37.7	2016	39.29	2082	40.93	2146	42.62	2218	44.36
1667	30.5	1721	31.86	1781	33.26	1836	34.71	1894	36.2	1953	37.74	2017	39.33	2083	40.97	2147	42.66	2218	44.41
1670	30.54	1723	31.9	1783	33.3	1837	34.74	1895	36.24	1955	37.78	2020	39.37	2087	41.01	2150	42.7	2219	44.45
1672	30.57	1724	31.93	1783	33.33	1837	34.78	1895	36.27	1956	37.82	2020	39.41	2088	41.05	2150	42.75	2222	44.5
1672	30.6	1725	31.96	1784	33.37	1838	34.82	1898	36.31	1957	37.86	2021	39.45	2088	41.09	2153	42.79	2223	44.54
1674	30.64	1726	32	1785	33.4	1841	34.85	1901	36.35	1960	37.89	2022	39.49	2090	41.13	2153	42.83	2224	44.58
1674	30.67	1729	32.03	1785	33.44	1843	34.89	1903	36.39	1961	37.93	2022	39.53	2092	41.18	2155	42.88	2226	44.63
1675	30.71	1731	32.07	1787	33.48	1843	34.93	1903	36.43	1963	37.97	2027	39.57	2092	41.22	2159	42.92	2225	44.67
1676	30.74	1734	32.1	1787	33.51	1845	34.96	1904	36.46	1964	38.01	2029	39.61	2095	41.26	2159	42.96	2230	44.72
1677	30.77	1735	32.14	1789	33.55	1845	35	1905	36.5	1966	38.05	2032	39.65	2095	41.3	2163	43.01	2232	44.76
1679	30.81	1737	32.17	1791	33.58	1847	35.04	1906	36.54	1967	38.09	2032	39.69	2096	41.34	2164	43.05	2233	44.81

Fig. 21E Page #4

Siphon Port Blocked – Complete Flush

WH	INT	WH	INT	WH	INT
2234	44.85	2335	46.67	2346	48.54
2237	44.9	2336	46.72	2344	48.59
2238	44.94	2336	46.77	2343	48.64
2238	44.99	2335	46.81	2345	48.69
2239	45.03	2336	46.86	2350	48.73
2242	45.08	2336	46.91	2353	48.78
2242	45.12	2337	46.95	2354	48.83
2244	45.17	2336	47	2354	48.87
2246	45.21	2336	47.05	2353	48.92
2247	45.26	2336	47.09	2353	48.97
2247	45.3	2336	47.14	2352	49.01
2251	45.35	2337	47.19	2353	49.06
2252	45.39	2336	47.23	2353	49.11
2256	45.44	2336	47.28	2353	49.16
2259	45.48	2334	47.33	2352	49.2
2260	45.53	2334	47.37	2351	49.25
2261	45.57	2335	47.42	2351	49.3
2262	45.62	2335	47.47	2353	49.34
2265	45.66	2335	47.51	2354	49.39
2268	45.71	2334	47.56	2353	49.44
2270	45.75	2334	47.61	2352	49.49
2272	45.8	2335	47.65	2352	49.53
2273	45.84	2336	47.7	2360	49.58
2274	45.89	2338	47.75		
2274	45.93	2339	47.79		
2275	45.98	2340	47.84		
2279	46.03	2341	47.89		
2281	46.07	2344	47.93		
2282	46.12	2346	47.98		
2283	46.16	2346	48.03		
2285	46.21	2346	48.08		
2306	46.25	2345	48.12		
2309	46.3	2346	48.17		
2313	46.35	2347	48.22		
2315	46.39	2348	48.26		
2333	46.44	2348	48.31		
2335	46.49	2347	48.36		
2334	46.53	2346	48.4		
2334	46.58	2347	48.45		
2335	46.63	2347	48.5		

Fig. 21E Page #5

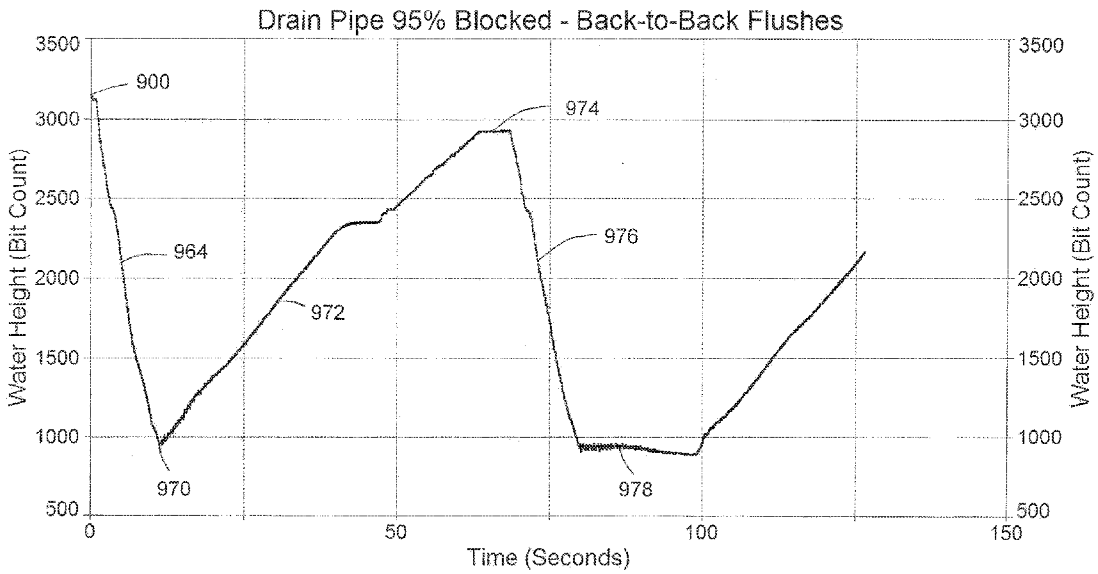

Drain Pipe 95% Blocked - Back-to-Back Flushes
Water Height (Bit Count)
3500
3000
2500
2000
1500
1000
500
Time (Seconds)
0
50
100
150
900
964
970
972
974
976
978

Fig. 22

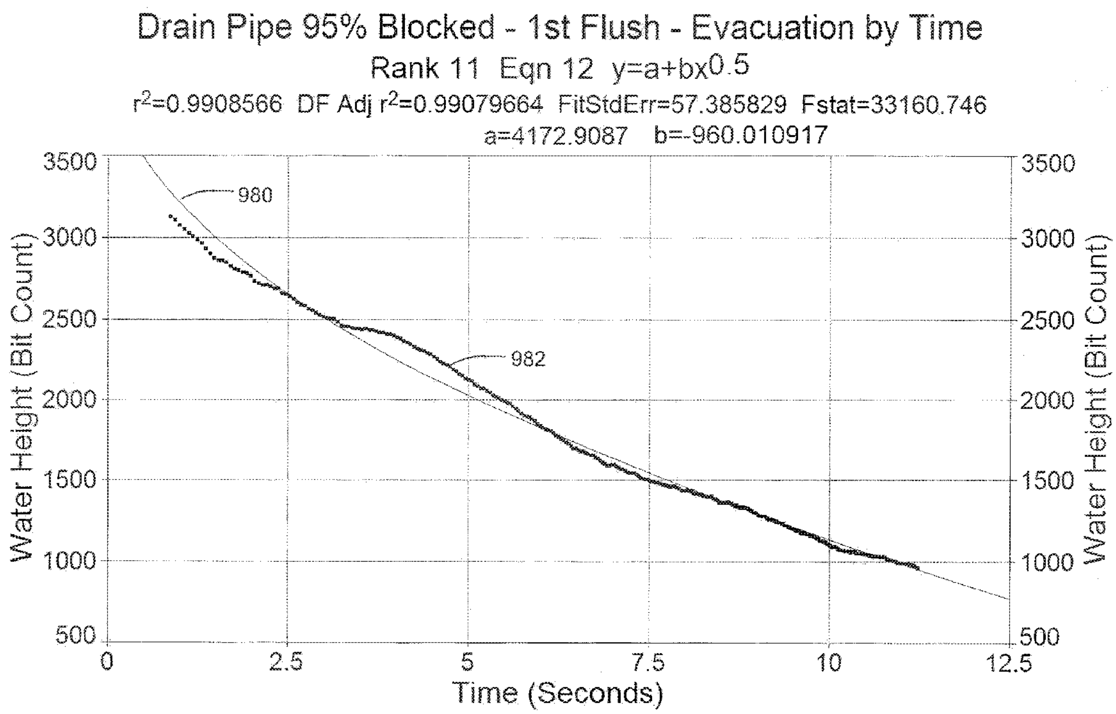

Drain Pipe 95% Blocked - 1st Flush - Evacuation by Time
Rank 11 Eqn 12 y=a+bx0.5
r2=0.9908566 DF Adj r2=0.99079664 FitStdErr=57.385829 Fstat=33160.746
a=4172.9087 b=-960.010917
980
982
Water Height (Bit Count)
Time (Seconds)
3500
3000
2500
2000
1500
1000
500
0
2.5
5
7.5
10
12.5

Fig. 22A

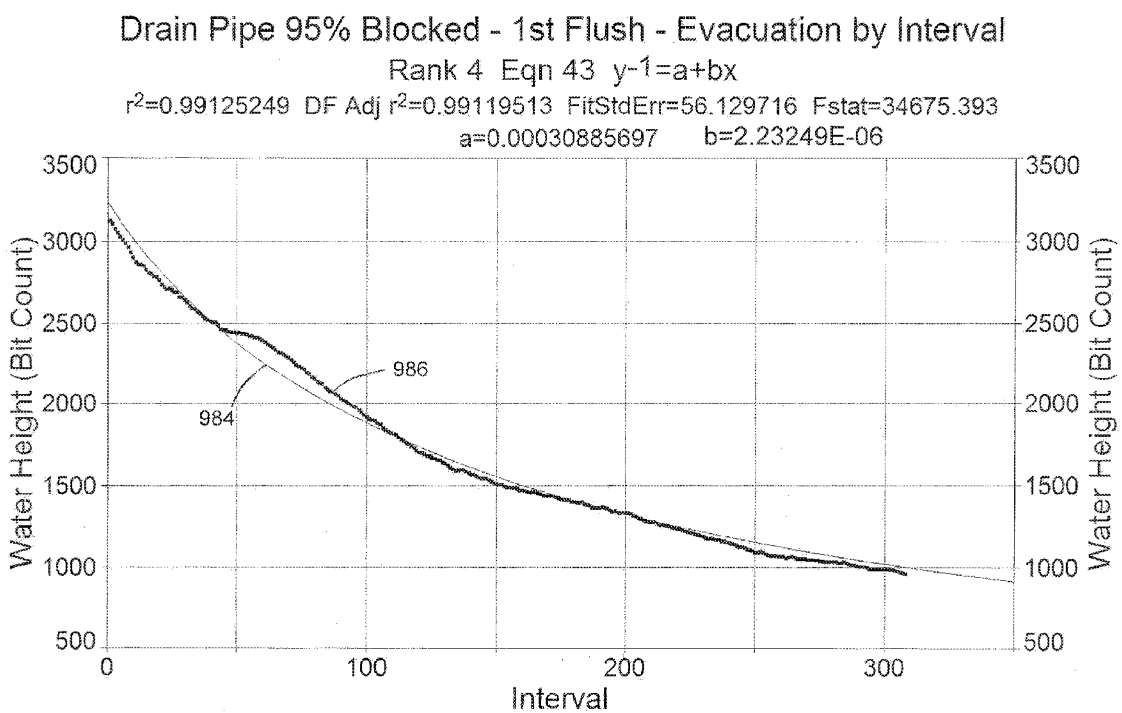
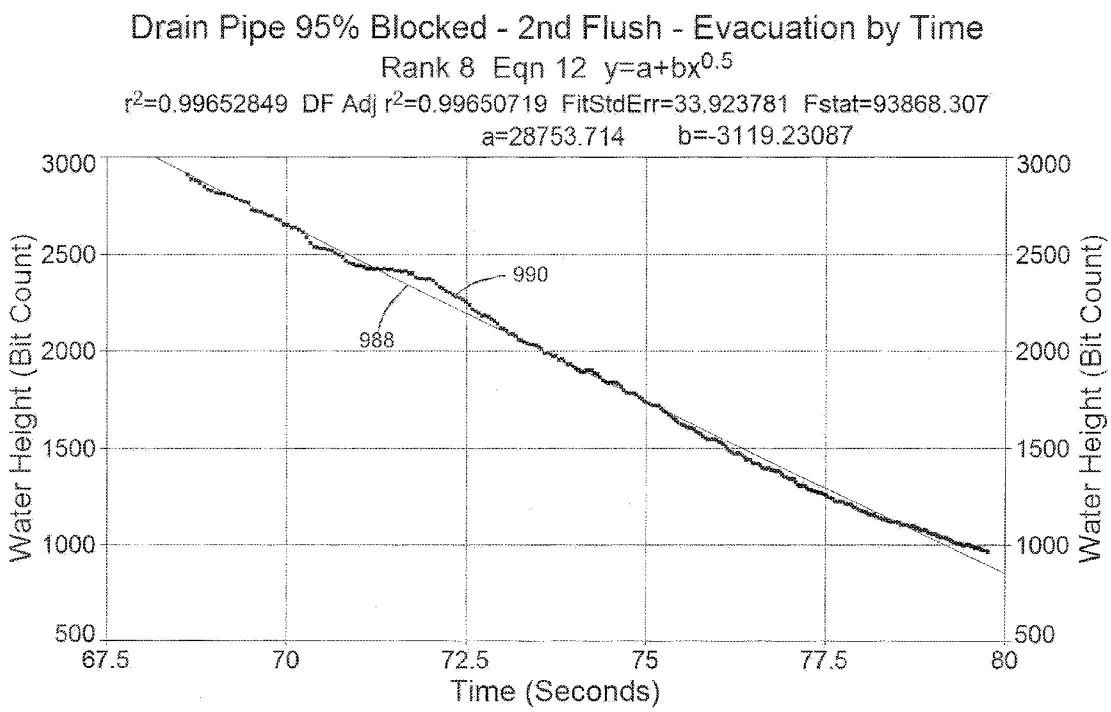

Drain Pipe 95% Blocked - 1st Flush - Evacuation by Interval
Rank 4 Eqn 43 y-1=a+bx
r2=0.99125249 DF Adj r2=0.99119513 FitStdErr=56.129716 Fstat=34675.393
a=0.00030885697 b=2.23249E-06
3500
3000
2500
2000
1500
1000
500
0
100
200
300
Interval
Water Height (Bit Count)
984
986

Fig. 22B



Drain Pipe 95% Blocked - 2nd Flush - Evacuation by Time
Rank 8 Eqn 12 y=a+bx^0.5
r^2=0.99652849 DF Adj r^2=0.99650719 FitStdErr=33.923781 Fstat=93868.307
a=28753.714 b=-3119.23087
Water Height (Bit Count)
3000
2500
2000
1500
1000
500
990
988
67.5
70
72.5
75
77.5
80
Time (Seconds)

Fig. 22C

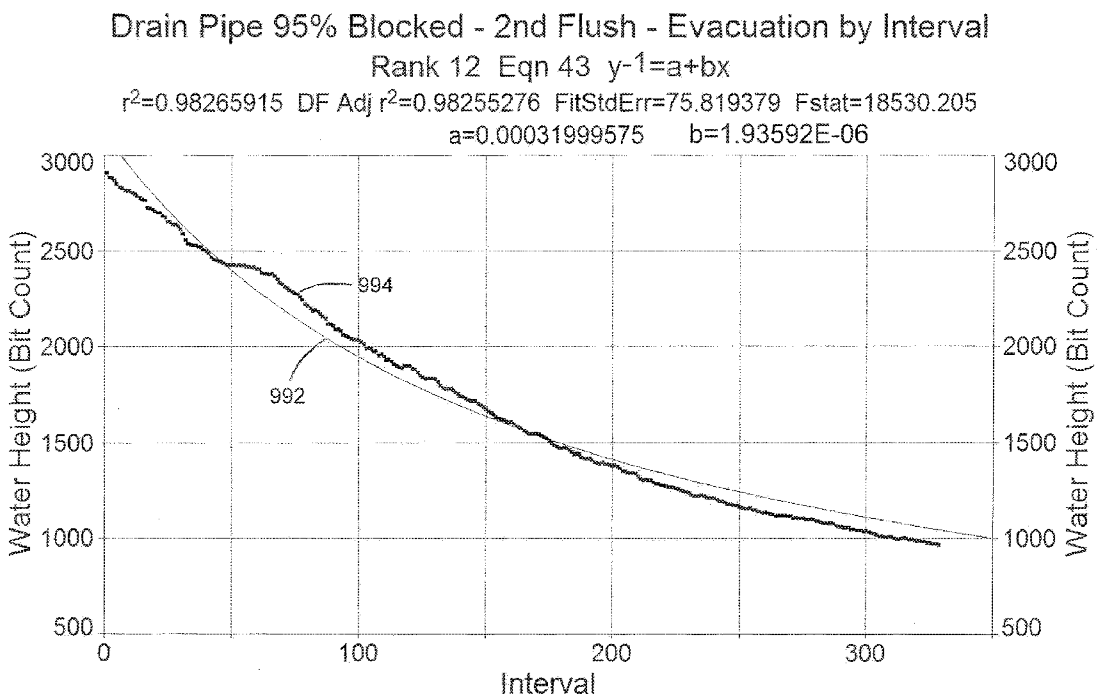

Drain Pipe 95% Blocked - 2nd Flush - Evacuation by Interval
Rank 12 Eqn 43 y-1=a+bx
r2=0.98265915 DF Adj r2=0.98255276 FitStdErr=75.819379 Fstat=18530.205
a=0.00031999575 b=1.93592E-06
3000
2500
2000
1500
1000
500
Water Height (Bit Count)
994
992
0
100
200
300
Interval

Fig. 22D

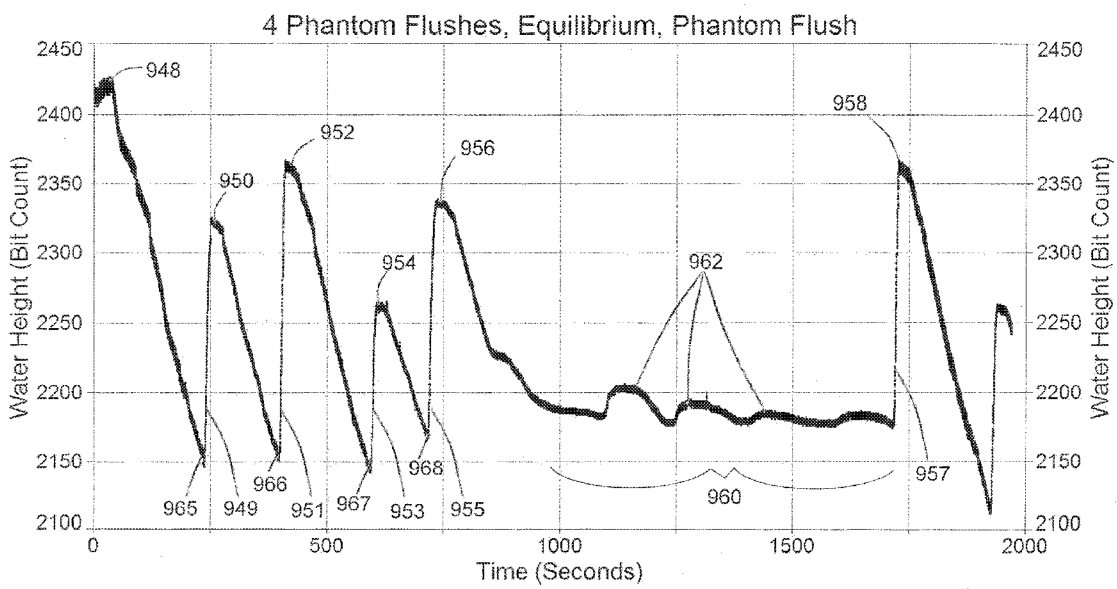

4 Phantom Flushes, Equilibrium, Phantom Flush
Water Height (Bit Count)
Time (Seconds)
2450
2400
2350
2300
2250
2200
2150
2100
0
500
1000
1500
2000
948
950
952
954
956
958
962
960
965
949
966
951
967
953
968
955
957

Fig. 23

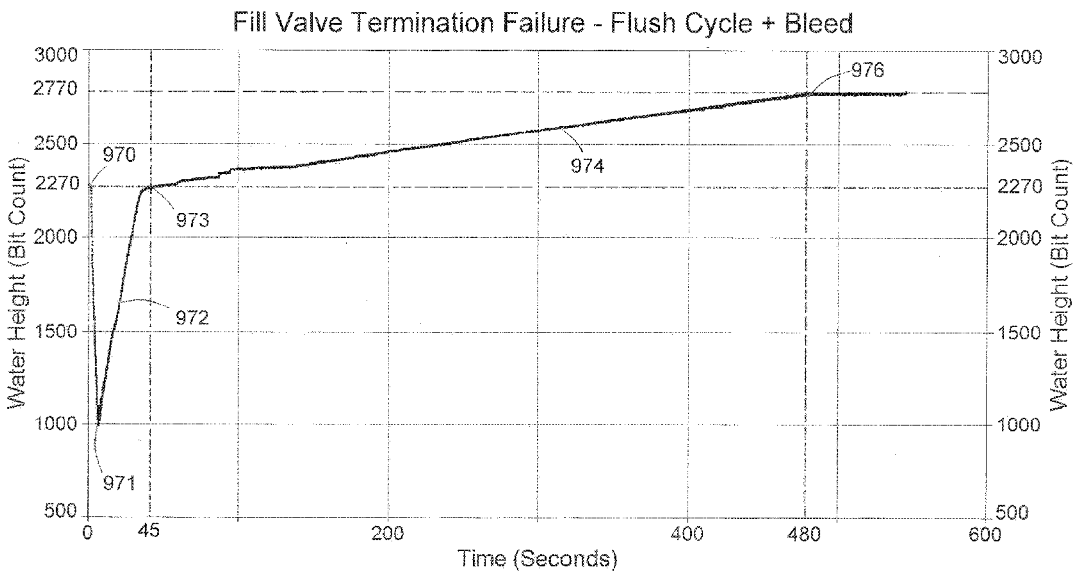


Fig. 24

	WH	TIME
PRE-FLUSH WATER HEIGHT 970:	2270	0
PRE-FLUSH WATER HEIGHT 972:	2270	45
PRE-FLUSH WATER HEIGHT 976:	2270	480

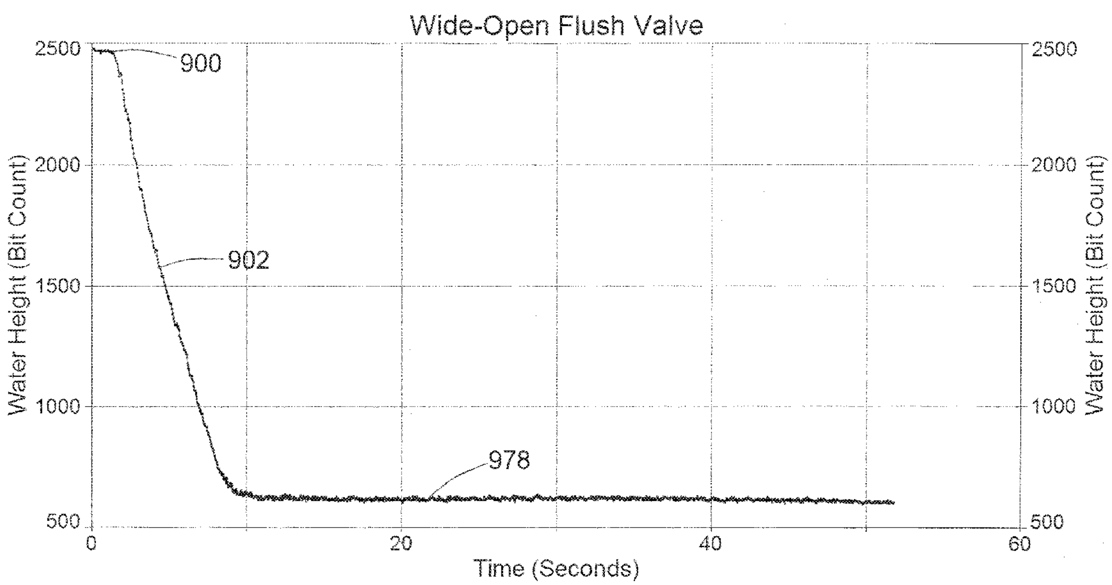

Wide-Open Flush Valve
2500
2000
1500
1000
500
Water Height (Bit Count)
900
902
978
0
20
40
60
Time (Seconds)
2500
2000
1500
1000
500
Water Height (Bit Count)

Fig. 25

Comparison of Complete Flush Cycles Between A Normal Flush And A Flush That Occurs When The Siphon Port Is Blocked

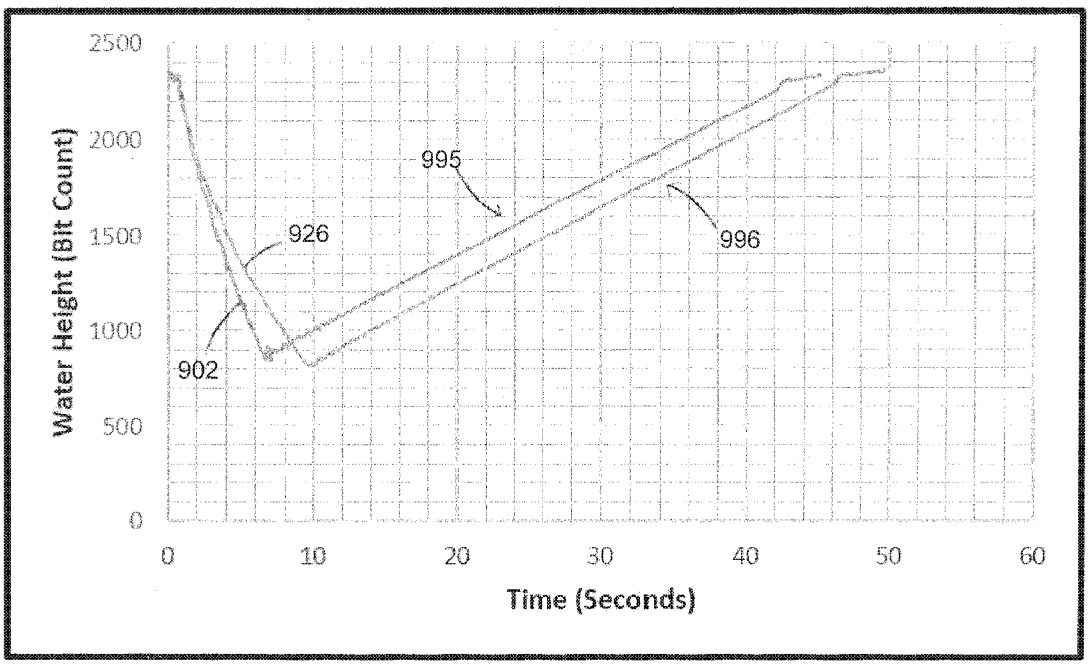


Fig. 26

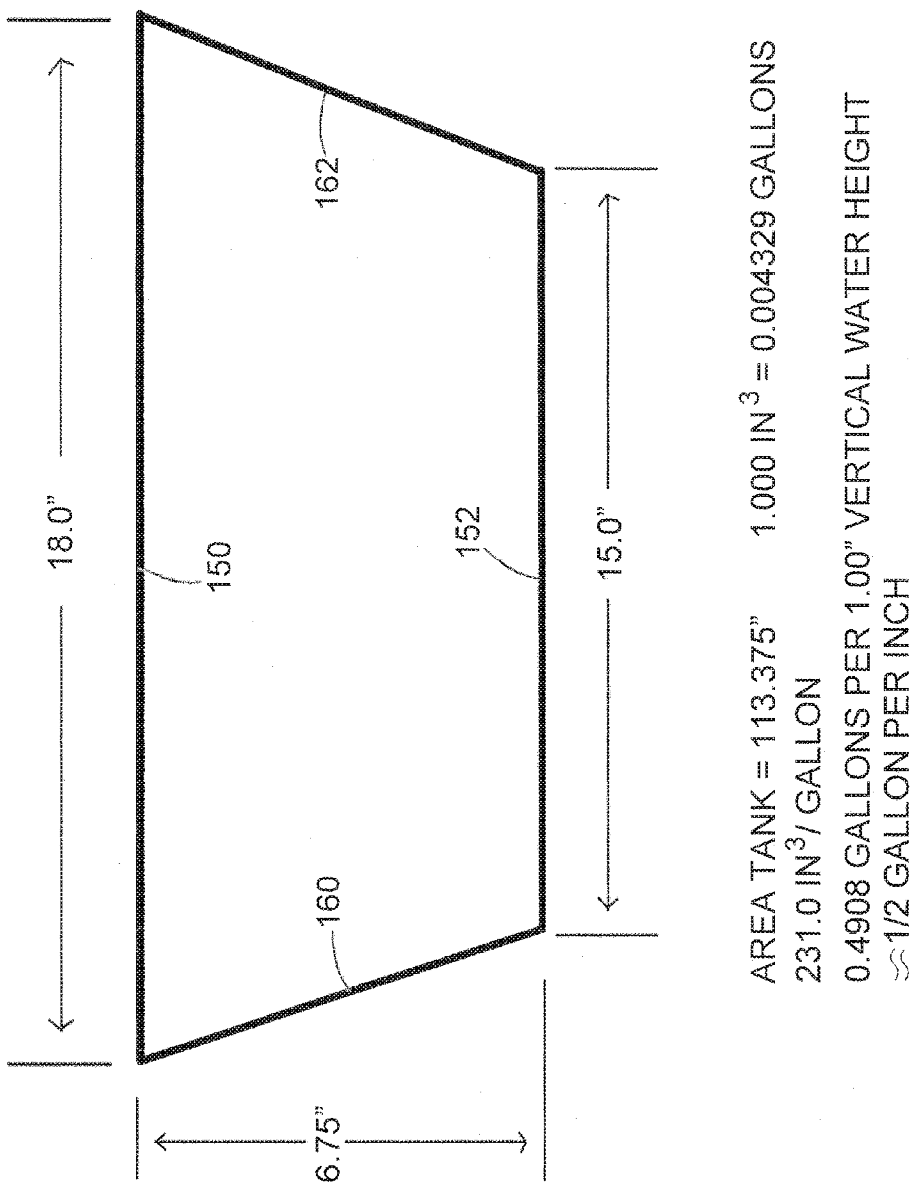

18.0"
15.0"
6.75"
150
152
160
162
AREA TANK = 113.375"
1.000 IN^3 = 0.004329 GALLONS
231.0 IN^3/ GALLON
0.4908 GALLONS PER 1.00" VERTICAL WATER HEIGHT
≈1/2 GALLON PER INCH

Fig. 27

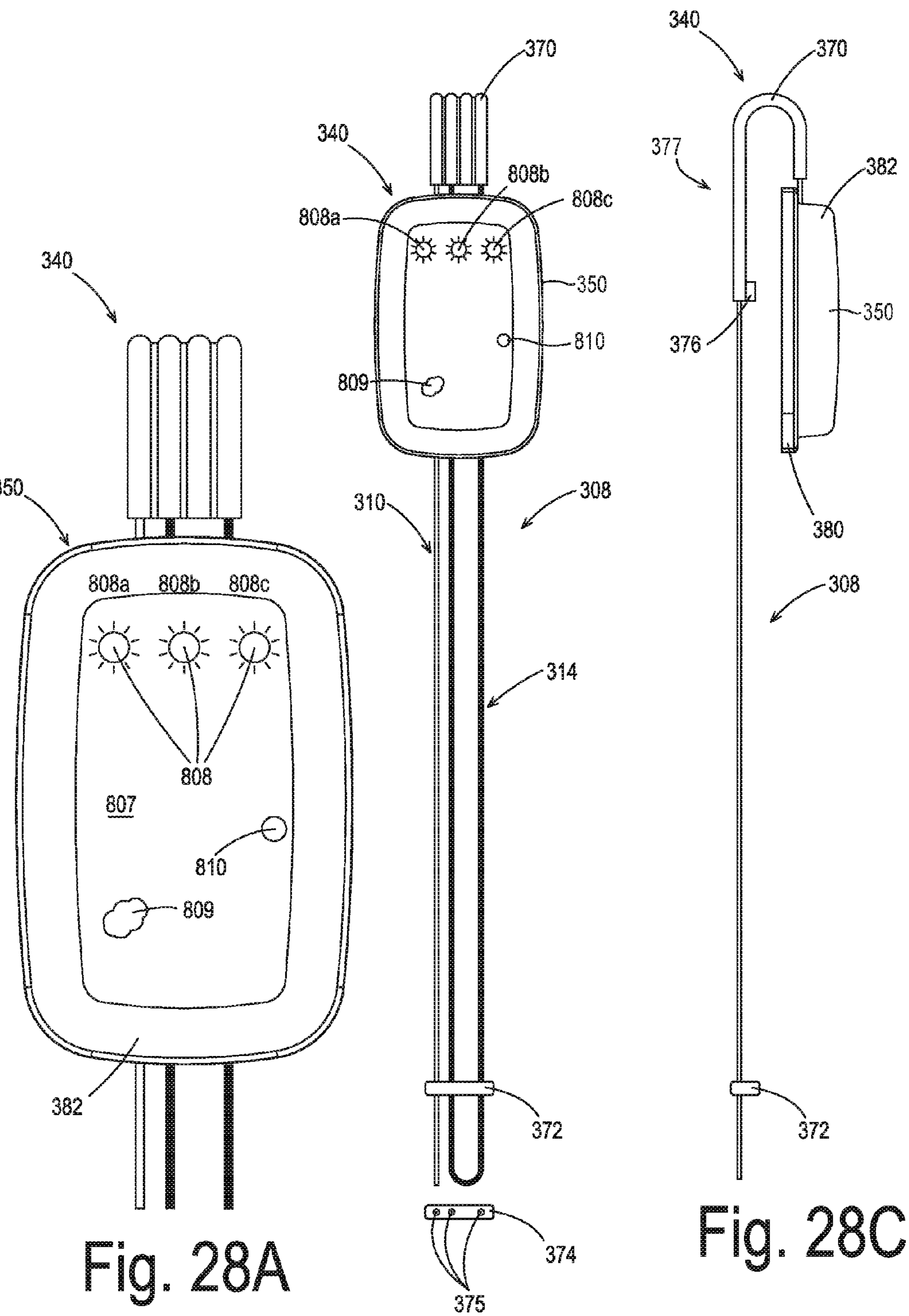
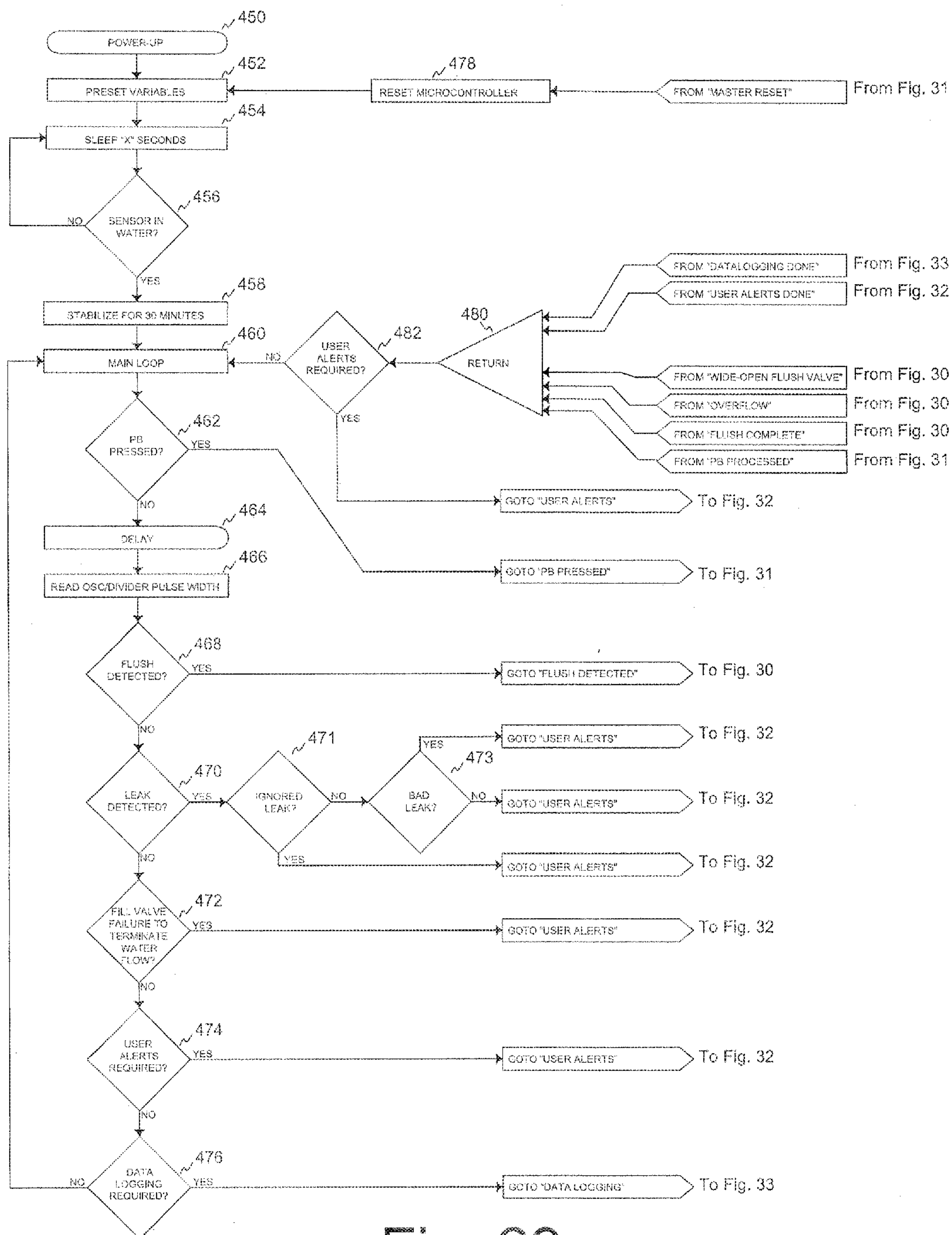


Fig. 28A

Fig. 28B

Fig. 28C



450
POWER-UP
452
PRESET VARIABLES
478
RESET MICROCONTROLLER
FROM "MASTER RESET"
From Fig. 31
454
SLEEP "X" SECONDS
456
SENSOR IN WATER?
NO
YES
458
STABILIZE FOR 30 MINUTES
460
MAIN LOOP
NO
482
USER ALERTS REQUIRED?
YES
480
RETURN
FROM "DATALOGGING DONE"
From Fig. 33
FROM "USER ALERTS DONE"
From Fig. 32
FROM "WIDE-OPEN FLUSH VALVE"
From Fig. 30
FROM "OVERFLOW"
From Fig. 30
FROM "FLUSH COMPLETE"
From Fig. 30
FROM "PB PROCESSED"
From Fig. 31
462
PB PRESSED?
YES
NO
GOTO "USER ALERTS"
To Fig. 32
464
DELAY
466
READ OSC/DIVIDER PULSE WIDTH
GOTO "PB PRESSED"
To Fig. 31
468
FLUSH DETECTED?
YES
NO
GOTO "FLUSH DETECTED"
To Fig. 30
471
470
LEAK DETECTED?
YES
NO
IGNORED LEAK?
NO
YES
473
BAD LEAK?
YES
NO
GOTO "USER ALERTS"
To Fig. 32
GOTO "USER ALERTS"
To Fig. 32
GOTO "USER ALERTS"
To Fig. 32
472
FILL VALVE FAILURE TO TERMINATE WATER FLOW?
YES
NO
GOTO "USER ALERTS"
To Fig. 32
474
USER ALERTS REQUIRED?
YES
NO
GOTO "USER ALERTS"
To Fig. 32
476
DATA LOGGING REQUIRED?
NO
YES
GOTO "DATA LOGGING"
To Fig. 33

Fig. 29

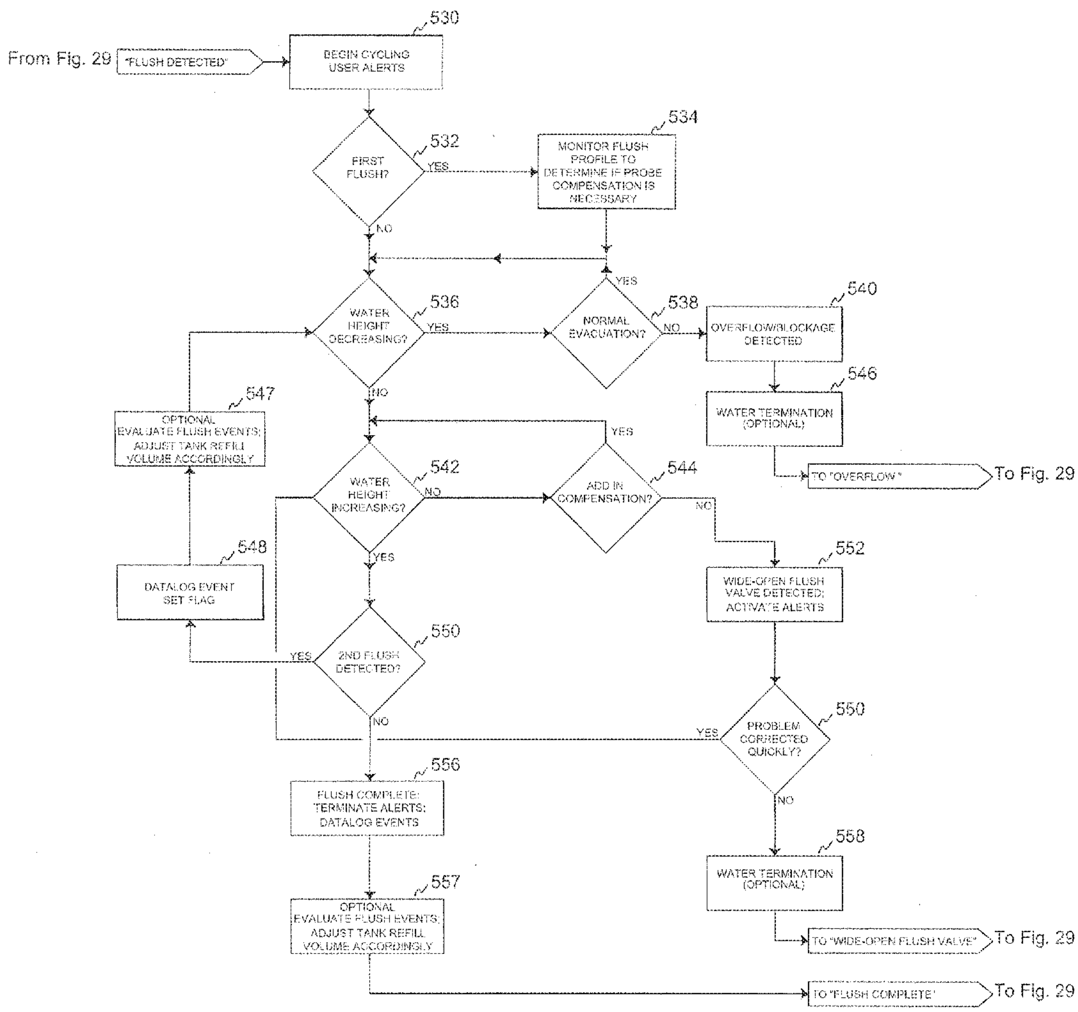

From Fig. 29
"FLUSH DETECTED"
530
BEGIN CYCLING USER ALERTS
532
FIRST FLUSH?
YES
NO
534
MONITOR FLUSH PROFILE TO DETERMINE IF PROBE COMPENSATION IS NECESSARY
536
WATER HEIGHT DECREASING?
YES
NO
538
NORMAL EVACUATION?
YES
NO
540
OVERFLOW/BLOCKAGE DETECTED
546
WATER TERMINATION (OPTIONAL)
TO "OVERFLOW"
To Fig. 29
547
OPTIONAL EVALUATE FLUSH EVENTS; ADJUST TANK REFILL VOLUME ACCORDINGLY
542
WATER HEIGHT INCREASING?
NO
YES
544
ADD IN COMPENSATION?
YES
NO
548
DATALOG EVENT SET FLAG
552
WIDE-OPEN FLUSH VALVE DETECTED; ACTIVATE ALERTS
550
2ND FLUSH DETECTED?
YES
NO
550
PROBLEM CORRECTED QUICKLY?
YES
NO
556
FLUSH COMPLETE; TERMINATE ALERTS; DATALOG EVENTS
558
WATER TERMINATION (OPTIONAL)
TO "WIDE-OPEN FLUSH VALVE"
To Fig. 29
557
OPTIONAL EVALUATE FLUSH EVENTS; ADJUST TANK REFILL VOLUME ACCORDINGLY
TO "FLUSH COMPLETE"
To Fig. 29

Fig. 30

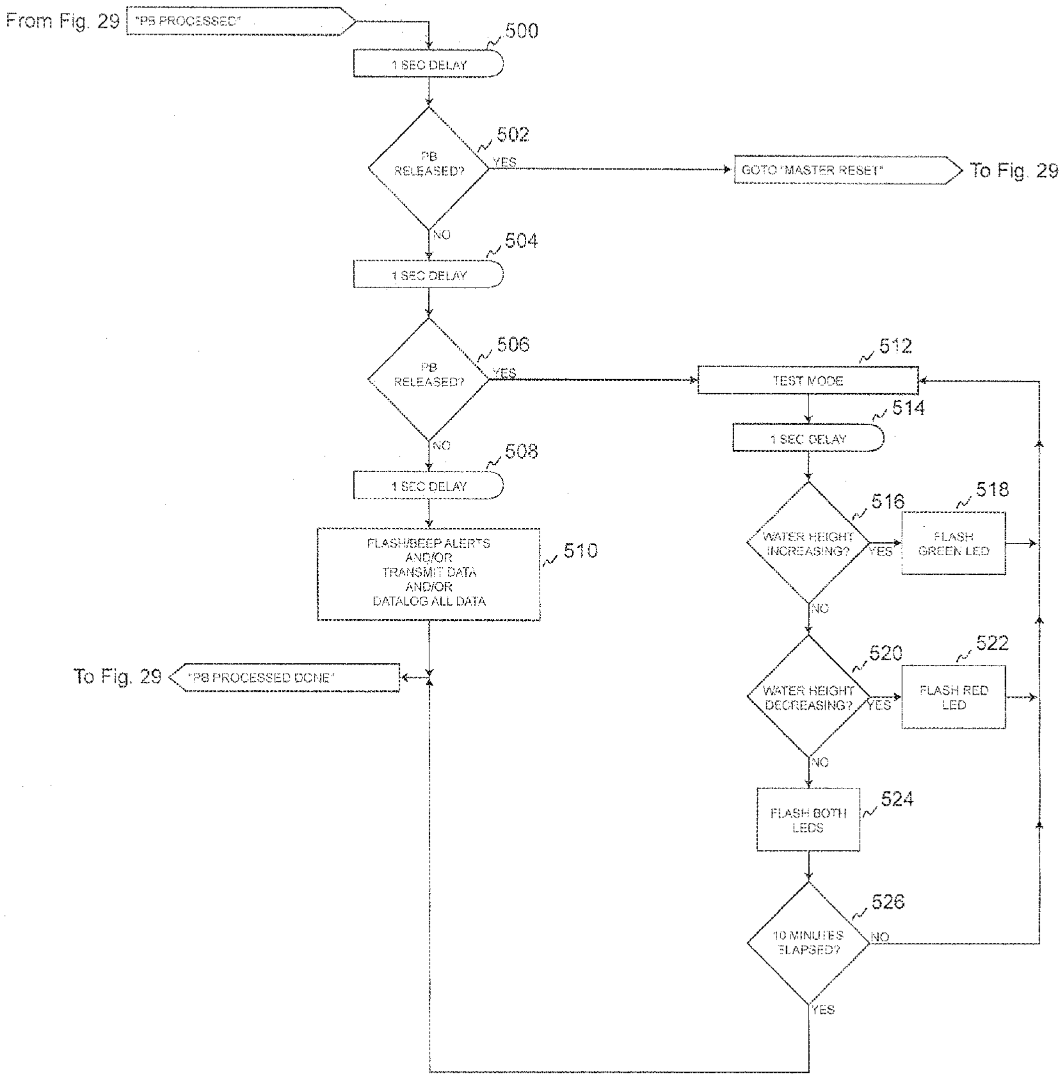

From Fig. 29
"PB PROCESSED"
500
1 SEC DELAY
502
PB RELEASED?
YES
GOTO "MASTER RESET"
To Fig. 29
NO
504
1 SEC DELAY
506
PB RELEASED?
YES
512
TEST MODE
514
1 SEC DELAY
NO
508
1 SEC DELAY
FLASH/BEEP ALERTS
AND/OR
TRANSMIT DATA
AND/OR
DATALOG ALL DATA
510
516
WATER HEIGHT INCREASING?
YES
518
FLASH GREEN LED
NO
To Fig. 29
"PB PROCESSED DONE"
520
WATER HEIGHT DECREASING?
YES
522
FLASH RED LED
NO
FLASH BOTH LEDS
524
526
10 MINUTES ELAPSED?
NO
YES

Fig. 31

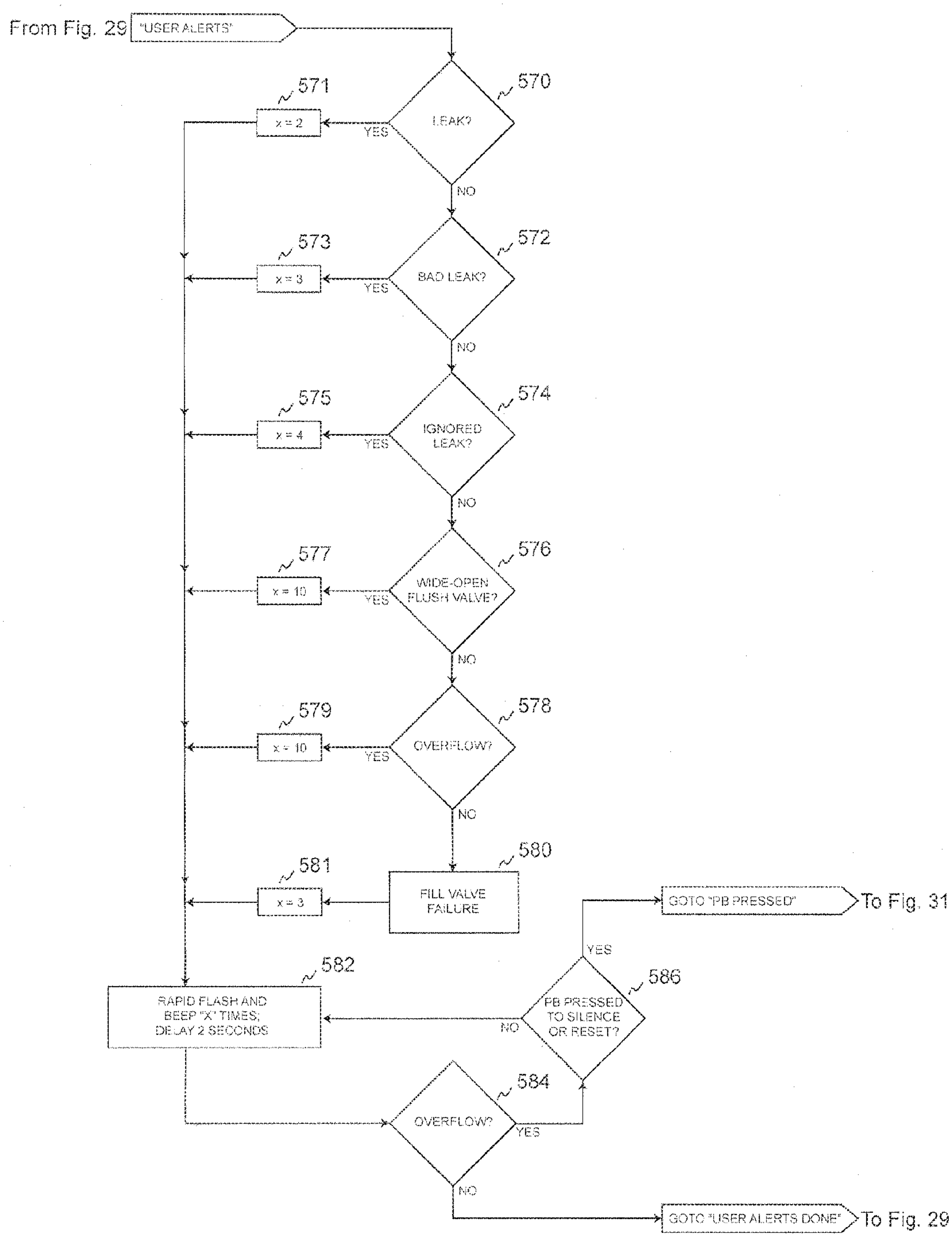

From Fig. 29
"USER ALERTS"
570
LEAK?
YES
NO
571
x = 2
572
BAD LEAK?
573
x = 3
574
IGNORED LEAK?
575
x = 4
576
WIDE-OPEN FLUSH VALVE?
577
x = 10
578
OVERFLOW?
579
x = 10
580
FILL VALVE FAILURE
581
x = 3
582
RAPID FLASH AND BEEP "X" TIMES; DELAY 2 SECONDS
584
OVERFLOW?
586
PB PRESSED TO SILENCE OR RESET?
GOTO "PB PRESSED"
To Fig. 31
GOTO "USER ALERTS DONE"
To Fig. 29

Fig. 32

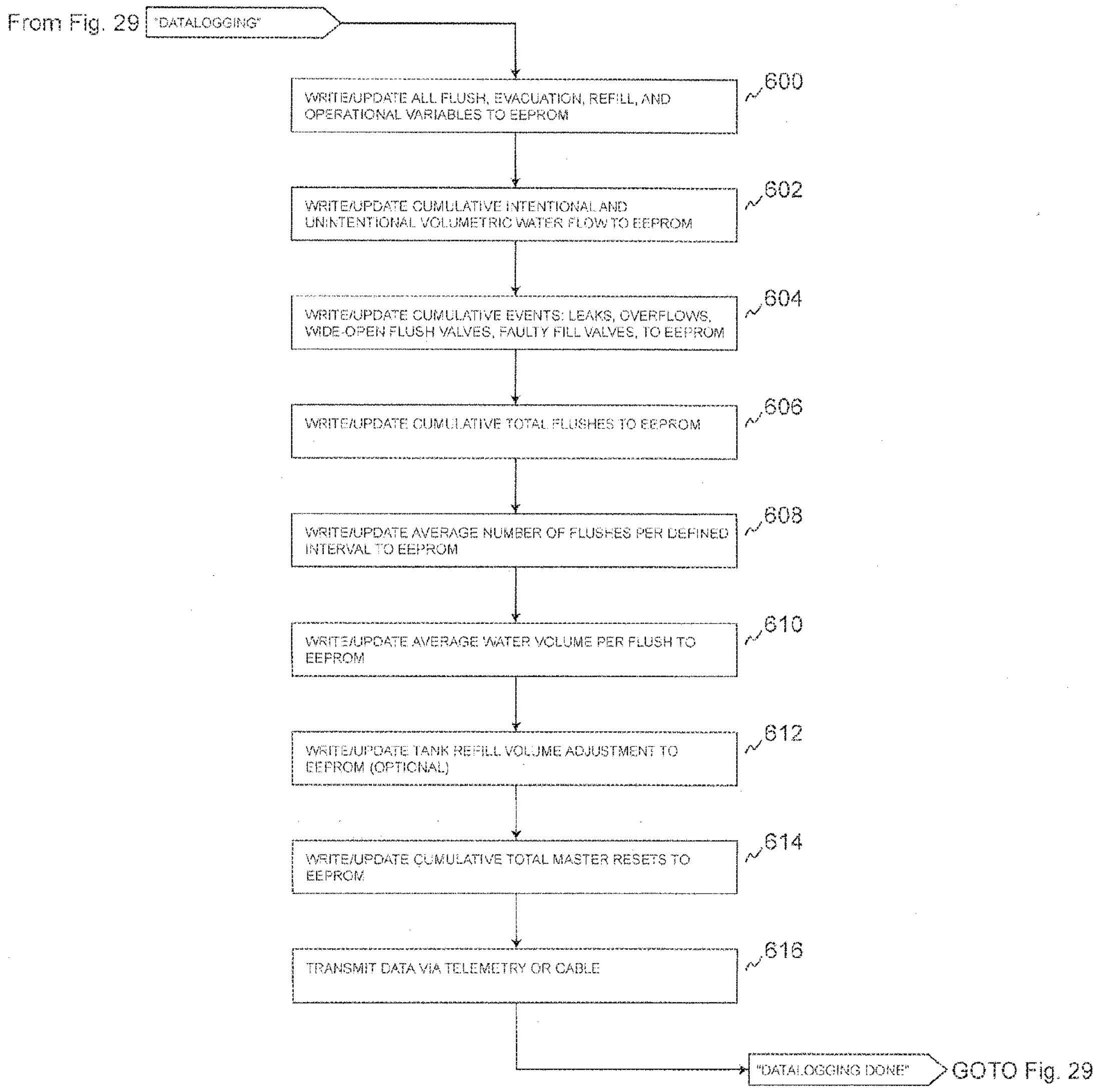

From Fig. 29
"DATALOGGING"
WRITE/UPDATE ALL FLUSH, EVACUATION, REFILL, AND OPERATIONAL VARIABLES TO EEPROM
600
WRITE/UPDATE CUMULATIVE INTENTIONAL AND UNINTENTIONAL VOLUMETRIC WATER FLOW TO EEPROM
602
WRITE/UPDATE CUMULATIVE EVENTS: LEAKS, OVERFLOWS, WIDE-OPEN FLUSH VALVES, FAULTY FILL VALVES, TO EEPROM
604
WRITE/UPDATE CUMULATIVE TOTAL FLUSHES TO EEPROM
606
WRITE/UPDATE AVERAGE NUMBER OF FLUSHES PER DEFINED INTERVAL TO EEPROM
608
WRITE/UPDATE AVERAGE WATER VOLUME PER FLUSH TO EEPROM
610
WRITE/UPDATE TANK REFILL VOLUME ADJUSTMENT TO EEPROM (OPTIONAL)
612
WRITE/UPDATE CUMULATIVE TOTAL MASTER RESETS TO EEPROM
614
TRANSMIT DATA VIA TELEMETRY OR CABLE
616
"DATALOGGING DONE"
GOTO Fig. 29

Fig. 33

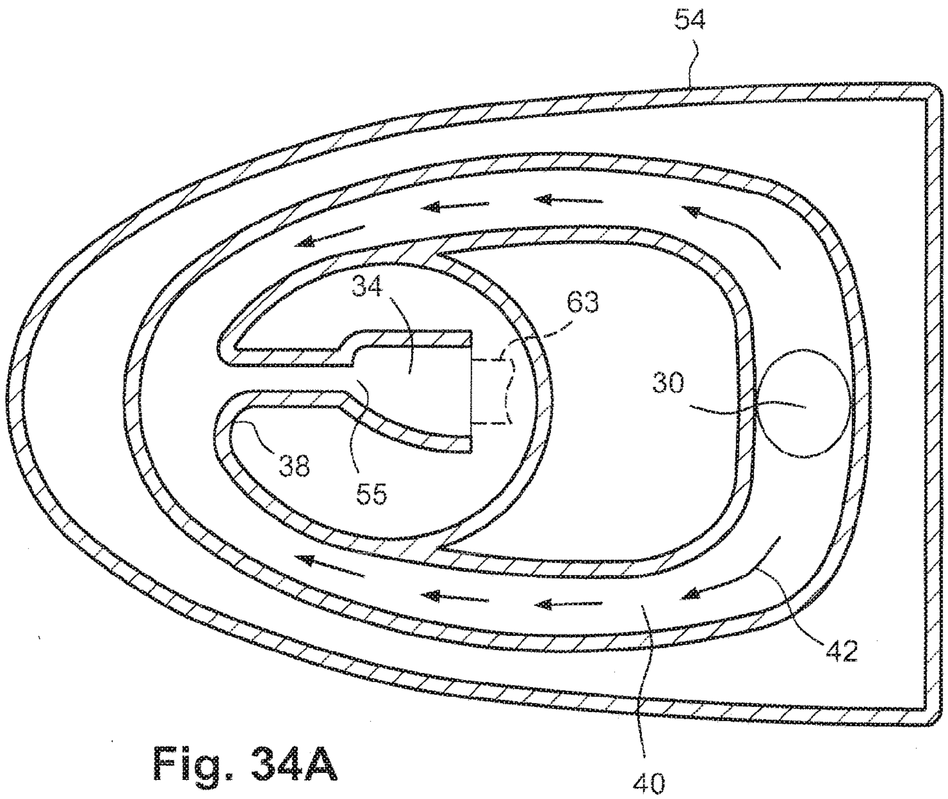


Fig. 34A

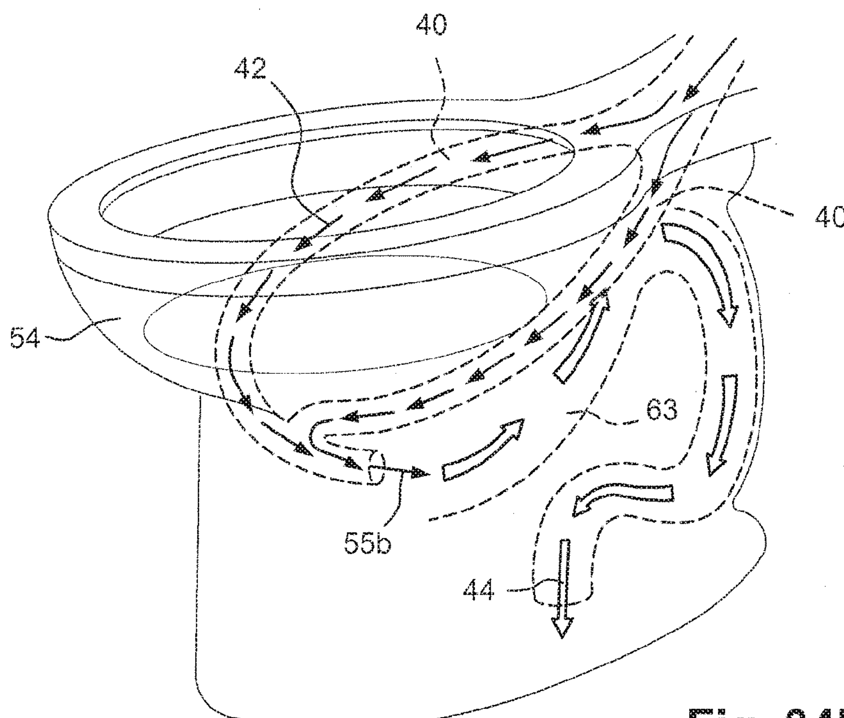


Fig. 34B

TOILET MONITORING AND INTELLIGENT CONTROL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit of U.S. Provisional Patent Application No. 62/423,502 filed Nov. 17, 2016, incorporated herein by reference.

FIELD

[0002] The technology herein relates to automatically monitoring the operation of a flush toilet, and in some embodiments, to automatic control of water supplied to a flush toilet.

BACKGROUND AND SUMMARY

[0003] Substantial work has been done in the past concerning automatic monitoring and control of conventional flush toilets. See for example commonly-assigned U.S. Pat. No. 8,704,671 ("Self-stick resonant enclosure that responds to flush toilet fill valve water inflow vibration"); U.S. Pat. No. 8,362,907 ("Self-stick resonant enclosure that responds to flush toilet fill valve water inflow vibration"); U.S. Pat. No. 8,310,369 ("Detecting unintended flush toilet water flow"); U.S. Pat. No. 8,166,996 ("Toilet bowl overflow prevention and water conservation system and method"); U.S. Pat. No. 7,757,708 ("Toilet bowl overflow prevention and water conservation system and method"), all incorporated herein by reference.

[0004] Further improvements are possible.

[0005] In one example non-limiting embodiment herein, a toilet monitor comprises a toilet tank water level sensor producing a toilet tank water level measurement signal. A processor is connected to receive the measurement signal. The processor detects the rate of change of the measurement signal and conditionally produces a responsive actuation signal in response to the detected rate of change. A transducer is connected to receive the actuation signal.

[0006] Further example non-limiting features include:

[0007] The processor may evaluate a sequence of rates of change to detect toilet operation abnormalities.

[0008] The processor detects predetermined sequences of rates of change. The processor detects rate of change using a rolling block interval analysis.

[0009] The processor uses a linear equation to analyze the rate of change measurement signal.

[0010] The processor determines an anomaly in water flow within the toilet bowl based on the rate of change of the toilet tank water level measurement signal.

[0011] The processor determines the toilet is leaking in response to the rate of change.

[0012] The processor determines the toilet is leaking by tracking the direction and/or the cycles of the rate of change.

[0013] The processor determines the toilet fill valve is defective in response to the rate of change.

[0014] The processor determines the toilet fill valve is defective by tracking the direction of the rate of change followed by the absence of rate change.

[0015] The processor determines the toilet flush valve is open in response to the rate of change.

[0016] The processor determines the toilet flush valve is open by tracking the absence of the rate of change.

[0017] The processor determines current and/or imminent toilet overflow in response to the rate of change.

[0018] The processor determines toilet overflow based on magnitude of rate of change.

[0019] The processor detects fluid volume usage based on rate of change.

[0020] The processor detects the prolonged absence of double flushes.

[0021] The sensor is configured for placement within a toilet tank, the water level sensor producing a measurement signal indicating the level of fluid within the toilet tank.

[0022] The transducer comprises at least one of (a) a valve, (b) an optical indicator, (c) an audible sound generator, and (d) a transmitter.

[0023] The water level sensor comprises a capacitive sensor but could be any type of water level sensor. The disclosed processes thus could work with a different type of sensor.

[0024] The capacitive sensor comprises first and second conductors, the first conductor being covered by an insulator.

[0025] The processor logs the rate of change for later retrieval and water usage tracking.

[0026] The sensor is configured to be disposed inside the tank and has a length that is less than the extent of the water level change within the tank, and the processor uses the measurement signal to extrapolate the measurements based on the extent of the water level change within the tank.

[0027] The processor is configured to sleep and to wake up at time intervals to sample the rate of change.

[0028] The toilet tank monitor is battery powered and has no on/off switch.

[0029] In another non-limiting embodiment, a toilet monitor comprises a toilet tank water level sensor producing a toilet tank water level measurement signal. A processor is connected to receive the measurement signal. The processor detecting the presence or absence of plural successive flushes within a predetermined time period based on the measurement signal and generating an actuation signal to affect toilet tank flush volume. A valve is connected to receive the actuation signal. The valve increasing or decreasing toilet tank flush volume.

[0030] In another non-limiting embodiment, a toilet monitor comprises a toilet tank water level sensor producing a toilet tank water level measurement signal. An electronic circuit is connected to receive the measurement signal. The electronic circuit determines an anomaly in water flow within the toilet bowl based on the toilet tank water level measurement signal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] Prior Art Diagrams:

[0032] FIG. **1** is a cutaway view of an example non-limiting exemplary conventional prior art toilet tank;

[0033] FIG. **2** shows the FIG. **1** conventional prior art toilet tank and conventional toilet bowl prior to being flushed;

[0034] FIG. **2**A shows conventional prior art toilet bowl internal plumbing details;

[0035] FIG. **3** shows the FIG. **2** toilet after the flapper has been opened and water is flowing from the tank into the bowl to evacuate the bowl;

[0036] FIG. 3A shows the conventional prior art FIG. 1 tank during a flushing operation into a clogged bowl;

[0037] FIG. 4 shows overflow of a conventional toilet;

[0038] FIG. 5 is an elevated perspective view of an exemplary illustrative non-limiting conventional prior art water fill valve;

[0039] FIG. 5A shows an elevated perspective detail of the FIG. 5 conventional prior art water fill valve with protective cap removed;

[0040] FIG. 5B shows an elevated perspective detail of the inside of the FIG. 5 prior art fill valve protective cap;

[0041] FIG. 5C shows a more detailed partially disassembled view of the FIG. 5 prior art conventional fill valve;

[0042] FIG. 6 shows an example of a mechanized water termination or interruption assembly that snaps onto the cap of conventional fill valve;

[0043] FIG. 6A shows a mechanized water termination or interruption assembly in view of a conventional fill valve to which it is to be attached;

[0044] Example Non-Limiting Embodiment Diagrams:

[0045] Figure YA and YB show example non-limiting block diagrams of toilet monitoring systems;

[0046] Figure Z shows an example non-limiting state diagram;

[0047] Figure Z1 shows an example non-limiting functional analysis diagram;

[0048] Example Non-Limiting Diagrams Showing Sensor Configurations

[0049] FIG. 7 shows an in-tank toilet monitoring and control system including a monitoring device, a solenoid valve, and various water heights representing several different possible tank refill termination levels which correlate directly to flush volumes.

[0050] FIG. 8 illustrates a conventional toilet tank in cutaway side-view showing water levels which correspond to different normal modes of operation and failure modes of operation;

[0051] Example Non-Limiting Toilet Operation Abnormalities that can be Detected

[0052] FIG. 9 illustrates a conventional toilet tank in cutaway side-view showing water levels which correspond to different normal modes and failure modes of operation, with the in-tank version of the toilet monitoring and control system mounted to, and extending into, the toilet tank;

[0053] FIG. 10 shows the conventional toilet as the bowl is being evacuated by water flowing from the tank into the bowl;

[0054] FIG. 11 is a cutaway front-facing view of an example toilet after an intentional flush operation, with the tank refilling through the fill valve after the flapper has returned to its down and sealed position;

[0055] FIG. 12 is a close-up internal view of a toilet tank leaking due to a defective flapper;

[0056] FIG. 13A is a cutaway view of an example toilet tank representing the abnormal increasing water height due to a faulty fill valve which fails to terminate water flow in response to the maximum height of the float;

[0057] FIG. 13B is a cutaway view of an example toilet tank refilling through the fill valve after sufficient water has leaked out through the defective flapper to cause a tank refill to begin;

[0058] Example Additional Non-Limiting Sensor Configurations

[0059] FIG. 14 shows the circuit diagram for a common resistive fixed point fluid level sensor;

[0060] FIG. 15 shows the operational circuit diagram of a commercially available type of capacitive fluid level sensor;

[0061] FIG. 15A shows the operational circuit diagram for a type of capacitive sensor that uses the fluid container vertical housing as the dielectric and the fluid as one plate of the capacitor;

[0062] FIG. 16 shows a typical Hartley oscillator whose frequency changes in response to the capacitor value, and a corresponding square wave that is produced in response to the change in capacitance;

[0063] FIG. 16A shows a typical unijunction transistor-type relaxation oscillator whose frequency changes in response to the capacitor value, and the corresponding output waveform;

[0064] FIG. 16B shows a simple resistor-capacitor (RC) type pulse measurement circuit connected to a microcontroller, and a corresponding pulse that is produced by the microcontroller input port in response to the discharge time of the capacitor;

[0065] FIG. 17 shows the exemplary integrated circuit (IC) type oscillator-divider using a precision resistor-capacitor (RC) type oscillator with a binary divider circuit, and a corresponding square wave that is produced in response to the change in capacitance, and an example microcontroller connected to the oscillator-divider;

[0066] FIG. 18A shows a capacitive water height sensor containing a single uninsulated wire and a single vertical insulated wire;

[0067] FIG. 18B shows the exemplary capacitive water height sensor containing a single uninsulated wire and a U-shaped single insulated wire;

[0068] FIG. 18C shows the FIG. 18A capacitive water height sensor submerged in liquid;

[0069] Example Non-Limiting Toilet Monitor Embodiment

[0070] FIG. 19 shows an exemplary toilet monitoring and intelligent control system with the exemplary capacitive water height sensor and the electronic control and annunciation module located inside the toilet tank;

[0071] Example Non-Limiting Characteristic Toilet Operation Signals

[0072] FIG. 20 graphically represents an example complete flush cycle of a typical tank-based toilet that is functioning properly with no blockages or obstructions, by tank water height and time;

[0073] FIG. 20A graphically represents an example tank evacuation of FIG. 20 by tank water height and time;

[0074] FIG. 20B graphically represents an example tank evacuation of FIG. 20 by tank water height and interval;

[0075] FIG. 20C graphically represents an example tank refill of FIG. 20 by tank water height and time;

[0076] FIG. 20D graphically represents an example tank refill of FIG. 20 by tank water height and interval;

[0077] FIG. 20E is a data listing by tank water height and time of the FIG. 20 graph;

[0078] FIG. 21 graphically represents an example complete flush cycle of a typical tank-based toilet with a blocked siphon jet, by tank water height and time;

[0079] FIG. 21A graphically represents an example tank evacuation of FIG. 21 by tank water height and time;

[0080] FIG. **21**B graphically represents an example tank evacuation of FIG. **21** by tank water height and interval;

[0081] FIG. **21**C graphically represents an example tank refill of FIG. **21** by tank water height and time;

[0082] FIG. **21**D graphically represents an example tank refill of FIG. **21** by tank water height and interval;

[0083] FIG. **21**E is an example data listing by tank water height and time of the FIG. **21** graph;

[0084] FIG. **22** graphically represents example back-to-back flushes of a typical tank-based toilet with a 95% blocked drain pipe, by tank water height and time;

[0085] FIG. **22**A graphically represents an example first flush tank evacuation of FIG. **22** by tank water height and time;

[0086] FIG. **22**B graphically represents an example first flush tank evacuation of FIG. **22** by tank water height and interval;

[0087] FIG. **22**C graphically represents an example second flush tank evacuation of FIG. **22** by tank water height and time;

[0088] FIG. **22**D graphically represents an example second flush tank evacuation of FIG. **22** by tank water height and interval;

[0089] FIG. **23** graphically shows an example sequence of 4 phantom flushes, followed by a period of time in which the fill valve is in equilibrium, and then a final phantom flush, by tank water height and time;

[0090] FIG. **24** graphically shows an example tank water height response to a fill valve termination failure with respect to time;

[0091] FIG. **25** graphically shows an example normal tank evacuation of an average tank-based toilet, followed by an example wide-open flush valve that prevents the refill of the tank, by tank water height and time;

[0092] FIG. **26** shows the FIG. **20** graph of an example normal unimpeded flush cycle of a typical tank-based toilet compared with the FIG. **21** flush cycle graph of the same toilet when the siphon jet is blocked and thereby preventing bowl evacuation, by tank water height and time.

[0093] Example Toilet Tank Dimensions and Volume

[0094] FIG. **27** shows an example 2-dimensional cross-section of a typical tank-based toilet as viewed from overhead;

[0095] FIG. **28**A-C show an exemplary non-limiting toilet monitoring and intelligent control system with the exemplary capacitive water height sensor located inside the toilet tank and the electronic control and annunciation module located outside the toilet tank;

[0096] Example Non-Limiting Toilet Monitoring and Control Operation

[0097] FIG. **29** shows an example power-up sequence and main loop flowchart of a microcontroller-based operating system of the exemplary toilet monitoring and intelligent control system;

[0098] FIG. **30** shows an example flush detection flowchart of a microcontroller-based operating system of the exemplary toilet monitoring and intelligent control system;

[0099] FIG. **31** shows an example user pushbutton flowchart of a microcontroller-based operating system of the exemplary toilet monitoring and intelligent control system;

[0100] FIG. **32** shows an example user alerts flowchart of a microcontroller-based operating system of the exemplary toilet monitoring and intelligent control system;

[0101] FIG. **33** shows an example datalogging flowchart of a microcontroller-based operating system of the exemplary toilet monitoring and intelligent control system; and

[0102] Example Toilet Suction Port Operation:

[0103] FIGS. **34**A & **34**B show example non-limiting toilet suction port operation.

DETAILED DESCRIPTION OF EXAMPLE NON-LIMITING EMBODIMENTS

[0104] (General Toilet & Actual Water Costs Due to Leaks & Wide-Open Flush Valves/Flappers) Chris Oxlade identified the toilet as one of the top innovations of all time in his 2009 book, "The Top Ten Inventions That Changed the World". What his book might have overlooked was the millions of home and business owners who have fallen prey to leaks, problems, and damage associated with or caused by toilets. Many water utilities and agencies cite toilets as being the #1 cause of high water bills. Many larger utilities field thousands of customer service calls each month regarding a spike or increase in their water-in/water-out invoices, which often results in angry customers with unresolved water problems in their home. Most utility customers refuse to believe that a toilet could be the culprit for their high water bill. Widely published statistics state that a silent and leaking flapper can easily account for 200 gallons of water wasted per day, and yet still go unnoticed by the occupants. Wide-open flush valves—which can occur for many reasons, but most frequently happen when the flush handle linkage chain gets hung up—can easily waste more than 4 gallons per minute, or more than 5,000 gallons per day. In places like Atlanta or Seattle where the water-in/water-out cost exceeds $15 per thousand gallons, it's easy to see how an overlooked toilet problem can lead to a "Water Bill Nightmare!"

[0105] (Overview of Damage & Costs Due to Overflows) Worse still is the billions of dollars in property damage that occur every year due to overflowing toilets. While conservationists and environmentalists applauded the mandates for low-volume-flush toilets beginning in the 1990's, the poop volcanoes that were once easily dealt with by high gallon-per-flush commodes began to result in "double-flushes", which often led to disastrous overflows. The specific reason "why" double-flushes often lead to toilet overflows will be explained in detail later in this specification, as it is often attributed to toilet malfunctions, when in fact that is not the case. Black mold remediation due to overflows has become big business in the United States and frequently costs more than $35,000.00 when the damage is extensive.

[0106] (Inferior Quality of Some Fill Valves Has Led to More Problems) While leaks, wide-open flush valves, and overflows, are the better-known toilet problems, there are several additional problems that can also lead to wasted water and high bills. 20 years ago Fluidmaster practically ruled the fill valve market in the United States, and rightly so. Their Model #400 fill valve is, in this inventor's opinion, the most reliable and dependable fill valve ever put into production. Over the last 10 years, other manufacturers have begun to crowd the space that Fluidmaster once owned, both in retail and industrial sales volume. Some fill valves are now even Model #400 knock-offs: they look similar, but they are less reliable. Market competition has resulted in more diverse fill valve product choices from multiple manufacturers, but it has also resulted in cheaply made inferior products that, in many instances, exhibit extraordinarily high failure rates. In fact, many of the fill valves now on the market commonly exhibit several types of failures that home owners are often unable to diagnose, and frequently even plumbers are unaware of these types of anomalies.

[0107] (Equilibrium Failure) The first failure exhibited by a high percentage of fill valves tested—even when new right out of the box—is what we will term herein as an "Equilibrium Failure". Equilibrium failures occur when the toilet is leaking, the water level in the tank is dropping, but the fill valve fails to refill the tank. Instead, the fill valve only partially opens and begins to allow water into the tank at the same volumetric rate as that of the leak, hence reaching a "state of equilibrium", specifically meaning that the water-in (entering from the water supply line) to the fill valve is exactly equal to the water-out (that which is draining into the tank and ultimately into the toilet bowl). This failure occurs for several reasons and is often never discovered because there is virtually no noise of any kind, and the water that is entering the toilet bowl—particularly a clean toilet bowl—is virtually invisible. Further compounding the likelihood of a leak not being detected is the absence of a "phantom flush", which a fill valve in equilibrium failure will not produce. A phantom flush is generally recognized as the periodic audible "whooosh" sound made by a properly working fill valve when the water level in the tank has dropped due to a leak, with the float on the fill valve responding by allowing water to refill the tank, producing tank turbulence and thereby causing the audible sound. Adding insult to injury for thousands of customers who experience high water bills and are then advised by the water agency or a well-meaning plumber or DIY professional to replace the flapper, is that despite correcting the initial cause of the leak, a faulty fill valve which exhibits equilibrium failure will likely exhibit another type of failure that can be even worse when it comes to water loss.

[0108] (Water Termination "Bleed" or "Valve Closure" Failure) The second type of fill valve failure is more nefarious, harder to detect, does not appear in water utility websites or customer literature handouts as an actual cause for water loss, and has frustrated more homeowners than "Sand on the Beach" (that's going to be the title of my second movie). At the end of the flush cycle the water level rises, raising the float, which should cause the fill valve to close and terminate the water flow into the tank. But when a valve closure failure occurs and the fill valve does not completely close, water continues to bleed into the tank despite the position of the float. This continued bleeding causes the water level to rise until it reaches the top of the overflow tube, where it then drains continuously into the toilet bowl. Extensive research has shown that not only does the fill valve continue to bleed, but in many instances, the volume of water will increase steadily over time. Because this type of failure is virtually unknown by the population at-large and by water utility customer service representatives seeking to help those callers complaining of a high water bill due to a suspected toilet malfunction or leak, a diagnostic approach may, in fact, prove that a leak exists, while the generally recommended "flapper replacement" fails to solve the problem.

[0109] (Various Failures Nearly Impossible to Detect, Let Alone Identify) Given the fact that only a small fraction of adults understand the purpose and function of a toilet flapper, it is not surprising that the more complex failures are often overlooked. Therefore, for general information purposes, an overview of the typical operation for a tank-based flush toilet follows.

[0110] (A General Overview of Tank-Based Toilet Operation) FIGS. **1**, **2** & **2**A show an exemplary illustrative non-limiting modern (prior art) toilet **50** comprising a tank **52** and a bowl **54**. The tank **52** holds a quantity of water W. Pulling on the flush handle **56** causes a lever **58** to lift a chain **60**, which in turn raises a "flapper" **62** at the bottom of the tank **52**. Flapper **62** is a kind of valve that flaps open and closed. When chain **60** raises flapper **62** off of flush valve seat **65**, water W from the tank **52** rushes downward through an opening into the bowl **54**. This inrush of water flows through rim holes **55***a* and siphon jet **55***b* (see FIG. **2**A). This water inrush increases the water pressure within the bowl, forcing water through exhaust port **63** and past vapor trap **55***c* beneath the bowl and down into waste pipe **57**. This flow of water and waste into the waste pipe **57** creates a strong siphon that evacuates the bowl through exhaust port **63**, producing the characteristic flushing sound familiar to most people. In most toilets, the bowl **54** is molded so that the water enters the rim, and some of it drains out through holes in the rim. A good portion of the water flows through a passageway down to a larger hole at the bottom of the bowl as shown in FIG. **2**A. This passageway and hole is known as the siphon jet **55***b*. It releases most of the water directly into siphon jet **55***b*. Because all of the water in tank **52** enters bowl **54** in a very short time (e.g., three seconds), it is enough to produce the siphon effect, and all of the water and waste in the bowl is sucked out.

[0111] When nearly all of the water has escaped from the tank **52**, the flapper **62** descends back down to its original position as shown in FIG. **2**, once again sealing the water passage between the tank and the bowl **54**. Fresh tap water flowing into the tank **52** through a fill valve **66** from an inlet pipe **64** begins to fill the tank. A float **112** rises with the rising water level. When the float **112** reaches a preset level, it closes the fill valve **66** and water ceases to flow into the tank **52**. The toilet **50** is now ready for another flush.

[0112] While toilets are generally reliable, they can malfunction from time to time, as previously noted. Perhaps the most common malfunction is when the flapper **62** remains partially open, leaks, or is misaligned, causing the toilet to "run." A stuck-open flapper **62** can waste a lot of water. This can be a serious problem, especially in cases of water shortages or droughts. Sometimes the fix is as simple as jiggling the flush handle **56**. Other times, it is necessary to replace the flapper **62**. It is occasionally possible to detect the flapper **62**'s failure to close by listening for water running continuously into the tank **52**, although the sound of trickling water can be barely audible. But suppose the trickling water is at least somewhat audible. Often, people are not home to hear the water running. Folks who are hearing impaired may not be able to hear water running. In many bathrooms, when the light is turned on, an exhaust fan also turns on, further decreasing the likelihood of a slightly audible toilet trickle being detected. Hundreds of gallons of water can be wasted in this way in a relatively short time. Some readily available water agency surveys estimate that of the approximately 300,000,000+ toilets in the United States, as many as one in five may be leaking at any point in time.

[0113] A running toilet can waste a lot of water but usually does not present health hazards. An overflowing toilet, on the other hand, can be a serious household hygiene disaster—as anyone who has ever had to clean up the consequences knows very well. Watching water rise to the top edge of a toilet bowl is a fearful experience. Overflowing toilet bowls can spread germs and disease, cause structural damage to homes and businesses, contribute to toxic mold, and cause other bad effects.

[0114] FIG. **3** shows an example normal evacuation situation and FIG. **3**A shows an example clogged toilet situation. When debris (e.g., a child's toy, excess quantities of toilet paper, a massive poop volcano, etc.) blocks the toilet exhaust port **63** or further down waste pipe **57** as shown in FIG. **3**A, flushing the toilet does not cause the bowl **54** to evacuate. Instead, the water level within bowl **54** continues to rise as water from the tank **52** rushes downward into the bowl. In many instances, the water will stop rising before the toilet overflows. This is because most toilet bowls **54** are designed to hold the entire contents of the tank **52** without overflowing—but only if the water in the tank falls low enough to allow the flapper **62** to seat so as to prevent further water from flowing into the bowl **54**. Overflows can occur with just a single flush when blocked siphon **55***b* port (see FIG. **2**A) prevents the rapid evacuation of the water in the tank **52** while the fill valve **66** is open.

[0115] Toilets can also overflow if the water level in the bowl **54** starts out higher than normal when the toilet is flushed. As FIG. **4** shows, when a toilet bowl **54** is clogged so that a single flush doesn't flush the bowl's contents away, some people will flush the toilet a second time in the hope that the additional water will push the bowl contents down through the outlet pipe **63**. Additional flushing rarely clears the clog, but can easily cause a toilet bowl to overflow, as will be described in detail later in the specification.

[0116] The second flush often overflows the bowl because when the bowl water height is substantially higher—or not—due to a previous flush AND the drain is partially or fully clogged, a further flush will fill the bowl, preventing the flapper from seating because the tank will not drain sufficiently to allow the positive buoyancy of the flapper to seat; and when the water-in from the fill valve exceeds the water-out of the obstructed drain, the overflow will occur at the delta differential rate, which can be several gallons per minute of contaminated water going over the edge of the bowl and onto the floor)

[0117] Parents should warn their children that when the water level in a toilet bowl is higher than normal, the toilet should not be flushed again. Unfortunately, it is common for children and others who do not know better to flush a toilet repeatedly in the hope that additional consecutive flushes will eliminate the blockage. Adding insult to injury, a lot of children love to experiment and play with toilets, tossing in toys and other objects, and smacking the flush handle. Often times when the water begins to rise precipitously in the bowl and the child (or adult!) does not know what to do and does not wish to call attention to the impending nightmare that is about to occur, the individual will discreetly sneak away, perhaps hoping that the problem will "fix itself", or minimally that they won't be identified as the culprit!

[0118] The reduction in the amount of water used to flush or evacuate toilets has also consumed the time and attention of water utilities, landlords, home and business owners, and manufacturers. Great strides have been made in the design of toilets which are capable of removing substantial amounts of waste from the bowl while using far less water than past toilet designs. Changes in flush valve and fill valve designs have made it possible to better control the volume-per-flush of many toilets, while dual-flush toilets have allowed users and property managers to control flush volumes on the basis of the need to evacuate solid or liquid waste. To-date, however, flush volumes are still primarily a function of preset fill valves and flush valves, or a user-based decision on dual-flush capable toilets. Property management, hospitality, and water utilities rightly desire better water conservation and less water waste, and recognize that when left solely to the discretion and control of customers, guests, residents, etc., that water savings is more of a politically correct manner of speech than it is actual reality . . . unless there is an imposed financial penalty.

[0119] Yet while the toilet is a much-used and needed product in civilized nations around the globe, its actual operation and the nature of its various failures remain a mystery to all but a few. With less than one percent (1%) of the planet's water being potable, an ever increasing global population, wide-spread and long-lasting regional and hemispherical droughts becoming more and more frequent, it is becoming more and more important to not just detect the various types of toilet problems and failures that lead to water being wasted (and the damage that wasted water often produces), but do so quickly, cost-effectively, and whenever possible, terminate excessive unintentionally wasted water.

[0120] (Prior Art Water Conservation Approaches in View of Tank Volume, Timing, etc.) Many different approaches have been used to conserve water when it comes to toilets. From dual-flush methodologies and increasingly efficient toilet designs to placing water-displacement bricks in the tank, a great deal of progress has been made when it comes to focusing specifically and only upon the toilet design and features. A new and novel water conservation approach will be described herein which uses the water height data analysis of each flush to determine user waste characteristics to automatically optimize flush volumes.

[0121] (Many Different Approaches Yet No Still No Cost-Effective Technology/Product for Various Markets; Reasons Why—Primary Reason is the Number of Permutations of Toilets, Flush Volumes, Fill Valves, Flush Valves, etc., have heretofore precluded the deployment of a single product solution) Many in the past have tried to use technology to detect toilet leaks, prevent overflows, reduce or control toilet flush volumes, and mitigate or stop the wasting of water. Most of the solutions that exist to-date have been ineffective, cost-prohibitive, too complicated to implement or install, or just too poorly conceived to be of practical use. Several existing solutions for terminating water flow to a "problem toilet" involve placing an electronic valve in the fluid fill line **64**, often with a plethora of unsightly and poorly conceived tank and bowl sensors which, for many users and property managers, is aesthetically unacceptable. Such installations also require plumbing knowledge, if not an actual plumber, in order to implement, which increases the overall installation cost. Other known solutions involve special toilet designs that provide overflow plumbing. Convoluted fill valve and flush valve designs and assemblies—impractical to manufacture and too expensive to implement—have frequently hit the market. Yet none of these approaches have ever been widely adopted, so the troublesome problems of toilet overflow and water waste still exist. Further, addressing the issue of leaks and fill valve failures has led to the development of products that have also never received wide acceptance. When it comes to the marketplace, the general public, property management, hospitality, and water utilities, need something that is ultimately as simple to install and use as the toilet itself. It is a significant challenge to solve these technical and market-based problems for the large number of toilets already installed in millions of homes and businesses.

[0122] The main reason that most mass market solutions have been unsuccessful comes down to simple mathematics: the number of different permutations of tank-based toilets installed around the globe is in the tens of millions. As a result, the combination of fill valve and flush valve types, toilet tank and bowl designs, flush volumes, water pressure, etc., makes designing a universal, easy to install and use simple apparatus, very difficult.

[0123] (Generic description/overview) What is needed is a simple, yet effective, reliable, relatively inexpensive "toilet problem detection" method and apparatus that can be universally used with all types of new and already existing toilets, which can be easily installed, readily understood, and installed in seconds without tools.

[0124] The exemplary illustrative non-limiting technology described herein provides a new and useful apparatus, located within or on the toilet tank, which can detect different types of toilet and toilet component failures that lead to water loss and/or damage and, in several embodiments, terminate the actual water flow in order to prevent the same.

[0125] Exemplary illustrative non-limiting technology is for use with tank-based flush toilets comprising float-based or pressure-based fill valves, flush valves, and wherein the tank water evacuates into a toilet bowl for the purpose of waste removal. The method and system includes a water height and water rate-of-change responsive detection method, and may or may not include a user alert and/or correspondingly responsive water termination method.

[0126] Exemplary illustrative non-limiting technology is further described for use with tank-based flush toilets, said non-limiting technology using toilet tank-located sensors in conjunction with unique linear and non-linear algorithms for detecting imminent toilet bowl overflows without the use of toilet bowl sensors. The method and system includes a real-time water height and water rate responsive detection method, and may or may not include a user alert and/or correspondingly responsive water termination method.

[0127] Exemplary illustrative non-limiting steps include removing the toilet tank lid, inserting the assembly on, over, or around the tank wall or fill valve, and automatically determining toilet or toilet component failures that result in unintentional water loss or water damage, alerting the user or property manager and, when connected, attached, or integrated into a fill valve, conditionally interferes with said fill valve to terminate or override the normal operation of said fill valve. (Reflects commonly-owned issued U.S. Pat. Nos. 7,757,708 and 8,166,996, which describe fill valve interruption for terminating water flow)

[0128] Further exemplary illustrative non-limiting unique features and/or advantages include:

[0129] Low power inexpensive circuitry that is optimized for extended battery life;

[0130] A circuit and method using a novel type of capacitive water height sensor capable of real-time tracking of water height, linear and non-linear water slope data analysis indicating intentional and unintentional water flow, and identifying the toilet components responsible for water loss and/or water damage;

[0131] A novel type of relative capacitive water height sensor, circuitry, and method, which does not require calibration or user set-up, which is exclusively deployed in the toilet tank while able to detect anomalies that occur within the toilet bowl;

[0132] A novel type of capacitive water height sensor, circuitry, and method, the operation and accuracy of which is not negatively impaired or affected by changes in water pressure, temperature, salinity, contamination, or electrode electrolysis;

[0133] An operational algorithm that accurately tracks and monitors the intentional and unintentional water use for survey, data recordation, and analysis purposes;

[0134] An operational algorithm which automatically optimizes flush volumes as a function or toilet use over time;

[0135] An operating system specific to property management and hospitality environments where guest and resident convenience is first and foremost, such that the visible and audible alerts are disabled, wherein remote telemetry and/or local access advises and/or alerts non-resident personnel to toilet problems and/or damage due to water;

[0136] An operating system that the user or property manager can customize to determine the type of toilet problems to be detected and the corresponding desired alerts and actions that result from the problems detected;

[0137] A tamper-proof feature for property management and hospitality whereby the novel capacitive water height sensor and operating system activate a self-contained or remote alarm in the event the device is removed from the water in the event of theft, damage, or tampering;

[0138] A water height monitoring algorithm capable of detecting and providing alerts for leaks, wide-open flush valves, toilet overflows, faulty flush valves, faulty fill valves, and various toilet failures generally not noticed and/or corrected by users and property managers;

[0139] Audible and visible user alerts in the event of leaks or toilet problems;

[0140] Remote telemetry and remote control capability which alerts non-resident or property management personnel to problems and/or allows non-resident personnel to selectively gain access to the toilet monitoring and intelligent control system in order to facilitate a response or repair;

[0141] Digital and/or analog output capabilities for facilitating remote control, telemetry, or selectively controlling actuators and/or valves connected to the toilet water feed line, fill valve, or flush valve, in order to terminate or mitigate water flow;

[0142] In order to satisfactorily and completely describe the toilet monitoring and intelligent control system herein, a description of the various types of toilet components and their operation, specific operational failures due to those same components, and the resulting water loss and damage due to component and toilet failures, may first be explained. The system and method described herein is capable of determining both the proper and improper operation of most tank-based toilets, advising the user or property manager accordingly and, as will be described in various embodiments, terminating water flow in order to prevent water loss and/or damage. A further capability of the system and method allows for the automatic adjustment of flush volumes in order to minimize water use as a function of the actual toilet users over time. For the sake of clarity, "intentional" operation of the toilet is that which the user initiates, generally referring to "flushing the toilet". "Unintentional" operation is any problem or failure related to the toilet in which water is wasted or water damage occurs, as the occurrence and result of such is unintended by the user.

Exemplary Prior Art Fill Valve Design, Operation, and Failure Modes

[0143] As explained above, conventional fill valve **66** in FIG. **1** and FIG. **2** functions to control the flow of water into the tank **52** of a toilet **50**. The fill valve **66** allows water to flow into the tank **52** until the tank is full, and then stops the flow of water. When the toilet **50** is flushed, the fill valve **66** senses the decrease in water level within the tank **52** and once again allows water to flow into the tank until the tank is again full.

[0144] Briefly, the fill valve **66** senses the decrease in water level based on the position of a buoyant "float" **112** that floats on the surface of the water within the toilet tank **52**. When float **112** falls, this typically indicates that the water level within tank **52** has dropped because someone has flushed the toilet. Fill valve **66** responds by letting more water flow into the tank **52**. When float **112** rises to a certain height, fill valve **66** responds by stopping the flow of water into the tank **52**. This is the basic principle on which most tank-based flush toilets have operated for decades, including for example "old fashioned" or alternative "ball cock" style floats made from copper, brass, rubber or other constructions.

[0145] In more detail, the particular conventional fill valve **66** shown in FIG. **5** includes a shaft like valve body **102** with a stem **104** that protrudes through a hole in the bottom of a toilet tank **52**. Water under pressure from a household or other cold water plumbing system is fed through the stem **104** into the valve body **102**. A conventional cold water feed toilet tank fitting is used to feed pressurized water from the cold water feed line (see FIG. **2**A) into the stem. Threads **104***a* may mate with a conventional lock nut (not shown) to firmly attach and seal the fill valve **66** to the toilet tank **52**. A flange **106** and associated shank washer forms part of this seal and also supports the fill valve **66** so it remains in a vertically upright position within the tank **52**.

[0146] A threaded shank **107** concentric to and surrounding fill valve body **102** provides a height adjustment mechanism. By rotating shank **107** relative to valve body **102**, the sleeve ascends or descends on the valve body along threads **108**. This height adjustment allows the end user to adapt fill valve **66** to a variety of differently sized toilet tanks and plumbing fixture arrangements, while also being the primary method for setting the total volume of water used during a flush. A plastic ring **110** retains the shank **107** on valve body **102** so that it does not slip off under location by the end user. One exemplary illustrative non-limiting implementation provides a height adjustment of up to five inches using this arrangement. See "Fluidmaster 400A Fill Valve Installation Instructions" Part No. 4-743 Rev. 1 (8/05) incorporated herein by reference.

[0147] Float **112** is retained by, and moves relative to, valve body **102**. In this particular exemplary illustrative non-limiting design, float **112** includes an upper portion **112***a* and a lower portion **112***b*. Upper portion **112***a* and lower portion **112***b* are each hollow cups. Upper and lower portions **112***a*, **112***b* are fastened together using conventional techniques to provide a waterproof fastening and thereby function as a flotation device, which is buoyant and therefore floats on or near the surface of the water.

[0148] In the exemplary illustrative non-limiting implementation, float **112** has defined therethrough a cylindrical channel **114**. Cylindrical channel **114** has a diameter that exceeds the outer diameter of shank **107**. Float **112** is designed so that the cylindrical channel inner wall **114***a* also provides a waterproof barrier to the hollow interior of float **112**. In some implementations, ridges that are vertically oriented on the cylindrical channel wall **114***a* nearly contact or do contact the shank **107** outer diameter to provide a low friction centering arrangement that is resistant to trapped debris and allows float **112** to freely move vertically on shank **107** as the water level changes within a toilet tank.

[0149] As shown in FIG. **5**C, at an upper end portion **116** of fill valve **66**, a protective cap or top **118** is used to protect an internal needle valve **117** that is disposed within an upper valve body **120**. Needle valve **117** is a pin diaphragm type valve. A pin **119** is connected to a sealing diaphragm **121**. When lever **122** is pushed up, the pin **119** pushes down on the diaphragm **121** which seals the valve so no water flows through the fill valve **66**. When lever **122** moves vertically downward, the pin **119** lifts the diaphragm **121** to open the seal. The needle valve **117** opens and water is permitted to flow from valve body **102** to outlet port **124** and also down through valve body **102** to water exit ports **123** at the bottom of the fill valve near flange **106**.

[0150] As shown in FIGS. **5**B and **5**C, protective cap **118** protects the needle valve **117** but is not involved in the operation of the valve. This cap **118** has a snap fit, and is designed to be removable to allow users to clean or replace the needle valve **117**. Retaining projections **118***b* molded within the inside of cap **118** allow the cap to be removably snap-fit onto mating structures **117** a extending from needle valve **117**.

[0151] In this exemplary illustrative non-limiting implementation, there is a partially cylindrically channeled, threaded retaining projection **126** formed integrally with or attached to float upper portion **112** a (see FIG. **5**A-C). An end **122***a* of lever **122** terminates in a horseshoe shaped retaining portion **128**. A vertically oriented water level adjustment rod **130** is loosely coupled to the lever end **122***a* and to projection **126**. Rod **130** may provide a threaded portion **132** to provide adjustability. The rod **130** is retained within the horseshoe-shaped portion **128**. An end user can rotate rod **130** to provide adjustments between the rod threads **132** and threaded projection **126**.

[0152] In use, when flush handle **56** is depressed, flapper **62** opens and tank **52** evacuates into bowl **54**. This causes the water level in tank **52** to drop. Gravity then exerts a downward pull on float **112**. This causes float **112** to descend along shank **107**. Rod **130** descends with float **112**. As rod **130** descends, it exerts a downward force on lever **122**. This downward force on lever **122** causes the lever to pull up on pin **119**, which causes the needle valve **117** to open and water to flow through the fill valve **66** into the toilet tank **52**.

[0153] As the water level within the tank rises, it eventually contacts float **112**. As mentioned above, the float **112** is buoyant and floats on or near the surface of the water. As the water level increases, it raises the level of float **112**. As float **112** rises, it exerts an upward pressure onto rod **130** which in turn raises the lever **122**. When the lever **122** has been raised sufficiently, it exerts a downward force on pin **119** to seal the needle valve **117**. Water then ceases to flow into the tank through fill valve **66**. In this state, the toilet tank is full and the toilet is ready to be flushed.

[0154] When the toilet is flushed, the water level within the tank rapidly falls. The descending water level within the tank allows float **112** to fall under the force of gravity. As the float **112** falls, it exerts a downward pressure through rod **130** onto lever **122** that again opens the needle valve **117** and allows water to begin flowing through fill valve **66** into the toilet tank **52**. This in turn, under normal conditions (i.e., assuming flapper **62** is closed), causes the water level within the tank to again rise, causing float **112** to rise again and eventually turn off the flow of water into the tank.

[0155] It should be apparent that this particular fill valve **66** shown in FIGS. **5**, **5**A, **5**B and **5**C is well designed, highly reliable and is capable of delivering long periods of trouble-free service, further evidenced by the millions of valves sold annually by the manufacturer through hardware stores and home improvement centers. As will be explained shortly, there are fill valves of inferior quality also available on the market that exhibit certain failures due to poor design and construction. Referring back to the fill valve **66** herein identified, it should be apparent that the proper operation of fill valve **66** depends entirely on the position of float **112**. When float **112** is in its lower position, fill valve **66** allows water to flow into the toilet tank **52**. When float **112** is in its uppermost position, flow valve **66** stops water from flowing into the toilet tank **52**. The operation of fill valve **66** is thus completely dependent on the position of float **112**, which in turn is completely dependent (under normal conditions) on the height of the water within the toilet tank **52**.

[0156] Suppose the float **112** were to become detached, or the fill valve **66** was to jam so that it never cut off the water flow into tank **52**. Theoretically, the tank **52** would overflow and flood the bathroom. But the overflow tube **199** is there to prevent that from happening, directing the extra water into the bowl **54** instead of onto the floor. Therefore, conventional toilet mechanisms have been designed to prevent overflow due to this type of malfunction of fill valve **66**.

[0157] FIG. **6** shows an example of a mechanized water termination or interruption assembly that snaps onto the cap of conventional fill valve, and FIG. **6**A shows a mechanized water termination or interruption assembly in view of a conventional fill valve to which it is to be attached;

Technical Description of the Fill Valve Failure-to-Terminate-Water-Flow when the Float Reaches its Preset Water Height Termination Point

[0158] Fill valves can also fail to terminate the water flow after float **112** has risen to its maximum mechanical height at the conclusion of a flush cycle, causing the water to rise to the height of overflow tube **199** and drain into the bowl. This type of failure is referred to herein as a Fill Valve Termination Failure. FIG. **13**A (see also FIG. **8** and FIG. **9**) shows a typical toilet tank cross-section with various water heights corresponding to different toilet tank and component operation, as well as various water heights corresponding to different types of failures. After a flush cycle has completed, float **112** on fill valve **66** has risen to valve-turn-off water level **80** and should terminate or turn-off any additional water flow through fill valve **66** and cease filling tank **52**. But when fill valve **66** exhibits a fill valve termination failure, water continues to seep or bleed into tank **52** through water exit ports **123** (FIG. **5**) and siphon tube **203**, resulting in the water rising in tank **52** to the overfill-water-level **82**, which results in water continuously escaping into bowl **54** via overflow tube **199**. Extensive testing has shown that once a fill valve begins to exhibit this type of failure, the volume rate of the leak tends to increase significantly over a relatively short period of time. As will be described and explained shortly, the toilet monitoring and intelligent control system described herein easily detects this type of failure.

Technical Description of a Fill Valve Equilibrium Failure

[0159] When the flapper or flush valve is leaking (as is more fully described in detail in the next section, "EXEMPLARY PRIOR ART FLUSH VALVE DESIGN, OPERATION, AND FAILURE MODES"), tank **52**'s water level will drop. When the fill valve float **112** drops to valve-turn-on water level **81** as shown in FIG. **13**B, a properly functioning fill valve **66** will turn on and refill tank **52** to valve-turn-off water level **80**. This type of tank refill is often referred to as a "phantom flush", and can often be audibly heard nearby as Canfield et al describes in detail in U.S. Pat. No. 8,310,369. But when float **112** of an inferior quality or worn fill valve drops to valve-turn-on water level **81** and does not fully open to fully refill tank **52** to valve-turn-off water level **80**, but instead "bleeds" or "seeps" water into the tank at the same rate as the flapper or flush valve leak, this type of fill valve failure is referred to herein as an "Equilibrium Failure". Equilibrium failure of the fill valve simply means that the water flowing into the fill valve is at the same rate as the water exiting tank **52** into the bowl through the leaking flapper or flush valve. Although the fill valve manufacturers might argue that the leak is the problem (not the fill valve), this overlooks several associated problems.

[0160] The first problem overlooked is that the fill valve equilibrium failure also allows water to bleed into siphon tube **203**, which then dumps into overflow tube **199** and down into bowl **54**. Extensive measurements of various types of fill valves exhibiting equilibrium demonstrate that the siphon tube **203** additional flow is approximately 30% of the volume leaking through flush valve **61**. For example, for every 10 gallons of water that leak through the flush valve, an additional 3 gallons are additionally wasted through the siphon tube **103**.

[0161] The second problem overlooked is that the audible "phantom flush" of the fill valve **66** refill does not occur. The absence of an audible "phantom flush" is simply one more reason why so many toilet leaks go undetected.

[0162] A third problem associated with equilibrium failure is that extensive testing has shown that once a fill valve exhibits this type of failure, the fill valve is likely to also begin exhibiting termination failures, as was previously described. This compounded problem has often led to home and business owners replacing flapper **62** to solve the toilet leak problem, which thereby prevents fill valve equilibrium failure, only to have the fill valve exhibit termination failure, which results in continued unintentional water loss that often goes undetected.

[0163] Fill valve "Equilibrium Failures" are widely overlooked, but represent a growing problem that needs to be addressed. As will be described and explained shortly, the toilet monitoring and intelligent control system described herein easily detects this type of failure.

Exemplary Prior Art Flush Valve Design, Operation, and Failure Modes

[0164] FIGS. **2** and **3** show flush valve assembly **61** in both the closed and open positions, respectively. When a user-initiated flush occurs, flush handle **56** is pressed downward, raising lever **58** upward, which raises chain **60**, which in turn raises flapper **62** off of flush valve seat **65**. Water W begins to escape out of tank **52** through flush valve **61** and into bowl **54** while flapper **62**, which has positive buoyancy, remains open until water W drops to flapper-close water level **83**, at which time flapper **62** closes and effectively seats and seals flush valve seat **65**, thereby stopping the flow of water from tank **52** into bowl **54**. As has been previously explained, fill valve **66** is open and filling tank **52** with water W which continues to rise until the valve-turn-off water level **80** is reached, at which time float **112** turns off the fill valve **66** water flow. A properly working flush valve **61** will completely seal and prevent water flow from tank **52** to bowl **54** when flapper **62** is seated upon flush valve seat **65**.

Technical Description of Leaking Flush Valves and Flappers

[0165] Flapper **62** can fail to completely seat and seal flush valve seat **65**, causing a leak from tank **52** into bowl **54**. To best describe this type of leak, assume that toilet **50** has just completed an entire flush cycle, as has been previously and fully detailed herein. Referring to FIG. **8**, Water W is now at valve-turn-off water level **80**, which has raised float **112** and lever **122**, causing fill valve **66** to terminate water flow into tank **52**. When flapper **62** is leaking tank **52** into bowl **54**, Water W will slowly begin to drop inside tank **52**. When Water W drops to valve-turn-on water level **81** and fill valve **66** is working correctly, float **112** and lever **122** cause fill valve **66** to turn on and refill tank **52**, producing what was previously identified herein as a "phantom flush". If fill valve **66** is not functioning properly and instead exhibits an equilibrium failure, water will bleed into tank **52** at the same rate as it enters fluid fill line **64**, while also producing additional flow through siphon tube **203**, which drains into overflow tube **199** and then into bowl **54**, as was previously described in detail. Those with a background in toilet leaks will also recognize that other types of toilet tank leaks can occur, such as the deterioration of the bolts and sealing washers which attach tank **52** to bowl **54**, deterioration of the flush valve seat **65** or the sealing gasket below it, etc.

Technical Description of a Wide-Open Flush Valve and the Numerous, Often Misunderstood, and Previously Unknown Reasons why they Occur

[0166] Now suppose that flapper **62** becomes stuck in an open position or is misaligned or otherwise does not seal properly. The fill valve **66** may never fill the toilet tank **52** with sufficient water to raise float **112** to an upper position. Instead, all water that fill valve **66** delivers into toilet tank **52** might be immediately (or soon) exhausted through the passage between the tank **52** and bowl **54** that flapper **62** is designed to seal under normal non-flushing conditions.

[0167] If the water that fill valve **66** is delivering into tank **52** escapes into the toilet bowl **54**, the water level within tank **52** may never rise and float **112** will similarly remain in a lower position and the toilet will continuously "run." Water will continue to flow through fill valve **66** through the toilet into the waste line **57** as long as flapper **62** remains open. This "running" condition can persist until a user takes corrective action to cause flapper **62** to close and seal. Even though fill valve **66** in this situation is operating exactly as it was designed to operate, toilet **50** is seriously malfunctioning and wasting huge amounts of water. During periods or in regions of water shortage or drought, this water waste can be a real problem. In a house with its own well, the owner of toilet **50** may potentially pump his or her well dry. If the house is connected to city water, the owner may receive a huge water bill for water that flows through the toilet and is wasted. In communities such as those located alongside rivers or water basins where water waste is stored in portable in-ground septic tanks to avoid contamination, a "running" toilet can overflow a tank, causing water damage while simultaneously draining into the nearby drinking water supply that the in-ground tank was supposed to protect. Adding insult to injury, this type of "running" toilet often goes undetected.

[0168] The development of this toilet monitoring and intelligent control system resulted in wide-open flush valve data being secured that has been previously unknown to water agencies and professionals. While there is certainly an awareness about the problem of wide-open flush valves, the extent of the water loss and the number of reasons why the flush valve won't close, and why this condition often goes undetected, has been understated and mostly misunderstood.

[0169] Referencing FIGS. **1**, **2**, **2**A, and **3**, the following is a short list of the main reasons why a flush valve or flapper won't close:

[0170] The extended portion of flapper hinge **422** on flapper **62** is stuck to overflow tube **199**;

[0171] Chain **60** gets hung up or caught on, or around, lever **58** or flapper **62**, which most frequently occurs when flush handle **56** is impatiently slapped or banged, or when chain **60**'s length has been improperly set during installation or flapper **62** replacement;

[0172] Any obstruction of siphon jet **55***b*, waste pipe **57**, or exhaust port **53**, can result in the tank water not dropping low enough to permit flapper **62** to close;

[0173] A purchased "Universal Flapper" to replace flapper **62** does not properly seat on flush valve **61**, resulting in a significant gap which results in excessive water flow into bowl **54**;

[0174] Flush handle **56** sticks or rubs against tank **52**, preventing flapper **62** from seating on flush valve **61**;

[0175] Flapper hinges **422** are weakened or degraded, allowing flapper **62** excessive side-to-side movement that occurs when water W from water exit ports **123** of fill valve **66** "push" flapper **62** during the flush cycle, preventing proper seating of flapper **62** on flush valve **61**.

[0176] So much for the primary causes of wide-open flush valves. The following is a partial list of why wide-open flush valves often go undetected:

[0177] Using the toilet is often the last thing a person does before leaving the apartment or home, and when the departure is for a lengthy vacation or long weekend, the water loss can be tens of thousands of gallons (and when that person is in a hurry, the handle is often "slapped, as was previously mentioned);

[0178] Seldom used bathrooms, such as those in a basement or in a remote area of a dwelling, can have wide-open flush valves go undetected for extensive periods of time;

[0179] Hearing-impaired, sensory-challenged, and those completely unaware of how a toilet is supposed to work, for whatever reason, frequently fail to detect wide-open flush valves;

[0180] An individual exiting the bathroom during an impending overflow of bowl **54** is unlikely to detect an audible abnormality when the characteristic audible "whoosh" that is often exhibited by a wide-open flush valve does not occur, despite the flush valve being wide-open, because the entire flapper **62** and flush valve **61** are completely submerged by water W, resulting in a comparatively quiet escape of water into bowl **54**;

[0181] Background noise, such bathroom and window fans, running sinks and tub faucets, hair dryers, music, loud conversation, televisions, yelling at children (just kidding—that never happens), yelling children (that always happens!), etc., can easily mask what might normally be an audible indication that the flush valve is wide-open.

[0182] As will be described and explained shortly, this type of toilet problem is readily detected by the toilet monitoring and intelligent control system described herein.

Technical Description of Clogged or Blocked Toilets that can Result in Bowl Overflows

[0183] Consider now the situation shown in FIG. **3** where the toilet bowl **54** is clogged or waste pipe **57** is blocked. If the flapper **62** fails to close, the overflow can occur within seconds and, as will be described shortly herein, there is a reason why flapper **62** may fail to close during a single user-initiated flush. Suppose however that the flapper **62** closes as it is supposed to do when the tank **52** is emptied when there is a clog or blockage preventing bowl **54** evacuation. This situation will allow water flowing through fill valve **66** to begin filling tank **52**. If fill valve **66** operates normally, it will continue to fill the tank **52** until float **112** has risen sufficiently to close the fill valve. Now the toilet tank **52** is full of water and the toilet is ready to flush once again. Unfortunately, in this instance bowl **52** is also now full of water. Any additional water delivered into the bowl cannot escape through waste pipe **57** due to the blockage **63**. Another flush (i.e., by depressing the flush handle **56**) will nevertheless once again open flapper **62** and cause the water within tank **52** to be expelled into the already-full bowl **54**. This can cause an overflow of bowl **54**, as shown in FIG. **4**. Referring to FIG. **8**, the overflow occurs even though fill valve **66** is operating normally and functioning exactly as intended because the water height in clogged toilet bowl **54** is preventing water W in tank **52** from rapidly evacuating, resulting in example water height **81** preventing positive buoyancy flapper **62** from closing. Simply stated, toilet overflows generally occur when the water volume entering the tank through fill valve **66** exceeds the water exiting through exhaust port **63**, which prevents flapper **62** from closing because the water level W in tank **52** forces flapper **62** to float instead of closing and sealing off flush valve seat **65**. As will be described and explained shortly, this type of toilet problem is readily detected by the toilet monitoring and intelligent control system described herein

Summary of Reasons and Purpose of Example Non-Limiting Embodiments

[0184] It can thus be seen that the intentional and unintentional operation of fill valve **66**, or problems associated with flush valve **61** and flapper **62**, can sometimes cause unintentional water loss or damage. The cost-effective immediate detection of unintentional water loss and damage, and when possible, the prevention of the same, is the primary focus of this toilet monitoring and intelligent control system. Another feature of this same system is to optimize and reduce the total intentional water usage by monitoring actual toilet use and responsively controlling the refill of the tank such as to actively limit the water volume per flush.

Brief General Discussion, Descriptions, and Analysis of Various Prior Art Leak and Damage Detection and Prevention Methods and Devices

[0185] Many of the devices are too costly to put into production and then sell into existing markets. For example, a home owner will not spend $50 or more on a product and then another $100 for a plumber to install the product.

[0186] Many of the devices are too complicated to easily attach to a toilet. Product complexity produces disinterest in the marketplace because retailers and customers cannot be convinced of the effectiveness of the product, and complexity fosters the perception that the individual may not be knowledgeable enough to install and/or use the product. Products which require plumbing expertise and the knowledgeable use of tools are primary detracting factors when the customer needs a simple solution.

[0187] For a product to be successful in the marketplace where millions of product and operational variations exist, a universal product that will work on any toilet, in any environment, is required. Much of the prior art assumes simplistic toilet structures and operation, while the actual number of toilet variations include a wide range of toilet tanks and water volume capacities, numerous types of fill valves and flush valves available from dozens of different manufacturers, variations in water pressure and drain pipe sizes, all of which determine the physics of water-in/water-out in all toilets, different and varying physical characteristics related to leaks and overflows, etc.

[0188] Aesthetics matter, so prior art which converts a common bathroom toilet into a Star Trek Klingon attack ship may be embraced by gadget freaks and bachelors who will never marry, but those "designs" are generally not favorably received by most home and business owners. Much of the prior art have mammoth valves on the water feed line, big boxes hanging onto the front or side of the toilet, and many even have unsightly wires around, inside, and on the outside surface of the toilet itself, including bowl sensors that are just downright ugly. Aesthetics is also a practical matter when it comes to cleanliness, as the ability to completely and easily clean the toilet surfaces and bowl is an important design consideration that is often overlooked by those who focus only on the problem, instead of the market and how users must necessarily interact—and in this case, clean—the product.

[0189] For the reasons stated above, the ideal device described herein is inexpensive, installs in seconds without tools, requires no calibration or set-up, does not compromise toilet aesthetics or present a barrier to cleanliness, yet absolutely identifies a multitude of toilet anomalies and problems and quickly alerts the user or property manager accordingly in order to prevent excessive water loss or damage, or automatically terminates water flow when the anomalies and problems are detected.

Example Non-Limiting Monitor Device Embodiments

[0190] FIGS. **28**A, **28**B, **28**C show an example non-limiting monitoring device **340**. Monitoring device **340** includes an annunciator module **350** and a probe **308**. As shown in FIG. **28**A, annunciator module **350** provides a user interface **807**. In one example implementation, user interface **807** may be relatively simple and low cost, consisting of indicator lights **808** and a push button **810**. Additionally, an audible annunciator **809** (which may be within enclosure **350**) provides audible output. Any number of indicators **808** may be used, and may comprise any technology including but not limited to light emitting diodes. Other example implementations could use different user interface technology such as a liquid crystal display or some other type of low powered display, more buttons or other input controls, a microphone, a speaker, a touch screen or touch panel, or a Bluetooth/Wi-Fi or other wireless interface to an external user interface device such as a Smartphone or IOT hub. The FIG. **28**A embodiment user interface **807** is non-limiting, but is preferred for at least some applications that require minimal cost and power usage as well as simplicity of operation.

[0191] In the particular example shown (see also FIG. **7**), a probe **308** is fixedly attached to annunciator module **350**. In this example non-limiting implementation, probe **308** includes several conductors **310**, **314** and a spacer **374**. The conductors **310**, **314** include an uninsulated conductor **310** and an insulated conductor **314**. The uninsulated conductor **310** when immersed in the water of a toilet tank provides direct electrical current conduction path into the water. The amount of conduction depends on several factors including the mineral content of the water. The uninsulated conductor **310** and the surrounding water it is conductively connected to forms one plate of a two-plate capacitor. The other conductor **314** is insulated and is thus not electrically connected to the surrounding water in the toilet tank. This other conductor **314** acts as a second plate of the two-plate capacitor. The equivalent circuit to conductors **310**, **314** is thus a 2-plate variable capacitor—with the capacitance between the two plates varying based on the level or height of the water into which the conductors are immersed as well as the mineral content, temperature and other characteristics of that water, and the length of at least the conductor **314**. Since temperature and mineral content of the water in the toilet tank are relatively stable and do not change erratically, they can be ignored or compensated for when measuring the capacitance between the two plates.

[0192] An important factor that changes the capacitance between the two capacitor plates and the equivalent circuit is thus the water level or height. By measuring the capacitance, a highly accurate determination of water level or height is possible.

[0193] In the example shown in FIG. **28**C, insulated conductor **314** comprises a loop or "U" that is insulated over its entire length. Spacing between the conductor **310** and the conductor **314** is constrained by a spacer **374** including holes **375** through which the conductors **310**, **314** pass as shown. Spacer **374** can be made of any light-weight non-conductive material such as plastic. In other embodiments, conductor **314** could comprise a single non-looped conductor or have other configurations. Similarly, in other embodiments, conductors **310**, **314** need not be parallel to one another over the entire lengths, nor would they need to be coextensive in length.

[0194] In the embodiment shown, the conductors **310**, **314** are hard-wired into the annunciator module **350**, exit the top of the annunciator module and are bent 90° at a bend **377**. This bend **377** is used as a hanger to hang monitoring device **340** on the lip of a toilet tank with the annunciator module **350** external to the tank and the probe **308** hanging down within the tank. Other material insulating tubing **370** can be used to protect the portions of conductors **310**, **314** that are in contact with the toilet tank lip and to also reduce transmitted vibration and allow compression of the rubber tubing when the toilet tank lid is in place. Such rubber tubing **370** thus allows the toilet tank lid to lock the monitoring device **340** in place so it does not move much in response to water turbulence within the tank. A bumper **376** may be provided to space the probe **308** away from the inside wall of the toilet tank, and spacer **372** similarly can be used to provide such spacing.

[0195] FIG. **19** shows an alternative embodiment in which a waterproof annunciator module **300** is configured to be disposed inside the toilet tank (some customers might not want to see the annunciator module). In this embodiment, the annunciator module **300** hangs from the toilet tank lip by hangers **332**, and the conductors **310**, **314** hangs downward from the module. The module **330** may be further equipped with a wireless communications capability (e.g., antenna **334**) to wirelessly communicate with a monitoring network, LAN or the like via Wi-Fi, WAN, Bluetooth or any other convenient wireless technology. Such wireless communications enables module **330** to communicate alerts to a user, management office or other remote location without the need to remove the toilet tank lid. Such installations might find particular application in hotels, rental properties, or ordinary homes or businesses equipped with IOT (Internet of Things) hubs or Wi-Fi networks. In such applications, it might be useful also to equip device **330** with temperature measuring capabilities (e.g., to allow an absentee homeowner to detect toilet freezing conditions) and remote control capabilities (e.g., to turn off a water supply valve remotely).

[0196] FIGS. YA and YB show example high level schematic block diagrams for a monitoring device **340**. In the FIG. YA non-limiting embodiment, a microcontroller **644** powered by a battery **640** receives measurement signals from a sensor **648** via an oscillator **646**. The microcontroller **644** analyzes the received measurement signals and conditionally generates alerts **642** via a user interface. In the FIG. YB alternative embodiment, the oscillator **646** is omitted and microcontroller **644** directly interacts with sensor **648**.

[0197] FIG. Z shows an example state diagram for the operation of the embodiments shown in FIGS. YA and YB. In the FIG. Z state diagram, a monitoring device **340** being powered on (state **660**) enters into a sleep mode until the microcontroller **644** detects that the sensor **648** has been placed in water (state **662**). In this particular embodiment, there is no power on and off switch. Rather, the power on state **660** is entered when the battery **640** is first connected to the monitoring device (e.g., at time of manufacture or in other embodiments, in the field). The microcontroller **644** occasionally wakes itself up and samples the measurement signal output by sensor **648** to detect whether the sensor has been placed in water. Once the measurement device **340** is awakened (state **664**), it begins taking consecutive measurements and tracks and analyzes those measurements (state **666**). It will alert the user to problems and/or turn the water off (in some embodiments) and/or log data (state **668**). It performs such state transitions and functions continually, sleeping whenever possible to reduce the drain on battery power.

[0198] FIG. Z**1** shows an example implementation of state **666** in one non-limiting implementation. In the FIG. Z**1** example, the level sensor **648** produces a measurement signal that the microcontroller **644** analyzes by calculating rate of change (i.e., derivative) $\Delta L/\Delta T$. The derived rate of change signal is then tested using n tests, with different tests or combinations of tests generating an activation signal.

Brief Explanation of Water Level Sensing Methods in View of the Various Types of Toilet Leaks and Failures

[0199] As will be explained shortly, in order to identify virtually any type of toilet anomaly or failure related to water flow using only a single in-tank sensor, or to precisely and automatically implement water conservation operation without user interaction or device calibration, real-time monitoring and tracking of water height W in tank **52** with a very high degree of accuracy, at a reasonably high sampling rate, is required. Before explaining the novel device and method embodied herein, a brief review of some prior art water and fluid height measurement methods is necessary.

[0200] A lot of prior art has been devoted to the sensing of water at specific levels in both toilet tanks and bowls. From limit switches and floatation switches to magnetic sensors and conductivity switches, just about everything has been tried and, to-date, all of it without much commercial success or market acceptance.

[0201] Perhaps the least expensive and ultimately most reliable type of fixed-position water level switch is the electrical conductivity switch. FIG. **14** shows a simple transistor-based circuit that turns on LED **705** when probes **700** and **702** both make contact with water. In this circuit, the NPN transistor turns on when the circuit detects conductivity between probes **700**, **702**, activating LED **705**.

[0202] While in theory a reasonable system capable of detecting various toilet problems could be made from multiple electrical conductivity switches, the number of switches required in both the toilet tank and the bowl, plus the necessary calibration and mounting of the switches, has been and will continue to be prohibitive in nature. Not to mention the rats nest of wires in and around the toilet. Single electrical conductivity sensors and switches are also incapable of determining the direction of water height (tank evacuation verses tank fill), as well as any time or slope-dependent measurements. While various resistive ladder-type electrical conductivity sensors and switches have been proposed, they lack accuracy, are cost-prohibitive, and are also cumbersome, making them impractical for toilet water height sensing. Resistive and potentiometer-type sensors also tend to drift substantially as liquid temperatures change, and it is not unusual for the pre-flush water temperature of a toilet tank to be substantially warmer or colder than the post-flush refilled tank temperature, resulting in measurement inaccuracies over a very short time duration which, for the purpose of discerning anomalies corresponding to changes in water height, could lead to numerous false positives or the inability to detect the anomalies and problems.

Exemplary Prior Art Pressure-Based Sensing of Water Levels

[0203] Pressure sensors and transducers have long been used for water level and water height measurements. From a practical perspective, however, the sensors and transducers have been too costly to be practically considered for use in toilet tanks and bowls. In most instances, a pressure sensor or transducer is connected to an air tube that is submerged completely into the toilet tank or bowl. As the water height changes, the pressure in the tube changes.

Exemplary Prior Art Capacitive Fluid Level Sensing Circuits and Methods

[0204] For practical and safety reasons, most devices attached to or inserted within a toilet will likely be powered by a battery, making conservation of power and battery life an important design consideration. Unlike pressure sensors which can consume substantial power, conductive and capacitive sensors require relatively little power to operate. And while the disadvantages of conductive, resistive, and potentiometer-type sensors have already been discussed, capacitive water height sensors could offer specific advantages if obstacles can be overcome in their design and methodology of use, such as the new and novel features described herein. Unfortunately, for a capacitive water height sensor to detect toilet anomalies, accuracy and high resolution are required.

[0205] Some well-known accurate and high resolution capacitive liquid level and height sensors are shown on FIGS. **15** and **15**A. Printed circuit board sensor **720** is a side view of the front view of PCB sensor **722**, which is a 4-layer printed circuit board where the non-conductive layers act as dielectrics and the conductive layers form the plates of the capacitive, with the outer-most plate directly contacting the liquid. The capacitance-to-digital converter **723** is connected to reference sensor C**2** and level measurement sensor C**1**, and the water level is then determined by the relationship of C**1**/C**2**. This circuit is accurate and exhibits very high measurement resolution, while also being impractical for mass production and deployment due to the prohibitive cost of manufacturing as the capacitance-to-digital converter **723** is an Analog Devices AD7746, which alone costs more than $8.00 in high quantities.

[0206] FIG. **15** shows the operational circuit diagram of a commercially available type of capacitive fluid level sensor.

[0207] The well-known circuit of the type shown in FIG. **15**A can use two different types of sensor configurations, but does not require direct contact with the liquid to be measured. Sensor **725** and sensor **727** both show plates P**1** and P**2** as being positioned on the outside of a non-conductive liquid container wall. Circuit **728** is essentially a square wave oscillator formed by resistors R**4**, R**5**, R**6**, and capacitor C**2**. The varying capacitance of sensor **725** or sensor **727** corresponds to a change in the liquid level inside the container, resulting in a frequency change at the output of operational amplifier A**1** at test point TP**1**. Although circuit **728** is configured to illuminate lamp L**1** when a specific liquid level occurs within the container, it is obvious that the varying square wave output of operational amplifier A1 could be directly resolved such as to indicate the liquid level inside the container.

[0208] These prior art capacitive sensors could be used for toilet tank water height measurements, except that they are prohibitively expensive to manufacture, even in large quantities, and often require some sort of calibration or, as is shown in FIGS. **15** and **15**A, require a separate "fixed plate" calibration sensor to ensure accuracy and repeatability as the temperature, conductivity, presence and concentration of contaminants, and other factors related to the water changes. The aforementioned capacitive sensors still tend to require too much power for battery operation, removing them from consideration in view of consumer and/or mass-produced products. For instance, the quiescent current of the Analog Devices AD7746 capacitance-to-digital converter **723** is approximately 750 microamperes, which would preclude the use an ideal battery such as the CR2032 lithium cell that is widely available and perfect for consumer products as its maximum power delivery is limited to approximately 220 milliampere-hours.

Detailed Description of Cost-Effective Circuits that Convert Capacitance to Square Waves and/or Pulses

[0209] Because cost, performance, ease-of-installation, simplicity-of-use, reliability, and maintenance-free are the most important factors to consider if the goal is to equip millions of toilets with a high quality water conservation and damage prevention product, extra attention must be paid to the important parameters of battery life and circuit operation, both of which read on all of the other factors. The sensor and circuit must therefore draw very little power, permitting low cost and readily available batteries to last for several years, or longer. The sensor itself must be extremely reliable, very accurate, repeatable over an extended period of time, resistant to degradation and corrosion, and yet still be inexpensively manufactured.

[0210] Before describing the novel capacitive sensor, circuitry, and method, some attention must be given to the types of circuits which could make use of such a sensor, and the type of output ideally desired from those circuits. In order to use a low cost microcontroller as the foundational component in a toilet monitoring and intelligent control system, the most advantageous outputs of a capacitive sensor circuit would ideally be either an analog voltage or square wave, both of which would vary as a function of capacitance. While analog-to-digital (ND) converters are widely available in many microcontrollers, it is more practical and cost-effective to measure the time periods of square waves using low-cost microcontrollers.

[0211] FIGS. **16**, **16**A, and **16**B, show three different example circuits that convert capacitance to measurable square waves or pulse widths. FIG. **16** is the classic and well-known Hartley oscillator **734** which those skilled in the art will immediately recognize, the frequency output of which is characterized by this equation:

$$f = \frac{1}{2\pi\sqrt{L_T C}}$$

where L_T is either the inductance of inductor **731**, or the total cumulatively coupled inductance if multiple coils are used, which would also include their mutual inductance. Assuming all other components remain fixed, the value of variable capacitor **730** would determine the frequency of sine wave **735**, which when directed to wave shaper **740** results in square wave **745** being generated. Square waves **746** and **747** reflect the change in frequency of sine wave **735** due to the increase in capacitance of variable capacitor **730**, as initially compared to square wave **745**. Summarily, the output frequency of wave shaper **740** varies with respect to the change in capacitance of capacitor **730**.

[0212] FIG. **16**A is shows UJT relaxation oscillator **754**, also known as a unijunction transistor relaxation oscillator. Resistor **753** and capacitor **748** determine the frequency of oscillation, the equation of which is usually given as: $F=1/(RC\ \ln(1/(1-\eta)))$, where η is the intrinsic standoff ratio and ln stand for natural logarithm. When power is applied, capacitor **748** starts charging through resistor **753**. Capacitor **748** keeps on charging until the voltage across it becomes equal to 0.7V plus ηVbb. This voltage is the peak voltage point Vp denoted in capacitor voltage waveform **751**. After this point the unijunction transistor **750** emitter resistance drops drastically and capacitor **748** starts discharging through this path. When capacitor **748** is discharged to the valley point voltage Vv in capacitor voltage waveform **751** the unijunction transistor **751** emitter resistance climbs again and capacitor **748** starts charging. This cycle repeats and results as the sawtooth waveform shown in capacitor voltage waveform **751**. Either base B**1** or B**2** of unijunction transistor **750** could then be directed to wave shaper **740**, resulting in similar square waves as shown in **745**, **746**, and **747** in FIG. **16**, as a function of the varying capacitance of capacitor **748** which, as should be noted, could be the novel capacitive sensor that will be described momentarily below.

[0213] FIG. **16**B shows another very simple approach to resolving the capacitance of any given capacitor or capacitive sensor. Circuit **759** consists of microcontroller **760**, resistor **762**, and capacitor **764**. Microcontroller **760** briefly takes port **765** low, or to ground, in order to fully discharge capacitor **764**. Port **765** is then made an input, at which time an internal timer begins counting in microcontroller **760**. With a high impedance now on port **765**, capacitor **764** begins to charge through resistor **762**. When the voltage across capacitor **764** crosses the input threshold of port **765** such as to force a transition from low to high, the internal timer of microcontroller **760** is stopped. The capacitance of capacitor **764** can thus be measured in terms of elapsed time. Replacing capacitor **764** with a variable capacitor, such as the novel capacitive sensor described shortly herein, it can then be seen that the variable pulse widths **770**, **772**, and **774**, are responsive to the change in said variable capacitor. This method of measurement, as performed by microcontroller **760**, can therefore be repeated as often as possible, in precisely timed intervals, in order to determine the value of the varying capacitance as a function of time.

[0214] At first glance, it would seem that FIG. **16**B would offer the least expensive method for simple capacitive sensor water height measurement. But as will soon be described, in order to detect a wide variety of toilet-related problems as a function of the change of toilet tank water height, a high degree of resolution and measurement accuracy is necessary. For the circuit and method of FIG. **16**B to be practical, the plates of capacitor **764** would have to be substantially large in order to produce distinguishably different pulse width resolutions relative to minute changes in water height, as a crucial determining factor is the microcontroller's clock speed, which establishes pulse width resolution. Microcontroller current consumption also increases with the clock speed, which reduces battery life. Another consideration is the overall capacitive sensor stability, which generally decreases as the plate surface area increases.

Detailed Description of the Novel Capacitive Toilet Tank Fluid Level Sensor and Accompanying Circuitry

[0215] (**4060** Description & Operation) The oscillator/divider circuit **815** shown in FIG. **17** shows an ideal low power approach and exhibits both a high degree of measurement accuracy with a physically small capacitive water height or fluid level sensor. Binary counter/oscillator IC **800** can be any of several conventional integrated circuits, like the CD4060 from Texas Instruments. RC oscillator circuit **820** is the exploded oscillator view of binary counter/oscillator IC **800**, which shows that capacitor **804** and resistors **805** and **806** set the fundamental oscillator frequency, which binary/divider oscillator IC **800** divides down to lower frequencies that are available on the various ports of IC **800**. To change the fundament oscillator frequency of oscillator/divider circuit **815**, an additional fixed or variable capacitance can be paralleled with capacitor **804**, as will be expanded upon below. To keep the current burden of oscillator/divider circuit **815** as low as possible, resistors **805** and **806** are necessarily in the order of megohms. To ensure stability over temperature and time, resistors **805** and **806**, and capacitor **804**, are 1% tolerance or less, with very low temperature coefficients. The inexpensive CD4060 from Texas Instruments, when used as binary/divider oscillator IC **800**, exhibits very little drift with respect to supply voltage, negating the need for a voltage regulator on battery operated circuits.

[0216] (Sensor Description) FIG. **18**A shows the basic mechanical and electrical construction of the novel capacitive water height or fluid level sensor. Uninsulated conductor **310** can be a bare copper, tinned, or gold-plated wire, but could also be virtually any conducting material which makes contact with the fluid or water, including the bolts which attach tank **52** to bowl **54**. Insulated conductor **311** is ideally an inexpensive enamel-coated wire, where center conductor **312** is copper wire and insulation **313** is the enamel coating. Insulated conductor **311** could also be virtually any electrical conductor that is fully covered with an insulator, such as a conformal-coated circuit board or similar. A variation of FIG. **18**A is shown in the exemplary sensor of FIG. **18**B, which shows U-shaped insulated conductor **314** as being substantially longer than insulated conductor **311**, the purpose for said U-shape which will momentarily be explained. The advantage of insulated conductor **311** or **314** being enameled-coated wire or similar is that the hydrophobic properties of the enamel coating prevent water from adhering to the surface during flush cycles, which allows for very accurate real-time tracking of the water height. A further benefit to using enameled coated wire or similar for insulated conductor **314** is the enamel itself is an excellent dielectric that is extremely consistent in thickness, enhancing sensor reliability and manufacturing predictability.

[0217] FIG. **18**C shows the novel capacitive water height or fluid level sensor of FIG. **18**A being inserted into water W to a water height H. Uninsulated conductor **310** makes direct electrical contact with water W, forming one plate of a capacitor as it surrounds insulated conductor **311**. Center conductor **312** forms the second plate of the capacitor, the total plate area of which can be defined in simple mathematical terms as $A=2\pi r\times L$, where r is the wire radius and L is the total length of the submerged wire as defined by water height H. Insulated conductor **311** therefore acts as the dielectric. The well-known formula $C=\varepsilon A/d$ shows that total area A multiplied by dielectric permeability ε, when divided by dielectric thickness d, will yield an approximation of the actual capacitance. It is therefore easily seen mathematically that the greater water height H, the greater the capacitance of the submerged sensor of FIG. **18**A. Further, it can be seen mathematically that the capacitance of the FIG. **18**A sensor is a linear function of water height H. The exemplary sensor of FIG. **18**B shows U-shaped insulated conductor **314**, which doubles the capacitance of the sensor in order to increase the resolution in terms of water height H. The sensor of FIG. **18**A requires the very tip of insulated conductor **311** to also be fully isolated from the water, while the exemplary sensor of FIG. **18**B does not require the tip to be isolated and, instead, can actually be easily and more cost-effectively deployed in production by attaching both ends of U-shaped insulated conductor **314** to the circuit enclosure or monitoring device **325** as shown in FIG. **19**, which shows monitoring device **325** as one possible configuration for in-tank use in a typical toilet.

[0218] (advantages of enamel-coated wires; points about enamel as a dielectric; resistance to water [hydrophobic] and contaminants;) (contaminants in water; ionization required for conduction; extremely high impedance; all point to virtually unchanging characteristics; plus, CMOS 4060 remains fairly constant over battery depletion) It is obvious that the uninsulated conductor **310** must be in contact with the same water or liquid as that of insulated conductor **314** for the sensors of FIG. **18**A and FIG. **18**B to function in accordance with the specification herein. However, extensive empirical testing has demonstrated that when uninsulated conductor **310** and insulated conductor **314** are in contact with the same container of water or liquid, that the mechanical form, shape, and length of uninsulated conductor **310** have little to no effect on the accuracy of the resulting capacitance measurement. Tests using other uninsulated conductors, such as connecting directly to conductive fluid fill line **64** or using a conductive flush chain **60**, have produced excellent and accurate results. Due to the very high impedance of RC oscillator **820** in FIG. **17**, the sensors of FIG. **18**A and FIG. **18**B exhibit no substantial variation in accuracy over a wide range of liquid or water impurities, conductivity, temperature, depth of submersion, or variation of metals that might be used to construct uninsulated conductor **310**.

[0219] When the sensor of FIG. **18**A or FIG. **18**B is connected to the circuit of oscillator/divider circuit **815**, such that uninsulated conductor **310** is attached to conducting probe input **802**, and insulated probe **311** or U-shaped insulated probe **314** is attached to insulated probe input **803**, the sensor, whether the sensor of FIG. **18**A or that of FIG. **18**B, presents a capacitance that is now parallel to that of capacitor **804**. Basic electronic theory shows that parallel capacitances are additive, where $C_T=C_1+C_2$, with the total capacitance being C_T, C_1 representing the fixed capacitor **804** and C_2 representing variable capacitance of sensor FIG.

18A or sensor FIG. **18**B, both of which will vary in capacitance as a function of water height H. When either sensor or one of similar construction is connected across capacitor **804** as was previously described, the total capacitance increases and the RC oscillator **820** frequency decreases, as do all of the divided down outputs of binary counter/oscillator IC **800**. When the sensor makes contact with water and as the water height H increases, the RC oscillator circuit **820** frequency decreases, resulting in square waves at the various divided down outputs of binary counter/oscillator **800**, the pulse widths of which are directly correlated to water height H. It should be noted that when the capacitive sensors have no contact with water, empirical and mathematical data demonstrate that the added capacitance is negligible, predictable, and extremely stable, permitting microcontroller **801** to "sleep", thereby drawing very little current, until the increase in total capacitance C_T indicates that the capacitive sensor has been placed in a toilet tank, having come into contact with water, whereby microcontroller **801** "wakes up" and begins to function as a toilet monitoring and intelligent control system. This feature is an operational benefit to the end-user, which permits the battery powering the circuit to be shipped installed and connected, further simplifying the operating instructions and use for the user.

[0220] (Description of remainder of FIG. **16**: microcontroller and ancillary circuitry; explanation of sensor/circuitry water height measurement) Microcontroller **801** preferably has very low quiescent current drain during operational and sleep modes, a configurable internal oscillator, program memory, EEPROM storage for datalogging, and sufficient ports for controlling the connected ancillary circuitry. For example, the Microchip 16LF series of microcontrollers offers a wide selection of components that are perfect for this type of application.

[0221] Water height measurement is initiated when port RC**0** of microcontroller **801** outputs logic "1", herein interchangeably defined as HIGH, Vdd, or the positive power supply rail, which turns on binary counter/oscillator IC **800**. Upon power-up, ports Q4 through Q14 of binary counter/oscillator IC **800** initialize as logic "0", herein interchangeably defined as LOW, GND, or the negative supply rail. Also upon power-up, the RC oscillator **820** section of binary counter/oscillator IC **800**, comprised of resistor **805**, resistor **806**, capacitor **804**, and the exemplary water height sensor of FIG. **18**B, immediately begins its astable operation. In the preferred circuit embodiment shown in FIG. **17**, the Q4 output of binary counter/oscillator IC **800** is selected, which divides the fundamental frequency of RC oscillator **820** by 16. If the initial fundamental frequency of RC oscillator **820** is X, then the frequency at Q4 would be X/16, and the t**1** period would be 1/(X/16). For example, assume an RC oscillator **820** frequency of 1,000 Hz at a given fixed water height. The Q4 output would be 62.5 Hz, with a t**1** period of 16 milliseconds. Timing diagram **830** shows the output of Q4. Power-up of binary counter/oscillator IC **800** begins with Q4 held LOW at oscillator power-up time **822** and remaining low for one-half of the normal t**1** period, shown as ½t**1** in FIG. **17**, or for 4 RC oscillator **820** clock cycles. Rising edge **824** occurs on the 5^{th} clock cycle, which causes microcontroller **801** port RA**2** to trigger an internal timer/counter. Falling edge **824** is detected by port RA**2** to terminate the internal timer/counter, the duration of which corresponds to the t**1** period of 8 RC oscillator **820** clock cycles, which varies as a function of the change in capacitance of the exemplary sensor of FIG. **18**B. When the t**1** period has been determined, port RCO goes LOW and powers down binary counter/oscillator IC **800** to conserve battery power. The resolution of the internal timer/counter of microcontroller **801** determines the water height measurement resolution of the exemplary sensor of FIG. **18**B. For example, if the internal timer/counter resolution is in 10 microsecond intervals and the RC oscillator **820** frequency of 1,000 Hz is assumed at a given fixed water height, the t**1** period of 8 milliseconds would be resolved as 800 increments, or bit counts, of the timer/counter. As will be explained shortly, each incremented timer/counter bit corresponds to a very precise and linear water height displacement amount. The RC oscillator **820** passive components, the variable capacitance range of the exemplary sensor of FIG. **18**B, the internal oscillator frequency of microcontroller **801**, and the resolution of the internal timer/counter used to clock the t**1** interval, determine the water height accuracy and resolution of the toilet monitoring and intelligent control system.

[0222] (Specifications relative to example operation and responsivity of exemplary sensor and electronics; sensor wire dimensions; displacement measurements) In practice, the combination of the exemplary sensor of FIG. **18**B, the timing characteristics of microcontroller **801**, and the RC oscillator **820** have been optimized to produce a baseline t**1** period of approximately 300 bit counts when the total conductor length **314**L of uninsulated conductor **310** and insulated conductor **314** of FIG. **19** or FIG. **28** is approximately 13 inches in total length and having no contact with water. For every linear inch of water that uninsulated conductor **310** and insulated conductor **314** are submerged, the internal timer/counter of microcontroller **801** increments approximately 324 bit counts, or approximately 3.25 bits for every 1⁄100th linear inch. For instance, if uninsulated conductor **310** and insulated conductor **314** are submerged to a depth of 5 inches in an average toilet tank or other liquid carrying vessel, the t**1** result of microcontroller **801**'s internal timer/counter would be the baseline of 300 bits, plus 324 bits multiplied by 5 inches, for a total t**1** count of 1920 bits. At a timer/counter resolution of 10 microseconds, the total resulting active microcontroller **810** and binary counter/oscillator IC **800** time required to determine t**1** is 19.2 milliseconds. Adding in the ½t**1** time of approximately 10 milliseconds, the total operational measurement conversion time is about 30 milliseconds. From the Microchip microcontroller 16LF or 18LF series datasheets, when the internal RC oscillator is configured for a clock speed of 4 mhz and binary counter/oscillator IC **800** is running, the average operational current during the complete measurement conversion cycle is less than 200 microamperes. Operationally and by way of example, if water height measurements are executed every 500 milliseconds and the average measurement conversion is approximately 30 milliseconds, the current required from the battery to power the circuits approaches a 6% duty cycle, or an average hourly drain of 12 microamperes. It should be noted that the microcontroller **801** is in the "sleep" or low-power mode during the remaining 94% of the time, drawing less than 2 microamperes. In view of the above current drain data, an average 225 mAh CR2032 lithium battery is more than capable of powering the preferred toilet monitoring and intelligent control system for up to 18 months without replacement.

[0223] There are several different measurement methods that can be used to track the water height in a typical tank-based toilet using the accurate and repeatable exemplary system described herein. Once a flush cycle has been detected, microcontroller **801** port RC**0** can enable binary counter/oscillator IC **800** to run continuously while port RA**2** and the internal timer/counter track sequential t**1** intervals, which provides the most accurate measurement of the water height with respect to time. During continuous measurements, the duty cycle of the resulting Q4 square wave is approximately 50%, although it should be obvious that the HIGH and LOW time periods will vary during flush cycles. During non-flush periods, periodic measurement conversion cycles can be executed, as was previously described, and the resulting interval data analyzed for leaks and other toilet malfunctions, the methods of which are described below.

[0224] FIG. **27** shows the top-down cross-section of the average tank-based toilet. From the trapezoidal measurements shown, the average area is approximately 113.375 inches. A gallon of water is 231 cubic inches. Therefore, a 1 inch displacement of water in tank **52** is approximately one-half gallon of water. The exemplary system described herein has the accuracy and resolution to track and detect intentional and unintentional water flow through tank **52** in virtually every mode of toilet operation including, but not limited to, flush cycles, leaks, wide-open flappers, overflows, and faulty fill valves.

Detailed Description of the Toilet Tank Water Level Responsivity During Normal Operation and in Response to Various Leaks and Failures

[0225] (FIG. **20** thru **26**: Data and graphs derived from exemplary sensor and microcontroller as they correspond to toilet operation) FIG. **21** through FIG. **26** show actual water height data gathered by the exemplary toilet monitoring and intelligent control system. The graphs will be used to demonstrate how the water height, as a function of time or cumulative water height intervals, can be used mathematically by equation, or with respect to time or intervals, in order to identify toilet problems and anomalies. For the purpose of clarity, it is mentioned here that binary counter/oscillator IC **800** is permitted to run non-stop in the astable mode when collecting any sequential data, such as during a flush cycle. In non-flush mode operation, however, the binary counter/oscillator IC **800** is operated in the low power mode, which collects t**1** intervals periodically, until a flush is detected, as was explained previously and again below. FIG. **20** graphs the complete normal flush cycle of a properly working toilet that exhibits no anomalies or problems of any kind. FIG. **20**E shows a complete listing of the graphed data, which will be used herein for reference. Starting water height **900** shows the toilet tank **52** water height at the moment the toilet is flushed. Tank evacuation **902** is the relatively linear decrease in water height that occurs as toilet tank **52** drains into unobstructed bowl **54** through flush valve **61**. After most of the water has drained from the tank, flapper **62** seals off flush valve **61** and terminates the tank evacuation process, shown as flush valve closure water height **904**. Fill valve **66**, which opened during tank evacuation when float **112** dropped, continues to allow water to enter tank **52**, resulting in tank refill **906**. End-of-flush water height **908** indicates that float **112** has reached it maximum vertical height, and water flow through fill valve **66** is terminated. FIG. **20**A shows only the tank evacuation **902** of FIG. **20**. Tank evacuation data trace **912** is the actual water height data gathered by the exemplary toilet monitoring and control system, which is best modeled and represented by $y=a+bx^{-0.5}$, where y is the water height and x is time. It has been found that for the normal flush for most tank-based toilets, the formula constants a and b are generally in the range of 3045 and −850, respectively. Therefore, when the exemplary toilet monitoring and intelligent control system is installed into any given toilet without calibration or set-up, the formula $y=a+bx^{0.5}$, when used with the a constant of 3045 and b constant of −850, can be used to determine if tank evacuation **902** is normal or abnormal. An explanation of how the formula can be used to detect abnormal tank evacuation will be explained shortly. But suppose after initial installation the exemplary toilet monitoring and intelligent control system simply monitors the first actual flush, recording the water height as a function of time. In that instance, it can easily be seen that the a and b constants can then be more accurately mathematically derived from the recorded data, if desired. During the initial flush it is also obvious, for example, that the water height could be sampled one or more times during tank evacuation **902**, as a function of time, and stored for later comparison, the purpose for which will be described shortly. For example, the water height in tank **52** could be sampled every one-half second and recorded. Recorded data during tank evacuation **902** can also be used to establish the rate of change of the data, in terms of water height with respect to time. From the FIG. **20**E data, it can be seen that time is the cumulative function of the t**1** interval of binary counter/oscillator IC **800**, and is derived by adding the LOW time period immediately preceding a given t**1** interval, to the t**1** interval, as is cumulatively represented in the FIG. **20**E column identified as “Time”. FIG. **20**B shows the normal tank evacuation profile of FIG. **20** of tank **52** water height as a function of interval, where the t**1** intervals are simply consecutively tracked on the graphs x-axis. In this graph, tank evacuation data trace **916** is shown in view of the derived tank evacuation equation trace **914**, which is of the form $y^{-1}=a+bx$. Using this equation and with respect to most toilets, the constants a and b are generally in the range of 0.000433 and 3.224E-6, respectively. Although those schooled in mathematics will recognize there are other possible equations that could be used for modeling and resolving the water height and time data, the simple linear equations above are optimum for use in inexpensive non-floating point microcontrollers.

[0226] Although different toilet designs may have different evacuation rates that can cause the a and b constants to change in order to more accurately model the evacuation mathematically, this is easily accommodated. The exemplary toilet monitoring and intelligent control system recognizes a flush when any t**1** interval falls below a predetermined setpoint of the average and/or standard deviation of 4 preceding t**1** intervals. For example, assume the water height W is stable in tank **52** with a bit count of 2500. When the user initiates a flush by pressing flush handle **56** and raising flapper **62** off of flush valve seat **65**, and water height W drops more than 50 bits within a single t**1** interval, the t**1** interval negative displacement compared to the average pre-flush water height W average and/or standard deviation indicates that a flush has occurred. Generally speaking, there is no anomaly or problem with any type of tank-based toilet that impairs or changes the flush cycle within the first 2 or

3 seconds of the flush. But within those first 2 or 3 seconds, the internal water channels **40** in FIG. **34**A and FIG. **34** B, which connect to siphon jet **55***b* and rim holes **55***a*, have completed filled, reducing the rate at which tank **52** can evacuate through flush valve **61** and into bowl **54**. FIG. **7** illustrates an example starting water height **94** before a flush is initiated, corresponding to starting water height **900** in FIG. **20**. Water heights **92**, **90**, and **88**, show the successively lower water heights at the 1 second, 2 second, and 3 second intervals, respectively. That 2 or 3 seconds after the flush has been initiated provides enough recorded data for the complete normal flush profile to be mathematically derived, in terms of the a and b constants, particularly if the sample rate during the mentioned 2 or 3 seconds was substantially high. The now derived a and b constants can now be used, for example, at the 5 second mark during the same flush cycle, in order to determine if an anomaly or problem has occurred. For instance, using the actual data of FIG. **20**E, suppose the water height data from approximately only the 0.695 second time, which is where the flush was detected as beginning, to the 2.04 second moment of tank evacuation **902**, was used to calculate the a and b constants used in the aforementioned or similar linear equation to predict where the water height in tank **52** should be at a future point in time, such as at 5 or 6 seconds within the same flush evacuation **902**. Using linear regression analysis, the a and b constants could be calculated by microcontroller **801**, allowing microcontroller **801** to predict that water height in tank **52** at a subsequent time in the same flush evacuation **902**. A deviation from the predicted and expected water height at said subsequent time would indicate an anomaly or problem, such as those described in the sections below.

[0227] FIG. **20**C and FIG. **20**D show only the tank **52** refill portion of the FIG. **20** complete normal flush cycle as water height with respect to time and interval, respectively. Similar to the evacuation graphs in FIG. **20**A and FIG. **20**B, the data is easily modeled. Because there is generally no anomaly or problem which can occur during the refill phase of the flush cycle, as long as the water supply pressure to the toilet remains constant, fill valve **66** will refill tank **52** and maintain the equation of $y=a+bx$, which the overlay of tank refill data trace **920** and tank refill equation trace **918** clearly show. For references purposes, FIG. **20**D, which shows the water height in view of intervals, is also shown and is represented by the equation $y^{0.5}=a+bx$. The graphed curve is the result of the changing interval time period that occurs as the water rises and the t**1** interval increases accordingly. The very linear and predictable consistency of the refill phase allows the exemplary system to accurately estimate the total volume of water for each flush cycle, as was previously described in terms of FIG. **27**, as well as the actual water flow rate into tank **52** from fill valve **66**. For example, if the starting water height in tank **52** is known prior to a flush cycle being initiated by the user, and the flush valve closure water height **904** is determined, the net difference in height as measured by the t**1** intervals, when multiplied by the tank **52** cross-section, will provide the total tank **52** flush volume. Further, extensive testing of different types of fill valves have shown that the additional water fill valve **66** dumps into overflow tube **199** through siphon tube **203** during an entire flush cycle, on average, is approximately 25% of the total tank **52** flush volume. In addition to the flush cycle, any of the anomalies and problems that produce unintentional water flow that results in any tank **52** change in water height, can be calculated accurately by simply measuring water displacement with respect to time and, if desired, recording or datalogging the same. The tank refill **906** also allows the volumetric water flow of fill valve **66** into tank **52** to be calculated accurately, as any desired water height interval can be finitely measured in terms of both displacement and time.

[0228] The graph and corresponding data of FIG. **20** establish the baseline from which most toilet-related anomalies and problems can be compared and therefore detected, which include not only the tank-specific problems of leaks, wide-open flush valves, and faulty fill valves, but the bowl-specific problems of overflows and the user-related anomaly of double-flushes. FIG. **21** through FIG. **26** provide actual comparison data in graph form.

[0229] (Blocked Bowl) FIG. **34**A shows a top down view of the toilet bowl **54** and FIG. **34**B shows a slightly rotated side view of the same toilet bowl **54**. When a flush is initiated by the user and flush valve **61** is opened, water enters bowl **54** through water entry port **30** and begins to fill the empty interior water channels **40**, exiting into bowl **54** through siphon jet **55***b* and rim holes **55***a*, with intake water flow arrows **42** showing the direction of flow into bowl **54** and exhaust water flow arrows **44** showing the direction of flow out of the bowl. During a normal flush where the water evacuating bowl **54** into exhaust port **63** is not impeded or blocked, such as shown in FIG. **3** where bowl **54** is empty or lacking substantial waste product, the tank evacuation **902** of FIG. **20** reflects a profile which consistently and repeatedly mirrors tank evacuation equation trace **910**. But when obstruction **68** in FIG. **3**A is in any way reducing the flow rate of water w**1** in bowl **54**, or if a blockage is present anywhere in or beyond exhaust port **63**, which in turn cause water w**1** in bowl **54** to begin to rise, the water evacuation of tank **52** through flush valve **61** into bowl **54** is impeded, resulting in a measurable change in tank evacuation **902**'s profile. When water w**1** in bowl **54** continues to rise until rim holes **55***a* are covered, the water flow from tank **52** into water channels **40** is further impeded, presenting the possibility of an imminent overflow if the water is not terminated immediately, the overflow being addressed herein shortly. FIG. **21** shows the graph of a complete single flush cycle when the siphon jet—also known as the siphon port—is blocked or there is an obstruction immediately in front of the siphon jet that is preventing the water in the toilet bowl from draining, as was just described above. In FIG. **21**, flush valve closure water height **928** indicates that despite the blockage, flapper **62** has seated on flush valve seat **65** and closed flush valve **61**, preventing further water evacuation into bowl **54** from tank **52**. Nevertheless, tank evacuation **926** is noticeably different from tank evacuation **902** shown in FIG. **20**. FIG. **26** shows the tank evacuation graphs of FIG. **20** and FIG. **21** overlaid onto as a single graph to make the visual comparison straightforward. Tank evacuation **926**, which is the result of obstruction **68**, results in a slower evacuation of tank **52**. Comparing the data in FIG. **20**E with that in FIG. **21**E shows that within 4 seconds, the water height W in tank **52** of tank evacuation **926** is lagging behind that of tank evacuation **902** by nearly 165 bits, which is roughly equivalent to one-half inch in terms of actual water displacement. At 6 seconds the lag is nearly 265 bits, which is more than three-quarter inch difference in water displacement. It can readily be seen that the failure of bowl **54** to evacuate properly can be determined by either time or equation, as was previously discussed. This indicates that at the same moment in time of a given flush cycle, the tank **52** water height as reflected by tank evacuation **926** due to bowl **54**'s obstruction is going to be higher than that of tank evacuation **902**, which does not have an obstructed bowl **54**. Any lag of more than one-quarter of one inch of water height difference in displacement from that of the profile established by tank evacuation **902** will cause exemplary system to recognize the developing problem and identify it accordingly as a blocked or obstructed bowl **54**. For the purpose of comparison with FIG. **20**B, FIG. **21**B has been included to show the graph of the obstructed bowl with respect to water height and interval. Also for the purpose of comparison, FIG. **21**C and FIG. **21**D show the tank refill with by time and interval, respectively. As was pointed out previously, despite the obstruction and change in the tank evacuation due to the obstruction in bowl **54**, the tank refill is basically unaffected and therefore mirrors the equations of $y=a+bx$ and $y^{0.5}=a+bx$ with respect to those shown in FIG. **20**C and FIG. **20**D.

[0230] (Double-Flush due to Blockage) FIG. **21** graphs the complete flush profile when only a single flush is initiated by the user. Unfortunately, a severe blockage of exhaust port **68** often results in an elevated water height w**1** in bowl **54** for a period of time following that initial flush. Because of a tendency by many people to believe that more water pressure is necessary to clear the blockage, or as a result of panic or embarrassment because it is now obvious that one's excrement has created a problem, the toilet is often flushed a second time shortly after the first flush, and often before the first flush cycle has completed, which frequently results in bowl **54** overflowing.

[0231] FIG. **22** shows the graph of a back-to-back flushes within a brief time interval when an obstruction is preventing exhaust port **68** from evacuating bowl **54**. In contrast to tank evacuation **902** of a normal flush that takes approximately 6 seconds, first flush tank evacuation **964** is more than 10 seconds in duration, during which time bowl water height w**1** is rising in bowl **54** due to the obstruction. Flush valve closure water height **970** shows that flapper **62** closed at the approximate water height **83**, as shown in FIG. **8**, and first flush tank refill **972** occurred within the expected approximately 45 seconds, but shortly after end-of-first-flush water height **974** occurred, the toilet was again flushed. Second flush tank evacuation **976** took more than 12 seconds, and flush valve wide-open interval **978**, which remains basically flat and stable, indicates that flapper **62** failed to close and seal off flush valve **61**, because the tank water height **84** has not dropped low enough for positive buoyancy of flapper **62** to drop, resulting in an overflow condition of bowl **54** where water w**1** is now above the rim and draining onto the floor. The exemplary system described herein is able to detect: (a) the obstruction on the basis of the change in either the time of evacuation, or by equation, of first flush tank evacuation **964**; (b) the brief interval between the first and second flush; (c) the impending overflow on the basis of the change in either time of evacuation, or by equation of the second flush tank evacuation **976**; and (d), the actual overflow condition on the basis of the absence of the rate of change in flush valve wide-open interval **978**, which followed the analysis of the second flush tank evacuation. FIG. **22**A, FIG. **22**B, FIG. **22**C, and FIG. **22**D show the exploded first and second tank evacuations by time and by interval, with their respective linear equations and the a and b constants associated with the same, for reference.

[0232] (Multiple Phantom Flushes, Fill Valve Equilibrium Failure, followed by a Phantom Flush) As has been described previously herein, a leak from tank **52**, which typically occurs due to a faulty flapper or fill valve, generally results in water moving from tank **52** to bowl **54**, or leaking from tank **52** directly onto the floor because of cracks in the porcelain, loose or rusted tank **52** retaining bolts, or a degraded or defective gasket immediately below and between flush valve **61** and bowl **54**. Fill valve **66** responds to the leak by refilling tank **52** and float **112** responds to the corresponding change in tank **52** water height. As was also previously described, fill valves may exhibit "phantom flushes" or "equilibrium" failures during the refill of tank **52**. FIG. **23** shows the tank water height response to a leak whereby the fill valve "phantom flushes" 4 times, followed by the fill valve temporarily exhibiting the "equilibrium" failure mode, concluding with 1 additional "phantom flush". Fill valve open water heights **965**, **966**, **967**, and **968**, all reflect the float **112** water height **81** in FIG. **13**B, at which point fill valve **66** allows water to fill tank **52** until fill valve closure water heights **950**, **952**, **954**, and **956**, which correspond to water height **80**, have been reached, causing fill valve **66** to terminate water flow. The exemplary system described herein can track and detect just the negative water height displacement over time, or the cyclic water height displacement over time, identifying either/or as a toilet leak. After fill valve closure water height **956** occurs, the leak once again causes a negative displacement of water, resulting in water height **81**, but instead of fill valve **66** responding by opening and once again filling tank **52** to water height **80**, fill valve equilibrium water height **960** occurs, which although is relatively stable, produces fill valve flow variation water height peaks **962** for a period of time. This is followed by tank refill **957**, fill valve closure height **958**, which is followed by a succession of additional "phantom flushes" (not shown in the graph). FIG. **23** models the water height in view of a fill valve exhibiting both "phantom flushes" and "equilibrium" failures, but any given fill valve can exhibit only one or the other condition, or both conditions. When the exemplary system described herein detects the sequence of an initial drop in tank **52** from water height **80** to a lower and stabilized water height **81** which does not substantially increase over time, a fill valve equilibrium failure is determined. If the exemplary system detects a "bad leak", which is herein is described as being more than several gallons per hour, regardless of the cause, an additional alert may be produced by microcontroller **801** on annunciator module **350**. Further, if a leak or faulty fill valve **66** goes uncorrected for a prolonged period of time, microcontroller **801** may have annunciator module **350** produce an additional alert. In addition to annunciator module **350**, monitoring device **325** and **340** could additionally transmit data and alerts via any one of several RF frequencies and protocols.

[0233] (Fill Valve Termination Failure) FIG. **13**A shows the tank **52** water displacement when a fill valve fails in the "open" condition, allowing water to "bleed" or "seep" into tank **52** when float **112** has risen to its maximum vertical height, which should cause a properly functioning fill valve to terminate water flow completely. However, because fill valve **66** is faulty and "bleeding", tank water height W has continued to rise to water height **82**, which is the maximum height of overflow tube **199**, and begins to drain into overflow tube **199** and then into bowl **54**. FIG. **24** shows the graph of this type of fill valve failure following a flush. A flush has been initiated and the sequence of tank evacuation **970**, followed by flush valve closure water height **971**, tank refill **972**, and fill valve closure water height **973**. Because fill valve **66** continues to "bleed" water into tank **52**, increasing water height ramp **974** continues to rise until it reaches overflow tube water height **976**, at which point the water drains into overflow tube **199** and then into bowl **54**. The FIG. **24** increase from fill valve closure water height **973** to overflow tube height **976** is approximately 500 bits, which represents a displacement of approximately 1.5 inches. From FIG. **24** it can be seen that increasing water height **974** spans a period of approximately 435 seconds, a timeframe that occurs 8.2 times per hour. From FIG. **27** and the previous water volume calculations described herein, the leak graphed in FIG. **24** is therefore approximately 8.2×1.5"×0.5 gallons, or 6.15 gallons-per-hour. The exemplary system described herein tracks the increasing water height **974**, thereby detecting the faulty fill valve **66**, as well as accurately tracking and/or datalogging the amount of water lost over any given period of time.

[0234] (Wide-Open Flush Valve) FIG. **3** shows flush valve **61**, comprised of flapper **62** and flush valve seat **65**, where flapper **62** is in the full vertical position, indicating that flush valve **61** is "open" and allowing water W to freely drain from tank **52** into bowl **54**. FIG. **25** shows a pre-flush water starting height **900**, at which point the user has initiated a flush. Tank evacuation **902** occurs, but the flapper **62** failing to close upon flush valve seat **65** creates flush valve wide-open duration **978**, which continues until the problem is corrected. The exemplary system described herein tracks and detects the wide-open flush valve problem, as well as accurately tracking and/or datalogging the amount of water lost over any given period of time. The wide-open flush valve can be determined by the exemplary system when: (a), wide-open duration **978** represents no rate of change for a period of time; or (b), when a tank refill does not occur within a period of time.

[0235] (Solenoid Valve) FIG. **7** shows monitoring device **325** deployed within tank **52**, while FIG. **28** shows a monitoring device **340** which hangs over tank **52**'s rim, with annunciator module **350** on the exterior surface and conductors **310**,**314** positioned inside tank **52** and in contact with water W. FIG. **7** also shows a solenoid valve **72** positioned between water supply valve **70** and fill valve **66**'s valve body stem **104**. Microcontroller **801**'s port **811** can be configured to actuate a simple circuit that is connected to solenoid valve **72**, turning it "on" or "off", as needed. Microcontroller **801**, for instance, may turn solenoid valve **72** "off" if a leak, wide-open flush valve, overflow, or faulty fill valve is detected.

[0236] (Automatic Flush Volume Control Method and Function) A major problem encountered by users of low-volume-flush toilets (LVFT's) is the need to double-flush, which not only defeats the purpose of having an LVFT, but often also results in overflows, which the exemplary system described herein can detect and, when desired, can alert the user as well as terminate the water flow. Despite the proliferation of LVFT's, many of these toilets have had their fill valve float heights improperly set, which means that the actual flush volumes are higher than the manufacturer's recommended volume-per-flush, and in many cases are unnecessary. Further, many non-LVFT toilets are installed around the world, frequently using 3, 4, and even 5 gallons-per-flush. Often times in low income property management environments where there are multiple housing units that are not sub-metered and where water conservation is a bottom line issue financially, maintenance personnel are not trained properly when it comes to setting the fill valve float height, leading to further unnecessary water waste when the float is set at, or near, it's maximum height. But the amount of water necessary to evacuate waste actually also varies as a function of the toilet users themselves. A large man with a hefty appetite is more likely to need additional water to evacuate the toilet bowl than a tiny woman on a vegan diet, yet their respective toilets may have identical flush volumes, despite the vast difference in the necessary amount of water required to reliably and consistently evacuate the toilet bowl.

[0237] Common sense suggests that a toilet that is rarely or never double-flushed may be wasting water because the flush volume exceeds the needs of the occupant. Common sense would also suggests that a toilet that is always double-flushed is likewise wasting water, particularly if a slight increase in flush volume would preclude the necessity of double-flushing. Another feature of the exemplary system is microcontroller **801**'s ability to track actual usage of the toilet to which it is attached by determining if and how often back-to-back double flushes are used and responsively turning "on" and "off" solenoid valve **72** to control the amount of that fills tank **52** through fill valve **66**. When monitoring device **325** or **340** is connected to solenoid valve **72**, in addition to terminating water flow due to a leak or other problem to prevent water loss and/or water damage, solenoid valve could be turned off prematurely before float **112** of fill valve **66** reaches its maximum height, and thereby decreasing the flush volume of the next flush. In one instance, no double-flushes or a minimum number of double-flushes are detected over a given time period. When the exemplary system detects the tank refill **906** occurring, solenoid valve could be turned "off" before water height W raises float **112** and fill valve **66** turns off, thereby decreasing the total flush volume. For instance, if no double-flush were detected for a given time period, solenoid valve may be turned off during tank refill **906** at reduced water height **92** (FIG. **7**) instead of float **112** water height **94**. If another period of time elapsed where no double-flushes occurred, microcontroller **801** may actuate port **811** to turn off solenoid valve **72** at reduced water height **90**. Conversely, consider a situation where the fill valve **66** float **112** is intentionally set at or near maximum height for a given user or tenant, with the purpose being to allow monitoring device **325** or **340** to optimize the flush volume over time. Further, that the automatically reduced flush volume is not sufficient for evacuating bowl **54** due to excessive double-flushes, in which case microcontroller **801** may allow port **811** to fill tank **52** to a higher water height W in order to increase the flush volume. Or, if the flush volume is already at its maximum level due to the setting of fill valve **66** float **112**, microcontroller could signal an alert that the flush volume is insufficient, which could also signal that the potential for overflows exists.

Toilet Monitoring and Intelligent Control System in Operation

[0238] FIGS. **29**-**33** show example operations performed by microcontroller **644** of monitoring device **340**. In the example shown, upon power up (block **450**) the microcontroller **644** resets variables (block **452**) and then sleeps for X seconds (block **454**). The microcontroller wakes itself up after X seconds and samples the output of sensor **648** to determine whether the sensor is in the water (decision block **456**). If the sensor is not in the water (no exit to decision block **456**), the microcontroller **644** again sleeps for X seconds (block **454**) and checks again. This operation will continue indefinitely until the microcontroller determines that the sensor **648** has been placed in water ("yes" to decision block **456**).

[0239] Once the microcontroller **644** determines the sensor **648** is in the water, the microcontroller times a predetermined time delay (e.g., 30 minutes) to permit the environment to stabilize (block **458**) and then begins executing a main loop (block **460**). In this main loop, the microcontroller **644** first checks whether the button **810** has been pressed (decision block **462**). If the button has not been pressed (no exit to decision block **462**), the microcontroller may delay a predetermined delay (block **464**) and then read the oscillator/divider pulse width (block **466**). The microcontroller **644** then analyzes the acquired sensor measurement signal to determine whether a flush has occurred (block **468**), whether a leak has been detected (block **470**), whether the fill valve has failed to terminate water flow (block **472**), and whether any other user alerts are required (block **474**). Whether or not any of said conditions have occurred, the microcontroller **644** may also determine whether data logging is required (decision block **476**). Each of decision blocks **462**, **468**, **470**, **472**, **474** and **476** can invoke additional conditional functions that are performed when the condition tested for has tested true. This main loop **460** is continually executed as long as the monitoring device **340** is in service.

[0240] In the example shown, decision block **470** detects a leak by tracking negative or cyclic water displacement during non-flush periods. See description above for more detail. Decision block **472** detects whether the fill valve has failed to terminate water flow and is bleeding into the tank by detecting positive water displacement.

[0241] FIG. **30** is a flow chart that shows an example function to be performed when a flush is detected by decision block **468**. Upon detection of a flush, the microcontroller **644** begins cycling user alerts (block **530**) and performs further tests based on historical data the microcontroller **644** previously collected and stored in local memory. For example, microcontroller **644** can determine whether the current flush is the first flush the monitoring device **340** has ever detected (i.e., it is newly installed) (block **532**). If it is the first flush (yes exit to decision block **532**), the microcontroller **644** monitors the flush profile to determine if any probe compensation is necessary (block **534**). In one embodiment, this compensation includes detecting how long the probe is out of the water between the last time it sees decreasing water height and the first time it sees increasing water height—thus estimating the distance between the bottom of the probe and the bottom of the tank. This allows microcontroller **644** to later extrapolate falling and rising water levels to the gap between the bottom of the probe and the bottom of the tank.

[0242] If the microcontroller **644** detects that this is not the first flush ("no" exit to decision block **532**), the microcontroller detects whether the water height or level is (still) decreasing (decision block **536**). If the water height/level is (still) decreasing (yes exit to decision block **536**), the microcontroller **644** determines whether the decrease in water level/height is due to a normal evacuation (decision block **538**). Microcontroller **644** has determined that the evaluation profile is not normal, resulting in overflow detection in block **540** (see description above). If not due to a normal evacuation (no exit to decision block **538**), microcontroller **644** declares that an overflow/blockage has been detected (block **540**). Under this detection condition, in some embodiments, the monitoring device **340** can terminate water supply to the toilet by closing a valve automatically (block **546**). Either way, the routine shown in FIG. **30** returns a flag or code to the main loop **460** (see "return" block **480** of FIG. **29**), which will cause the microcontroller **644** to generate a user alert alerting the user to the problem (decision block **482**).

[0243] Decision blocks **536**, **538** provide a "do until" loop that enables the controller **644** to detect when the water level is no longer decreasing—meaning that the tank is drained. At this point, the flapper valve should close and the tank should begin to fill up again. If microcontroller **644** detects that the water height is no longer decreasing (no exit to decision block **536**), it then determines whether the water height begins to increase (decision block **542**). If the water height does not increase (no exit to decision block **542**), microcontroller **644** determines whether to add in a compensation factor (block **544**) that accounts for the sensor **308** potentially not being long enough to extend to the bottom of the tank (if the sensor is not long enough, then the tank could have begun to refill and the sensor will not yet "see" the refilling because it hasn't yet reached the level of the sensor). The process then loops back to decision block **542** to check again whether the water height is increasing.

[0244] If no compensation is to be added in (no exit to decision block **544**) (e.g., based on a certain time period passing by which time the sensor should be detecting a water height increase or in cases when no compensation is needed) and the sensor still has not detected a water level increase (No exit to decision block **544**), the microcontroller **644** declares a wide open flush valve has been detected and activates alerts (block **552**). This is based on recognizing that (a) a flush has occurred, (b) the water level is no longer decreasing and (c) the water level is not increasing even after waiting a period of time that would allow the rising water level to reach the level of the sensor). The monitor device **340** then detects, by monitoring the sensor **648** output, whether the problem of the rising water has been corrected quickly—for example by a flapper valve falling into a seal position late (decision block **560**). If so, control returns to continually monitor water height to detect the end of the flush cycle (decision block **542**). If the problem is not corrected quickly (no exit to decision block **560**), this means refill water is continuing to escape the tank through the flush valve and potentially wasting tremendous amounts of water. When this condition is detected, embodiments the microcontroller **644** can automatically close the water valve to terminate water flow into the toilet (block **558**) and return an error code to the main loop for generating user alerts (FIG. **29**, block **480**, **482**).

[0245] If the water height is neither (no longer) increasing nor decreasing and the current flush is not a first flush, then the microcontroller **644** looks at historical data (e.g., a flag or an event log) to determine whether the current flush is a second flush (block **550**). In this context, "second flush" does not mean the second flush the device **340** has ever detected but rather a subsequent flush in a sequence of flushes in rapid succession during typical operation. Often, users will flush twice if they think or detect that something is wrong with the toilet. Microcontroller **644** in this context detects a second flush by detecting a flush cycle that occurs relatively close in time to a previous flush cycle. If the second flush (yes exit to decision block **550**), the microcontroller **644** data logs an event set flag (block **544**) and optionally may evaluate flush events to adjust tank refill volume accordingly (block **547**).

[0246] If the current flush is not a second flush (no exit to decision block **550**), the microcontroller **644** detects that a flush operation is complete, terminates all alerts and data logs events (block **556**) and then optionally may evaluate flush events and adjust tank refill volume based on measured volume of water flow during the flush cycle (block **557**).

[0247] FIG. **31** shows an example flow chart for a routine microcontroller **644** performs in response to user manual depression of push button **810** (see FIG. **29** decision block **462**). Upon depression of push button **810**, microcontroller **644** introduces a one second delay (block **500**) and then detects whether the push bottom has been released (decision block **502**). If the microcontroller **644** detects a push button depression with a duration of less than one second (yes exit to decision block **502**), it invokes a master reset by sending a master reset code back to the FIG. **29** routine which then causes the microcontroller to reset (see FIG. **29**, block **478**). If, on the other hand, the push button remains depressed after one second (no exit to decision block **502**), the microcontroller **644** detects whether the push button is released before another one second delay (block **504**) has passed (decision block **506**). If the user has depressed the push button for more than one second but less than two seconds (yes exit to decision block **506**), the microcontroller **644** enters a test mode (block **512**) in which it times a one second delay (block **514**) and then detects whether the water height is increasing (decision block **516**) or decreasing (decision block **520**). If the water height is detected as increasing (decision block **516** yes exit), the microcontroller **644** will flash a green light either way (block **518**). If the microcontroller **644** detects that the water height is decreasing (yes exit to decision block **520**), the microcontroller **644** will flash a red LED (block **522**). This tells the user the device is working. If the microcontroller **644** detects that the water height is neither increasing nor decreasing (no exit to decision block **520**), the microcontroller **644** will flash both the red and green LED (block **524**). In the example non-limiting embodiment, the microcontroller **644** continues this test mode operation for ten minutes (decision block **526**) and then automatically reverts to normal operation (yes exit to decision block **526**). In some embodiments, an additional button pressed at this time could be detected for to release the unit from the test mode.

[0248] If the decision block **506** detects that the push button was pressed for more than two seconds ("no" exit to decision block **506**), the microcontroller **644** may interpret that button press as a request to test all user interface devices by flashing indicators **808**, providing an audible alert on annunciator **809** and/or transmitting data and/or data logging of all data (block **510**).

[0249] FIG. **32** shows an example non-limiting flow chart of function that microcontroller **644** may perform in order to generate a user alert (see decision block **474** of FIG. **29**), e.g., based upon error codes returned by the various other test routines. In this particular example, the microcontroller **644** encodes the error condition for the number of LED light flashes that indicators **808** flash. Thus, if a leak has been detected (decision block **570**), the variable X is set to 2. If a bad leak has been detected (decision block **572**), the variable X is set to 3. If a leak has been ignored (decision block **574**), the variable X is set to 4. If a wide open flush valve has been detected (decision block **576**), X is set to 10. If an overflow has been detected (decision block **578**), X may also be set to 10. If a fill valve failure has been detected (block **580**), then X may be set to 3. Microcontroller **644** then flashes the LEDs X number of times as well as activates the audio annunciator **809** that same number of X times (block **582**). Microcontroller **644** may then delay two seconds (block **582**) and detect whether an overflow condition exists (decision block **584**). If the overflow condition does not exist (no exit to decision block **584**), the FIG. **32** routine may return to the main loop shown in FIG. **29**. However, if an overflow condition does exist (block **584** yes exit), the monitoring device **340** may continue to generate an alert unless/until the user presses the push button **810** to silence or reset the alert (decision block **586**).

[0250] FIG. **33** shows an example data logging function which allows, in some embodiments, monitor device **340** to harvest and transmit toilet operating data for further analysis such water usage analysis. In these embodiments, the microcontroller **644**:

[0251] writes/updates all flush, evacuation, refill, and operational variables to internal memory as they occur (block **600**)

[0252] writes/updates all cumulative intentional and unintentional volumetric water flow to the internal memory (block **602**)

[0253] writes/updates cumulative events such as leaks, overflows, wide open flush valves, faulty fill valves and the like to internal memory (**604**)

[0254] writes/updates cumulative total number of flushes to keep track of the number of flushes that the toilet has experienced (block **606**)

[0255] writes/updates average number of flushes per defined interval (block **608**). writes/updates average water volume per flush to the memory, as well as tank refill volume adjustments (block **610**, **612**)

[0256] writes/updates cumulative total number of master resets (block **614**)

[0257] transmits all of this data on demand of periodically via telemetry, cable or other communications means of any sort for external analysis (block **616**).

The invention is not to be limited to the above disclosed embodiments, but rather is intended to cover variations and equivalents with the spirit and scope of the claims.

We claim:

1. A toilet monitor characterized by

a toilet tank water level sensor producing a toilet tank water level measurement signal;

the toilet monitor further comprising

a processor connected to receive the measurement signal, the processor being configured to detect the rate of change of the measurement signal and conditionally produce a responsive actuation signal in response to the detected rate of change; and

a transducer connected to receive the actuation signal.

2. The toilet monitor of claim **1** wherein the processor is further configured to evaluate a sequence of rates of change to detect toilet operation abnormalities.

3. The toilet monitor of claim **1** wherein the processor is further configured to detect predetermined sequences of rates of change.

4. The toilet monitor of claim **1** wherein the processor is further configured to detect rate of change using a rolling block interval analysis.

5. The toilet monitor of claim **1** wherein the processor is further configured to use a linear equation to analyze the rate of change measurement signal.

6. The toilet monitor of claim **1** wherein the processor is further configured to determine an anomaly in water flow within the toilet bowl based on the rate of change of the toilet tank water level measurement signal.

7. The toilet monitor of claim **1** wherein the processor is further configured to determine the toilet is leaking in response to the rate of change.

8. The toilet monitor of claim **1** wherein the processor is further configured to determine the toilet is leaking by tracking the direction and/or the cycles of the rate of change.

9. The toilet monitor of claim **1** wherein the processor is further configured to determine the toilet fill valve is defective in response to the rate of change.

10. The toilet monitor of claim **1** wherein the processor is further configured to determine the toilet fill valve is defective by tracking the direction of the rate of change followed by the absence of rate change.

11. The toilet monitor of claim **1** wherein the processor is further configured to determine the toilet flush valve is open in response to the rate of change.

12. The toilet monitor of claim **1** wherein the processor is further configured to determine the toilet flush valve is open by tracking the absence of the rate of change.

13. The toilet monitor of claim **1** wherein 1 the processor is further configured to determine current and/or imminent toilet overflow in response to the rate of change.

14. The toilet monitor of claim **1** wherein the processor is further configured to detect the prolonged absence of double flushes.

15. A method of controlling a flush toilet comprising:

producing a toilet tank water level measurement signal;

detecting the presence or absence of plural successive flushes within a predetermined time period based on the measurement signal and generating an actuation signal to affect toilet tank flush volume; and

increasing or decreasing toilet tank flush volume in response to the actuation signal.

16. The method of claim **15** further including evaluating a sequence of rates of change of the measurement signal to detect toilet operation abnormalities.

17. The method of claim **15** further including tracking the direction of rate of change of the measurement signal.

18. A toilet monitor comprising

a housing containing electronics; and

a water level sensing probe extending from the housing, the probe comprising at least one conductor; wherein the monitor is further comprising a portion of the at least one conductor being bent or bendable to hang over the lip of a toilet tank to suspend and support the housing on the tank lip, the at least one conductor having a length such that an additional portion of the at least one conductor extends from the bent/bendable portion into immersion contact with water in the tank.

19. The toilet monitor of claim **18** further comprising a processor connected to receive a measurement signal provided by the water level sensing probe, the processor being configured to detect the rate of change of the measurement signal and conditionally produce a responsive actuation signal in response to the detected rate of change.

20. The toilet monitor of claim **19** wherein the processor is further configured to detect the prolonged absence of double flushes.

* * * * *