



US006109614A

[54]	REMOTE SENSING APPARATUS OF SUPERSONIC PROJECTILE	4,514,621	4/1985	Knight et al. .
		4,885,725	12/1989	McCarthy et al. .
		5,025,424	6/1991	Rohrbaugh et al. .
[75]	Inventor: Christopher A. Ciarcia, Los Alamos, N. Mex.	5,095,433	3/1992	Botarelli et al. .
		5,247,488	9/1993	Borberg et al. .
		5,349,853	9/1994	Oehler .
[73]	Assignee: Tardis Systems, Inc., Los Alamos, N. Mex.	5,447,315	9/1995	Perkins 273/371
		5,504,717	4/1996	Sharkey .

[21] Appl. No.: 08/895,649

[22] Filed: Jul. 17, 1997

Related U.S. Application Data

[60]	Provisional application No. 60/022,553, Jul. 19, 1996.
[51]	Int. Cl. ⁷ G06F 15/20
[52]	U.S. Cl. 273/372; 273/371; 434/1; 434/9; 235/400
[58]	Field of Search 273/371, 372; 367/906; 235/400, 412; 434/1, 6, 9, 15

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4,350,882	9/1982	Phillips .	
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4,425,500	1/1984	Knight et al. .	

Primary Examiner—Valencia Martin-Wallace

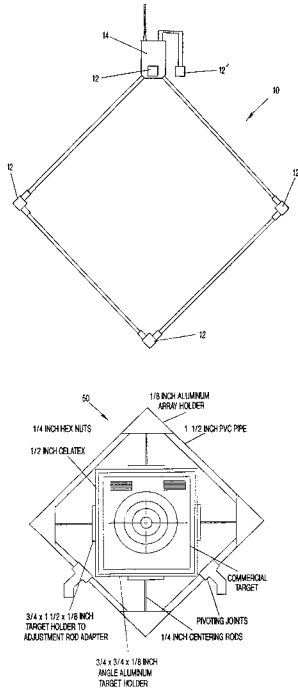
Assistant Examiner—John M Hotaling, II

Attorney, Agent, or Firm—Jeffrey D. Myers; Deborah A. Peacock; Andrea L. Mays

[57] ABSTRACT

A remote targeting apparatus and method comprising surrounding a projectile target with a sensor array, computing projectile impact data, transmitting the data receiving the data at a controller; and displaying information corresponding to the data. RF transmission/reception is performed, most preferably at a frequency of between approximately 902 and 928 MHz, with the controller having RF Faraday cage shielding and collision avoidance being employed to permit multiple sensor arrays to operate in a vicinity of one another. Projectile impact locations within twelve inches of the center of the projectile target are calculated to an average RMS accuracy of less than approximately fifty thousandths of an inch, directly in an orthogonal Cartesian coordinate system. Velocity is also determined via an additional sensor at a predetermined distance from the sensor array which measures a difference in time between the projectile passing the additional sensor and the sensor array. The preferred sensor array has at least two pairs of acoustical sensors, with an additional acoustical transducer orthogonal to the two pairs.

58 Claims, 47 Drawing Sheets



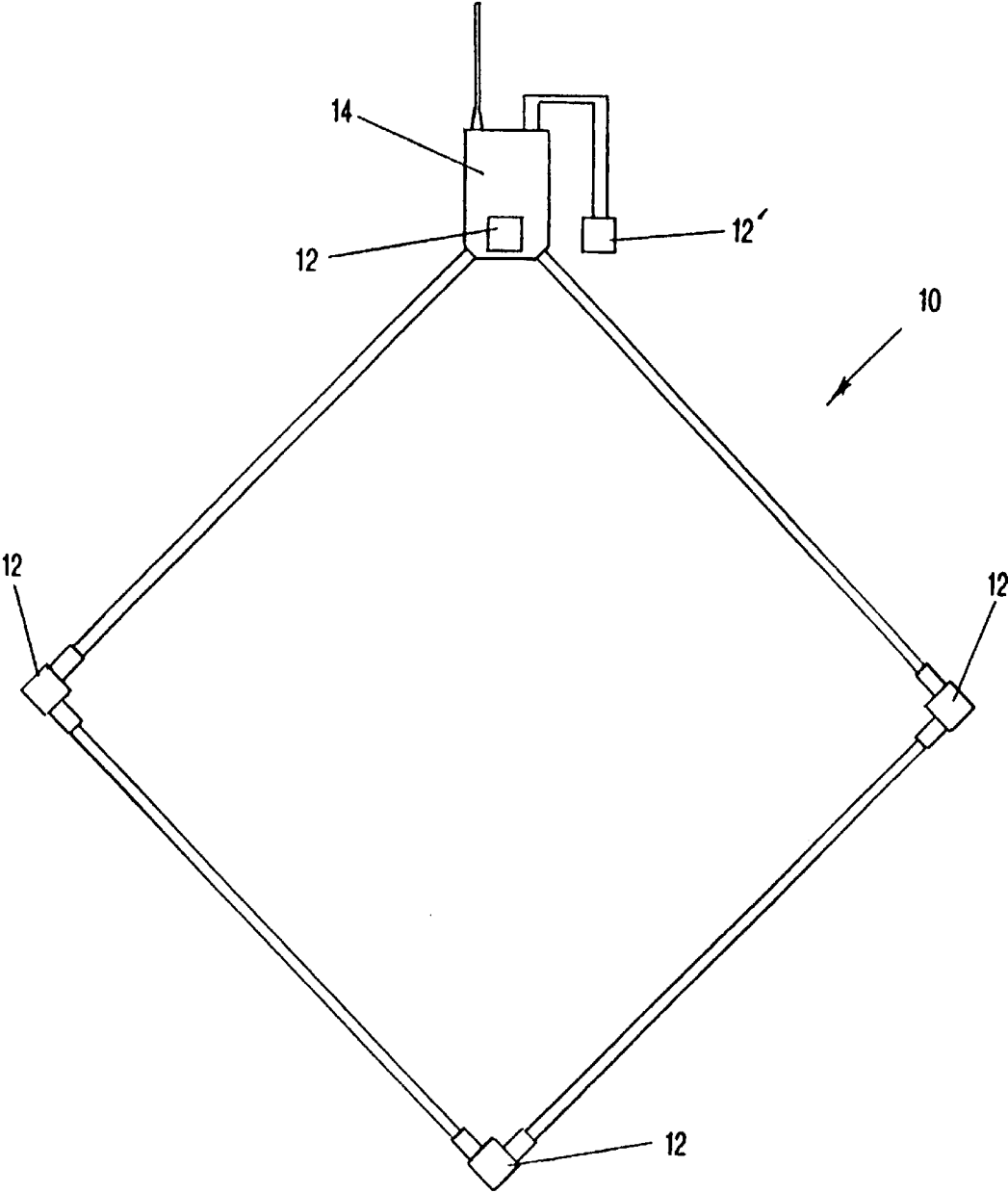


FIG-1

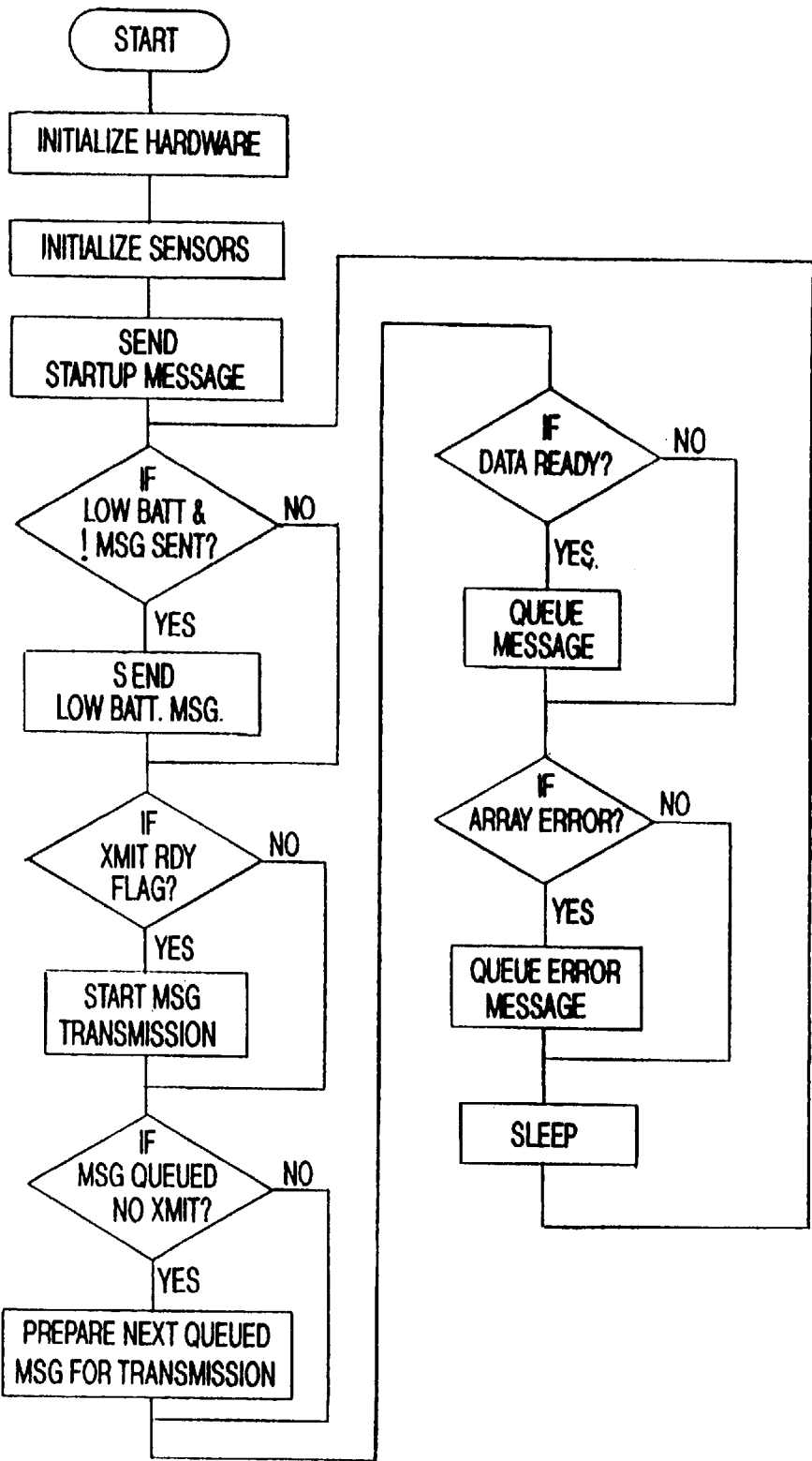


FIG-2

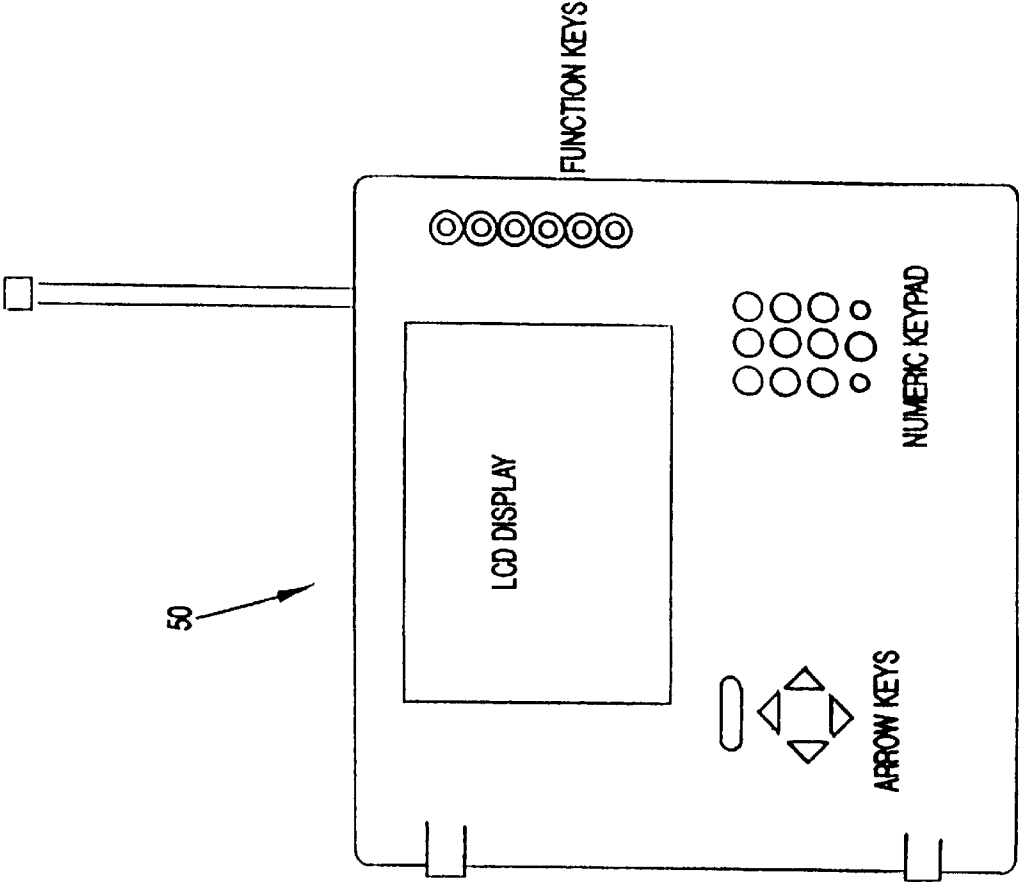


FIG-3 (a)

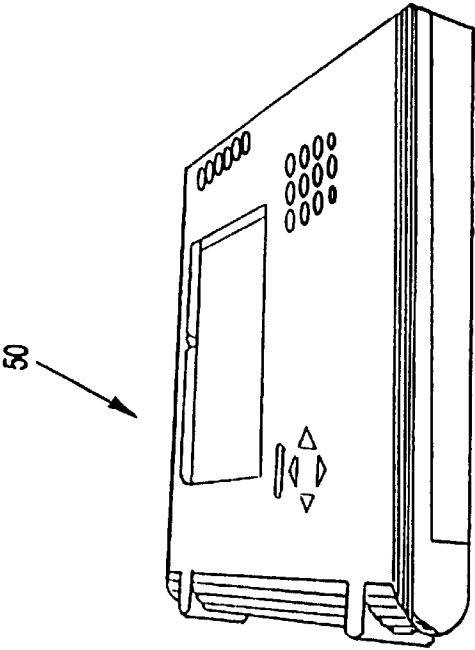


FIG-3 (b)

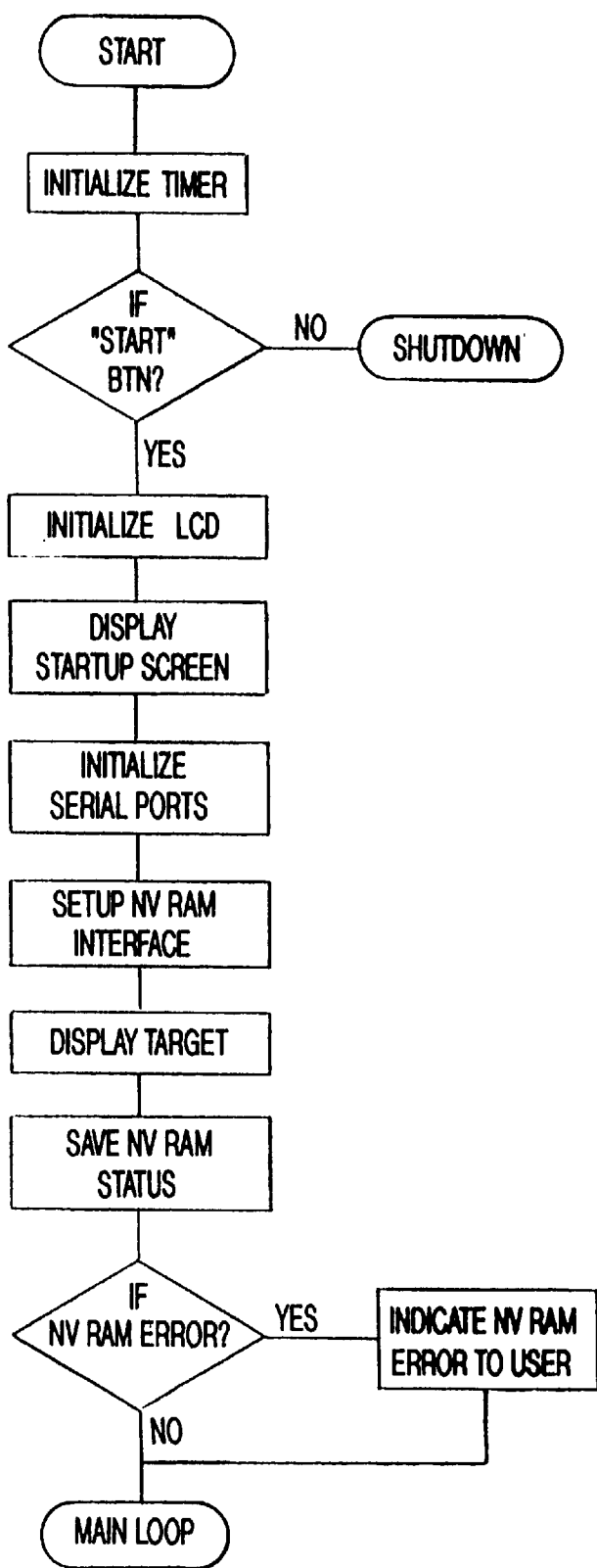


FIG-4

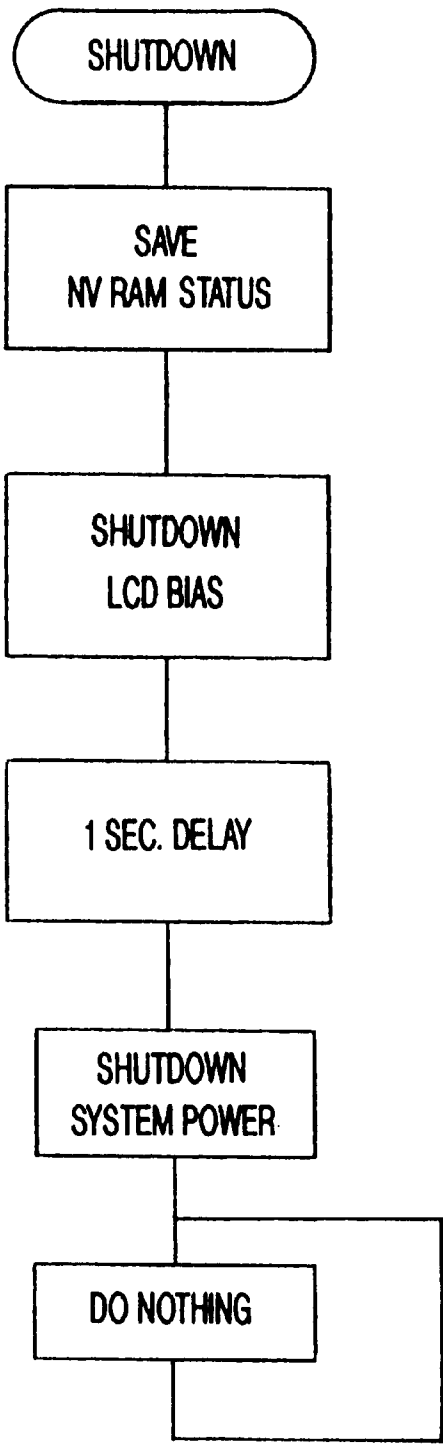


FIG-5

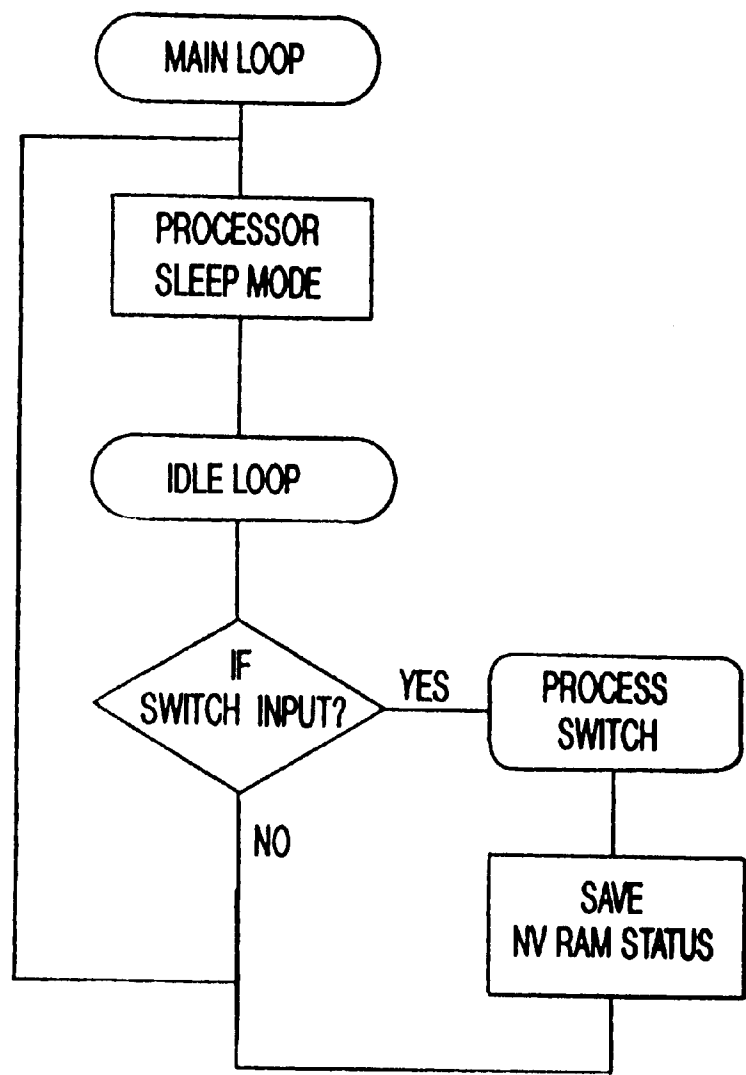


FIG-6

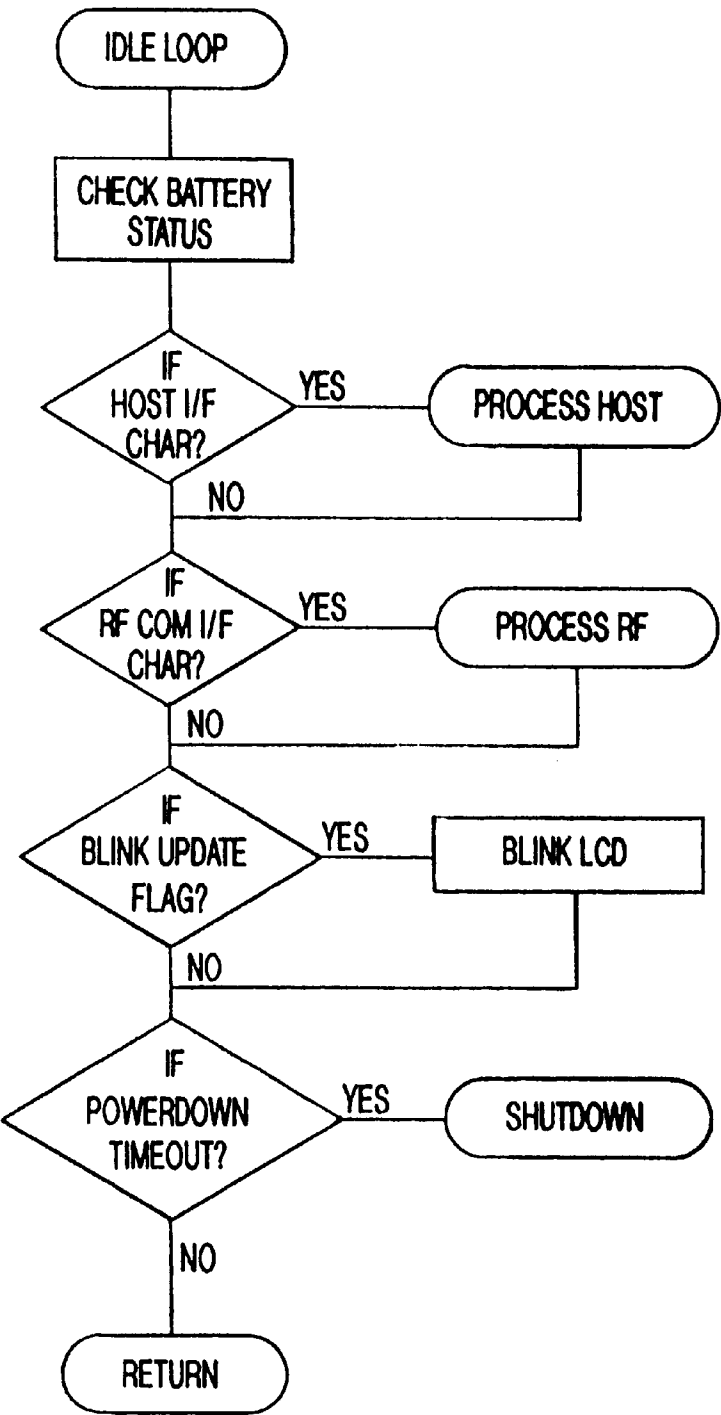
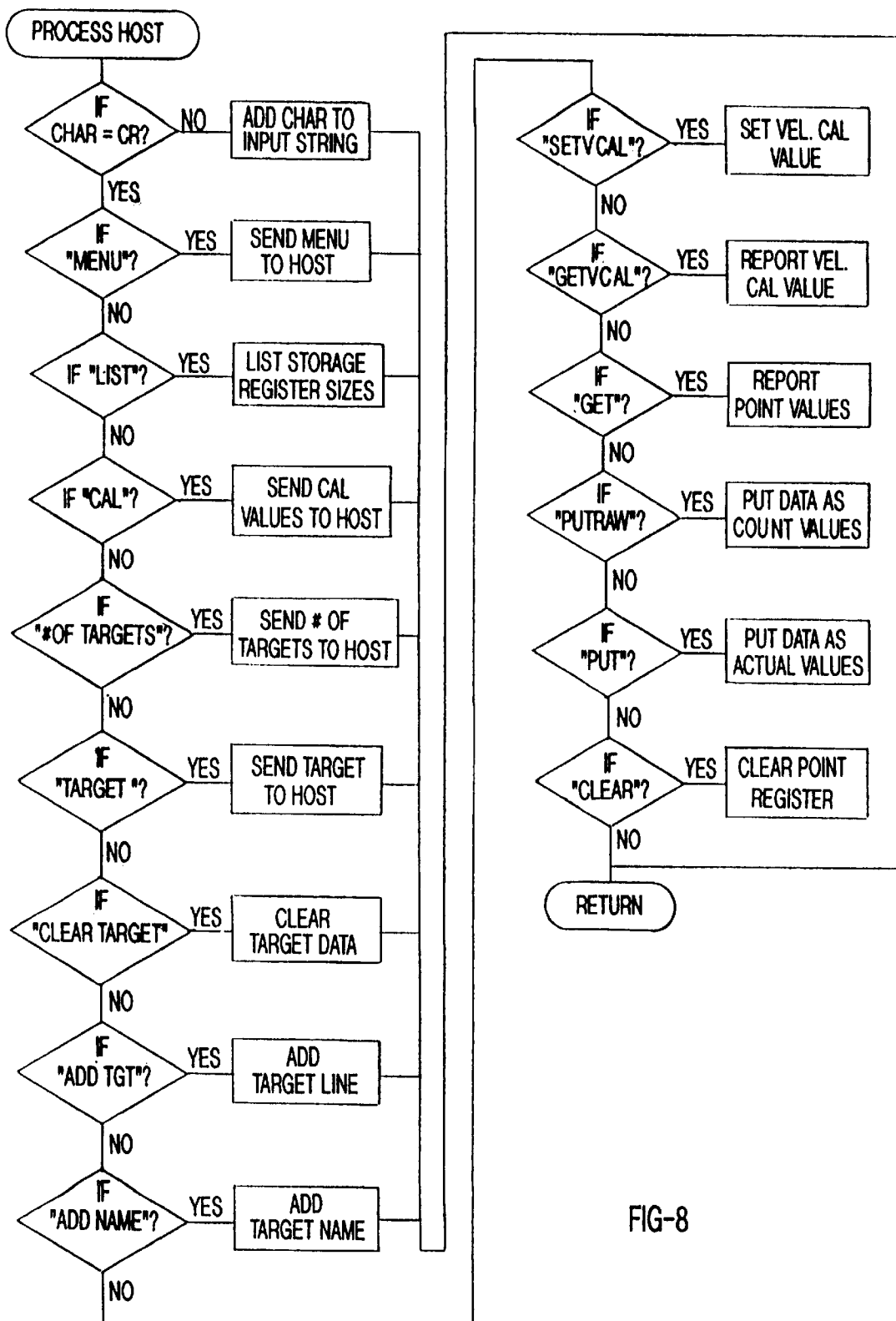


FIG-7



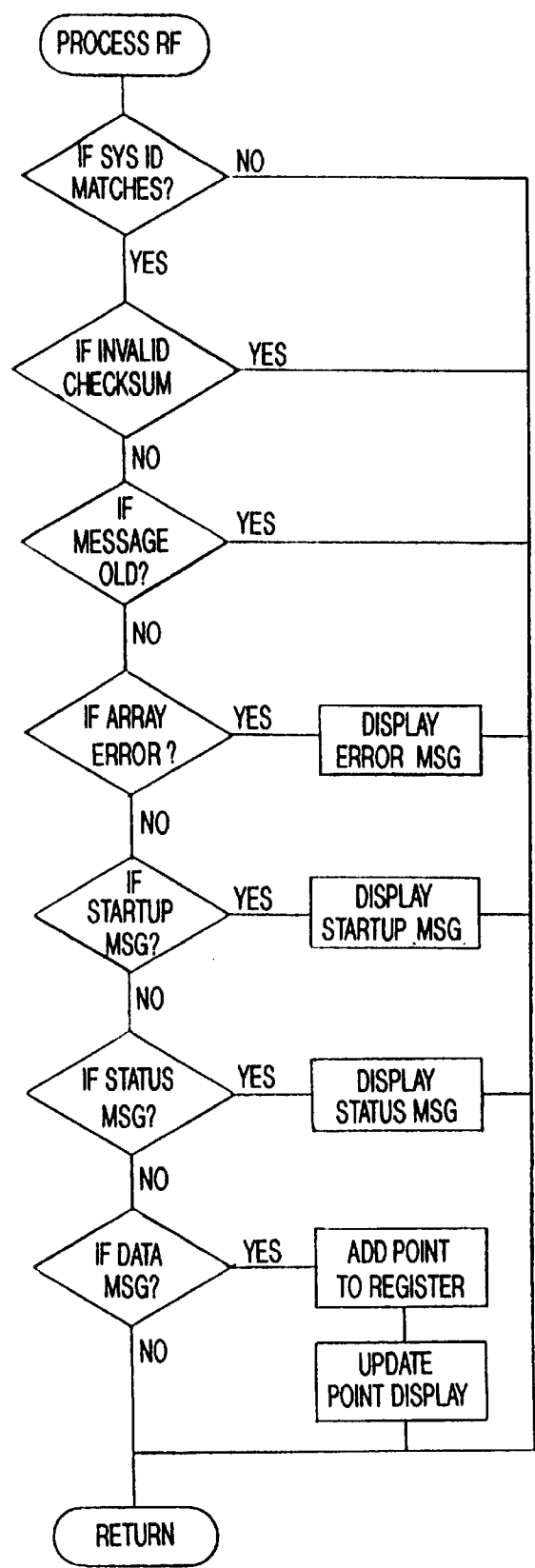


FIG-9

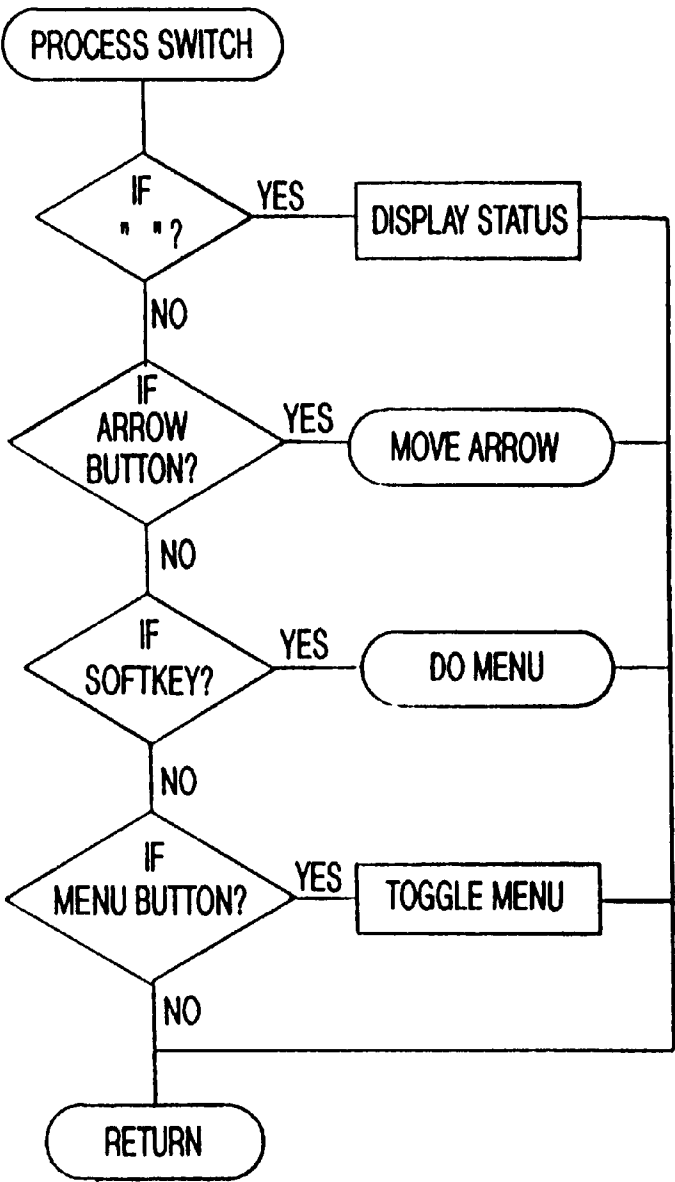


FIG-10

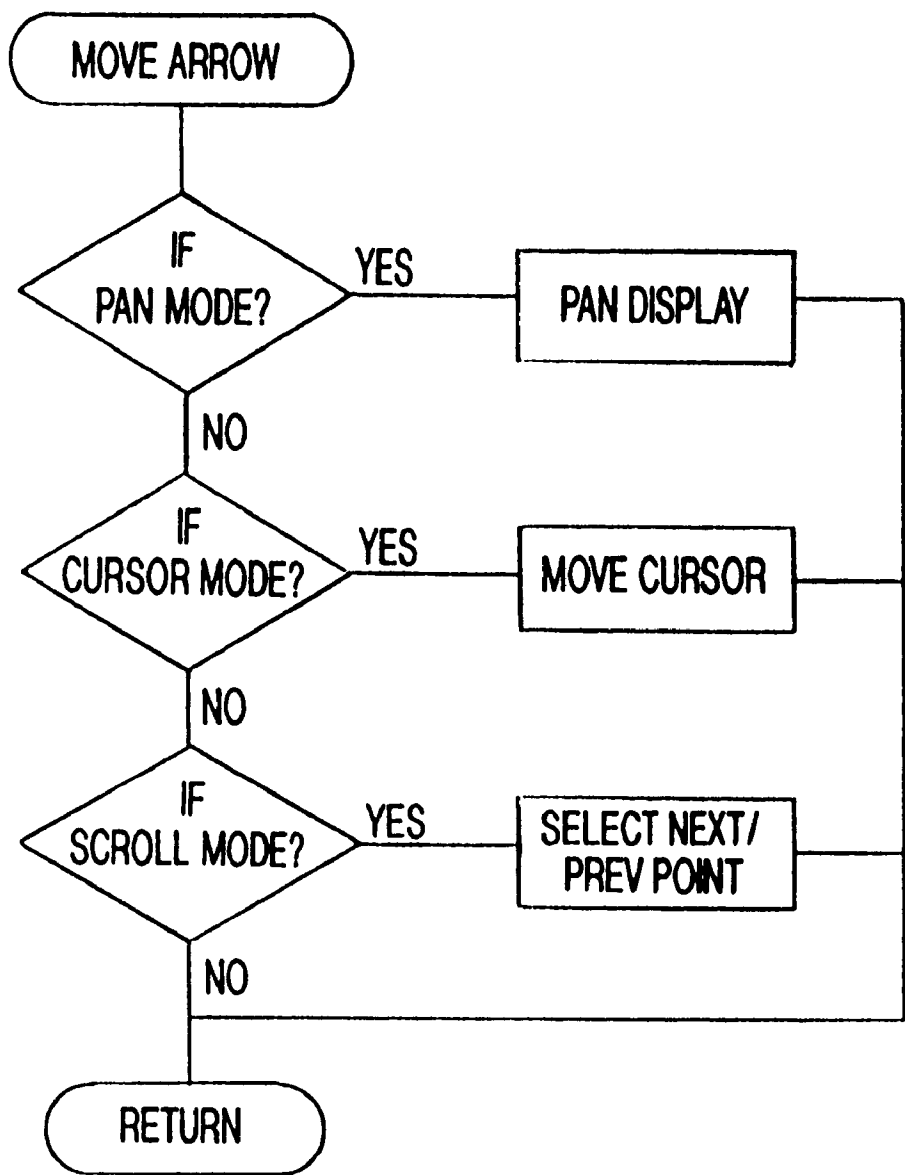


FIG-11

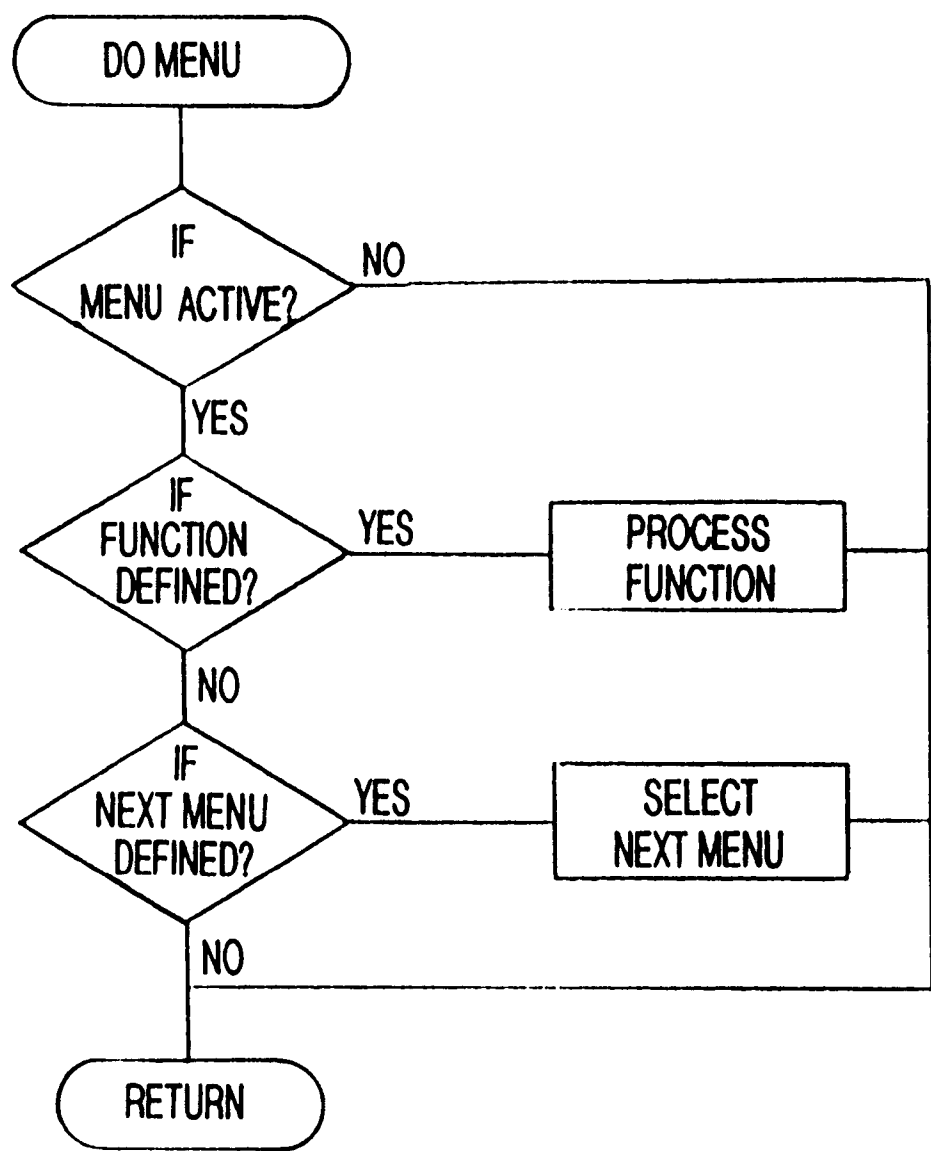


FIG-12(a)

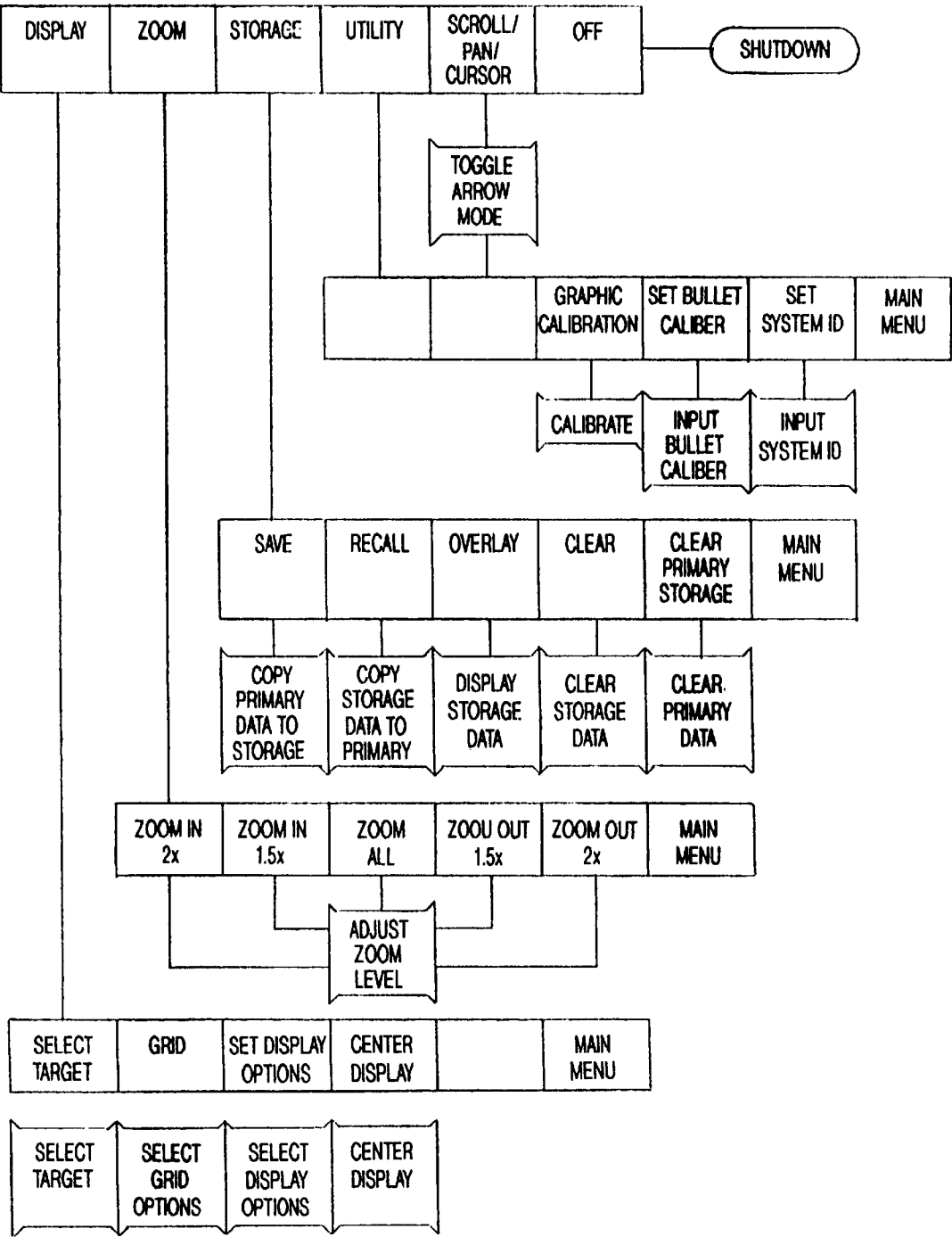
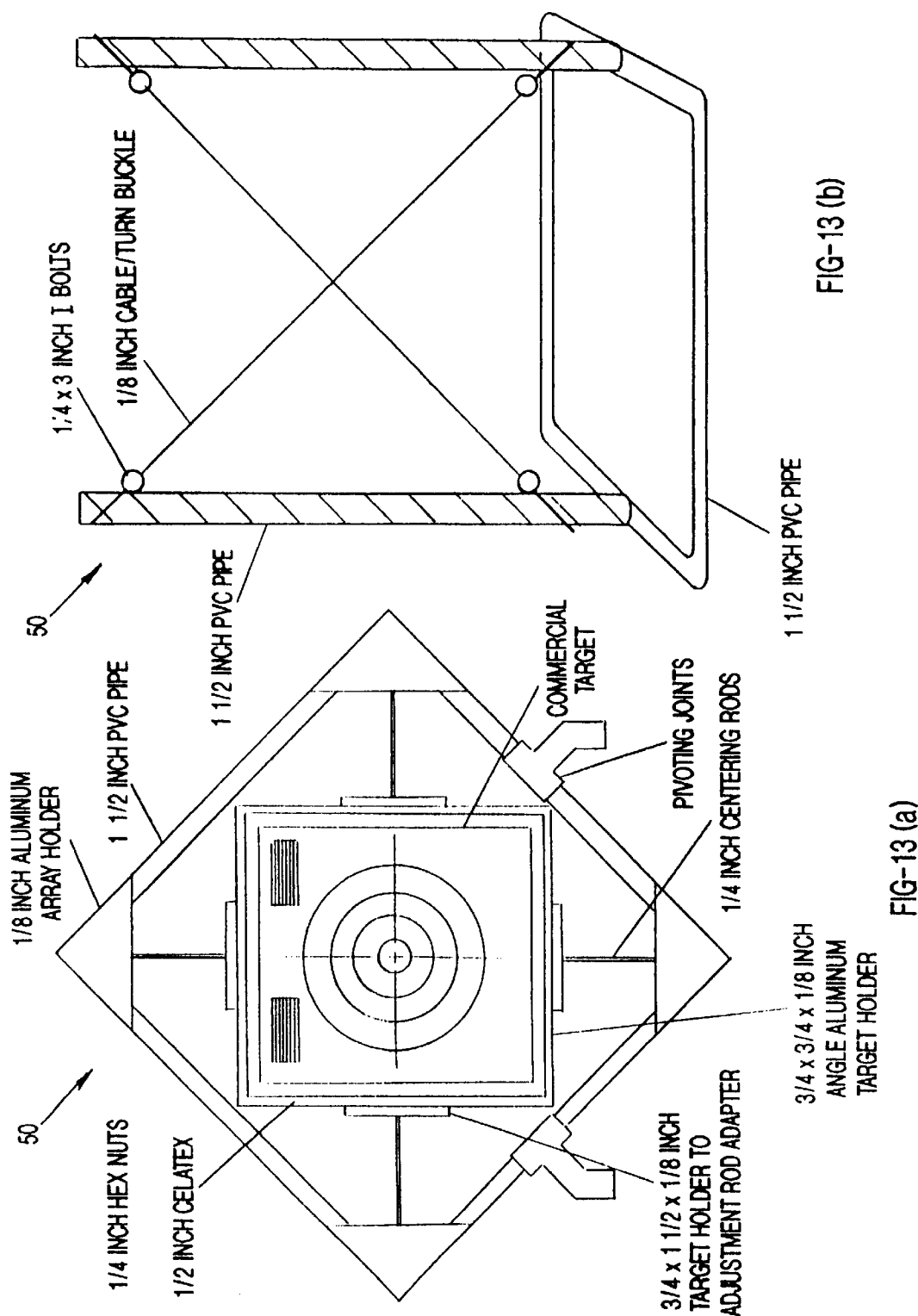


FIG-12 (b)



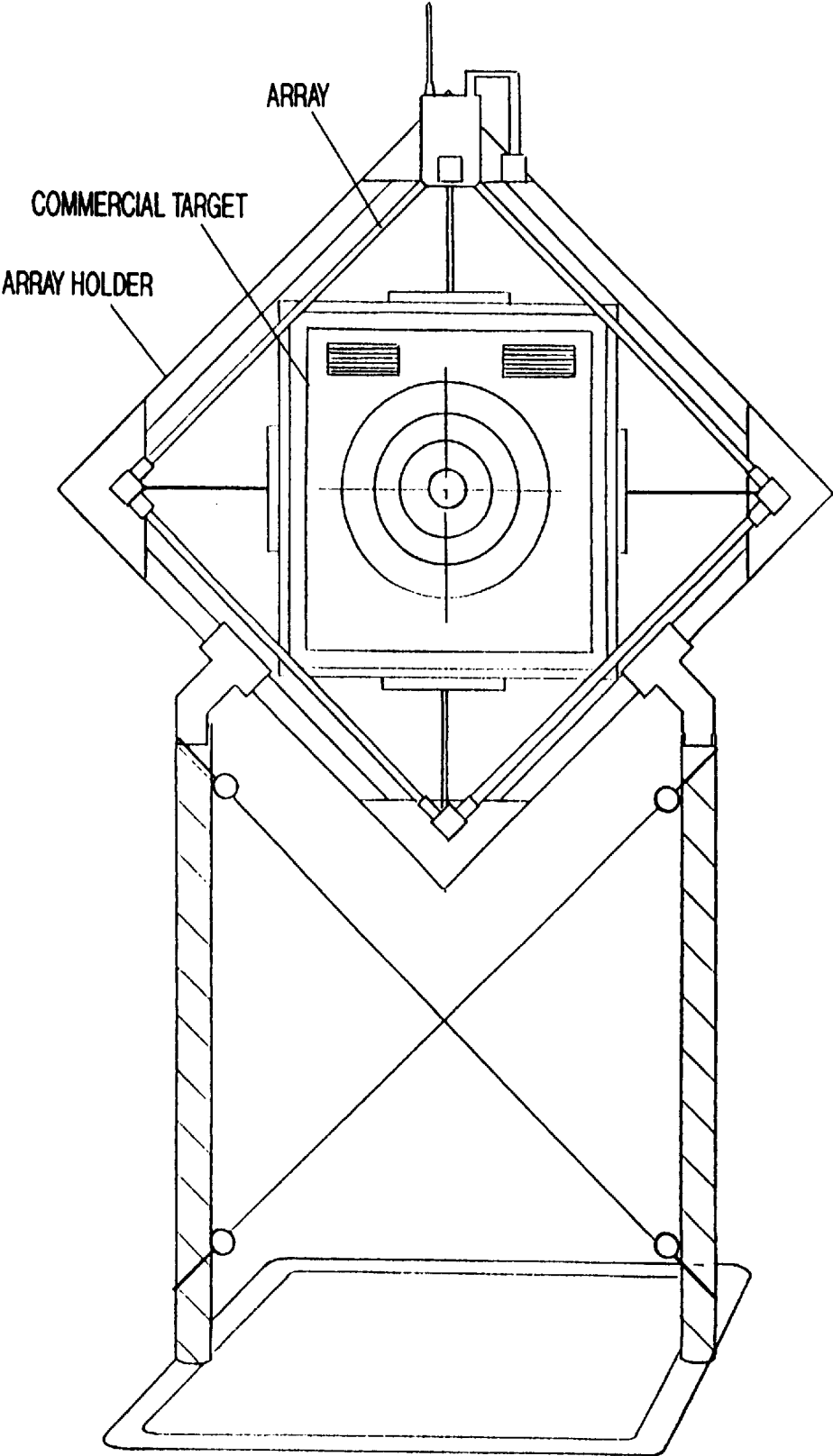
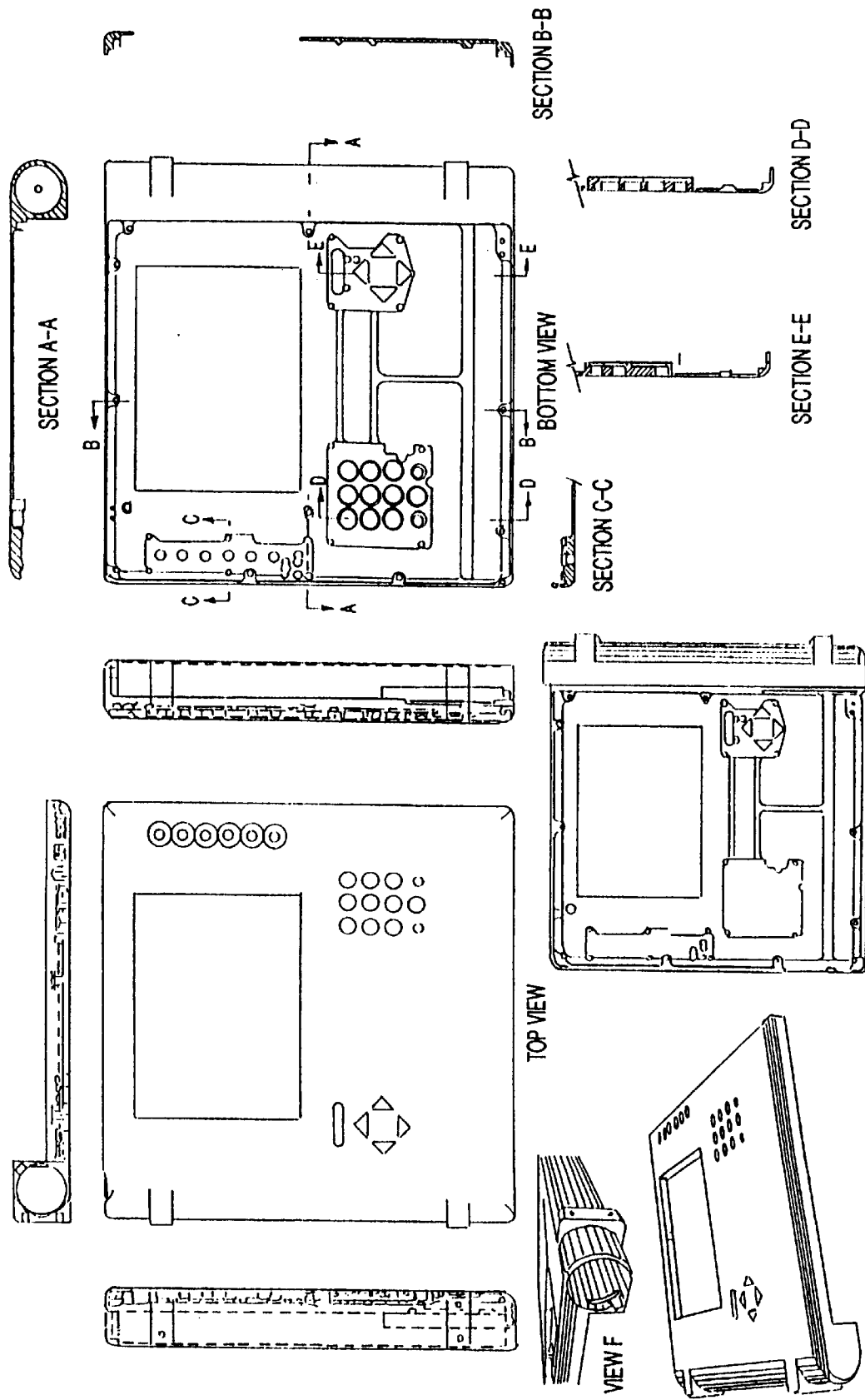


FIG-14



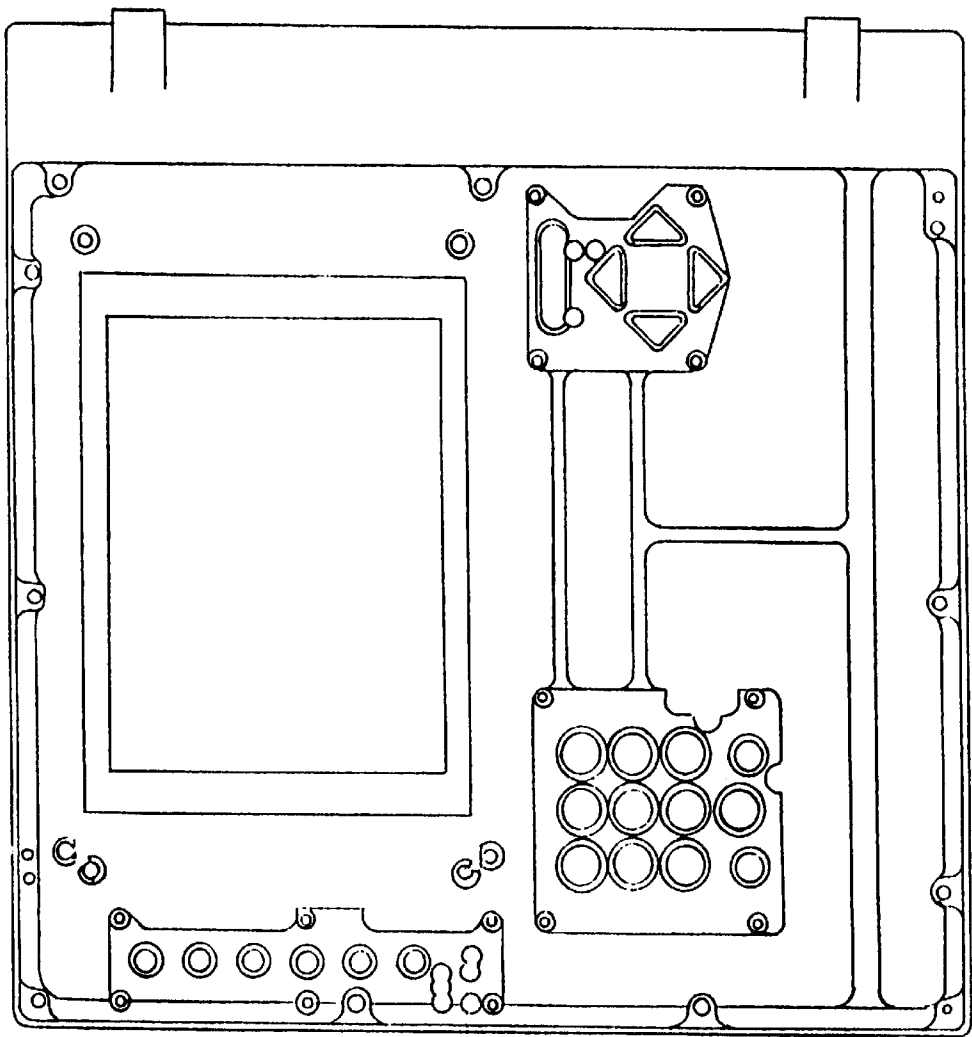
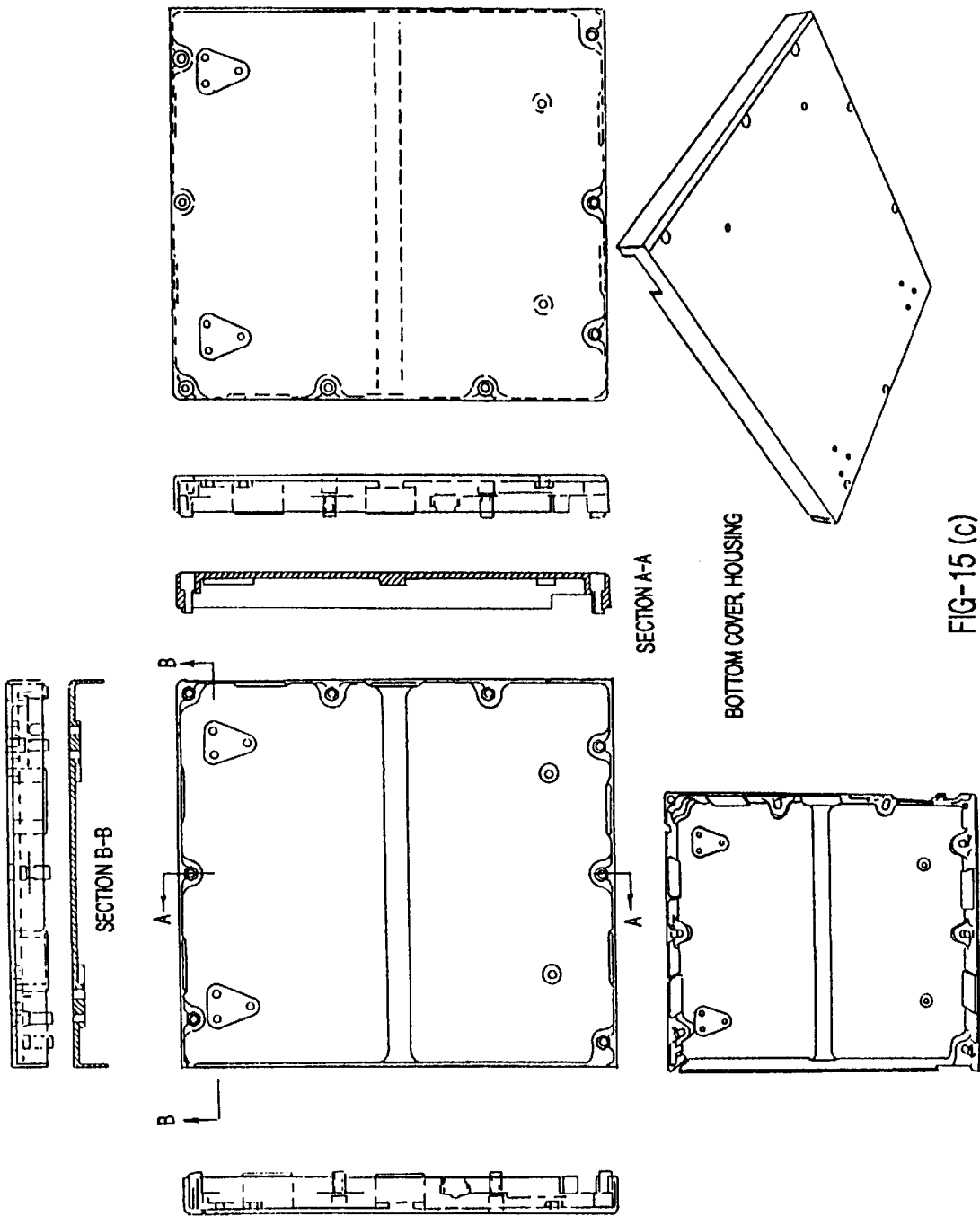
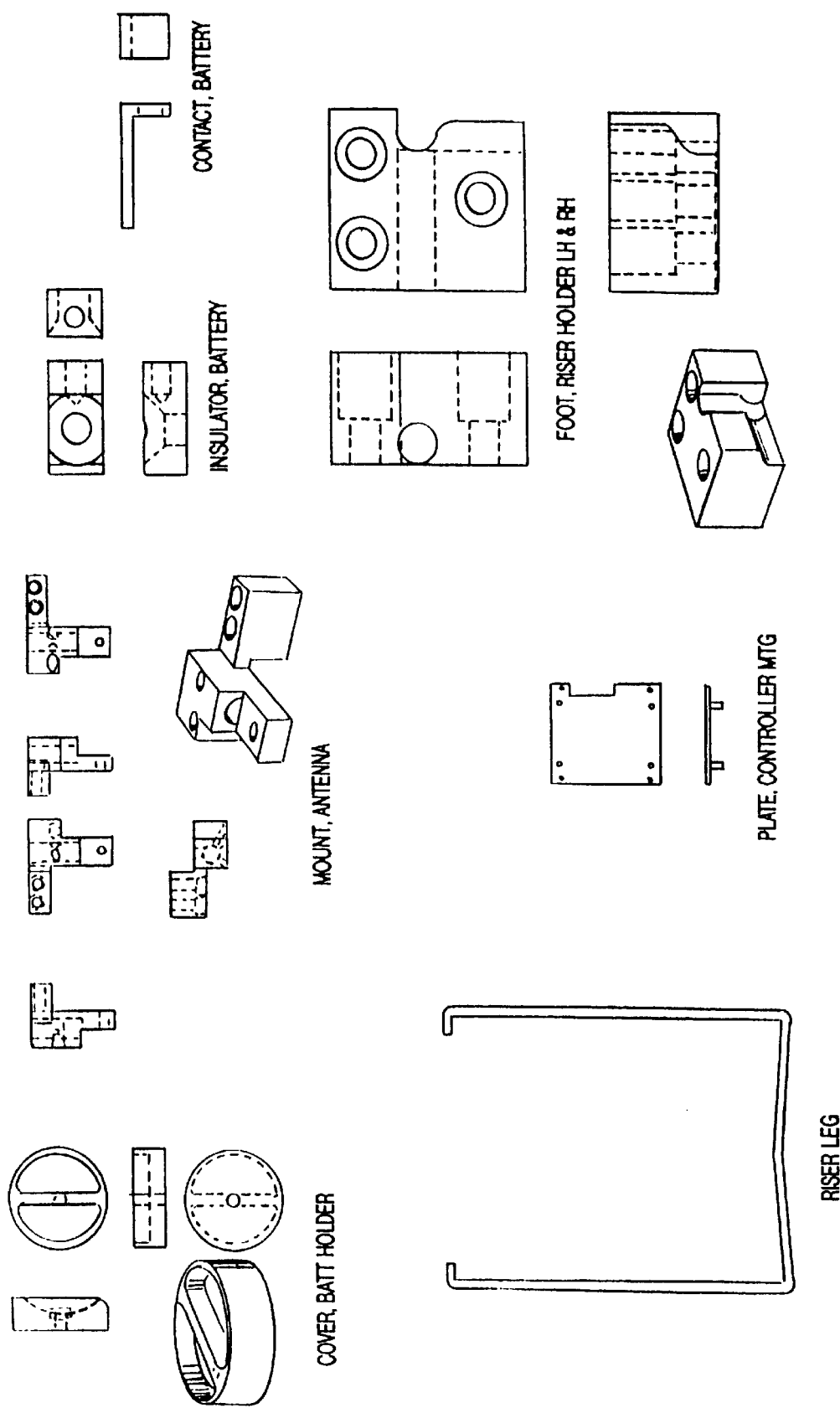
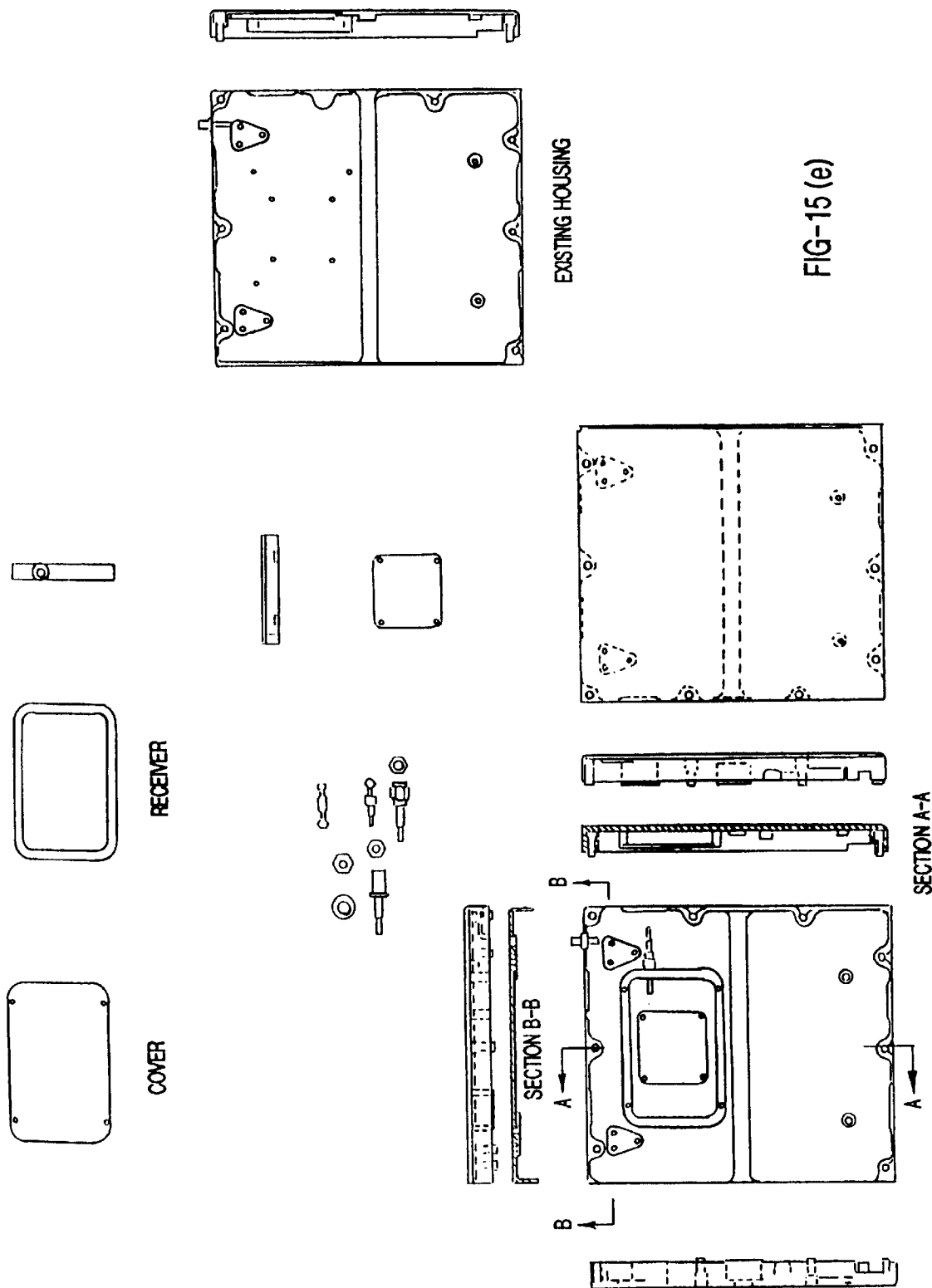


FIG-15 (b)







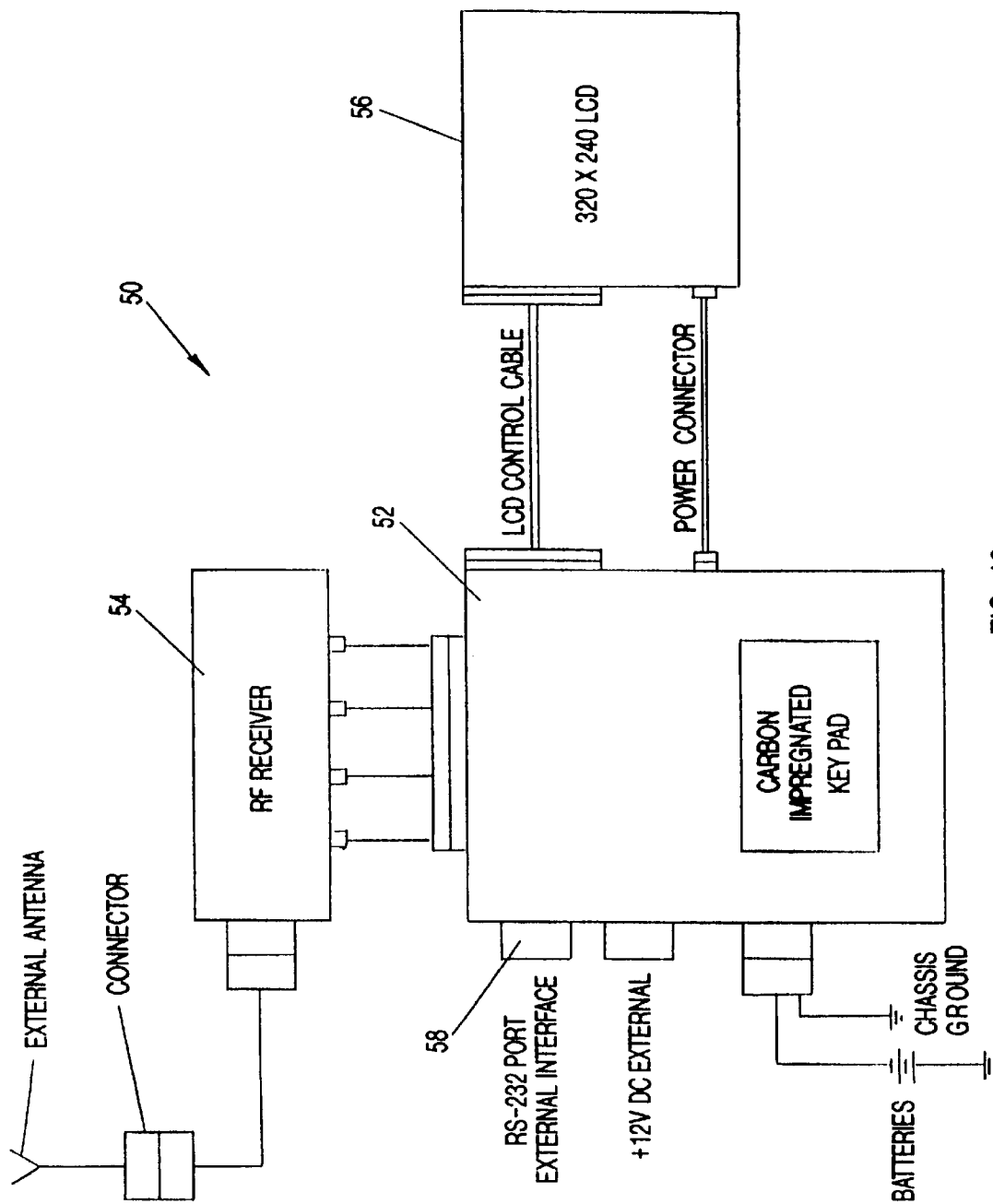


FIG-16

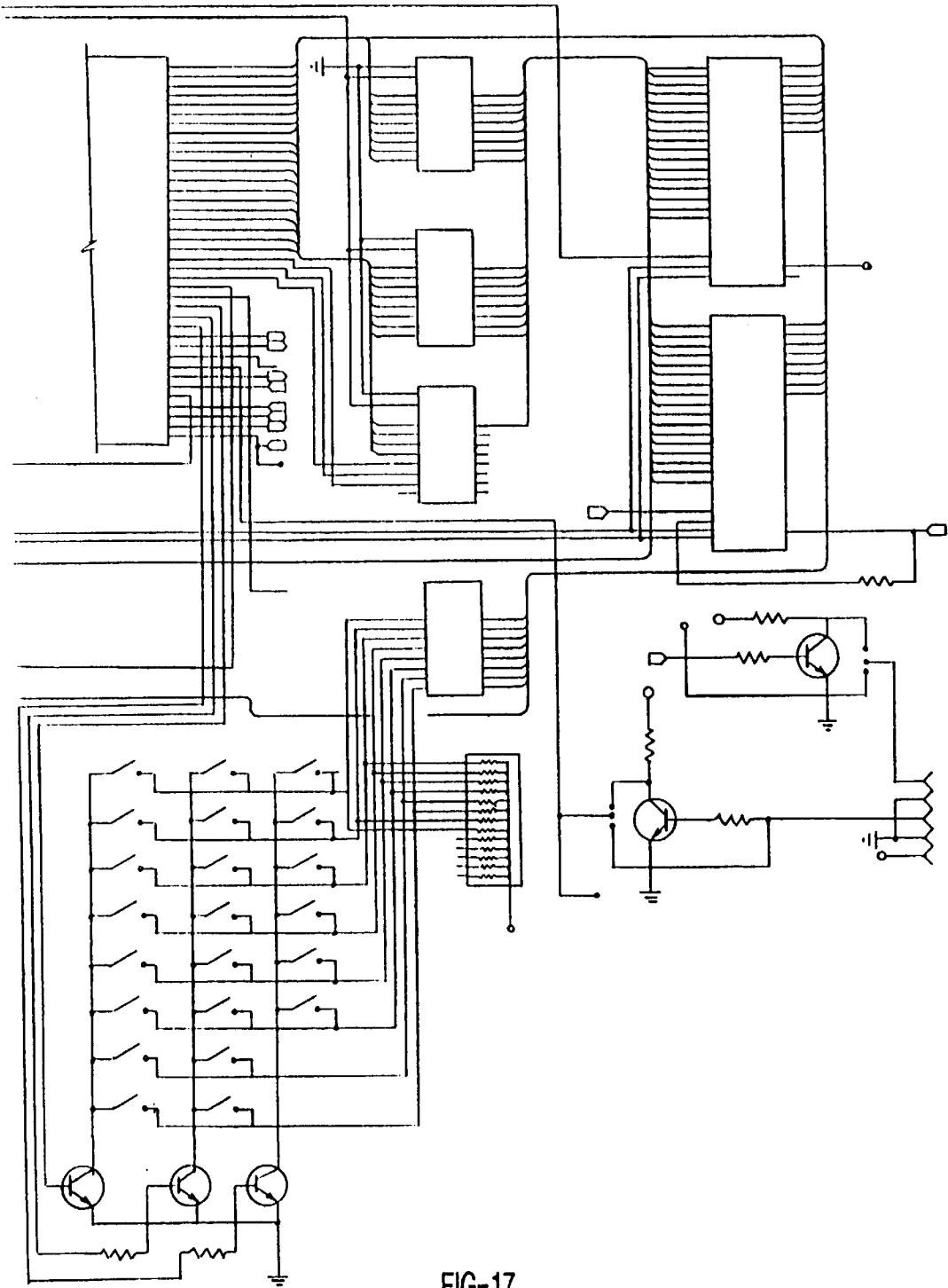


FIG-17
SHEET 2

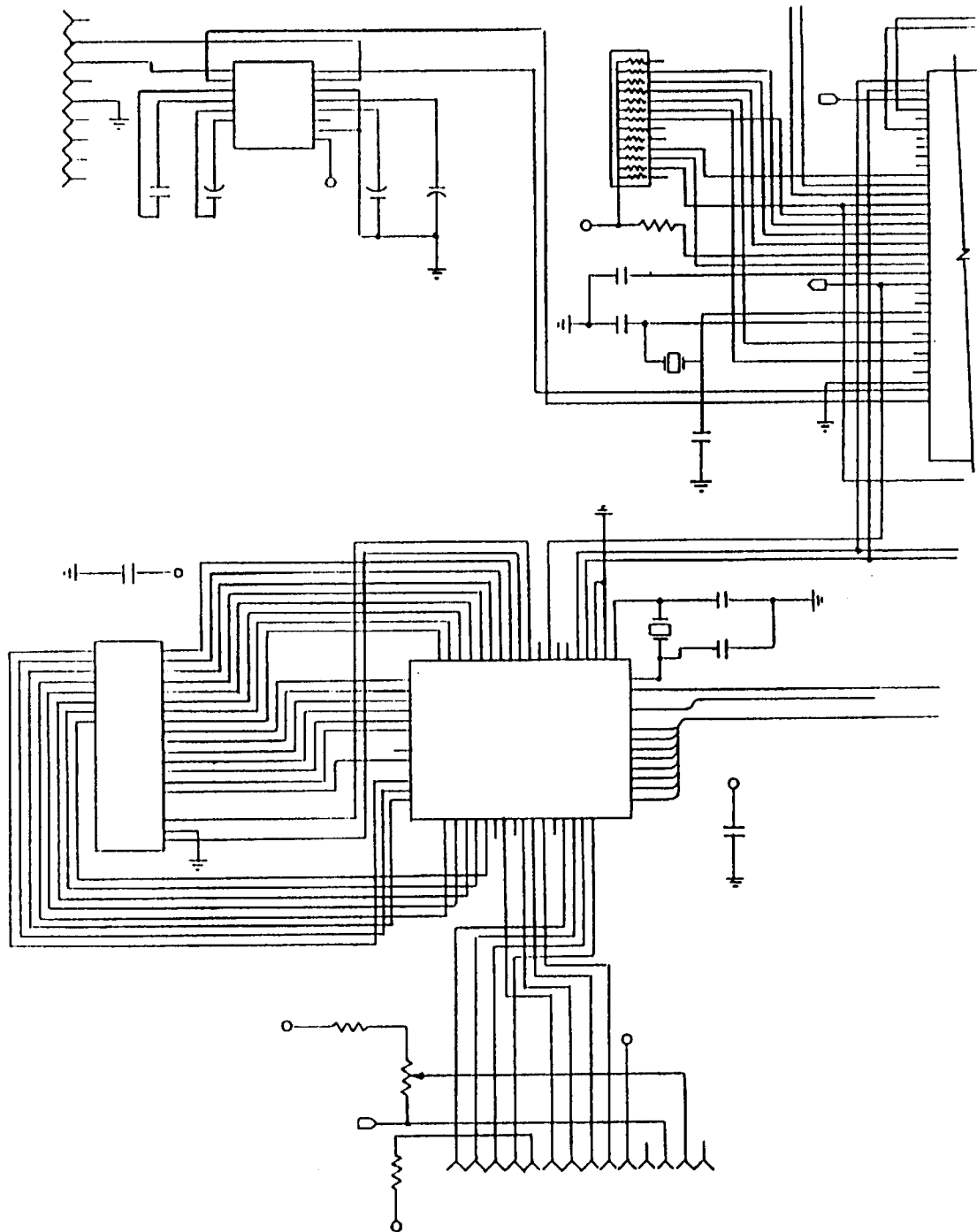


FIG-17 (a)
SHEET 1

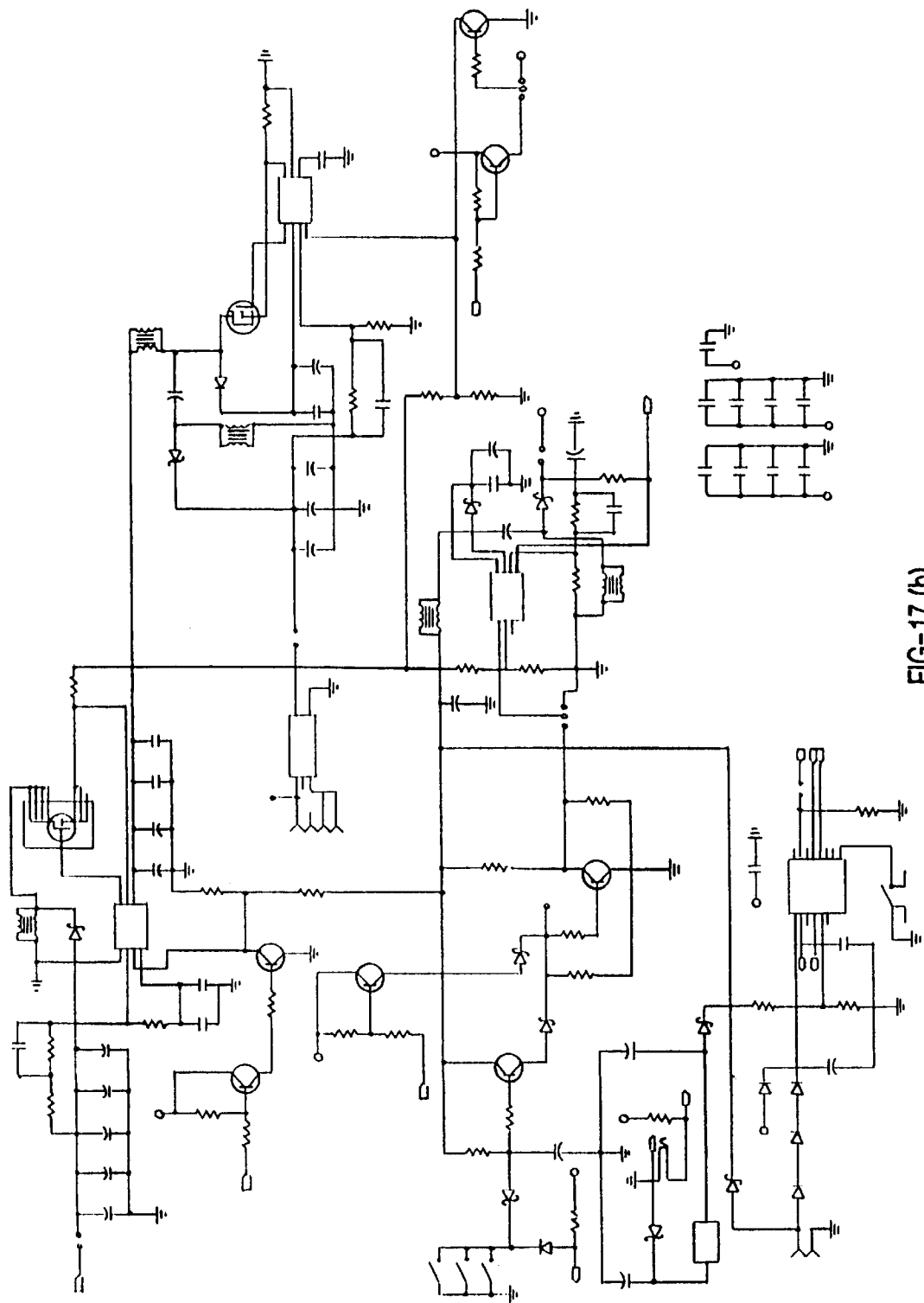


FIG-17 (b)

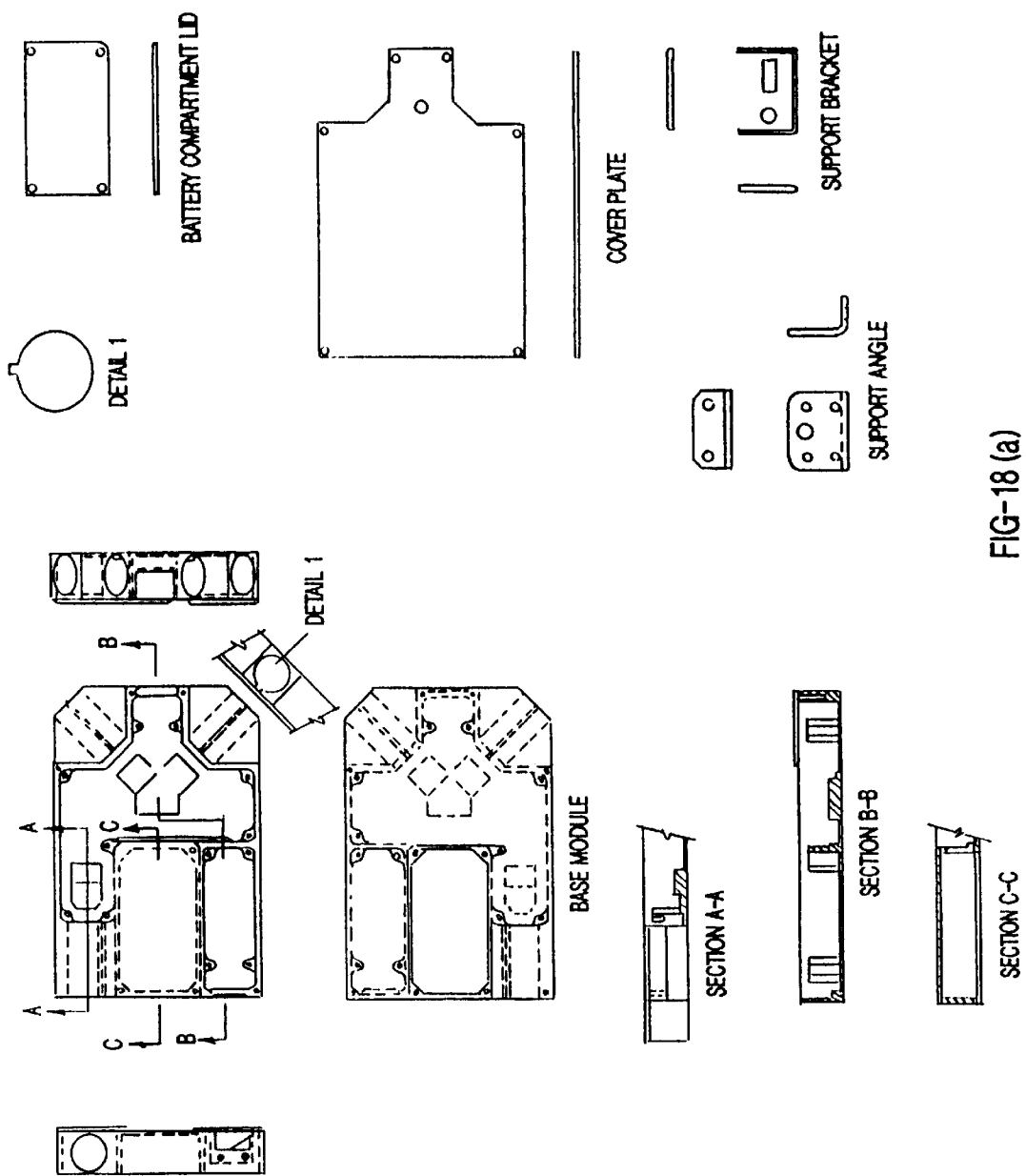
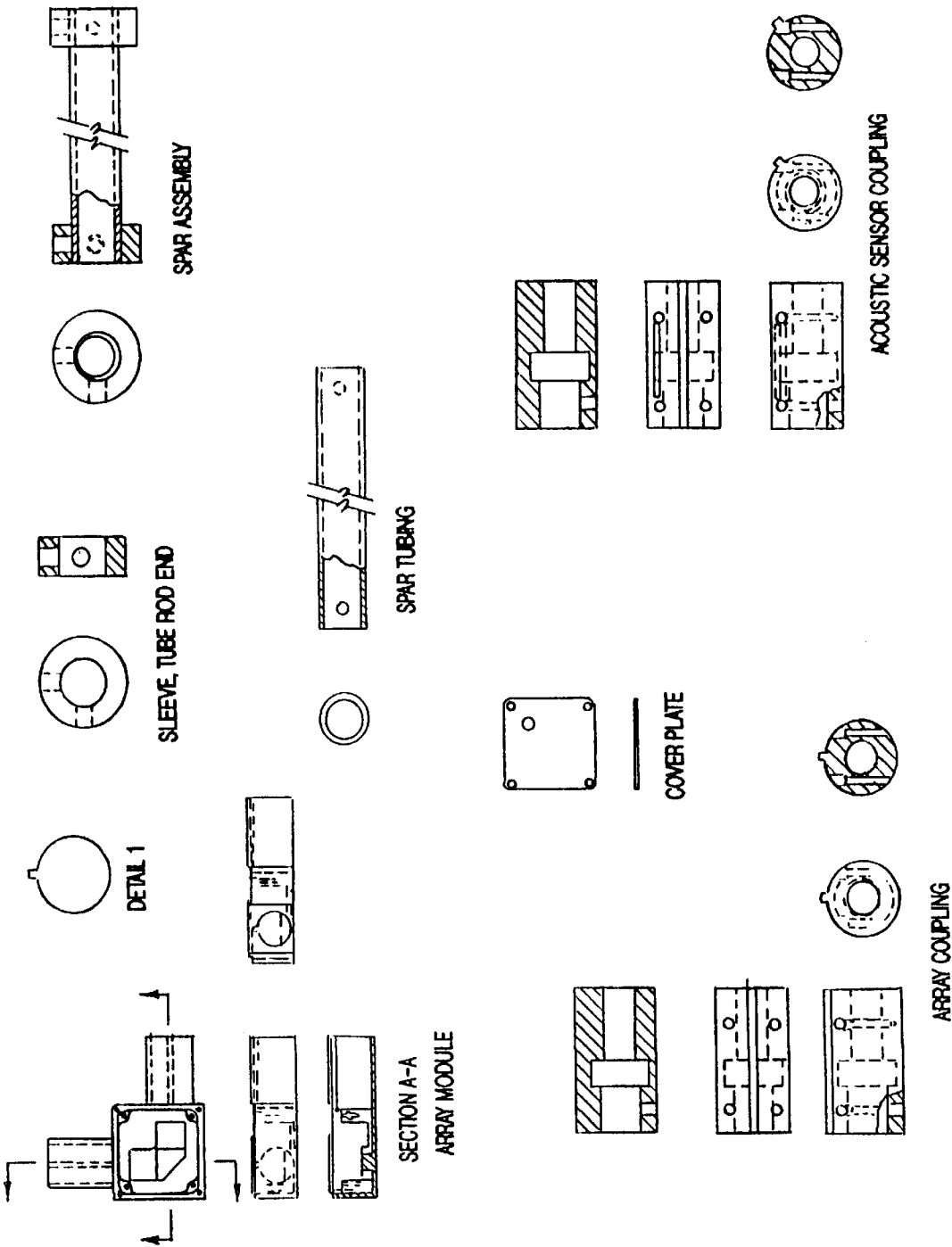


FIG-18 (a)



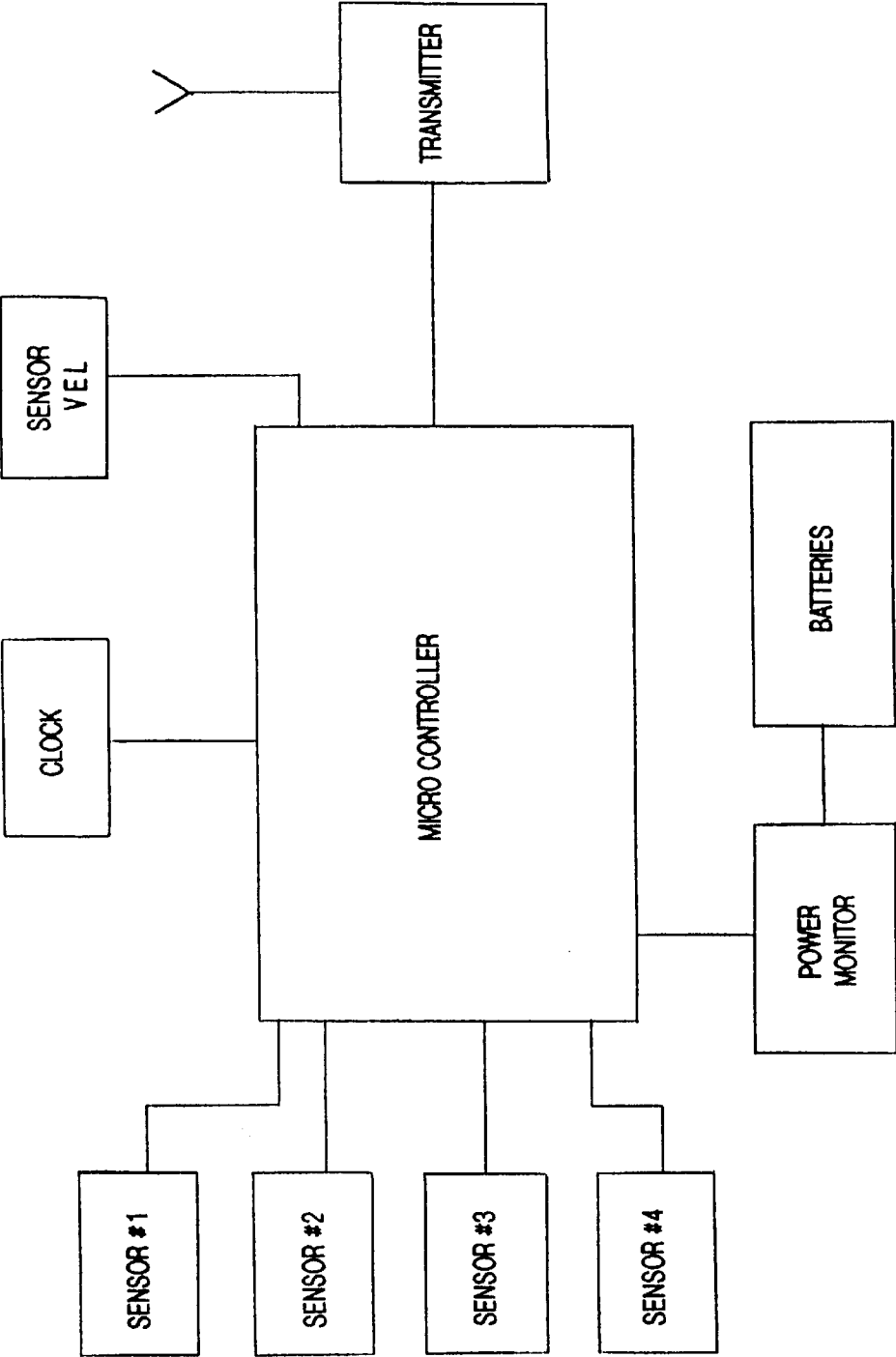


FIG-19

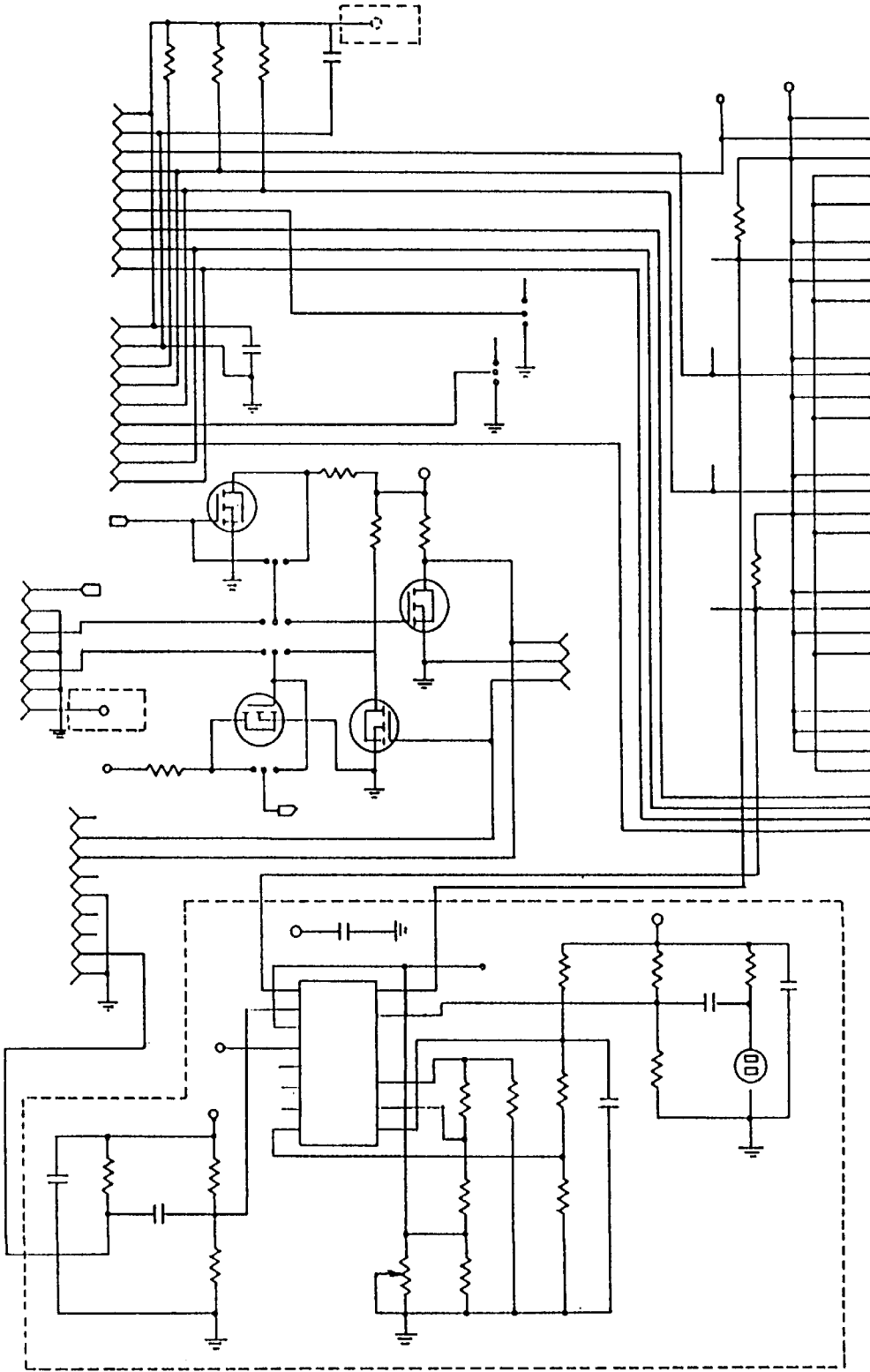


FIG-20
SHEET 1

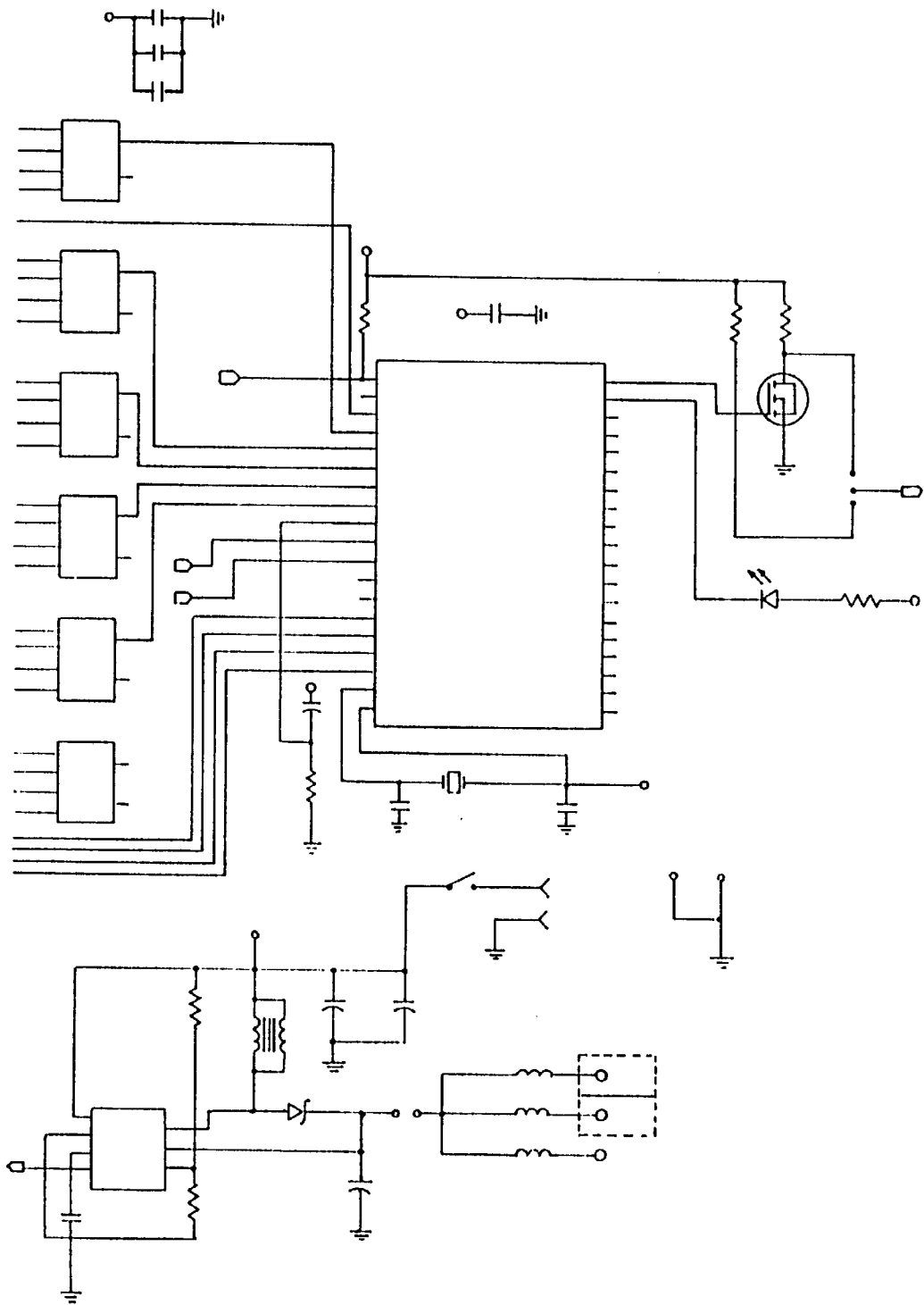


FIG-20
SHEET 2

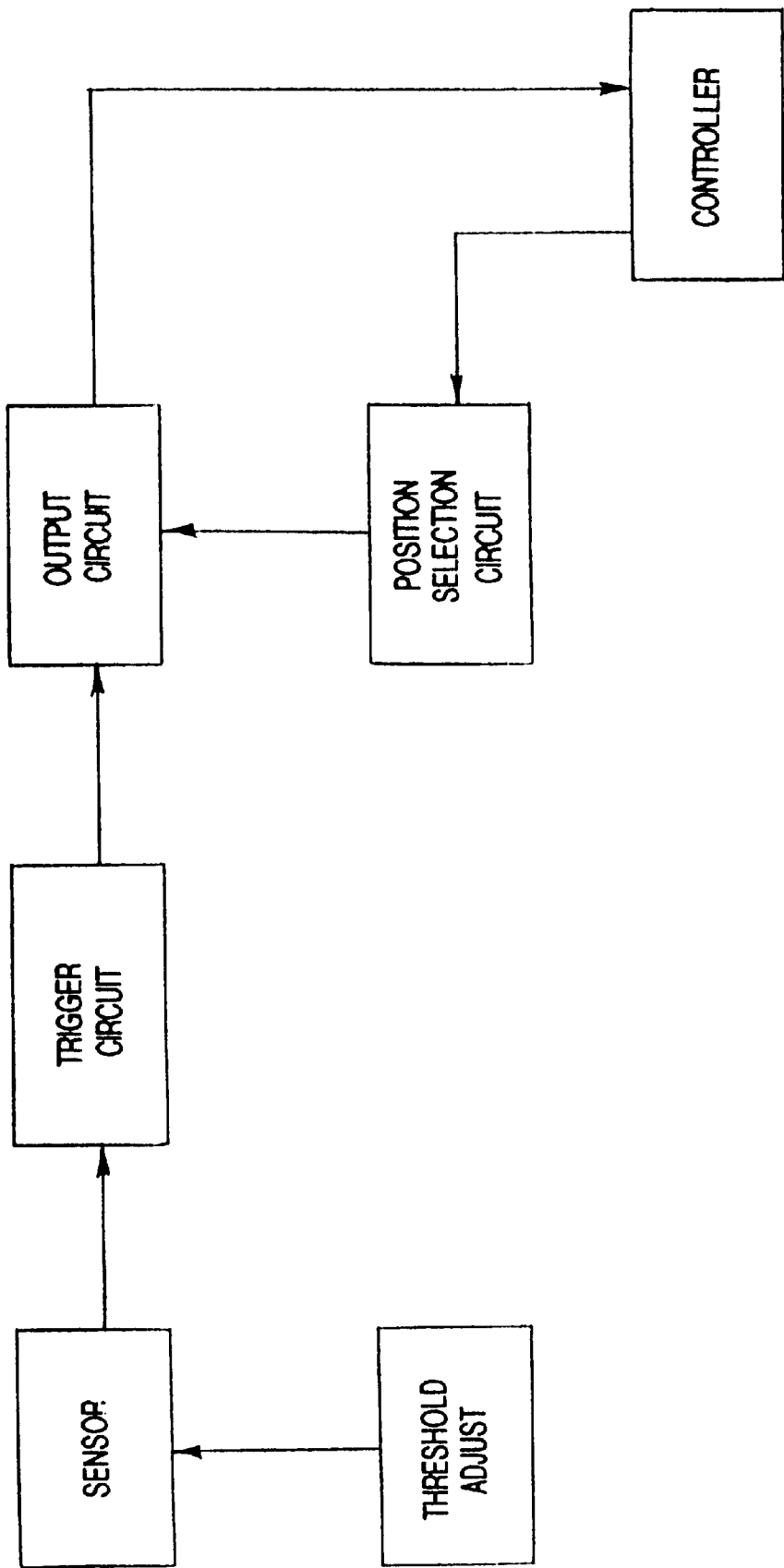


FIG-21

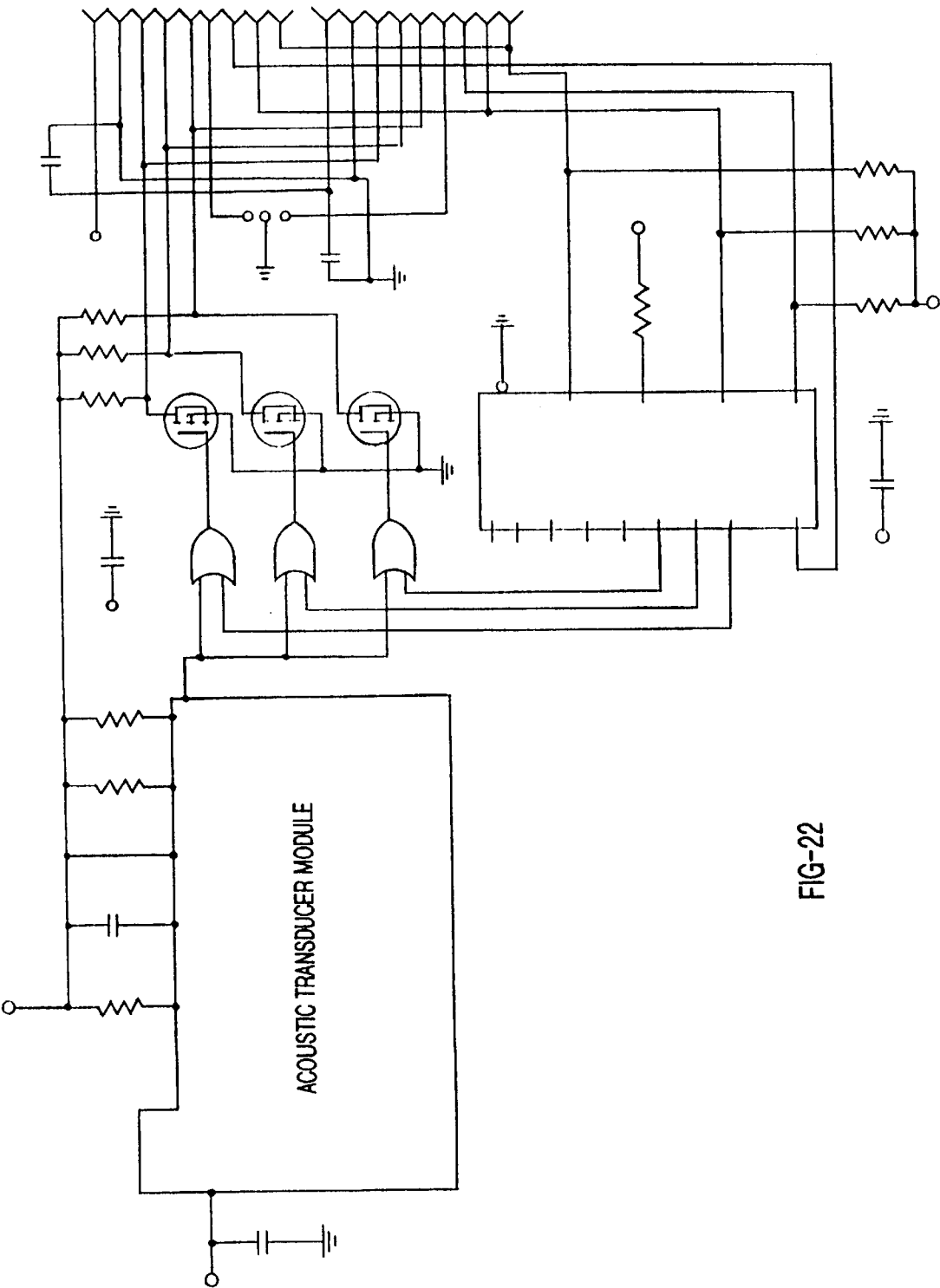
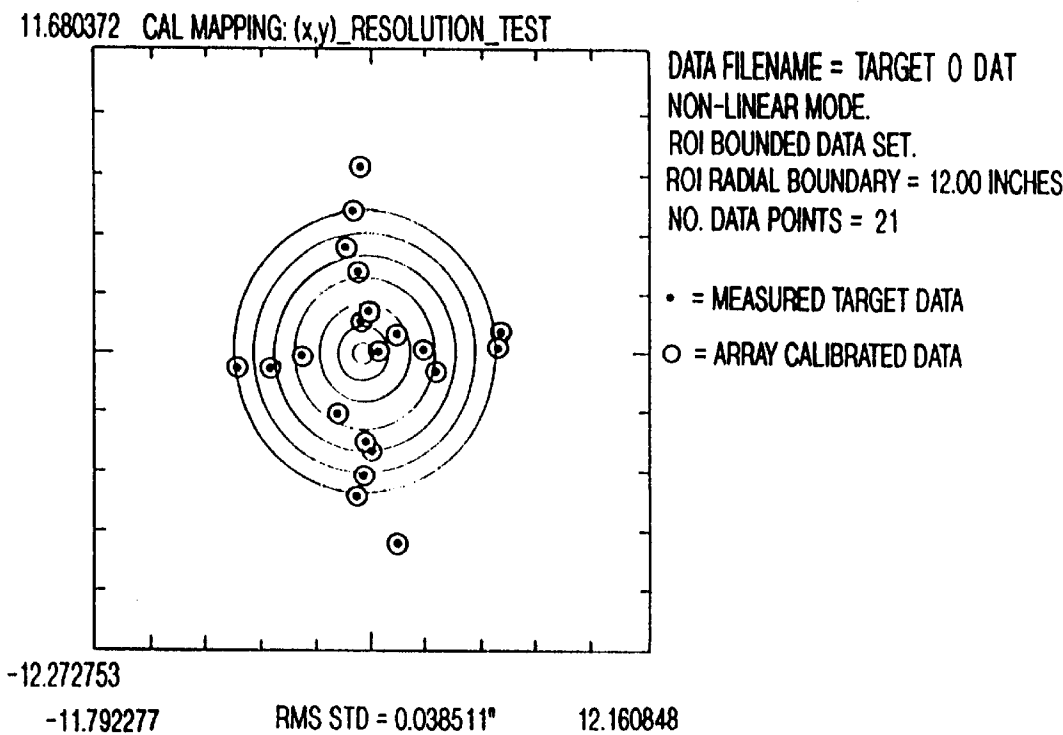


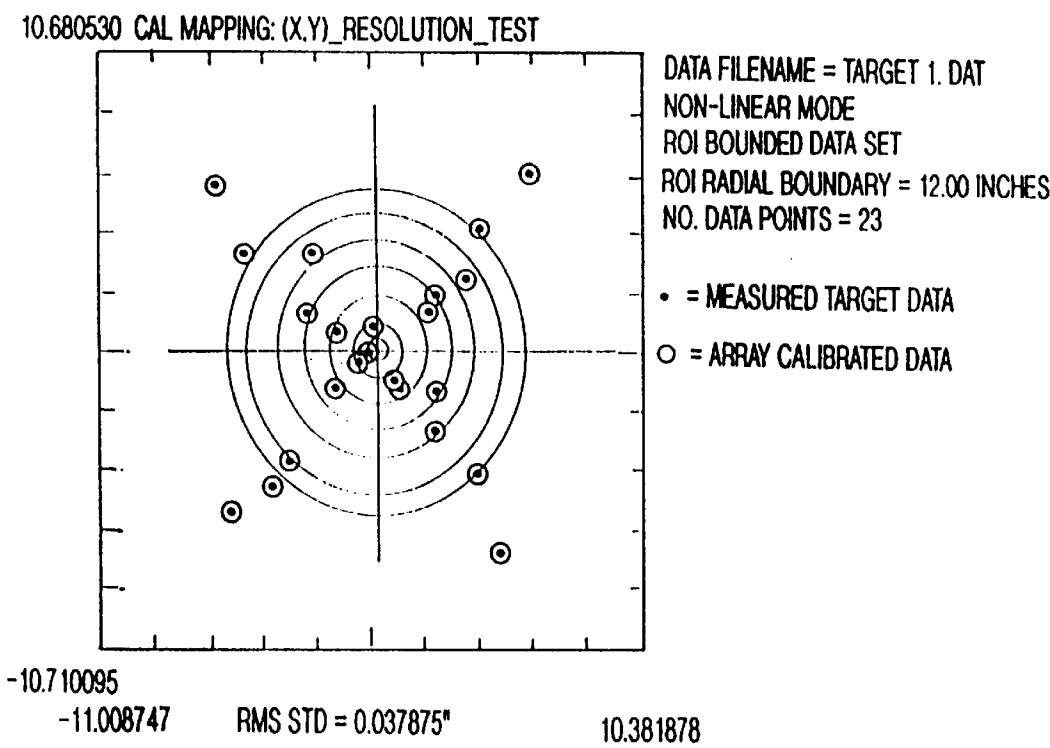
FIG-22



TARGET 0. DAT

ARRAY X	ARRAY Y	ARRAY V	X	Y	V
38	778	1457	.17	1.62	2920
497	420	1460	1.44	.70	2914
-498	-803	1470	-1.19	-2.58	2894
-1076	92	1439	-2.78	-.21	2957
-145	1390	1442	-.4	3.20	2950
916	168	1411	2.43	0.0	3015
-37	-1211	1442	-.08	-3.66	2950
-1587	-86	1439	-4.16	-.66	2957
-345	1760	1420	-.90	4.31	2996
1113	-166	1437	2.95	-.82	2961
32	1347	1427	.13	-4.0	2982
-2107	-79	1419	-5.59	-.71	2998
-226	2321	1420	-.65	5.75	2996
2142	187	1417	5.75	.09	3003
-82	1738	1416	-.17	-5.06	3005
-101	2952	1391	-.27	7.48	3059
2193	440	1430	5.90	.84	2975
-187	-2076	1425	-.39	-5.91	2986
465	-2798	1438	1.51	-7.85	2959
-114	629	1401	-.30	1.29	3037
181	152	1403	.47	-.04	3033

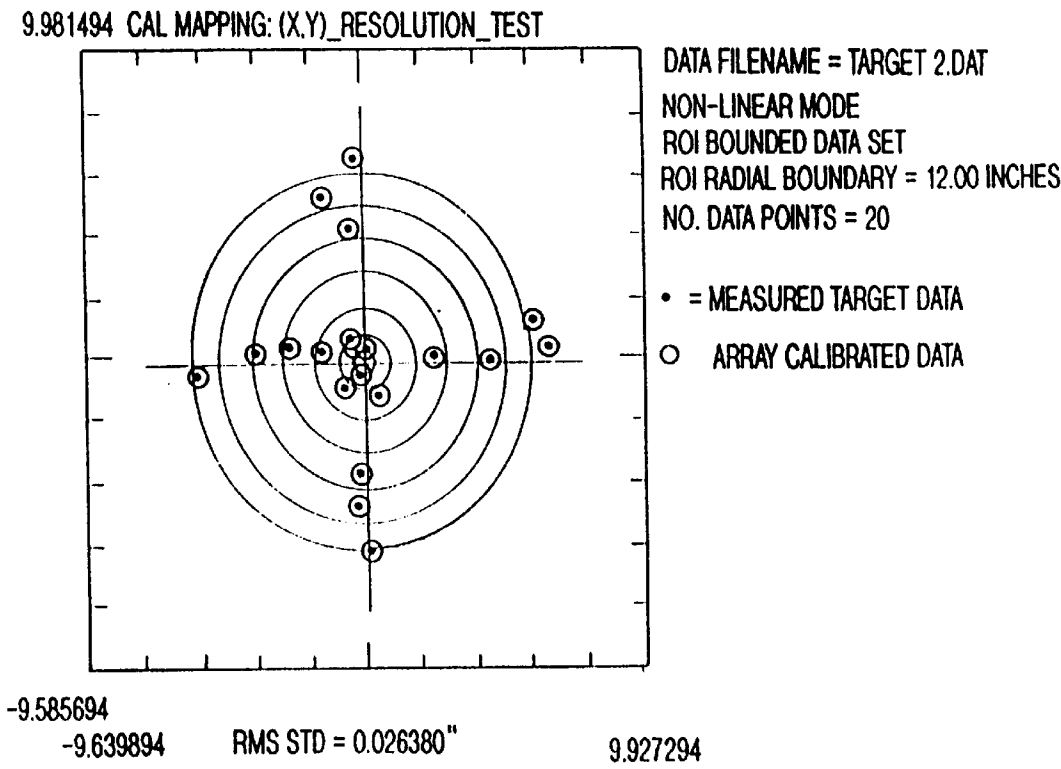
FIG-23



TARGET 1. DAT

ARRAY X	ARRAY Y	ARRAY V	X	Y	V
-337.000	31.000	1384.000	-0.970	-0.380	3074.000
-666.000	423.000	1409.000	-1.880	0.710	3020.000
-1101.000	697.000	1404.000	-3.010	1.440	3030.000
-997.000	1505.000	1416.000	-2.740	3.620	3005.000
-1961.000	1500.000	1406.000	-5.360	3.720	3026.000
-2332.999	2351.000	1394.000	-6.600	6.180	3052.000
167.000	-209.000	1374.000	0.430	-1.020	3097.000
232.000	-311.000	1400.000	0.591	-1.270	3059.000
777.000	-362.000	1402.000	2.060	-1.420	3035.000
753.000	-892.000	1395.000	1.980	-2.790	3050.000
1331.000	-1452.000	1405.000	3.610	-4.360	3020.000
1649.000	-2453.000	1410.000	4.670	-7.170	3017.000
-197.000	163.000	1382.000	-0.510	0.000	3079.000
686.000	727.000	1381.000	1.850	1.480	3081.000
776.000	953.000	1379.000	2.100	2.100	3085.000
1209.000	1155.000	1400.000	3.250	2.670	3059.000
1408.000	1819.000	1388.000	3.810	4.490	3065.000
2091.000	2489.000	1401.000	5.820	6.520	3037.000
-128.000	525.000	1395.000	-0.380	1.010	3050.000
-692.000	-318.000	1421.000	-1.860	-1.270	2994.000
-1360.000	-1280.000	1404.000	-3.710	-3.930	3030.000
-1607.000	-1599.000	1415.000	-4.400	-4.820	3007.000
-2162.000	-1922.000	1390.000	-5.960	-5.850	3048.000

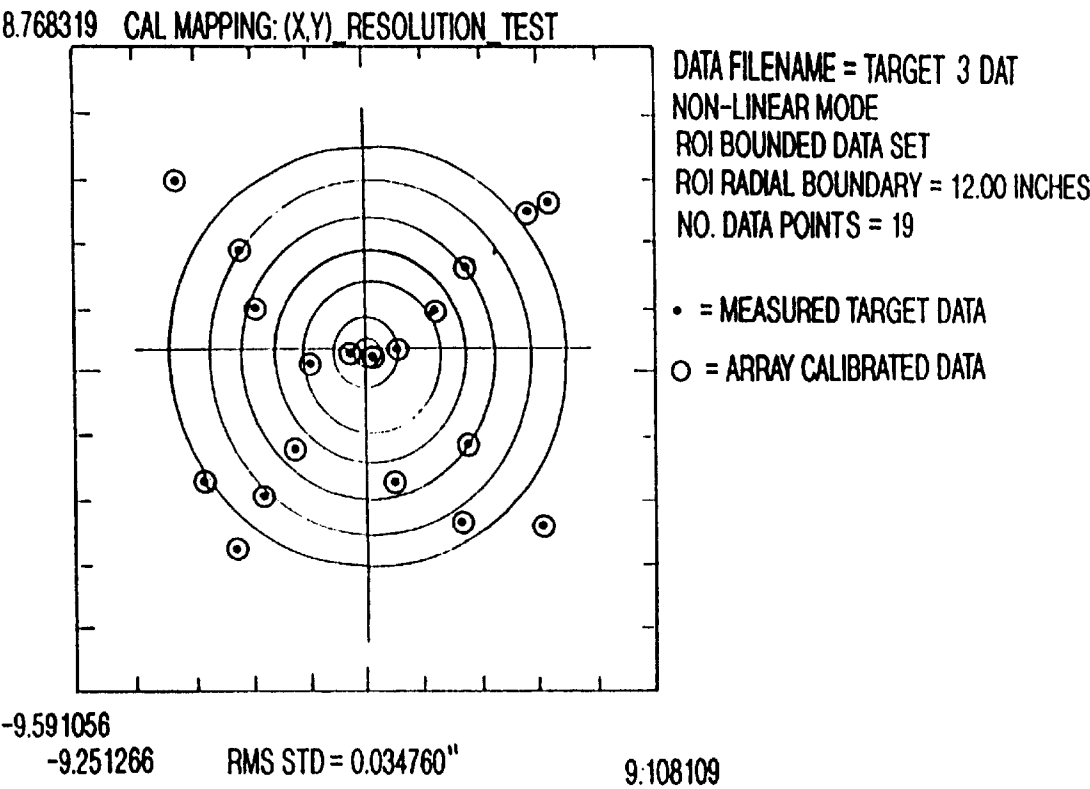
FIG-24



TARGET 2. DAT

ARRAY X	ARRAY Y	ARRAY V	X	Y	V
-62.000	-14.000	1401.000	-0.164	-0.450	3037.000
-179.000	443.000	1404.000	-0.489	0.770	3030.000
-175.000	1749.000	1389.000	-0.450	4.260	3063.000
-513.000	2123.000	1378.000	-1.388	5.280	3088.000
-103.000	2585.000	1415.000	-0.280	6.523	3007.000
-133.000	372.000	1399.000	-0.310	0.584	3041.000
167.000	-259.000	1392.000	0.540	-1.139	3056.000
-80.000	-1153.000	1431.000	-0.099	-3.489	2973.000
-113.000	-1543.000	1437.000	-0.204	-4.554	2961.000
45.000	-2093.000	1369.000	0.200	-6.000	3108.000
-267.000	-164.000	1397.000	-0.622	-0.853	3046.000
903.000	229.000	1389.000	2.471	0.140	3063.000
1654.000	180.000	1398.000	4.480	0.076	3043.000
2247.000	653.000	1409.000	6.051	1.382	3020.000
2442.000	327.000	1400.000	6.510	0.473	3059.000
31.000	326.000	1424.000	0.102	0.439	2988.000
-537.000	278.000	-1421.000	-1.394	0.330	2994.000
-937.000	326.000	1403.000	-2.620	0.416	3033.000
-1388.000	248.000	1421.000	-3.710	0.215	2994.000
-2198.000	-23.000	1421.000	-5.750	-0.445	2994.000

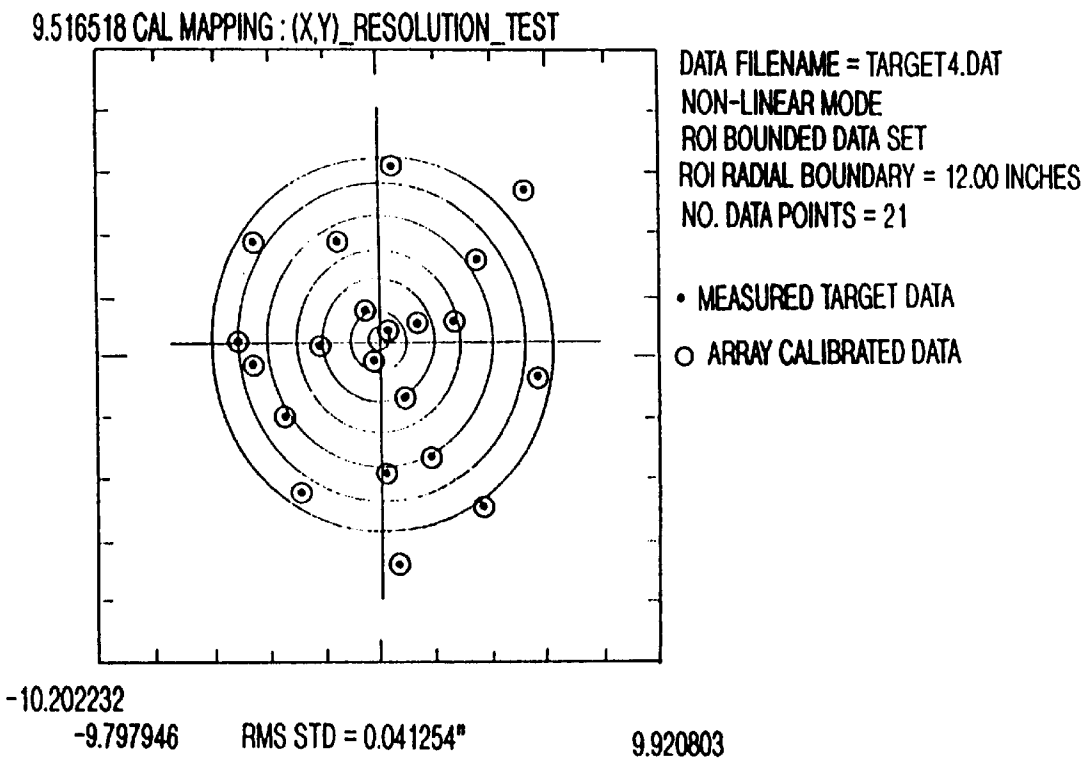
FIG-25



TARGET 3. DAT

ARRAY X	ARRAY Y	ARRAY V	X	Y	V
-693	108	1401	-1.8	-1.56	3037
-1315	691	1405	-3.50	1.44	3028
-1490	1297	1415	-4.04	3.07	3007
-2191	1979	1400	-6.01	5.06	3039
329	257	1414	.93	.23	3009
289	-1107	1410	.86	-3.39	3017
1155	-716	1429	3.14	-2.38	2988
1078	-1526	1404	3.01	-4.55	3030
2007	-1557	1417	5.55	-4.79	3003
-227	208	1396	-.62	.16	3048
778	673	1390	2.11	1.37	3016
1141	1127	1402	3.07	2.62	3035
1849	1690	1308	5.02	4.23	3065
2090	1782	1397	5.74	4.53	3946
42	166	1394	.14	.05	3052
-881	-770	1390	-2.28	-2.50	3061
-1229	-1251	1369	-3.39	-3.86	3108
-1906	-1098	1397	-5.10	-3.51	3059
-1539	-1829	1382	-4.19	-5.44	3079

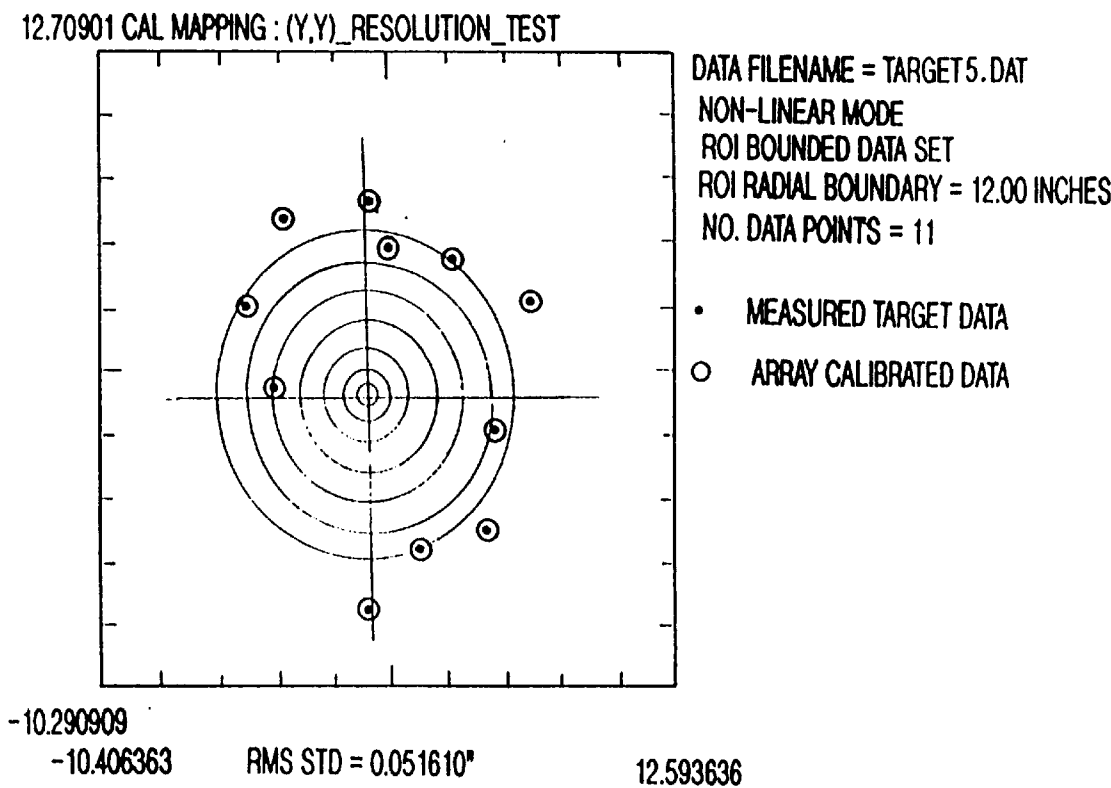
FIG-26



TARGET 4. DAT

ARRAY Y	ARRAY X	ARRAY V	X	Y	V
80	326	1421	.28	.43	2994
-1675	1349	1387	-4.5	3.25	3068
458	415	1396	1.30	.66	3048
-558	1350	1378	-1.44	3.44	3088
141	2282	1372	.37	5.72	3101
913	424	1373	2.56	.69	3099
2026	-221	1401	5.49	-1.05	3037
283	-433	1407	.79	-1.56	3024
610	-1129	1389	1.75	-3.47	3063
1292	-1752	1399	3.59	-5.17	3041
-105	-28	1377	-.19	-.50	3090
1221	1147	1374	3.44	2.65	3097
1862	1968	1368	5.20	5.02	3110
-217	561	1409	-.47	1.04	3020
28	-1339	1378	.12	-4.0	3088
198	-2473	1407	.7	-6.9	3024
-1284	-650	1399	-3.37	-2.22	3041
-1065	-1578	1377	-2.83	-4.71	3090
-807	155	1398	-2.09	0	3043
-1707	-64	1393	-4.48	-.66	3054
-1893	202	1395	-4.93	.15	3050

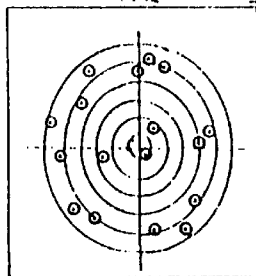
FIG-27



ARRAY X	ARRAY Y	ARRAY V	X	Y	V
-1299	301	1430	-3.46	.38	2975
-1690	1401	1419	-4.64	3.43	2998
-1110	2597	1381	-3.15	6.63	3081
77	2851	1388	.23	7.23	3065
332	2185	1400	1.02	5.46	3039
1259	2011	1390	3.61	5.08	3061
2384	1429	1415	6.60	3.62	3007
1836	-241	1415	4.94	-1.07	3007
1689	-1543	1410	4.78	-4.72	3017
699	-1790	1407	2.10	-5.25	3024
-62	-2603	1410	0	-7.49	3017

FIG-28

8.128011 CAL MAPPING (X,Y)_RESOLUTION_TEST



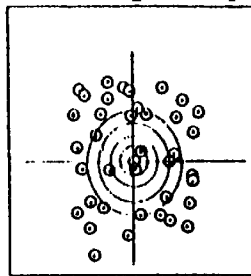
DATA FILENAME = TARGET6.DAT
NON-LINEAR MODE
ROI BOUNDED DATA SET
ROI RADIAL BOUNDARY = 6.00 INCHES
NO. DATA POINTS = 17

• = MEASURED TARGET DATA
○ = ARRAY CALIBRATED DATA

-7.606354

-8.292599 RMS STD = 0.006059° 7.4411776

13.674588 CAL MAPPING (X,Y)_RESOLUTION_TEST



DATA FILE NAME = TARGET6.DAT
NON-LINEAR MODE
ROI BOUNDED DATA SET
ROI RADIAL BOUNDARY = 12.00 IN
NO. DATA POINTS = 40

• = MEASURED TARGET DATA
○ = ARRAY CALIBRATED DATA

-11.350788

-12.519088 RMS STD = 0.077538° 12.515288

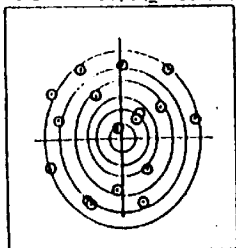
TARGET 6.DAT

ARRAY X

-1978.000	2466.000	1373.000	-4.920	6.382	3099.000
-1035.000	2902.000	1363.000	-2.443	7.462	3122.000
-486.000	2690.000	1371.000	-0.788	6.813	3103.000
933.000	2716.000	1380.000	3.239	7.010	3083.000
-2165.000	2679.000	1357.000	-5.647	6.878	3135.000
-2165.000	2629.000	1357.000	-5.647	6.878	3135.000
-1096.000	2366.000	1359.000	-2.464	5.965	3131.000
-255.000	1788.000	1380.000	-0.095	4.384	3083.000
-323.000	2642.000	1348.000	-0.336	6.685	3156.000
386.000	1888.000	1375.000	1.606	4.695	3094.000
1650.000	2309.000	1374.000	5.366	6.052	3087.000
36.000	2043.000	1390.000	0.637	5.112	3061.000
-2309.999	1748.000	1367.000	-5.913	4.456	3112.000
-1347.000	1815.000	1380.000	-3.208	4.524	3083.000
1438.000	1778.000	1378.000	4.525	4.501	3088.000
2238.000	1949.000	1380.000	6.880	5.137	3083.000
-1951.000	2648.000	1344.000	-5.102	6.917	3166.000
-2257.000	738.000	1348.000	-5.610	1.540	3156.000
-1527.000	1135.000	1366.000	-3.619	2.630	3115.000
148.000	629.000	1358.000	0.940	1.220	3133.000
1409.000	535.000	1377.000	4.460	1.040	3090.000
2031.000	1252.000	1391.000	6.210	3.110	3059.000
-2070.000	29.000	1360.000	-4.940	-0.400	3128.000
-109.000	20.000	1354.000	0.400	-0.310	3142.000
1209.000	297.000	1351.000	3.817	-0.405	3149.000
2025.000	-152.000	1365.000	6.039	-0.813	3117.000
1067.000	-933.000	1354.000	3.515	-3.000	3142.000
-1238.000	-1300.000	1350.000	-2.800	-4.036	3152.000
-1725.000	-1079.000	1354.000	-4.100	-3.520	3142.000
2087.000	-347.000	1363.000	6.227	-1.411	3122.000
-2234.000	-1446.000	1353.000	-5.510	-4.590	3145.000
-1754.000	-1986.000	1384.000	-4.220	-6.020	3074.000
122.000	-1570.000	1379.000	0.960	-4.680	3085.000
1210.000	-1703.000	1381.000	4.030	-5.120	3081.000
1781.000	-1894.000	1371.000	5.730	-5.730	3103.000
1945.000	-1120.000	1381.000	5.950	-3.550	3081.000
861.000	-1552.000	1370.000	3.090	-4.730	3106.000
-1559.000	-2887.000	1358.000	-3.810	-8.560	3133.000
-368.000	-2262.000	1370.000	-0.240	-6.590	3106.000
-1096.000	20.000	1351.000	-2.280	-0.440	3149.000

FIG-29

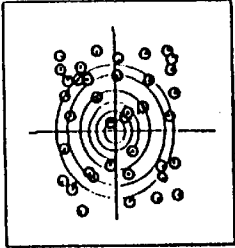
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DATA FILENAME = TARGET7.DAT
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ROI RADIAL BOUNDARY = 6.00 INCHES
NO. DATA POINTS = 18
• = MEASURED TARGET DATA
○ = ARRAY CALIBRATED DATA

-8.012014
-0.837014 RMS STD = 0.036500° 8.518236

12.773837 CAL MAPPING : (X,Y)_RESOLUTION_TEST



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NON-LINEAR MODE
ROI BOUNDED DATA SET
ROI RADIAL BOUNDARY = 12.00 IN
NO. DATA POINTS = 40
• = MEASURED TARGET DATA
○ = ARRAY CALIBRATED DATA

-11.522837
-11.820437 RMS STD = 0.078246° 12.476437

TARGET 7.DAT					
ARRAY X	ARRAY Y	ARRAY V	X	Y	V
-2265.000	2237.000	1347.000	-5.690	5.670	3159.000
-1471.000	2367.000	1348.000	-3.560	5.950	3156.000
-2293.000	2786.000	1338.000	-8.040	7.310	3180.000
-838.000	2932.000	1323.000	-1.870	7.390	3216.000
-36.000	2653.000	1350.000	0.490	6.690	3152.000
-109.000	2042.000	1327.000	0.280	4.980	3208.000
953.000	2798.000	1380.000	3.300	7.140	3128.000
1786.000	2872.000	1373.000	5.710	7.620	3098.000
1953.000	2203.000	1354.000	6.070	5.730	3142.000
2063.000	1387.000	1378.000	6.330	3.460	3088.000
1852.000	849.000	1362.000	5.680	1.340	3124.000
185.000	649.000	1362.000	5.660	1.340	3124.000
1545.000	-1533.000	1427.000	5.120	-4.780	2982.000
2085.000	-980.000	1378.000	6.360	-3.210	3088.000
2152.000	-2098.000	1381.000	6.840	-6.380	3081.000
1337.000	-2231.000	1381.000	4.560	-6.630	3081.000
283.000	-2388.000	1362.000	1.570	-6.960	3124.000
-1489.000	-2675.000	1350.000	-3.580	-7.930	3152.000
-1489.000	-2675.000	1350.000	-3.580	-7.930	3152.000
-2258.000	-1585.000	1395.000	-5.640	-5.130	3050.000
-2189.000	-435.000	1375.000	-5.320	-1.860	3094.000
-1926.000	886.000	1370.000	-4.700	1.360	3106.000
-1569.000	1925.000	1353.000	-3.920	4.760	3145.000
-1275.000	1836.000	1344.000	-3.000	4.720	3188.000
-1993.000	1873.000	1351.000	-4.840	4.870	3149.000
-2138.000	1336.000	1367.000	-5.110	3.150	3112.000
1101.000	1880.000	1376.000	3.660	4.680	3092.000
-325.000	479.000	1380.000	-0.280	0.820	3083.000
-879.000	1294.000	1346.000	-1.790	2.970	3161.000
894.000	964.000	1361.000	3.050	2.150	3126.000
454.000	-554.000	1385.000	1.870	-2.020	3072.000
-353.000	-1073.000	1374.000	-0.380	-3.420	3087.000
-1179.000	-1340.000	1357.000	-2.470	-4.220	3155.000
311.000	-1387.000	1373.000	1.510	-4.290	3099.000
1570.000	-1089.000	1393.000	5.010	-3.530	3054.000
-1075.000	-1437.000	1383.000	-2.330	-4.480	3076.000
293.000	809.000	1369.000	1.430	1.660	3108.000
-1894.000	-1904.000	1360.000	-4.50	-5.88	3128
1984.000	2566.000	1351.000	6.160	6.780	3149.000
233	669	1364	1.20	1.33	3119

FIG-30

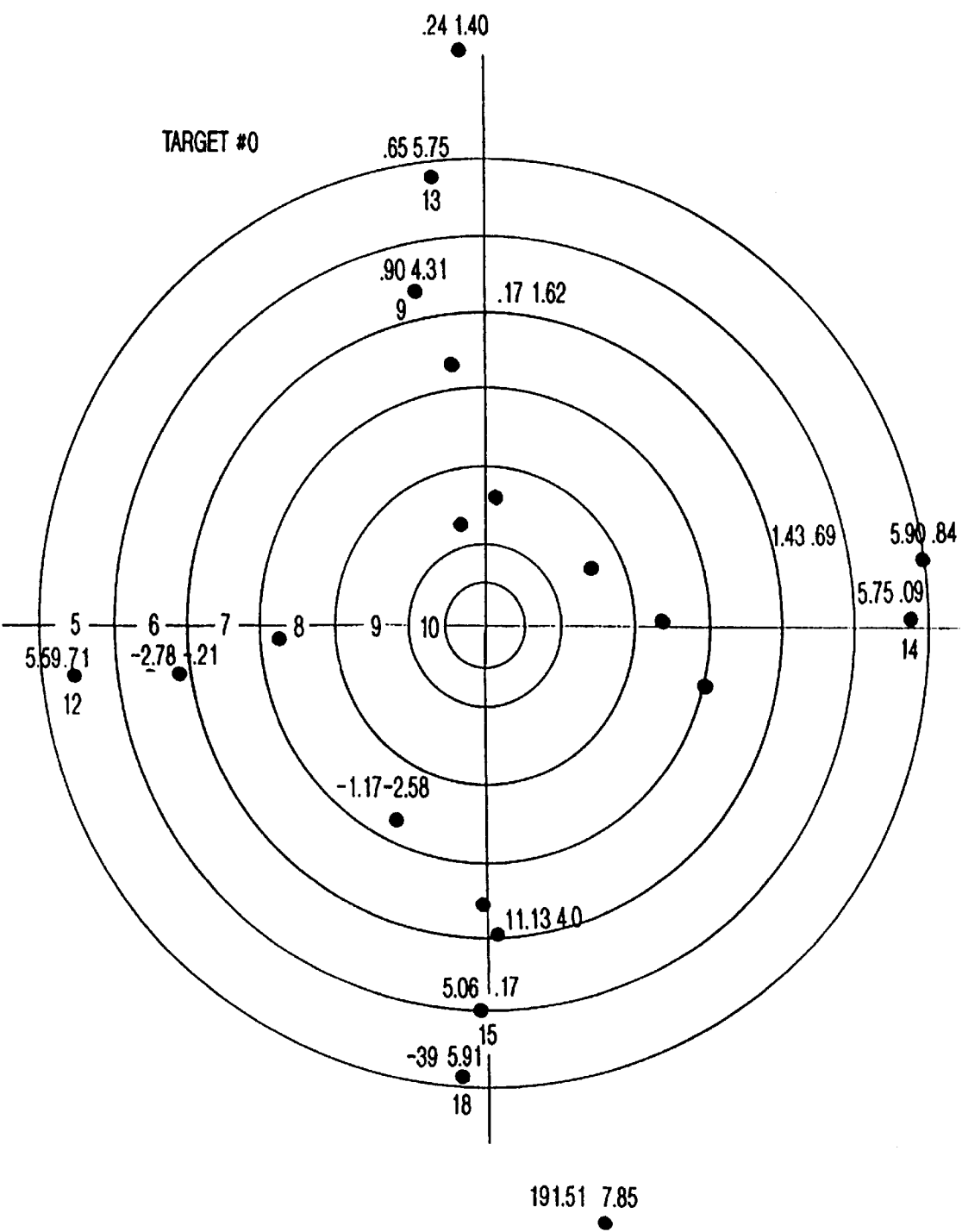


FIG-31

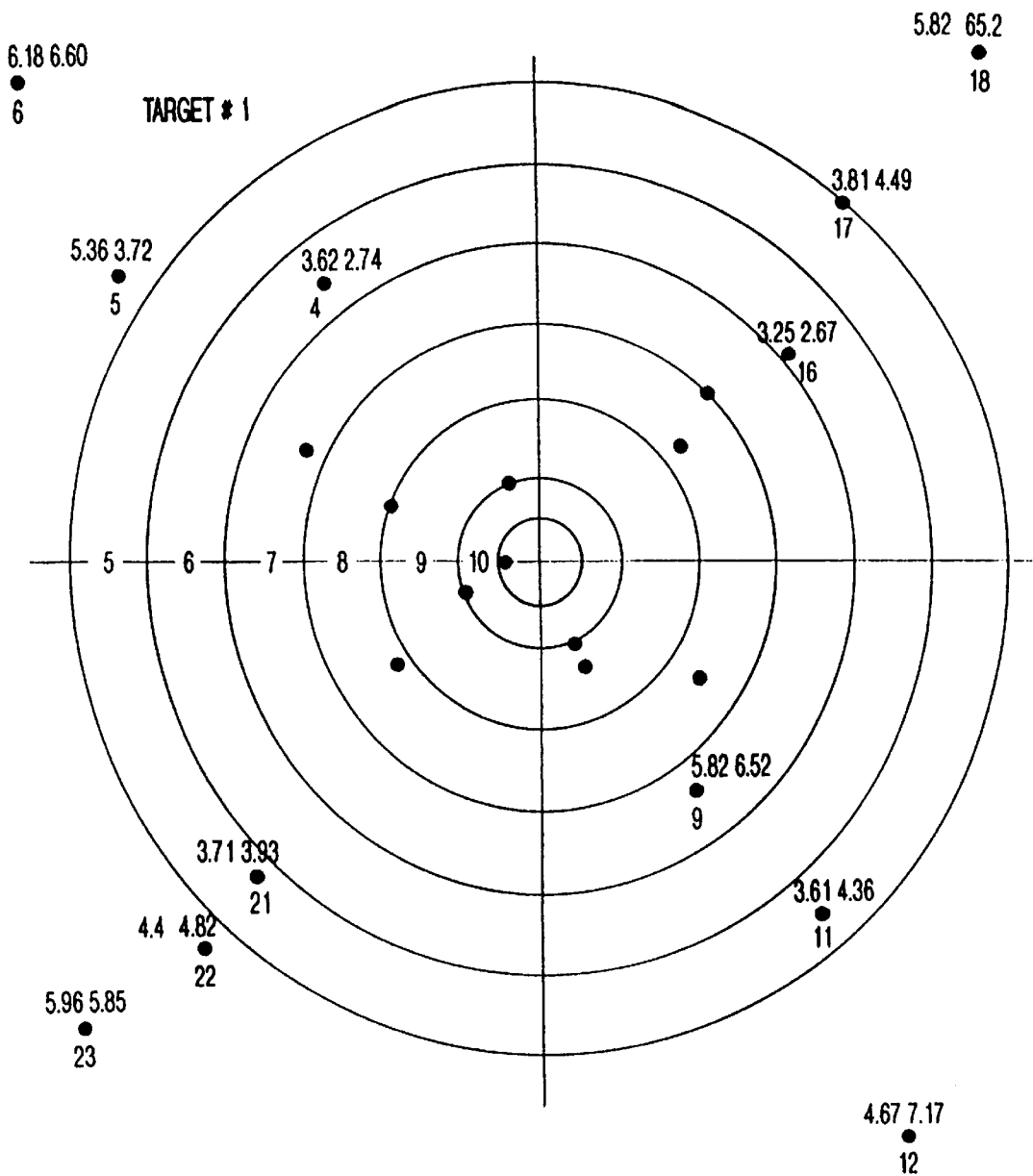


FIG-32

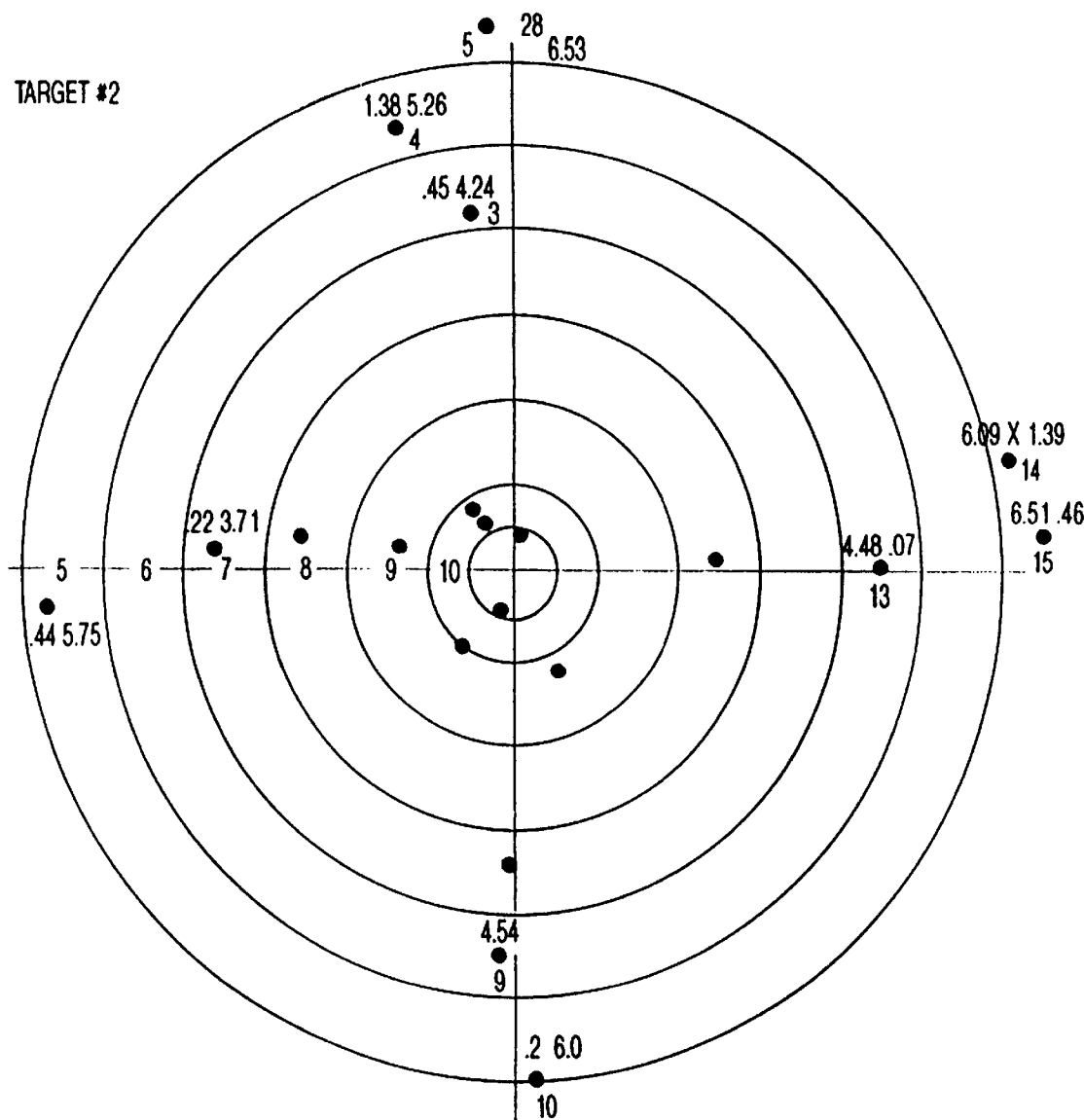


FIG-33

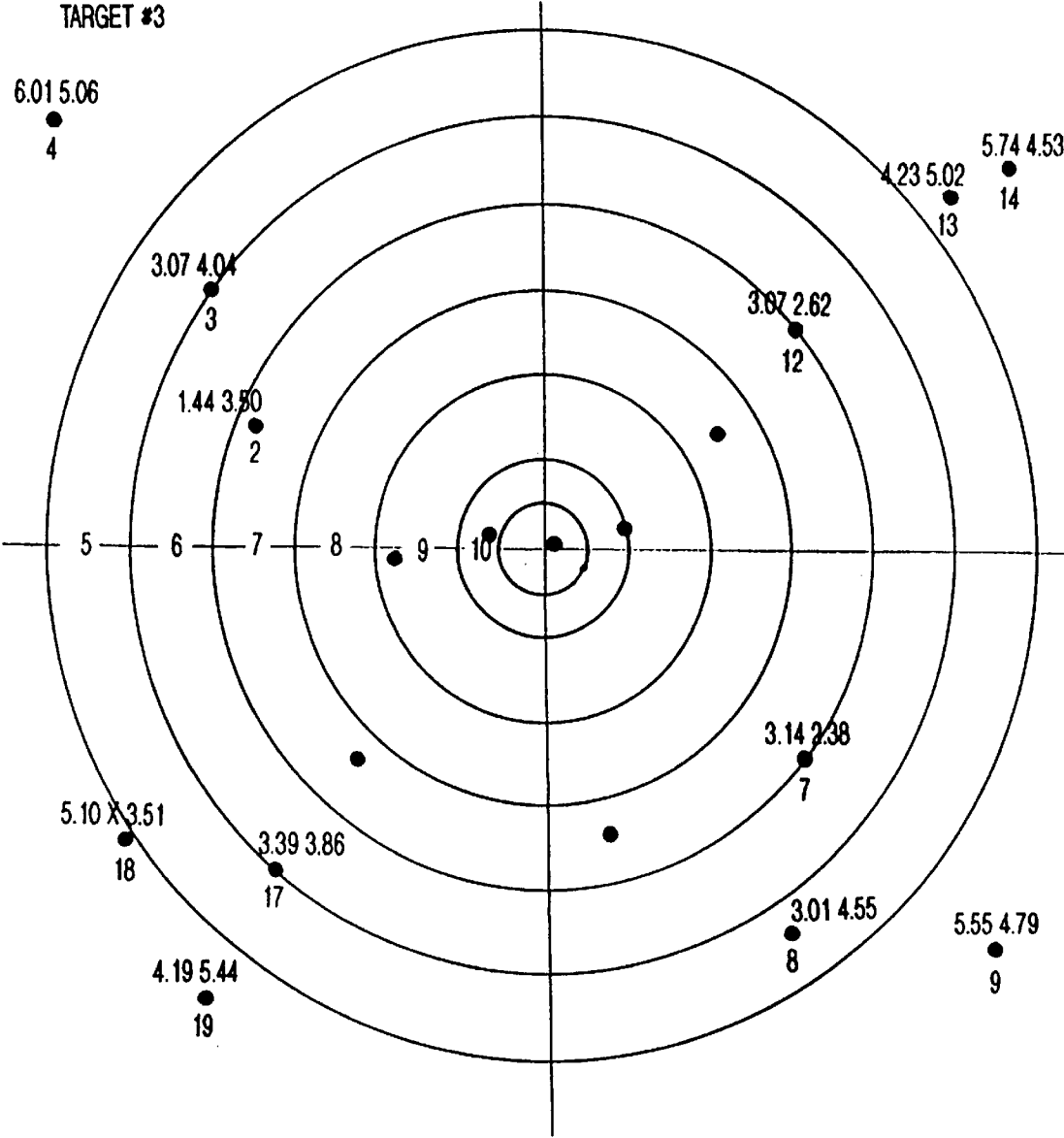


FIG-34

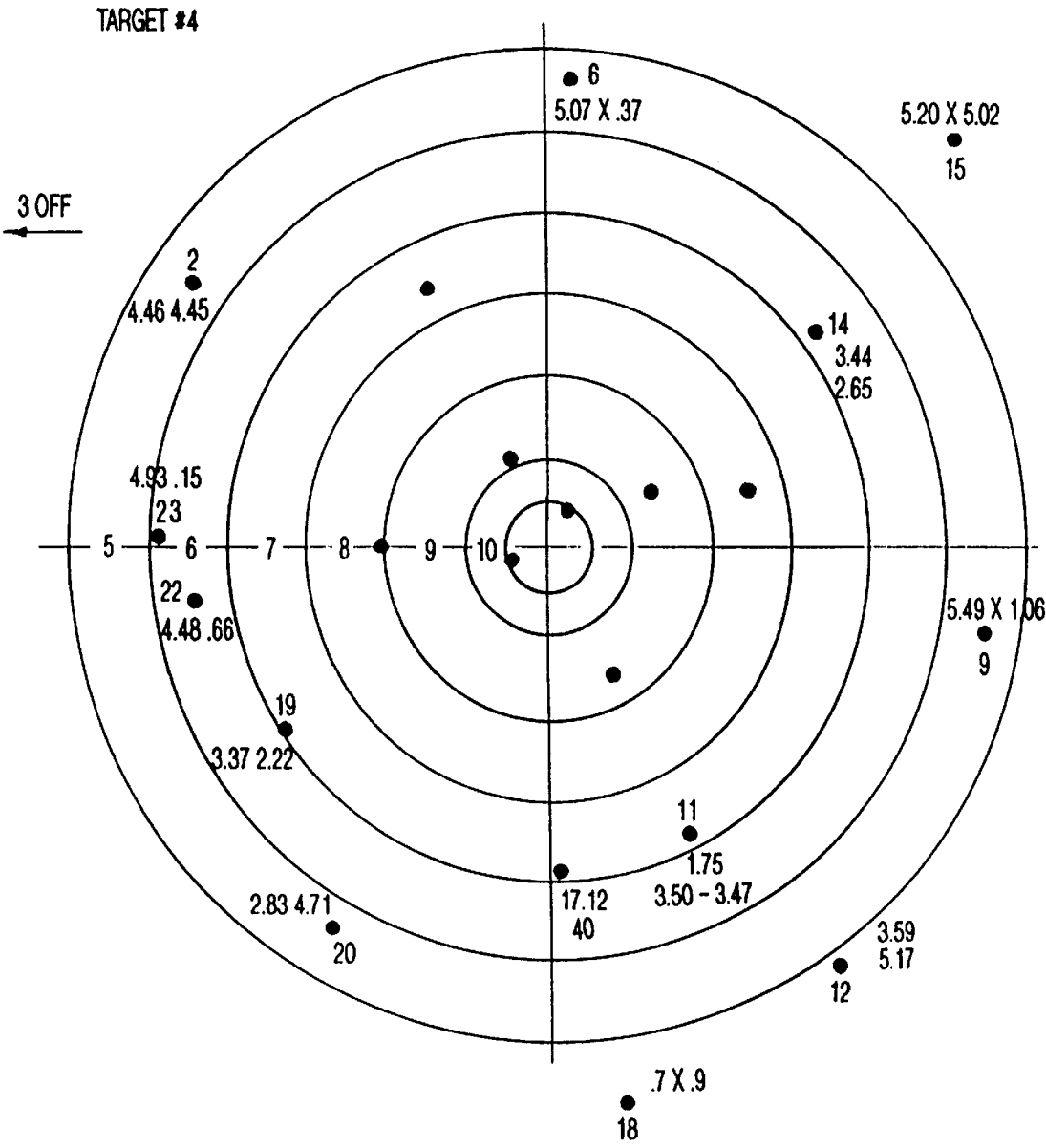


FIG-35

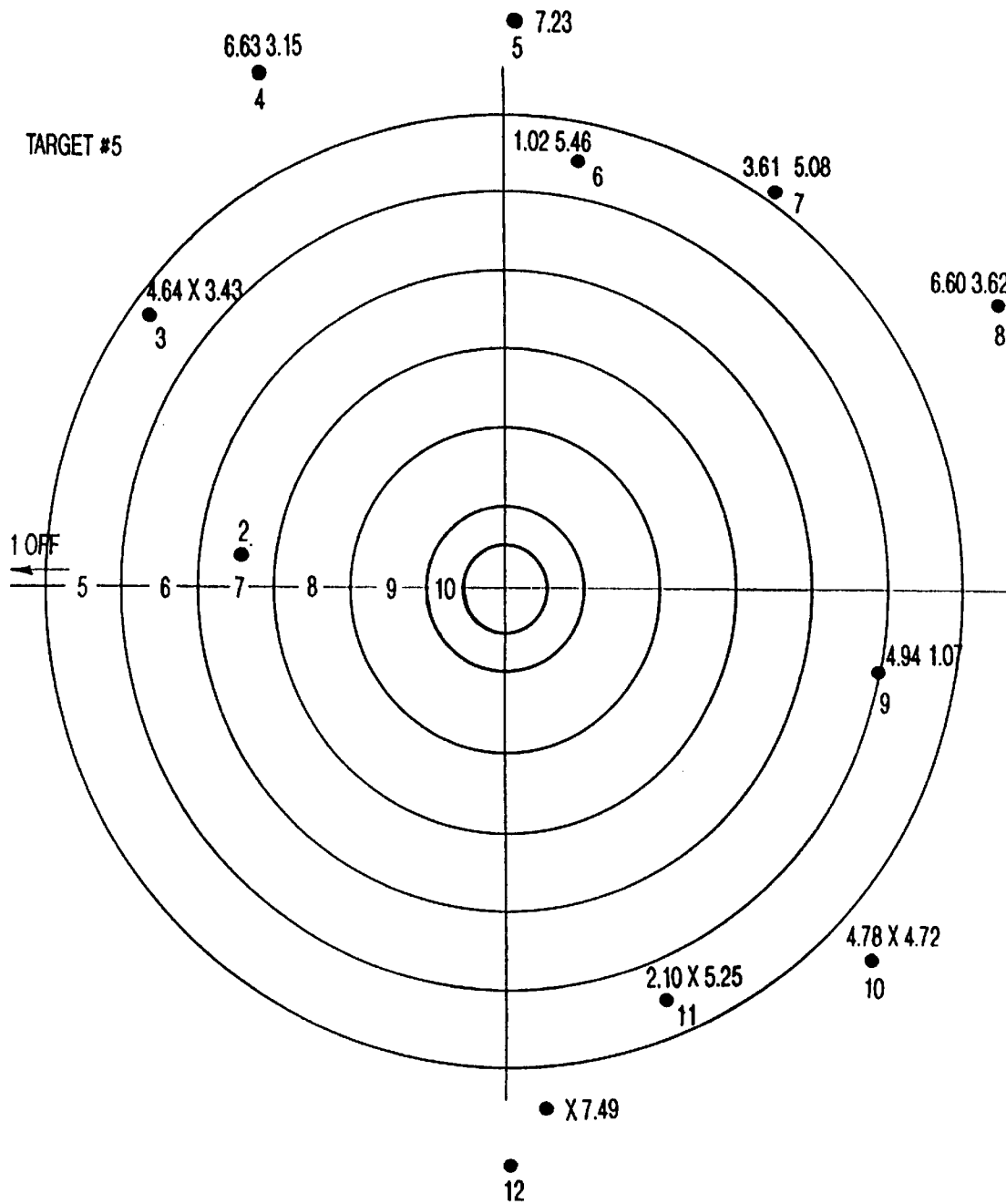


FIG-36

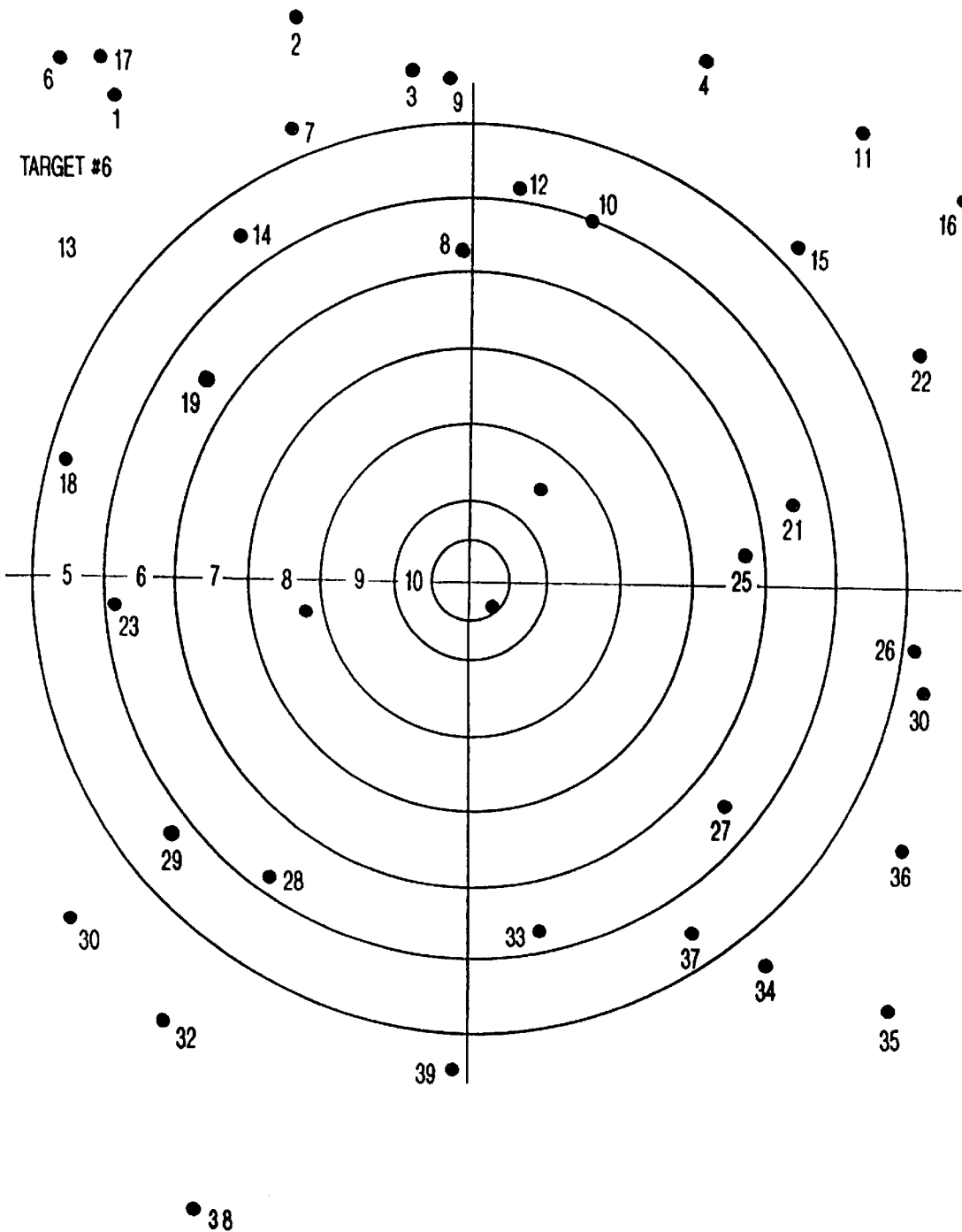


FIG-37

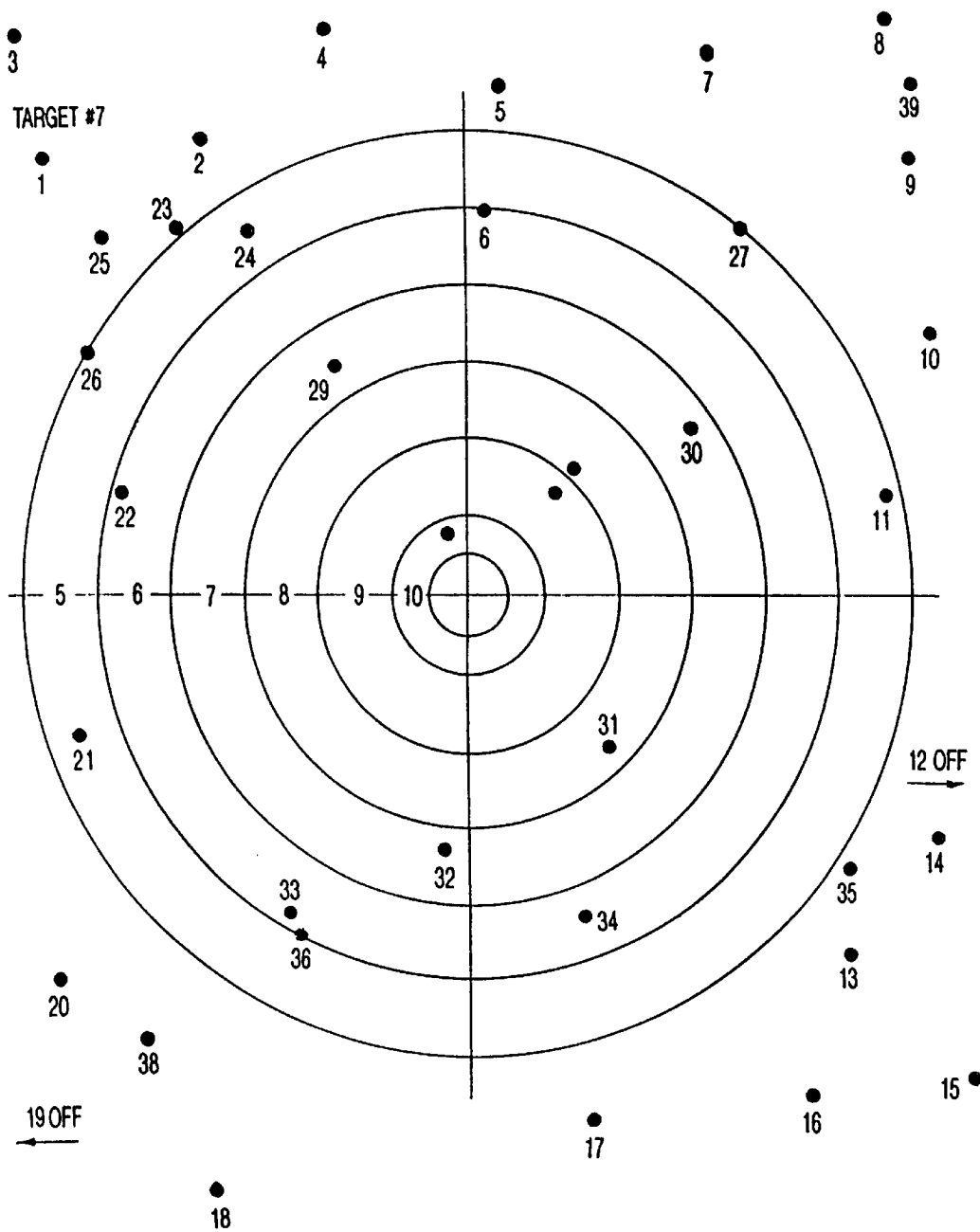


FIG-38

REMOTE SENSING APPARATUS OF SUPERSONIC PROJECTILE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of the filing of Provisional Application Serial No. 60/022,553, entitled "Remote Target Display System", filed on Jul. 19, 1996, and the specification thereof is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention (Technical Field)

The present invention is related generally to methods and apparatuses for measuring the position, velocity, energy and impact characteristics of a projectile traveling at supersonic speeds.

2. Background Art

Existing methods for the measurement of the velocity and intersection position of a shot on a target are based on pressure shockwave concepts. A supersonic projectile generates a conically shaped expanding shockwave called a Mach-cone where the local and temporal air turbulence effects can be characterized by a steep change in ambient air pressure (shock front) which expands radially outward from the projectile path. However, existing systems are based on directional triangulation techniques where an acoustical sensor array is used only to determine the acoustic energy emitted by a passing bullet and determines the directions from which this shock front arrives at the sensor microphones.

Primary examples of the current prior include U.S. Pat. No. 5,349,853 (Oehler) and U.S. Pat. No. 5,025,424 (Rohrbaugh). Both employ the acoustical energy directional technique, but address the issue of accuracy with two divergent approaches. Oehler uses a complete ballistic history computation procedure to improve measurement resolution and Rohrbaugh uses a sensor design to meet the same goal.

Oehler's invention is designed to observe the complete ballistic history of a projectile with acoustical shock wave mapping being only one component. Oehler does employ acoustical sensors, but uses a data-acquisition design, measurement and positional computational scheme based on full ballistic profiling. Oehler employs the integration of three separate measurements to predict the projectile impact point. These are (1) a firearm-pressure-strain measurement of bullet explosive characteristics and drive-force pressure, (2) a series of bullet trajectory (muzzle) detector measurements to determine initial projectile path and velocity parameters, and (3) three-point acoustical sensory array measurements to determine time-of-arrival and relative spacial displacement. This information is then integrated by an external personal computer program to compute the full trajectory profile of the bullet from the muzzle to the target. Oehler thus requires multiple measurement procedures and instrumentation for bullet placement determination, velocity, trajectory and relative time measurements. At the target plane, Oehler uses three acoustical sensors in a triangular format, for common time-zero reference determination relative to the time the bullet left the muzzle and nominal spacial positioning for the overall ballistic computation and "hit" location prediction. The three-point system restricts the relative target-area operational field-of-activity. The communication link from the acoustical array is land-line based. This limits functionality, range, and use. Oehler cannot perform any

form of self analysis and diagnostic checks. In summary, Oehler is a full-profile ballistic measurement system designed to determine the characteristics of the bullet trajectory from the muzzle to the target. As such it is not designed to be portable or for general use by the public.

U.S. Pat. No. 5,025,424 (Rohrbaugh) discloses an automatic shock wave scoring apparatus for scoring a "hit" of a supersonic projectile. The Rohrbaugh invention is a single-site, fixed-location, automatic gunnery targeting system which uses the shock profile of a passing projectile to determine the placement of the projectile impact point above the sensor field. It employs several curved acoustic sensor rods which are positioned below the target-active area. These curved sensor rods are surface pressure-sensitive (to the acoustical shock wave) such that a secondary transverse shock wave is generated in each sensor by the incident shock cone. These secondary waves then propagate through each sensor to the transducers located at their ends. The relative time difference between the arrival of the secondary shock at each end is then used to determine the point of incidence of the projectile shock point on the outside of each sensor. Each curved sensor effectively emulates a two-dimensional array of discrete sensors with first incidence discrimination. In effect, they act like fan detectors to the passing projectile. Based on the geometry of these fan detectors, curvilinear remappings are projected and the relative position of the incident projectile is computed. In general, Rohrbaugh is designed for target projectile mapping. The basis of Rohrbaugh's invention is the unique form, composition, and action of the discrete fan detectors. Rohrbaugh employs two curved (polar) two-dimensional sensors that sense the profile of the shock in a curvilinear polar space, with all of the sensors positioned below the target area. As such, targeting is based on a two-point detection scheme employing a vector-directional cross-correlation technique. The current invention employs four discrete sensors, each of which samples a single point on the surface of the shock cone, within an orthogonal Cartesian coordinate system to ensure independence and separability in its sensor measurements. The Rohrbaugh unit requires resolution of a 2-dimensional cross-dependent projection remapping to determine positioning. The current invention employs simple orthogonal coordinate transform equations.

Other patents which relate to targeting include U.S. Pat. No. 5,247,488 (Borberg et al.), U.S. Pat. No. 4,885,725 (McCarthy et al.), U.S. Pat. No. 2,925,582 (Mattei et al.), U.S. Pat. No. 4,514,621 and 4,282,453 (Knight et al) and U.S. Pat. No. 4,261,579 (Bowyer et al.).

SUMMARY OF THE INVENTION (DISCLOSURE OF THE INVENTION)

The present invention is of a remote targeting apparatus and method comprising: surrounding a projectile target with a sensor array, the sensor array comprising at least two pairs of acoustical sensors; computing projectile impact data; transmitting the data; receiving the data at a controller; and displaying information corresponding to the data. In the preferred embodiment, RF transmission/reception is performed, most preferably at a frequency of between approximately 902 and 928 MHz, with the controller having RF Faraday cage shielding and collision avoidance being employed to permit multiple sensor arrays to operate in a vicinity of one another. The controller preferably graphically simulates a target and projectile impact locations thereon, in real-time. Projectile impact locations within twelve inches of the center of the projectile target are calculated to an average RMS accuracy of less than approximately fifty

thousandths of an inch, directly in an orthogonal Cartesian coordinate system. Velocity is also determined via an additional sensor at a predetermined distance from the sensor array which measures a difference in time between the projectile passing the additional sensor and the sensor array. Velocity dependent variations in projectile shock front characteristics are corrected for automatically, and correction of data display translation, rotation, and resolution differences with respect to the projectile target and the sensor array may be engaged. Preferably two pairs of acoustical transducers (most preferably acoustical microphones) are placed in a plane at cardinal compass points of the projectile target, with the additional acoustical transducer orthogonal to the two pairs. Projectile velocity is computed from data provided by the additional acoustical transducer and a paired acoustical transducer. Each of the transducers in the plane is located within an elbow of a housing, which housing has arms connecting the elbows, all of which are modular. An arm or a sensor may be incapacitated and the sensor array will continue to function. The sensor array executes self-diagnostic and self-wiring procedures.

The invention is also of a sensor apparatus and method for a projectile target, comprising calculating projectile impact locations within twelve inches of a center of the projectile target to an average RMS accuracy of less than approximately fifty thousandths of an inch. In the preferred embodiment, the sensor array comprises at least two acoustical sensors, and preferably at least two pairs of acoustical sensors, most preferably two pairs of acoustical transducers placed in a plane at cardinal compass points of the projectile target, with an additional acoustical transducer orthogonal to the two pairs. Projectile velocity is determined from data provided by the additional acoustical transducer and a paired acoustical transducer. Where two pairs of sensors are employed, the are preferably located within four elbows of a diamond-shaped housing. An arm or a sensor may be incapacitated and the sensor array will continue to function. The preferred sensors are off-the-shelf acoustical microphones. The array executes self-diagnostic and self-wiring procedures, calculates projectile impact locations in an orthogonal Cartesian coordinate system, and corrects for velocity dependent variations in projectile shock front characteristics.

The present invention was designed to overcome the inherent limitations in the prior art by employing a novel array measurement technique in combination with fast and reliable communications and data relay-display technology. As such, the apparatus and method defined in this invention have resulted in a compact, light-weight, portable remote targeting system that provides an integrated targeting system for real-time visual display, measurement, and analysis in a long-range target shooting environment. The present invention: (1) provides a high-performance, low-cost measurement device for the general consumer market, as well as military, industrial and law enforcement applications; (2) provides instant visual verification of shot placement and shot groups; (3) provides instantaneous measurement of a bullet's impact velocity; (4) provides computation of impact kinematics at the target, i.e., energy, power, energy dissipation, force per unit area and penetration estimates of the bullet at the target; (5) eliminates the need for a spotting scope and problems with scope-associated viewing alignment difficulties; (6) provides immediate integrated analysis of a target shooting session; (7) enables real-time accurate scoring and score updating; (8) eliminates the need to walk downrange to replace used targets; (9) provides computation and display of the mean group center; (10) provides shot-

to-shot sighting adjustment information for windage and elevation; (11) eliminates ambiguity of bullet placement arising from bullets passing through holes in the target; (12) eliminates the need to replace targets or physically mark previous shot holes; (13) improves the cost of rifle/pistol sight/scope calibration by minimizing ammunition expenditures; (14) allows the shooter to compare bullet types, loads and weights as a function of accuracy in a real-time mode; (15) provides a high accuracy measurement device for quality control applications within the arms and ammunition manufacturing industries; (16) provides a real-time tool for law enforcement, military and public firearms training; and (17) provides a high-precision instrument for law enforcement and military studies into projectile penetration and damage studies.

Other objects, advantages and novel features, and further scope of applicability of the present invention will be set forth in part in the detailed description to follow, taken in conjunction with the accompanying drawings, and in part will become apparent to those skilled in the art upon examination of the following, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated into and form a part of the specification, illustrate several embodiments of the present invention and, together with the description, serve to explain the principles of the invention. The drawings are only for the purpose of illustrating a preferred embodiment of the invention and are not to be construed as limiting the invention. In the drawings:

FIG. 1 is a schematic diagram of the sensor array of the invention.

FIG. 2 is a flowchart for the operation of the sensor array.

FIGS. 3(a) and (b) are front and front perspective views of the Control/Display Unit ("CDU") of the invention.

FIG. 4 is a flowchart of the CDU startup procedure.

FIG. 5 is a flowchart of the CDU shutdown procedure.

FIG. 6 is a flowchart of the main CDU operations loop.

FIG. 7 is a flowchart of the CDU idle state process loop.

FIG. 8 is a flowchart of the procedure for host command execution on the CDU.

FIG. 9 is a flowchart of the procedure for array message process handling on the CDU.

FIG. 10 is a flowchart of the CDU switch input process.

FIG. 11 is a flowchart of the CDU graphics screen arrow control process.

FIG. 12(a) is a flowchart of the general CDU menu process.

FIG. 12(b) is an organizational map of the CDU menu structure.

FIGS. 13(a) and (b) are front views of the two components of the stabilized, portable array stand of the invention.

FIG. 14 is a front view of the stand of FIGS. 13(a) and (b) when assembled.

FIGS. 15(a)-(e) are schematic diagrams of CDU housing components including the face plate, battery holder, back plate stand, battery plug, and the RF shield cavity.

FIG. 16 is a block diagram of the CDU hardware.

FIGS. 17(a) and (b) are schematics for the main board within the CDU, including microprocessor, 29f010 flash

ROM, RS-232 serial interface, 900 MHz RF link, key pad, battery, step up/step down power converters, and external power interface.

FIGS. 18(a) and (b) are schematics of the sensor array components, including array control unit housing, battery housing lid, cover plate, antenna support bracket, switch/LED support bracket and spar/elbows sensor.

FIG. 19 is a block diagram of the sensor array hardware of the invention.

FIG. 20 is a schematic of the array sensor controller/transmitter PC board, including micro-controller, sensor interface circuitry, power converter, and transceiver.

FIG. 21 is a block diagram of the sensor-elbow with circuitry for the matched pair acoustic traducers.

FIG. 22 is a schematic diagram of the sensor elbow.

FIG. 23 is a compilation and plot of the resolution test for data set target0.dat.

FIG. 24 is a compilation and plot of the resolution test for data set target1.dat.

FIG. 25 is a compilation and plot of the resolution test for data set target2.dat.

FIG. 26 is a compilation and plot of the resolution test for data set target3.dat.

FIG. 27 is a compilation and plot of the resolution test for data set target4.dat.

FIG. 28 is a compilation and plot of the resolution test for data set target5.dat.

FIG. 29 is a compilation and plot of the resolution test for data set target6.dat.

FIG. 30 is a compilation and plot of the resolution test for data set target7.dat.

FIG. 31 is an image of actual target data generated during acquisition of target0.dat.

FIG. 32 is an image of actual target data generated during acquisition of target1.dat.

FIG. 33 is an image of actual target data generated during acquisition of target2.dat.

FIG. 34 is an image of actual target data generated during acquisition of target3.dat.

FIG. 35 is an image of actual target data generated during acquisition of target4.dat.

FIG. 36 is an image of actual target data generated during acquisition of target5.dat.

FIG. 37 is an image of actual target data generated during acquisition of target6.dat.

FIG. 38 is an image of actual target data generated during acquisition of target7.dat.

DESCRIPTION OF THE PREFERRED EMBODIMENTS (BEST MODES FOR CARRYING OUT THE INVENTION)

The present invention is of a remote sensing apparatus and method for the measurement of the instantaneous velocity and sensor plane intersection Cartesian coordinates of a supersonic projectile within a targeting environment. The system records, displays and analyzes target shot patterns within a pistol or rifle range by remotely and unobtrusively detecting the positioning of an incident bullet, relays the targeting information from the target area back to the shooter into a portable control-display unit, and then analyzes the shot patterns in real-time.

Measurement is accomplished by examining the characteristics of the Mach-wave, an expanding conical pressure-

wave shock front set up by the projectile as it passes through the air between matched pairs of acoustical transducers. Positional and velocity measurements are accomplished by determining the time-of-flight (arrival) differences in the Mach-cone between sensors. This time-based data is then directly correlated to spacial measurements for shot positioning and velocity determination.

As used herein, the term "acoustic energy" means either a pressure wave or shock wave generated by a supersonic projectile. The term "projectile or bullet" includes any recognized structure of the type capable of being launched or projected by a pistol or rifle firearm or any like device up to 0.50 caliber. As such, the words "bullet" and "projectile" will be used interchangeably throughout this disclosure. The term "controller" means a micro-processor based system employing digital memory and some form of input/output. The term "sensor array" means the sensor package for supersonic event detection, including the acoustic transducers, the array controller processing, and the RF transmitter. The following abbreviations are used: CDU—the base station hand-held control display unit used to analyze array targeting data; and RMS—root-mean-square.

The apparatus of the invention preferably comprises two units, a plug-together sensor array 10 (FIGS. 1–2 and 18–22) and a base station 50 (CDU; FIGS. 3–12 and 15–17) for display and analysis.

The sensor array preferably comprises three (although the pair measuring velocity may be eliminated, and more than three pairs may be employed if redundancy is desired) pairs of acoustical transducers 12 that detect the expanding compression wave of the projectile as it passes the array sensor imaging plane. In alternative embodiments, two or three sensors may also be utilized. An internal timing unit then computes the vertical and horizontal targeting placement components and the intersection plane velocity at the target. As the projectile's shock cone passes between the paired acoustical traducers, the relative time-of-arrival differentials in both the horizontal and vertical (sensor-plane) directions, for the radially expanding wave front, are measured. Orthogonally, a similar measurement is made as the projectile travels down line, with the time measurement being representative of the time-of-flight between two known spacial coordinates. The velocity is then computed as the ratio of the sensor pair displacement divided by the time. All placement timing and data acquisition occurs in the micro-processor at the target and is independent of the shooter's initial projectile characteristics.

The CDU contains an RF receiver 54 and a microprocessor 52 for shot pattern analysis and control of the LCD graphical/numerical display 56. This unit allows for the display of individual shot characteristics and group pattern measurements, with automatic scoring, elevation and wind-age adjustment computation, along with multiple target pattern selection and pan-zoom display features. It is preferably small, compact (e.g., 9"x9"x1.5" deep), light weight and operates on standard C-cell batteries. It preferably employs battery life extension electronics and apparatus diagnostic procedures. The invention also includes complete capability for multiple unit discrimination and multiple shooter false trigger discrimination. Multiple unit and multiple shooter discrimination is based on a simple bi-directional RF link keyed to a three-byte binary coded, system identification number. This allows for 2^{24} different unit identifiers between the array and the CDU. Since each data transmission sequence contains this identifier, each targeting unit is able to uniquely recognize its array/CDU counter part. If multiple arrays relay information

simultaneously, i.e., generating an RF interference collision mode, each array continues to transmit data until it receives an acknowledgment of receipt from the CDU. Once the array-CDU handshaking is completed, both units enter an idle state until the next event occurs. If multiple array events occur before proper communication has been achieved, the array buffers the additional data (for up to 20 projectiles) and adds it to the data stream on the next data transmission attempt. This data is then relayed over an RF link 14 to the control-display base station (CDU) next to the shooter. For

off-line interactive analysis of a shooting session, the invention includes a serial port 58 to access a personal computer based (e.g., Windows 95) application for targeting analysis, target file editing and handling data input/output.

Referring to the Tables and Figures, the present invention is a compact, light-weight, portable remote targeting system designed to be used to measure, record, display and perform real-time analysis of supersonic projectile patterns within a long-range targeting environment. A description of the apparatus features and specifications are given in Tables 1 and 2.

TABLE 1

APPARATUS FEATURES		
GENERAL	SENSOR ARRAY	CDU (control-display unit)
provides instantaneous visual display of bullet-target impact points	battery operated	battery operated
measures bullet velocity at the target	power management for extended battery life	contains its own microprocessor and memory for stand-alone, full-function operation
calculates the energy of a bullet at the target	easy snap together assembly and deployment	provides fast, near instantaneous visual display of a bullet's impact point on a target
provides real-time target scoring	all sensors and extension poles are interchangeable	provides numerical information about the bullet's target point and a group's mean coordinates
provides rifle-scope sight adjustment corrections	low cost replacement of sensors and poles	enables the storage of up to (>)10 different shot group sessions
enables real-time comparison and analysis of bullet weight/powder load-tests	contains automatic self-diagnostics for sensor failure detection	a shot group can have up to (>)150 individual shots or more
operates over long ranges greater than 0.25 miles.	contains a long range (keyed) data transmitter for ranges in excess of ¼ mile	individual shot groups can be stored and then recalled for display
employs a powerful radio link	contains an LED 'array-health indicator' to show when the unit is on and when it is operating properly	different shot groups can be graphically overlaid so visual and numeric comparisons of group accuracy can be made
contains a high-resolution graphical and numeric LCD display	contains its own internal microprocessor so it can tell when a shot hits within the target or outside	provides direct computation of rifle-scope windage and elevation corrections
its shape and form is ergonomically designed for ease of use with simple functionality		automatically score target shooting sessions
provides for a PC interface for data IO		provides for the internal display different target patterns
contains internal self-check diagnostics		enables the downloading of a custom target pattern
employs advanced power management functions to optimize battery performance		the display target field can be panned and zoomed to enhance viewing of target shot groups
light weight		contains full power management capability for extended battery life
portable		includes a low battery indicator
easily deployed (snap together components) and disassembled		contains a backup system to save the memory when the unit is shut-down or when the batteries are replaced
low cost		contains an optional AC adapter
		has a serial output port for downloading stored shot data to a computer or uploading a new target pattern
		contains a high-speed radio receiver link for long range operation (>¼ mile)
		employs an automatic power shut-down

Unlike all of the prior art, the invention preferably utilizes two pairs of orthogonally matched acoustical transducers for sensing the conical shock front of a projectile in order to differentiate projectile position to an average RMS positional accuracy of less than fifty thousands of an inch. The system is composed of two units, a fast plug-together sensor array, FIG. 1, and a custom designed base station called the ‘control display unit’, FIG. 3, for display and analysis. The specifications for the preferred apparatus is given in Table 2 for both the sensor array and the CDU.

TABLE 2

APPARATUS SPECIFICATIONS	
Characteristic	Specification
Sensor Array	
(Measurement)	
Measurement Sampling Interval	2.765 mega-samples per second
Measurement Spatial Location Uncertainty	shot group average RMS deviation is less than 0.050"
Data Collection Rate	minimum of 10 shots per second
Data Buffering	up to 20 individual shot data sets
Data Transfer Rate (Transmitter Radio Link)	4800 baud
Carrier Frequency	within the 902–928 MHZ band and optionally 418 MHZ band
Modulation Type	frequency shift keying (FSK)
Range	greater than ¼ mile (rural)
Output Power	750 micro watts ERP (FCC Part 15)
Antenna (Physical)	omni-directional 1.0 dBi
Operating Temperature Range	32° to 100° F.
Power	2 “AA” batteries
Battery Life	25–30 hours minimum
Size, sensor array area	32" × 32" area = 1024 square inches
Weight	less than 15 oz.
Control/Display Unit (CDU)	
(Receiver Radio Link)	
Carrier Frequency	within the 902–928 MHZ band
Modulation Type	frequency shift keying (FSK)
Range	greater than ¼ mile (rural)
Receive Sensitivity	–80 dBm
Antenna (Physical)	omni-directional 1.0 dBi
Operating Temperature Range	32° to 100° F.
Power	4 “C-Cell” batteries
CDU Dimensions	9.0" × 9.0" × 1.5" (LWH)
LCD Display Size	3.0" × 4.0" (HW) @ 320 × 240 pixel array
Weight (System)	3.1 lbs.
Operating System	Flash Ram/EPROM/ROM based
CPU	25 MHZ microprocessor
PC Interface	Serial Port at 9600 baud
PC Support Software	for Windows 3.1 and Windows 95

The sensor array preferably comprises four paired microphones placed at the cardinal-compass points that detect the expanding compression wave of the projectile as it passes. A fifth sensor is paired orthogonally with one of the planar interaction sensors to provide for the time-of-flight measurement of a projectile as it passes through the sensor apparatus, over a path length of, preferably, eighteen inches. The preferred sensors may be standard off-the-shelf acoustical microphones. A process flow diagram for the array is shown in FIG. 2. Mechanical design, block layouts and electronic circuits are shown in FIGS. 18–22.

Comparator circuits coupled to a microprocessor compute the vertical and horizontal shock cone edge time-of-arrival

differentials, using a preferred sampling rate at 360 nano-seconds or 2.765 mega samples per second and generate array relative placement parameters that are then relayed over a radio link to the CDU base station. The velocity of the projectile is handled in a similar manner. The radio link preferably operates in the 902–928 MHZ band, with a minimum data rate of 4800 to 9600 baud and an effective range of one-quarter mile. All placement timing and data acquisition takes place in the microprocessor at the target, and is independent of the shooter’s initial projectile characteristics.

The base station CDU shown in FIG. 3, and contains a wireless radio data link receiver, a microprocessor for shot pattern analysis and control of the 320×240 liquid crystal display (LCD) graphical/numerical display. Overall process control, defined by software controller code resident on the microprocessor, is shown in FIGS. 4–12, for the (1) main loop process flow, (2) idle loop process flow, (3) host command processing, (4) array message processing, (5) switch input processing, (6) keypad arrow control, and (7) menu along with the menu map. Mechanical design, block layouts and electronic circuits are shown in FIGS. 15–17. For stationary testing, an array mounting stand 60 was designed and implemented. This is shown in FIGS. 13–14.

The present invention uses a completely different sensing array configuration than shown in the prior art. It relies entirely on the high-resolution measurement of the shock front shape and time motion differentials and initial calibration information. The invention uses two independent planar-orthogonal channels for placement triangulation, and a single cross-orthogonal channel for velocity determination on a sampling interval (e.g., 350 nanosecond). This provides for optimal spacial resolution without the introduction of less effective and less accurate timing cross-term components derived from a multi-sensor directional cross-coupled configuration.

Each discrete acoustic sensor samples a single point on the surface of the shock cone measuring its time response function and characteristic profile. The data is, by virtue of the array geometry, organized in an orthogonal Cartesian coordinate system to ensure independence and separability in sensor measurements. This eliminates the need for cross-dependent projection remapping terms other than rotational and transnational components. Choice of this type of configuration was based on the truism that there exists an inherent fundamental positional uncertainty built into the prior art where restrictions and limits on the dynamic range of placement projections resulted from directional based design configurations where directional triangularization aspects do not allow for equal aspect in orthogonal direction resolution. The present invention avoids this problem entirely and optimizes for accuracy by equalizing its sensor spacial resolution aspect, thereby minimizing cross-term correction effects by setting its sensors orthogonal to each other and measuring their parameters independently. This design simplifies timing electronics and allows for faster real-time at-the-array analysis rates.

The time-amplitude profile of the acoustical shock front impingement on each microphone sensor is recorded and subjected to a simple shape analysis for event discrimination and triggering. The primary pulse (not late time ringing) of the sensor signal is analyzed as regards its rise-time, peak amplitude, full-width at half height and long-time decay profile. These parameters provide necessary input for determining the type of event and the relative trigger time differential offset; which, when compared with its matched pair companion, provides an array based timing differential reported as one of the array time-directional coordinates.

A fast calibration transform is incorporated within the invention to correct for the projectile-array intersection point measurement as regards visual CDU display translation, rotation and resolution limits based on the number of discrete sampling sensors. The resulting positional coordinates are therefore subjected to an array-sourced, non-linear multi-order cross-detection field correction procedure to account for velocity dependent variations in the shock front time and space profile. This unique calibration transform enables the present invention to maintain extremely high placement and velocity measure resolutions. Array coordinates are relayed in absolute time differentials, relative to the array sensor center, in units based on the array microprocessor clock frequency. This tunable frequency is currently set to 2.76475 MHz. The calibration transform converts these time coordinates into spacial coordinates consistent with physical targets placed within the array sensor field. The calibration transform is based on the comparison of a set of correlated data measurements between array-time coordinates and spacial-target coordinates, which represent the measurement of the same events in two different coordinate systems. Translation, rotation, scale extent and weighted off-field correction terms are convoluted together to form a correction transform matrix which is used to convert array measurements to target placements.

Industrial Applicability

The invention is further illustrated by the following non-limiting examples.

EXAMPLES 1-8

Table 3 tabulates the results from a series of eight resolution measurements derived using a 55 grain 0.223 caliber projectile over a range of 100 yards.

TABLE 3

ARRAY SENSOR RESOLUTION RESULTS		
Radial(x,y) RMS deviation measurements, in inches, for data derived from a series of tests using a 55 grain, 0.223 caliber projectile at a range of 100 yards		
Array Data (6" radial)	Linear Calibration Correction	Non-Linear Calibration Corrected
Target0	0.036	0.038
Target1	0.054	0.038
Target2	0.037	0.026
Target3	0.033	0.034
Target4	0.060	0.041
Target5	0.066	0.052
Target6	0.033	0.037
Target6 (>12" radial)	0.078	0.076
Target7	0.047	0.037
Target7 (>12" radial)	0.079	0.079
	for placement within a 6" radius about the center axis of the array: ave = 0.046" min = 0.033" max = 0.066" for placement within a 12" radius from the center axis of the array: ave = 0.055" min = 0.026" max = 0.079"	for placement within a 6" radius about the center axis of the array: ave = 0.038" at a 17.4% improvement in resolution min = 0.026" max = 0.052" for placement within a 12" radius from the center axis of the array: ave = 0.048" at a 12.7% improvement in resolution min = 0.026" max = 0.079"

In general, within a six inch radius from the center the array or along the axial lines, the array has demonstrated a placement accuracy of 0.038 inches deviation from actual

bullet target holes. For a range up to twelve inches from the center of the array, the placement accuracy of 0.048 inches deviation from actual bullet target holes has been achieved. The measured target data, array calibrated data, and CDU graphical plot of the data for the eight examples are shown in FIGS. 23-30. The actual targets for the eight examples are shown in FIGS. 31-38.

The preceding examples can be repeated with similar success by substituting the generically or specifically described reactants and/or operating conditions of this invention for those used in the preceding examples.

Although the invention has been described in detail with particular reference to these preferred embodiments, other embodiments can achieve the same results. Variations and modifications of the present invention will be obvious to those skilled in the art and it is intended to cover in the appended claims all such modifications and equivalents. The entire disclosures of all references, applications, patents, and publications cited above are hereby incorporated by reference.

What is claimed is:

1. A remote sensing apparatus comprising:

a sensor array surrounding a projectile target for sensing a supersonic shock cone prior to a projectile impacting a target, said sensor array comprising at least two pairs of independent orthogonally matched acoustical sensors for detecting a single point on the trajectory of said projectile from a single circular wave generated by said supersonic shock cone based on a absolute time differential of each sensor relative to the center of the sensor array, supersonic projectile impact data computation means, and data transmission means; and
a controller comprising data reception means and data display means.

2. The apparatus of claim 1 wherein said data transmission and reception means comprise RF data transmission and reception means.

3. The apparatus of claim 2 wherein said RF data transmission and reception means operate at a frequency of between approximately 902 and 928 MHz.

4. The apparatus of claim 2 wherein said controller comprises RF Faraday cage shielding.

5. The apparatus of claim 1 wherein said data transmission and reception means comprise collision avoidance means permitting multiple remote targeting apparatus to operate in a vicinity of one another.

6. The apparatus of claim 1 wherein said data display means comprises graphical data display means simulating a target and projectile impact locations thereon.

7. The apparatus of claim 6 wherein said graphical data display means operates in real-time.

8. The apparatus of claim 1 wherein said projectile impact data computation means comprises means for calculating projectile impact locations within twelve inches of a center of said projectile target to an average RMS accuracy of less than approximately fifty thousandths of an inch.

9. The apparatus of claim 1 wherein said projectile impact data computation means comprises means for calculating projectile impact locations in an orthogonal Cartesian coordinate system.

10. The apparatus of claim 1 further comprising means for determining velocity of the projectile.

11. The apparatus of claim 10 wherein said velocity determination means comprises an additional sensor at a predetermined distance from said sensor array which measures a difference in time between the projectile passing said additional sensor and said sensor array.

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12. The apparatus of claim 1 additionally comprising means for correcting for velocity dependent variations in projectile shock front characteristics.

13. The apparatus of claim 1 additionally comprising means for correcting for data display means translation, rotation, and resolution differences with respect to said projectile target and said sensor array.

14. The apparatus of claim 1 wherein said pairs of acoustical sensors comprise two pairs of acoustical transducers placed in a plane at cardinal compass points of said projectile target.

15. The apparatus of claim 14 wherein said pairs of acoustical sensors comprise an additional acoustical transducer orthogonal to said two pairs.

16. The apparatus of claim 15 wherein said projectile impact data computation means comprises means for computing projectile velocity from data provided by said additional acoustical transducer and a paired acoustical transducer.

17. The apparatus of claim 1 wherein each of said sensors is located within an elbow of a housing.

18. The apparatus of claim 17 wherein said housing comprises arms connecting said elbows, which arms and elbows are modular.

19. The apparatus of claim 1 wherein said pairs of acoustical sensors comprise acoustical microphones.

20. A sensor system apparatus for a projectile target for detecting a single point on the trajectory of said projectile from a single circular wave generated by the supersonic shock cone prior to a projectile impacting a target based on an absolute time differential of each sensor relative to the center of the sensor array, said apparatus comprising means for calculating supersonic projectile impact locations within twelve inches of a center of said projectile target to an average RMS accuracy of less than approximately fifty thousandths of an inch.

21. The apparatus of claim 20 wherein said apparatus comprises a sensor array surrounding a projectile target for sensing the projectile trajectory prior to said projectile impacting a target, said sensor array comprising at least two independent orthogonally matched acoustical sensors.

22. The apparatus of claim 21 wherein said sensor array surrounding a projectile target comprises at least two pairs of independent orthogonally matched acoustical sensors.

23. The apparatus of claim 22 wherein said pairs of acoustical sensors comprise two pairs of acoustical transducers placed in a plane at cardinal compass points of said projectile target.

24. The apparatus of claim 22 wherein said pairs of acoustical sensors comprise an additional acoustical transducer orthogonal to said two pairs.

25. The apparatus of claim 24 wherein said projectile impact data computation means comprises means for computing projectile velocity from data provided by said additional acoustical transducer and a paired acoustical transducer.

26. The apparatus of claim 23 wherein said sensors of said two pairs of acoustical sensors are located within four elbows of a diamond-shaped housing.

27. The apparatus of claim 22 wherein said pairs of acoustical sensors comprise acoustical microphones.

28. The apparatus of claim 20 additionally comprising projectile impact data computation means for calculating projectile impact locations in an orthogonal Cartesian coordinate system.

29. The apparatus of claim 20 additionally comprising means for correcting for velocity dependent variations in projectile shock front characteristics.

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30. A remote sensing method comprising the steps of:

- a) surrounding a projectile target with a sensor array for sensing a supersonic shock cone prior to a projectile impacting a target, the sensor array comprising at least two pairs of independent orthogonally matched acoustical sensors for detecting a single point on the trajectory of the projectile from a single circular wave generated by the supersonic shock cone based on an absolute time differential of each sensor relative to the center of the sensor array;
- b) computing projectile impact data;
- c) transmitting the data;
- c) receiving the data at a controller; and
- e) displaying information corresponding to the data.

31. The method of claim 30 wherein transmitting and receiving is done by RF.

32. The method of claim 31 wherein transmitting and receiving occurs at a frequency of between approximately 902 and 928 MHz.

33. The method of claim 31 wherein receiving occurs at a controller comprising RF Faraday cage shielding.

34. The method of claim 30 wherein transmitting and receiving comprising avoiding collisions to permit multiple sensor arrays to operate in a vicinity of one another.

35. The method of claim 30 wherein displaying comprises graphically simulating a target and projectile impact locations thereon.

36. The method of claim 35 wherein displaying occurs in real-time.

37. The method of claim 30 wherein computing comprises the step of calculating projectile impact locations within twelve inches of a center of the projectile target to an average RMS accuracy of less than approximately fifty thousandths of an inch.

38. The method of claim 30 wherein computing comprises the step of calculating projectile impact locations in an orthogonal Cartesian coordinate system.

39. The method of claim 30 further comprising the step of determining velocity of the projectile.

40. The method of claim 39 wherein determining velocity comprises employing an additional sensor at a predetermined distance from the sensor array which measures a difference in time between the projectile passing the additional sensor and the sensor array.

41. The method of claim 30 additionally comprising the step of correcting for velocity dependent variations in projectile shock front characteristics.

42. The method of claim 30 additionally comprising the step of correcting for data display translation, rotation, and resolution differences with respect to the projectile target and the sensor array.

43. The method of claim 30 wherein the surrounding step comprises providing two pairs of acoustical transducers placed in a plane at cardinal compass points of the projectile target.

44. The method of claim 43 wherein in the surrounding step the pairs of acoustical sensors comprise an additional acoustical transducer orthogonal to the two pairs.

45. The method of claim 44 wherein computing comprises the step of computing projectile velocity from data provided by the additional acoustical transducer and a paired acoustical transducer.

46. The method of claim 30 wherein in the surrounding step each of the sensors is located within an elbow of a housing.

47. The method of claim 46 wherein in the surrounding step the housing comprises arms connecting the elbows, which arms and elbows are modular.

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48. The method of claim 30 wherein in the surrounding step the pairs of acoustical sensors comprise acoustical microphones.

49. A sensor method for a projectile target, for detecting a single point on the trajectory of the projectile from a single circular wave generated by the supersonic shock cone prior to a projectile impacting a target based on a absolute time differential of each sensor relative to the center of the sensor array, the method comprising calculating supersonic projectile impact locations within twelve inches of a center of the projectile target to an average RMS accuracy of less than approximately fifty thousandths of an inch.

50. The method of claim 49 additionally comprising the step of surrounding a projectile target with a sensor array comprising at least two independent orthogonally matched acoustical sensors.

51. The method of claim 50 wherein in the surrounding step the sensor array comprises at least two pairs of independent orthogonally matched acoustical sensors.

52. The method of claim 51 wherein in the surrounding step the pairs of acoustical sensors comprise two pairs of acoustical transducers placed in a plane at cardinal compass points of the projectile target.

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53. The method of claim 51 wherein in the surrounding step the pairs of acoustical sensors comprise an additional acoustical transducer orthogonal to the two pairs.

54. The method of claim 53 wherein the calculating step comprises computing projectile velocity from data provided by the additional acoustical transducer and a paired acoustical transducer.

55. The method of claim 52 wherein in the surrounding step the sensors of the two pairs of acoustical sensors are located within four elbows of a diamond-shaped housing.

56. The method of claim 51 wherein in the surrounding step the pairs of acoustical sensors comprise acoustical microphones.

57. The method of claim 49 wherein calculating comprises calculating projectile impact locations in an orthogonal Cartesian coordinate system.

58. The method of claim 49 additionally comprising the step of correcting for velocity dependent variations in projectile shock front characteristics.

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