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(54) **COMPENSATION SYSTEM FOR ELECTRONIC COMPASS**

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(52) **U.S. Cl.** **33/356**

(57) **ABSTRACT**

An electronic compass is described for use in vehicles. The compass employs a magnetoresistive sensor for sensing the earth magnetic field and the sensor is operated in alternate set/reset bias modes. In a first embodiment, the compass is provided with deviation compensation by a closed loop system including measurement of the sensor output signals and an offset current strap for nullifying the vehicle deviation field. In a second embodiment, deviation compensation is provided by operation in an initial calibration mode and by operation in a normal compensation mode to adjust compensation, as needed, on a long term basis during normal operation of the compass. In the initial calibration mode, while the vehicle is being driven, the signal peak values are adjusted to a nominal earth field level by changing the offset current. Then, compensating signal reference values for each axis are determined as each peak for that axis is determined. The system automatically exits the initial calibration mode when certain criteria have been met. In the normal compensation mode, The signal reference value for each axis is adjusted at least once during the time interval between turn-on and turn-off of the vehicle ignition switch.

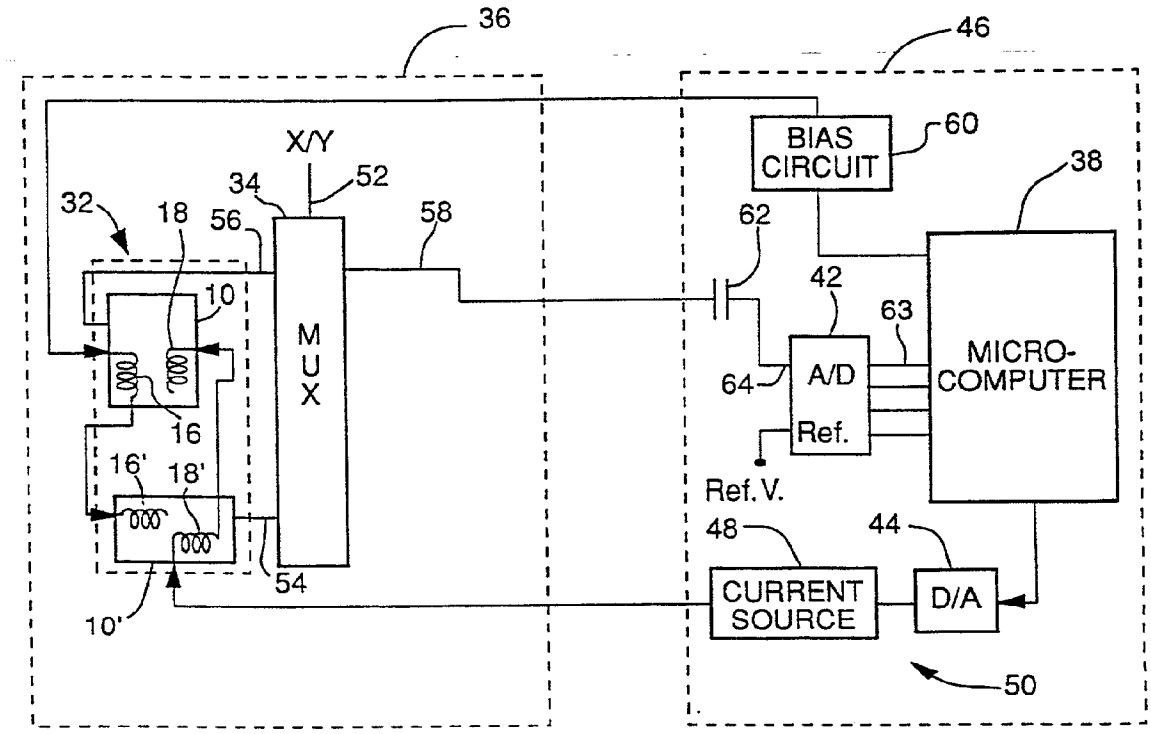


FIG - 1

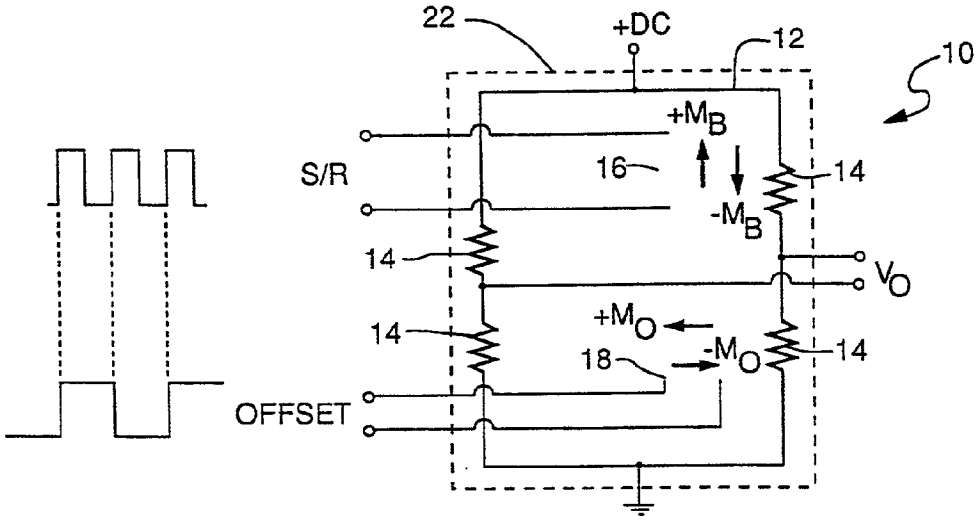

22
+DC
12
10
+M_B
S/R
16
14
-M_B
14
V_O
+M_O
14
-M_O
14
18
OFFSET

FIG - 2

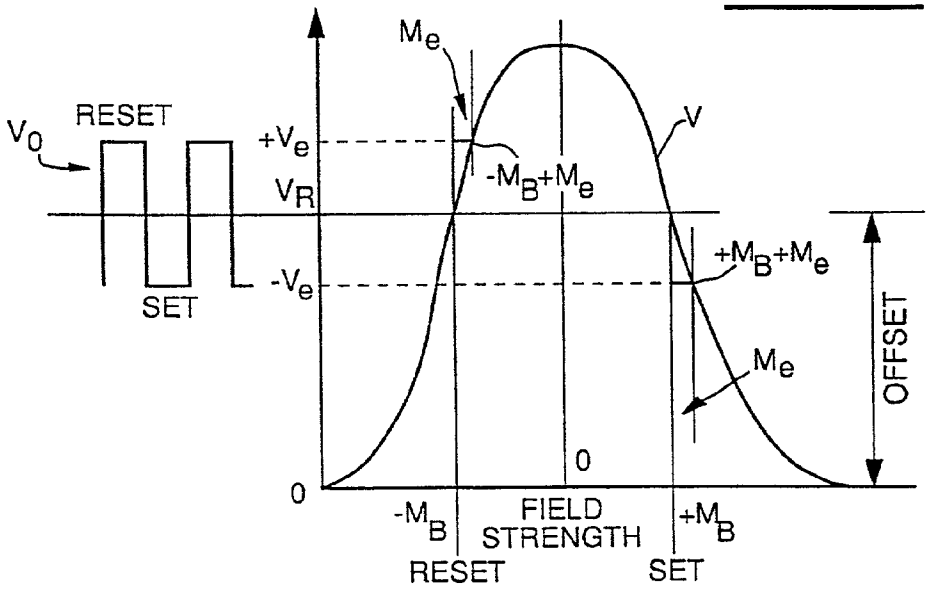

M_e
V_0
RESET
+V_e
V
V_R
-M_B+M_e
+M_B+M_e
-V_e
SET
M_e
OFFSET
0
0
-M_B
FIELD STRENGTH
+M_B
RESET
SET

FIG - 3

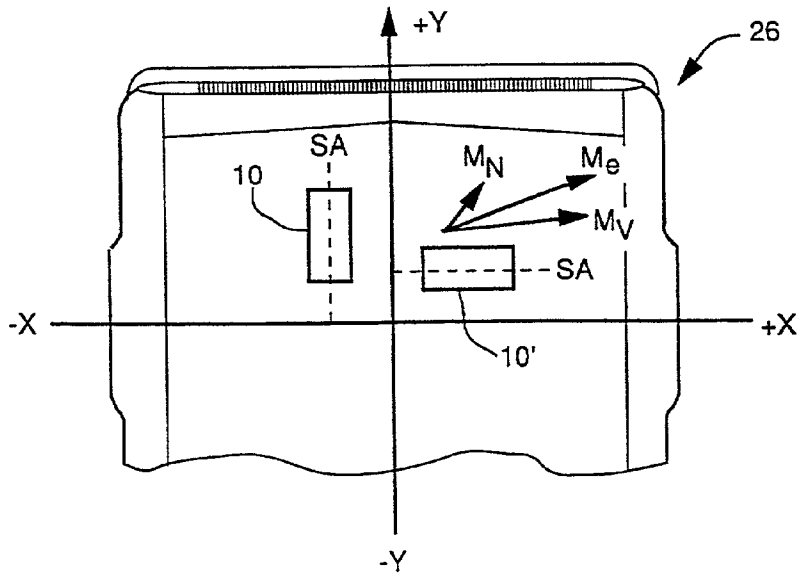

+Y
26
SA
10
M_N
M_e
M_V
SA
-X
+X
10'
-Y

FIG - 4

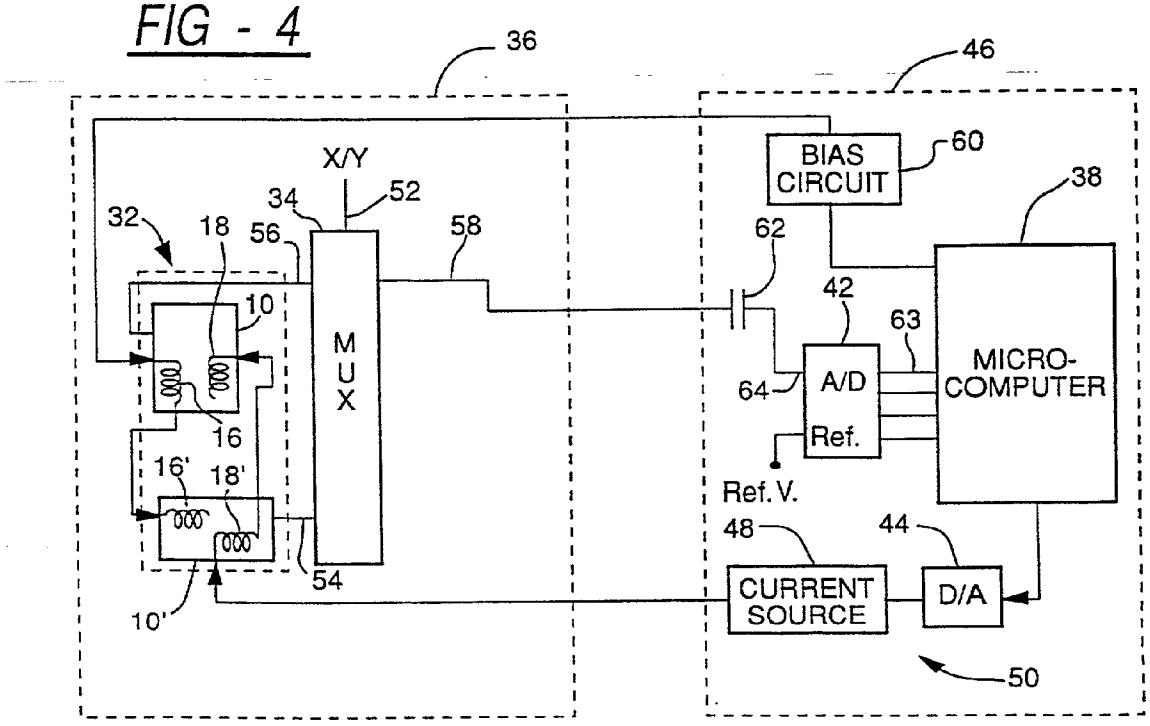

36
46
X/Y
34
52
32
18
56
58
10
MUX
16
16'
18'
54
10'
BIAS CIRCUIT
60
38
62
42
63
64
A/D
Ref.
MICRO-COMPUTER
Ref. V.
48
44
CURRENT SOURCE
D/A
50

FIG - 5A

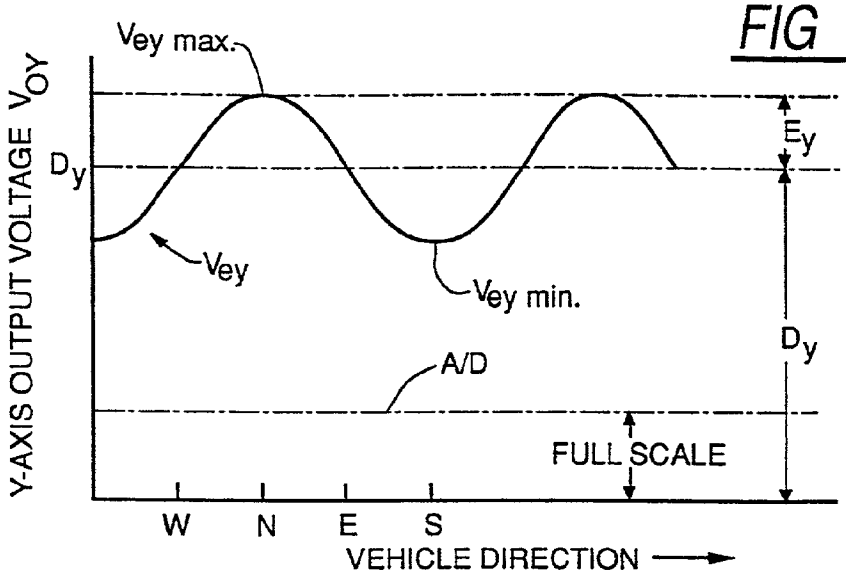


FIG - 5B

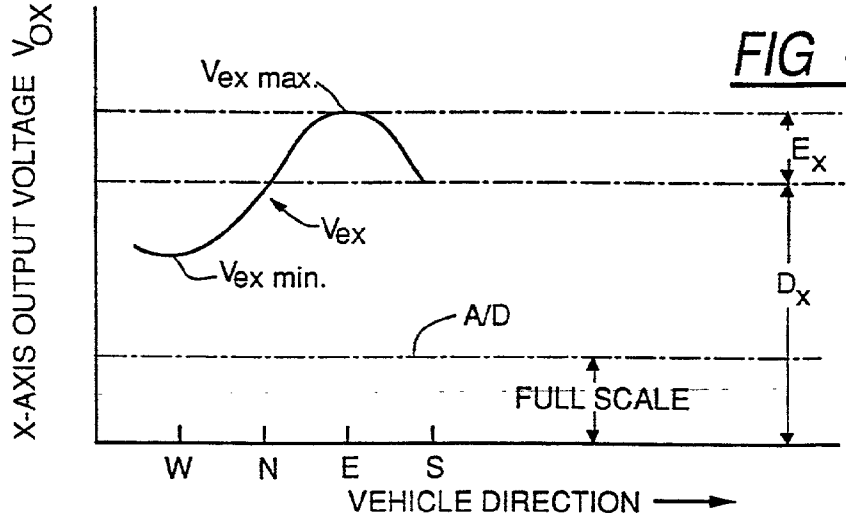
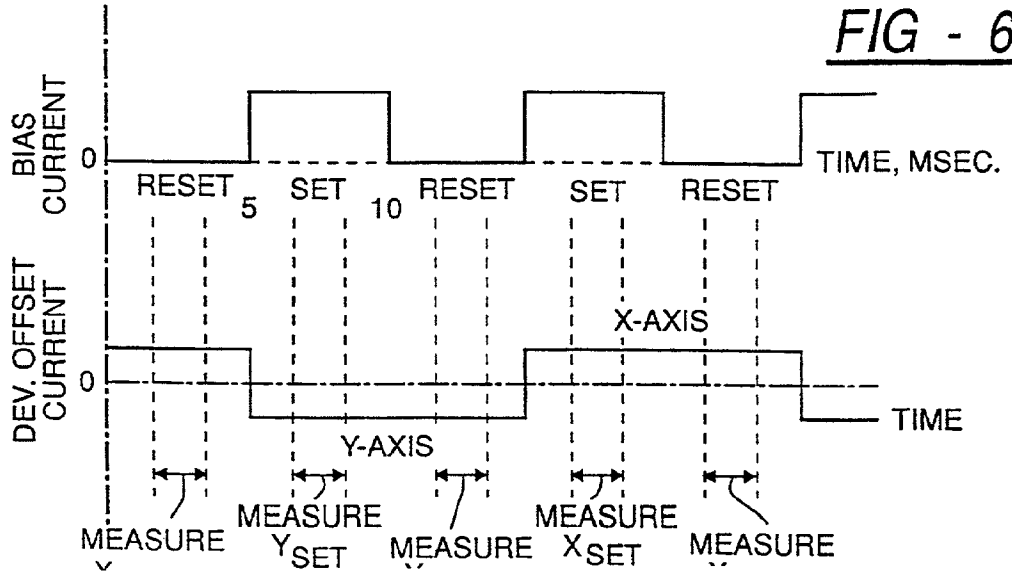


FIG - 6



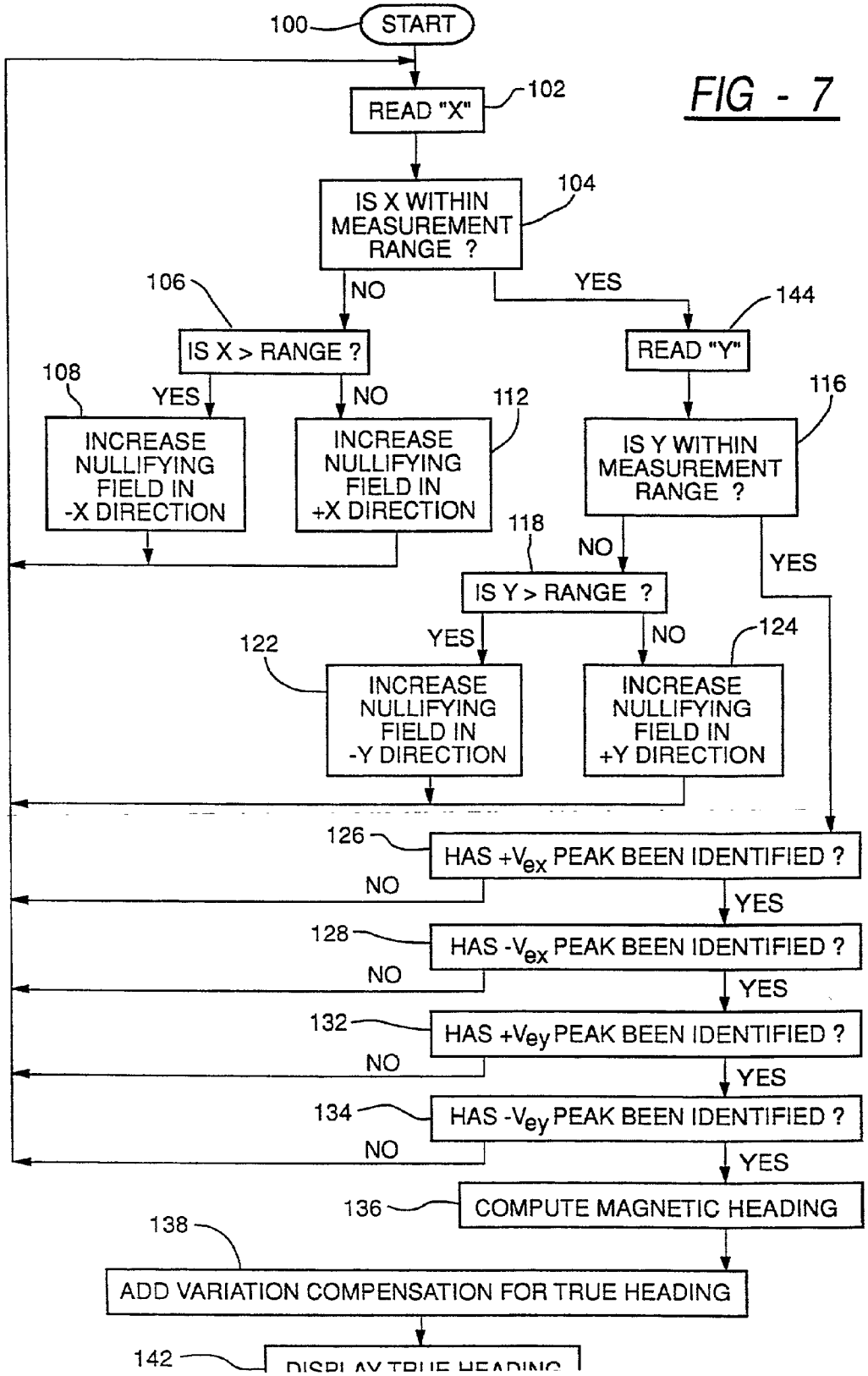
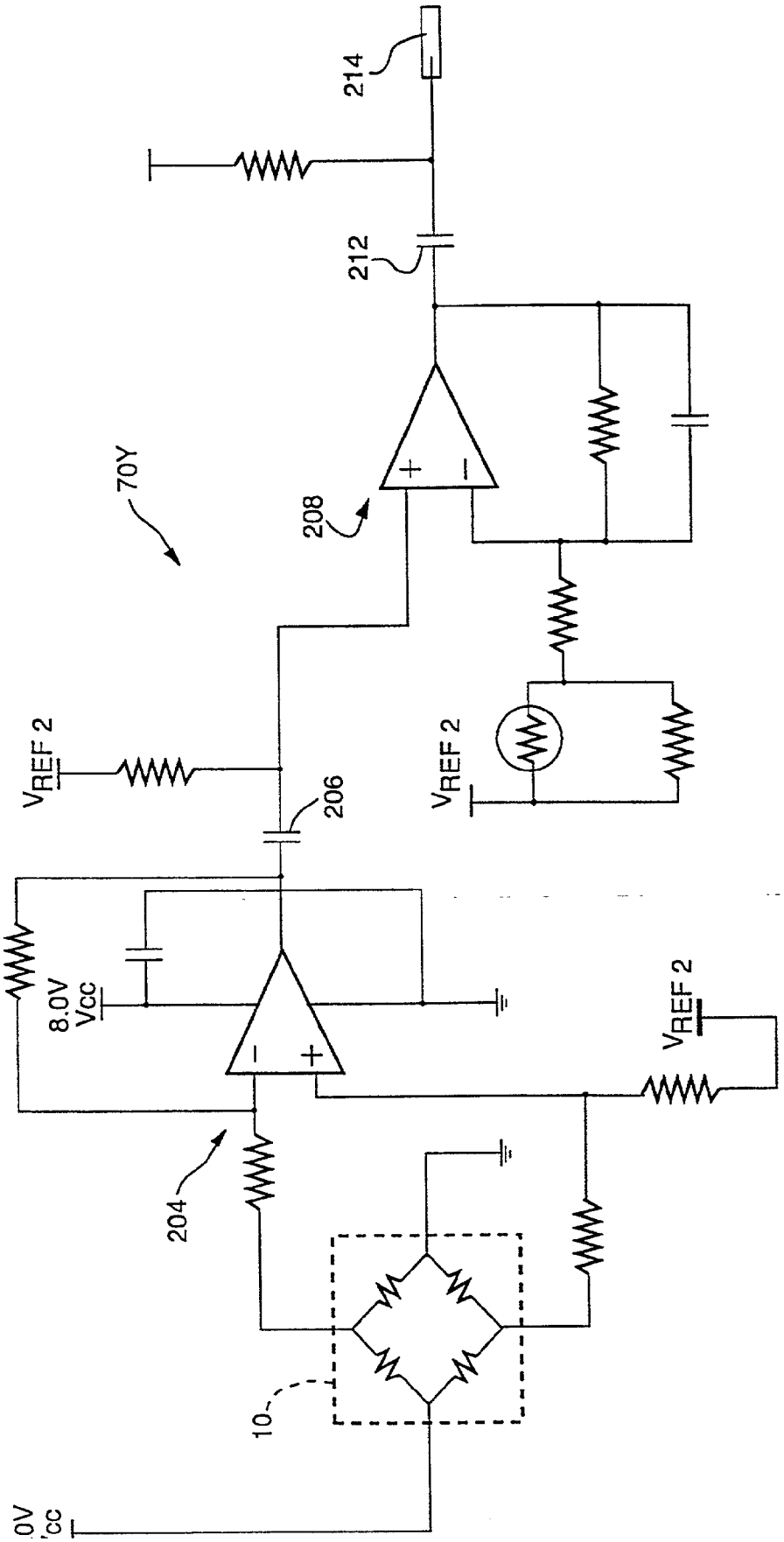

100
START
READ "X"
102
IS X WITHIN MEASUREMENT RANGE ?
104
NO
YES
106
IS X > RANGE ?
144
READ "Y"
108
YES
NO
112
INCREASE NULLIFYING FIELD IN -X DIRECTION
INCREASE NULLIFYING FIELD IN +X DIRECTION
116
IS Y WITHIN MEASUREMENT RANGE ?
118
NO
YES
IS Y > RANGE ?
YES
NO
122
124
INCREASE NULLIFYING FIELD IN -Y DIRECTION
INCREASE NULLIFYING FIELD IN +Y DIRECTION
126
HAS +Vex PEAK BEEN IDENTIFIED ?
NO
YES
128
HAS -Vex PEAK BEEN IDENTIFIED ?
NO
YES
132
HAS +Vey PEAK BEEN IDENTIFIED ?
NO
YES
134
HAS -Vey PEAK BEEN IDENTIFIED ?
NO
YES
136
COMPUTE MAGNETIC HEADING
138
ADD VARIATION COMPENSATION FOR TRUE HEADING
142
DISPLAY TRUE HEADING

FIG - 7

FIG - 8



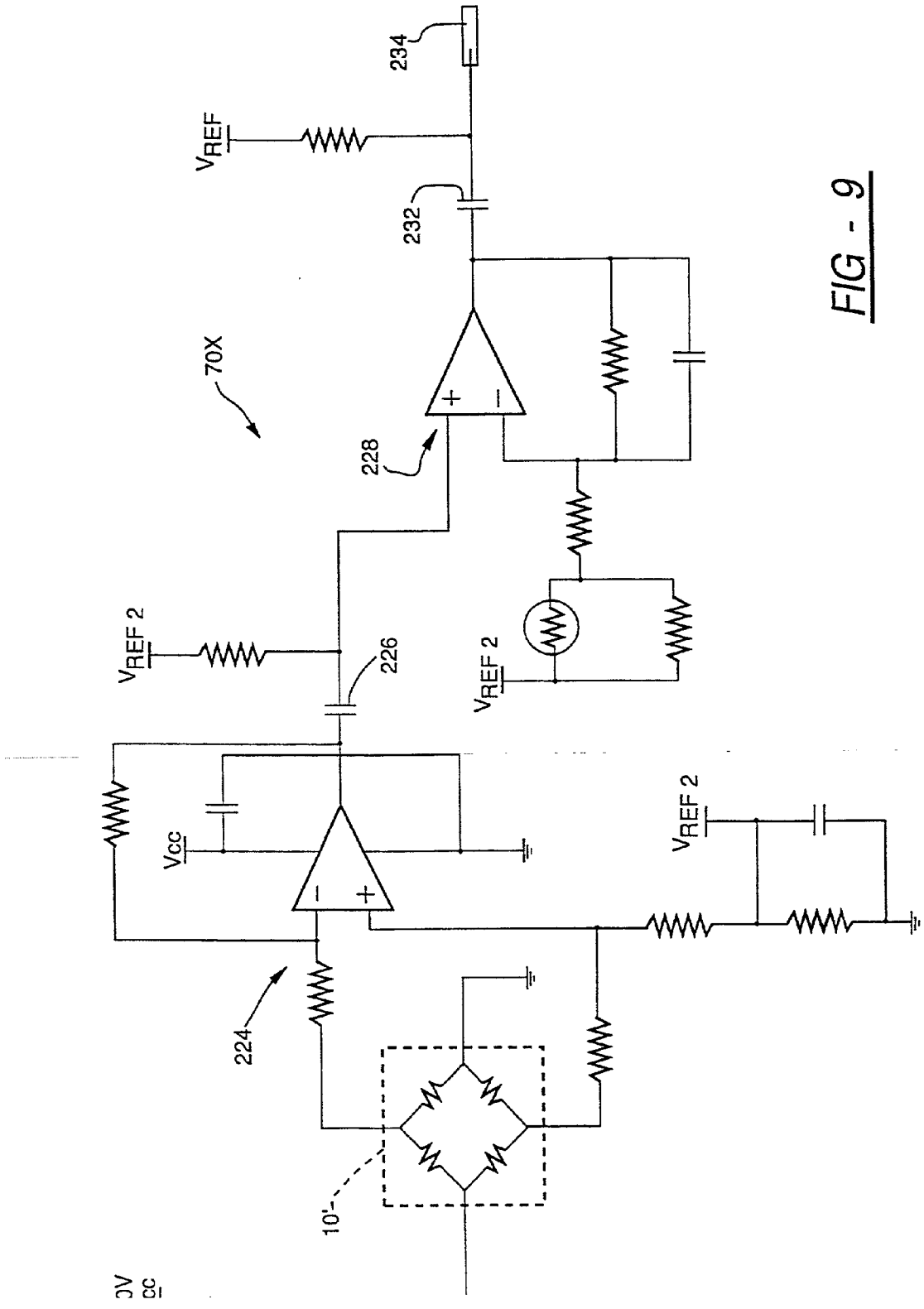


FIG - 9

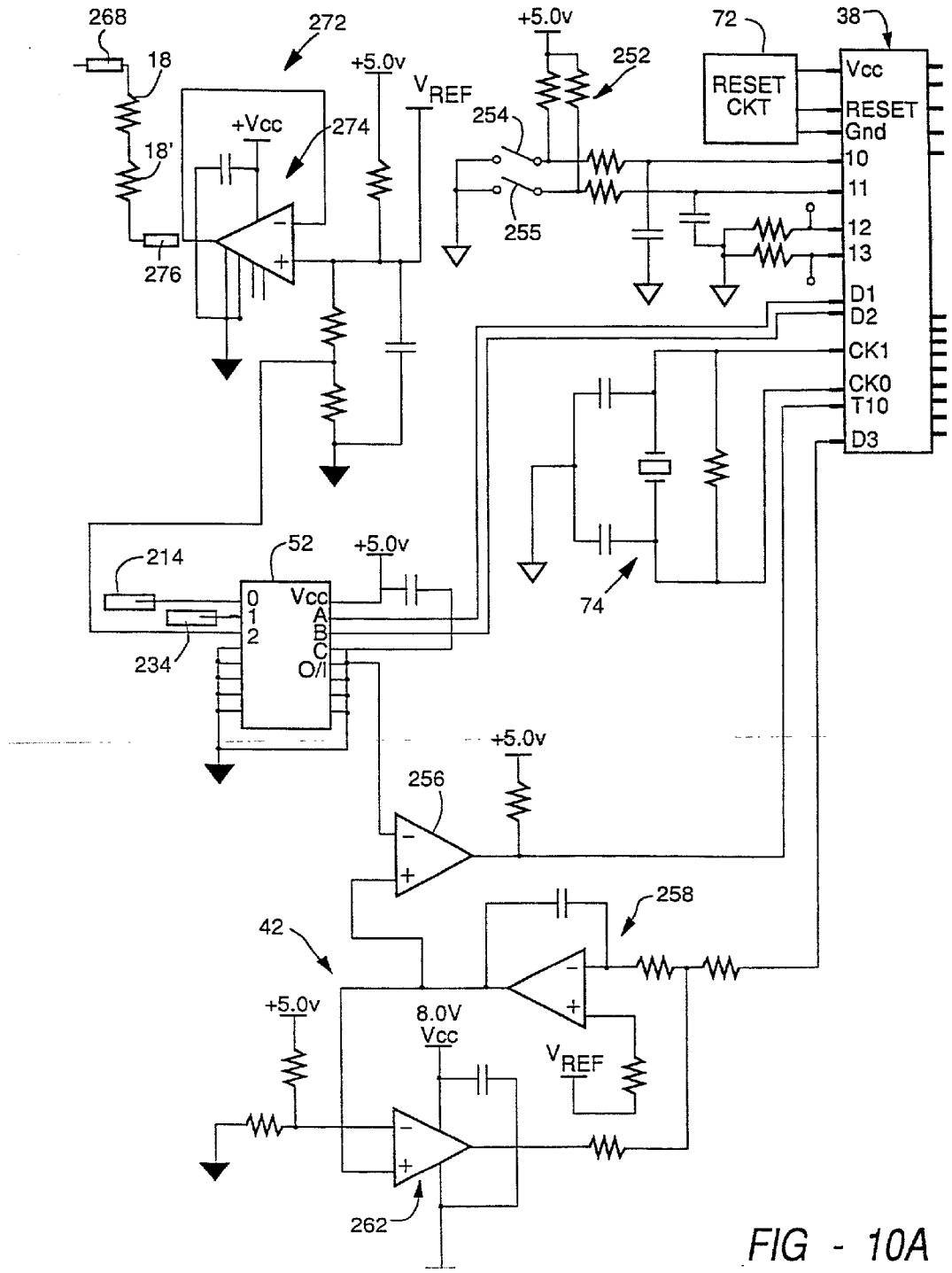
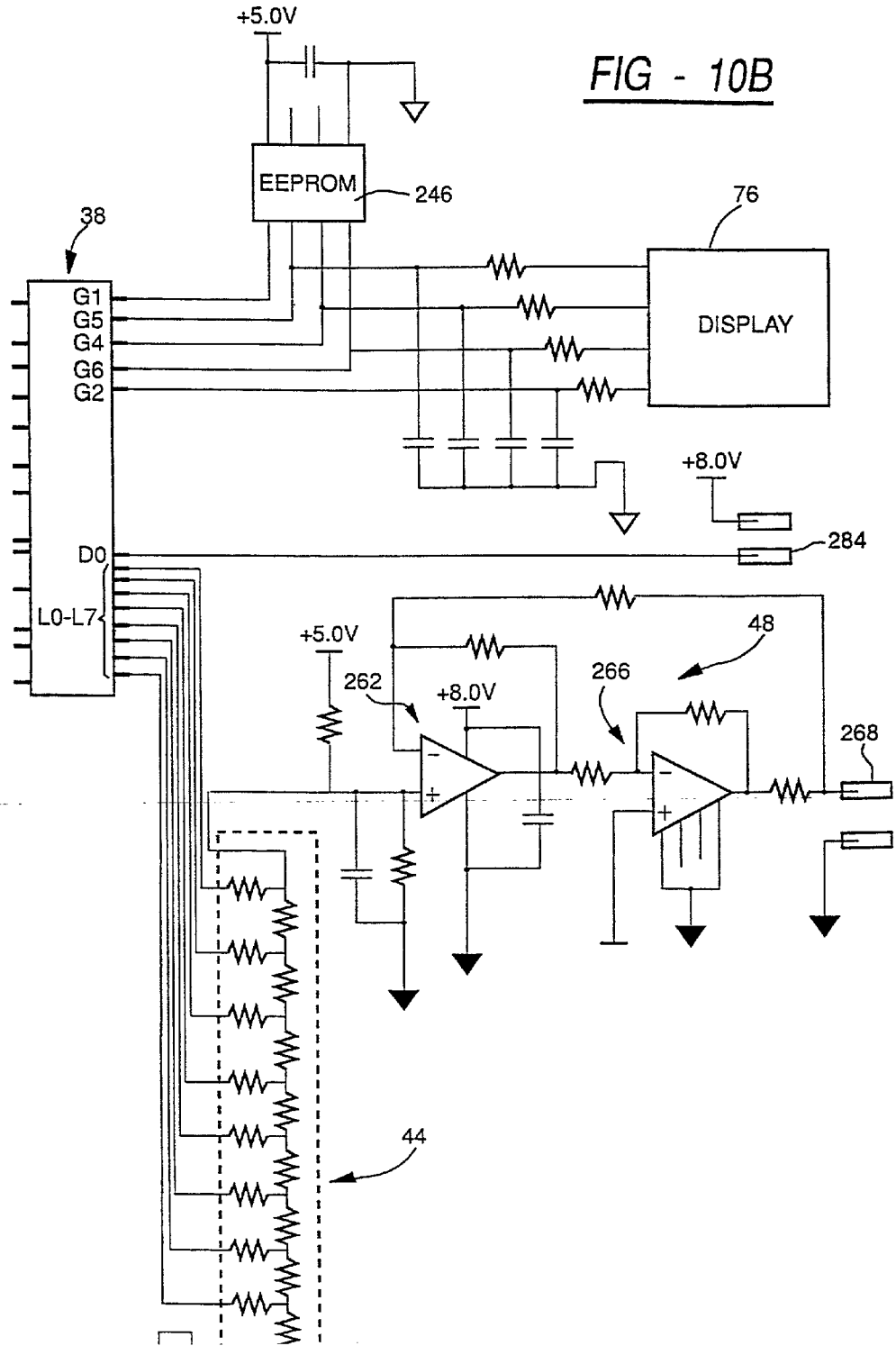

268
272
+5.0v
72
38
18
+5.0v
V_{REF}
252
RESET CKT
Vcc
RESET
Gnd
254
+Vcc
274
18'
10
11
255
12
13
276
D1
D2
CK1
CK0
T10
D3
214
52
+5.0v
0
1
2
Vcc
A
B
C
O/I
74
234
+5.0v
256
258
42
+5.0v
8.0V
Vcc
V_{REF}
262

FIG - 10A

FIG - 10B


+5.0V
EEPROM
246
76
38
G1
G5
G4
G6
G2
DISPLAY
+8.0V
284
D0
L0-L7
+5.0V
48
262
+8.0V
266
268
44

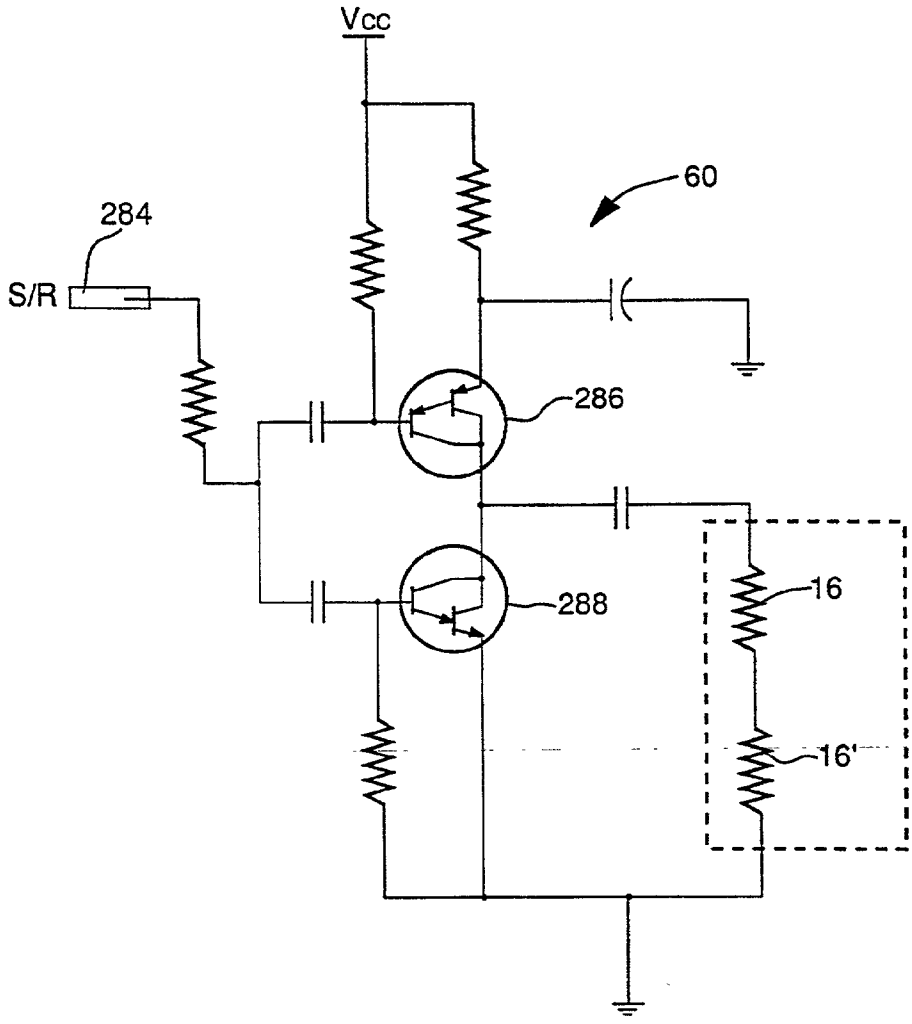


FIG - 11

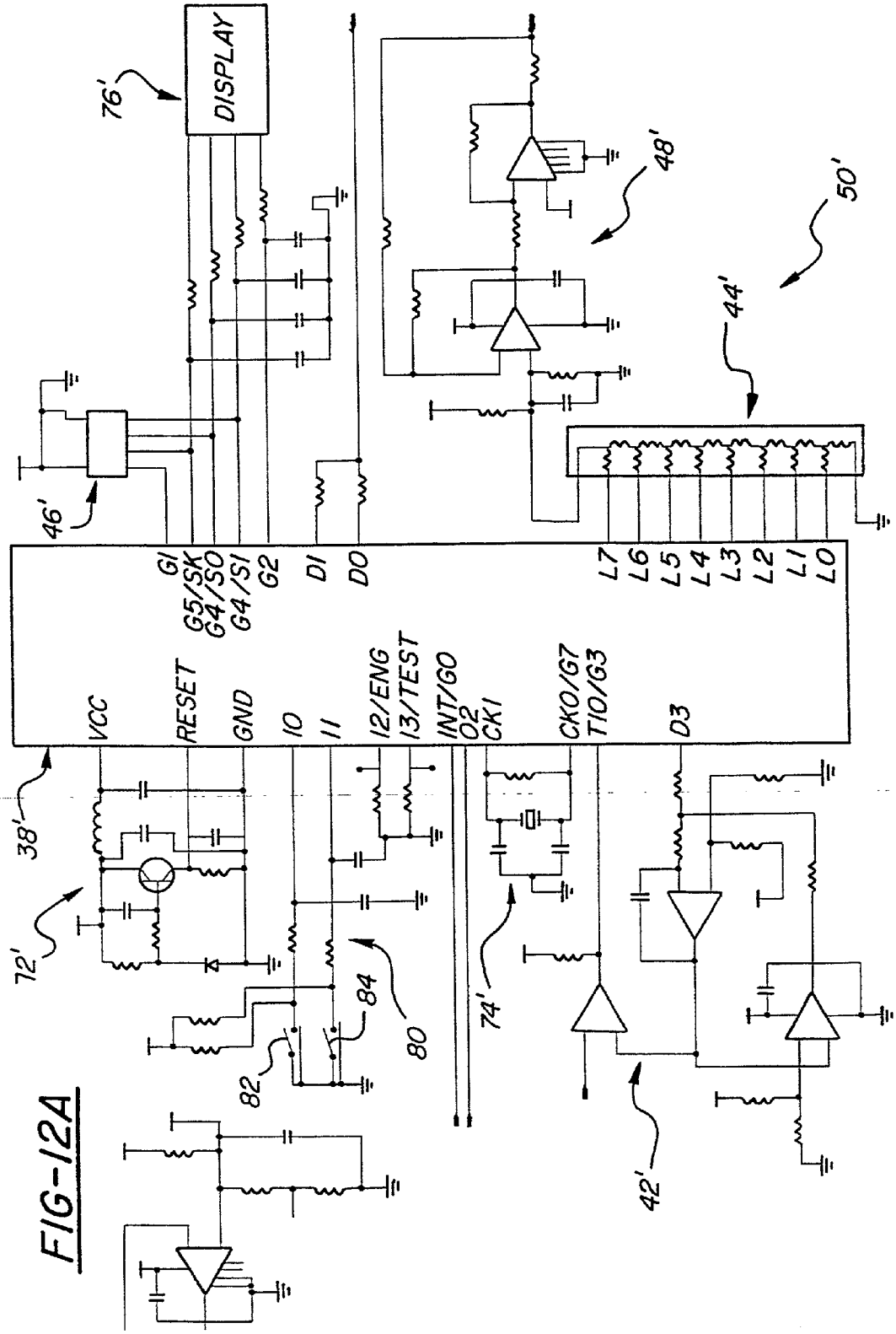

DISPLAY
76'
48'
50'
44'
46'
GI
G5/SK
G4/SO
G4/SI
G2
DI
DO
L7
L6
L5
L4
L3
L2
L1
L0
VCC
RESET
GND
I0
I1
I2/ENG
I3/TEST
INT/GO
O2
CKI
CKO/G7
TIO/G3
D3
38'
72'
74'
80
82
84
42'

FIG-12A

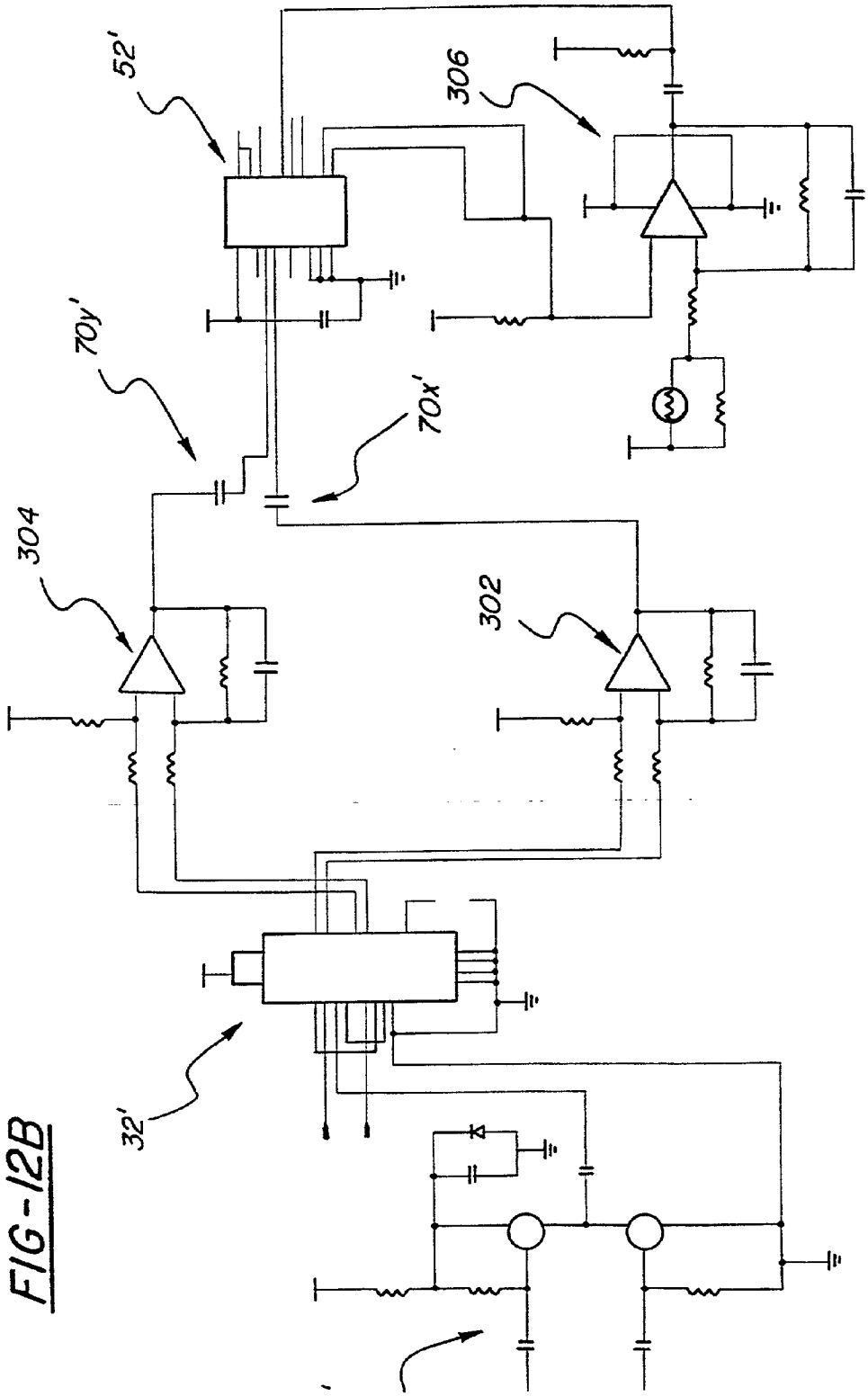


FIG-12B

FIG-13

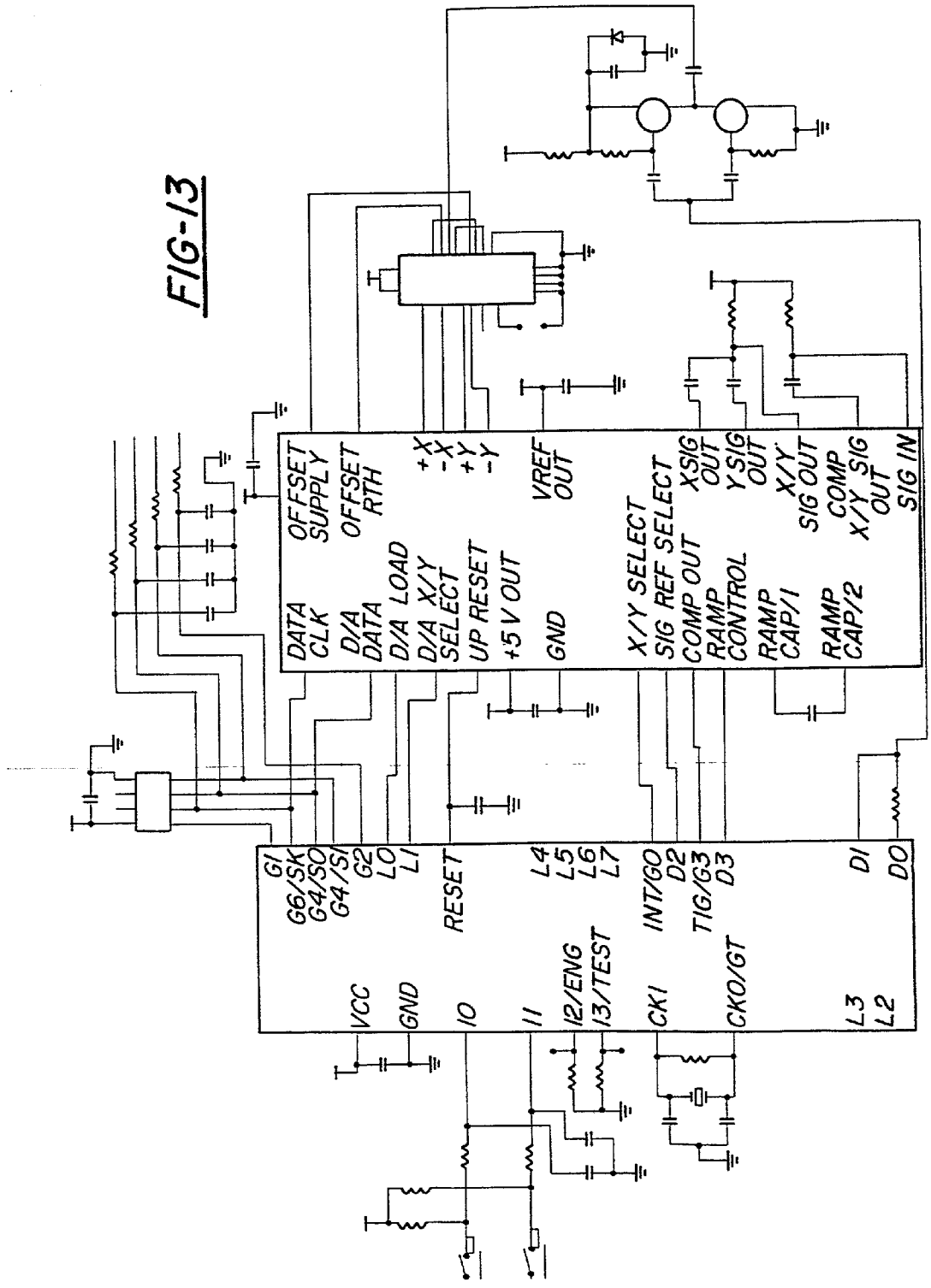

OFFSET SUPPLY
OFFSET RTH
+X
-X
+Y
-Y
VREF OUT
XSIG OUT
YSIG OUT
X/Y SIG OUT
COMP X/Y SIG OUT
SIG IN
DATA CLK
D/A DATA
D/A LOAD
D/A X/Y SELECT
UP RESET
+5 V OUT
GND
X/Y SELECT
SIG REF SELECT
COMP OUT
RAMP CONTROL
RAMP CAP/1
RAMP CAP/2
G1
G6/SK
G4/SO
G4/SI
G2
L0
L1
RESET
L4
L5
L6
L7
INT/GO
D2
TIG/G3
D3
DI
DO
VCC
GND
I0
I1
I2/ENG
I3/TEST
CK1
CKO/GT
L3
L2

FIG - 14A

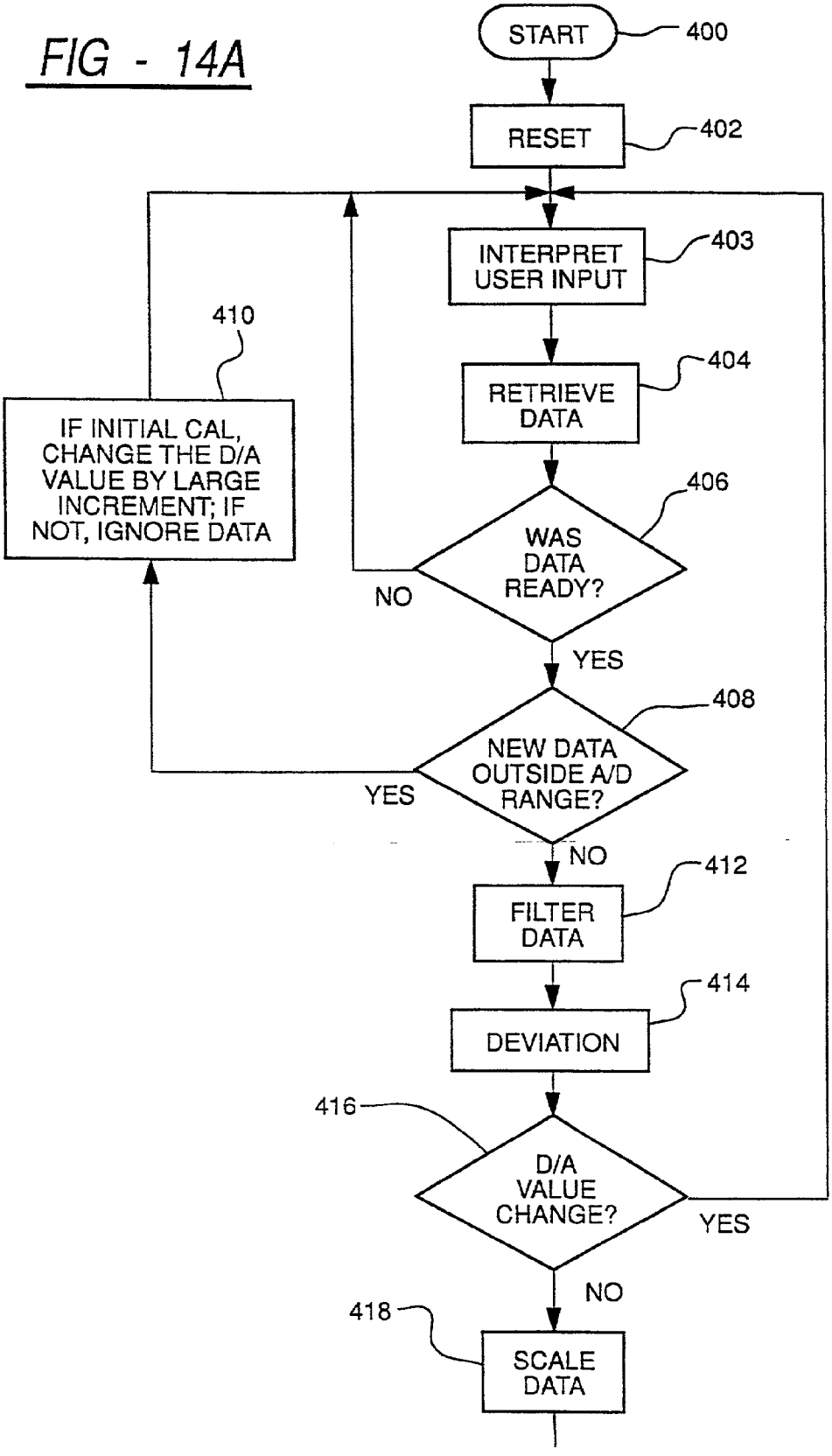
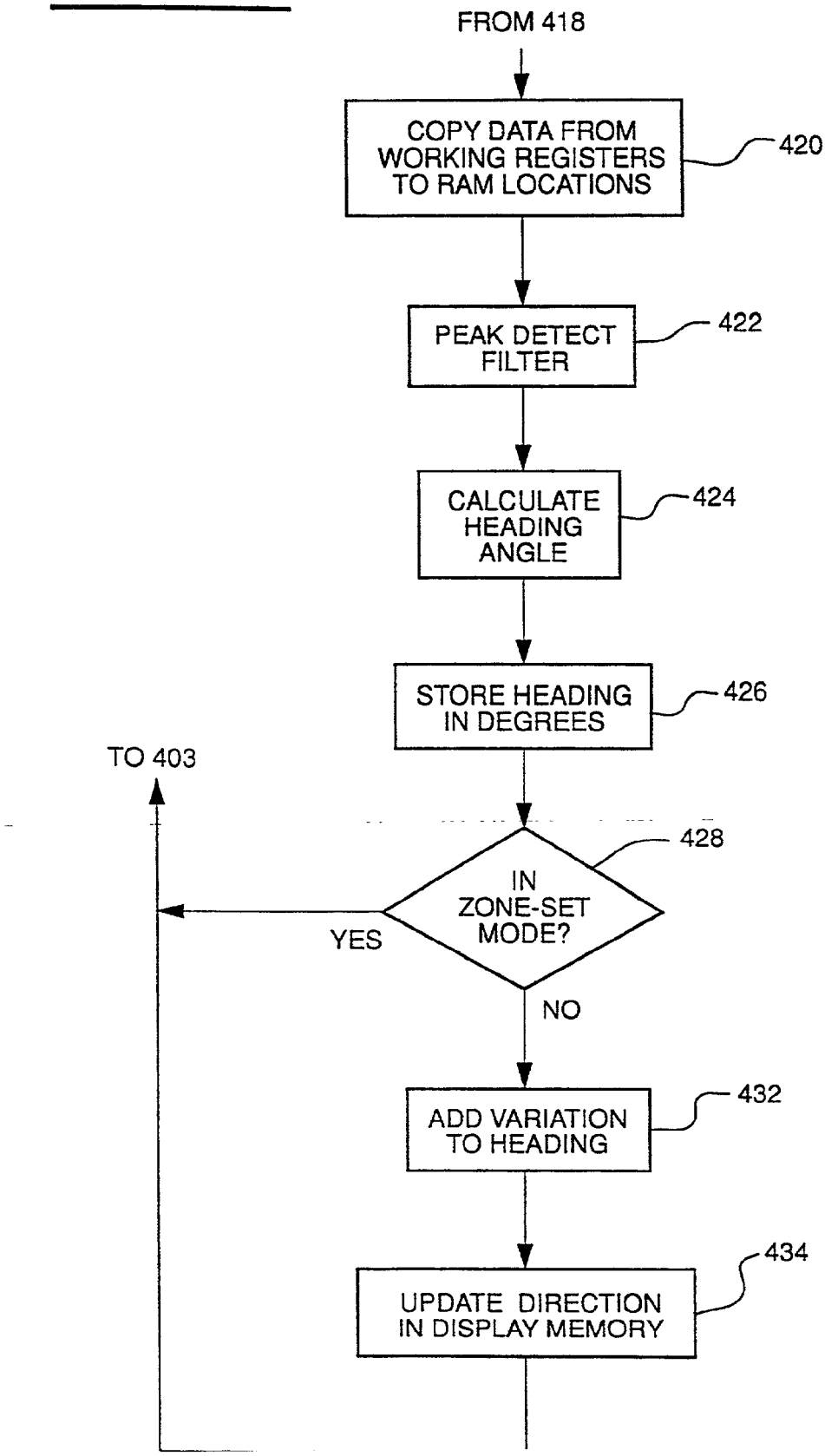

START
400
RESET
402
INTERPRET USER INPUT
403
RETRIEVE DATA
404
WAS DATA READY?
406
NO
YES
NEW DATA OUTSIDE A/D RANGE?
408
YES
NO
IF INITIAL CAL, CHANGE THE D/A VALUE BY LARGE INCREMENT; IF NOT, IGNORE DATA
410
FILTER DATA
412
DEVIATION
414
D/A VALUE CHANGE?
416
YES
NO
SCALE DATA
418

FIG - 14B


FROM 418
COPY DATA FROM WORKING REGISTERS TO RAM LOCATIONS
420
PEAK DETECT FILTER
422
CALCULATE HEADING ANGLE
424
STORE HEADING IN DEGREES
426
TO 403
428
IN ZONE-SET MODE?
YES
NO
ADD VARIATION TO HEADING
432
UPDATE DIRECTION IN DISPLAY MEMORY
434

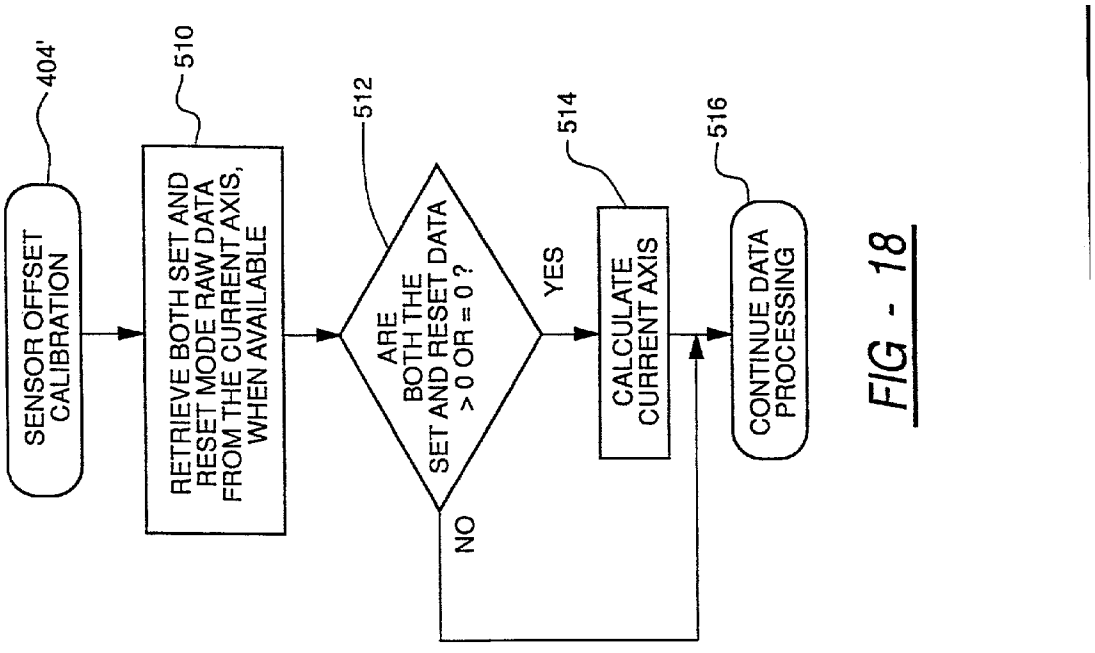
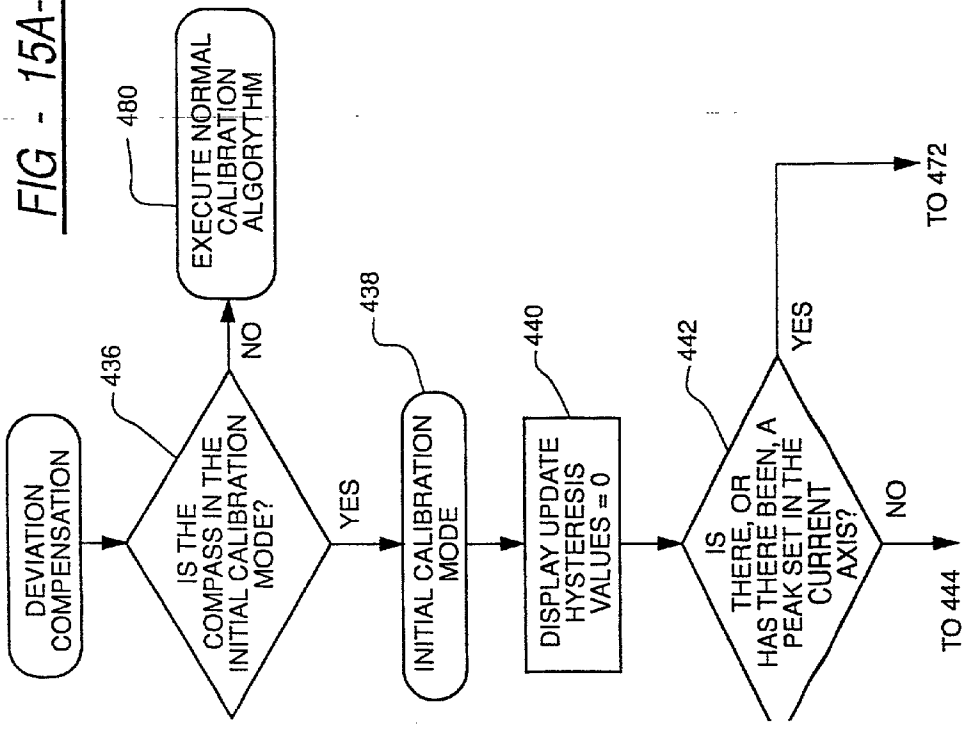


FIG - 18

FIG - 15A-1



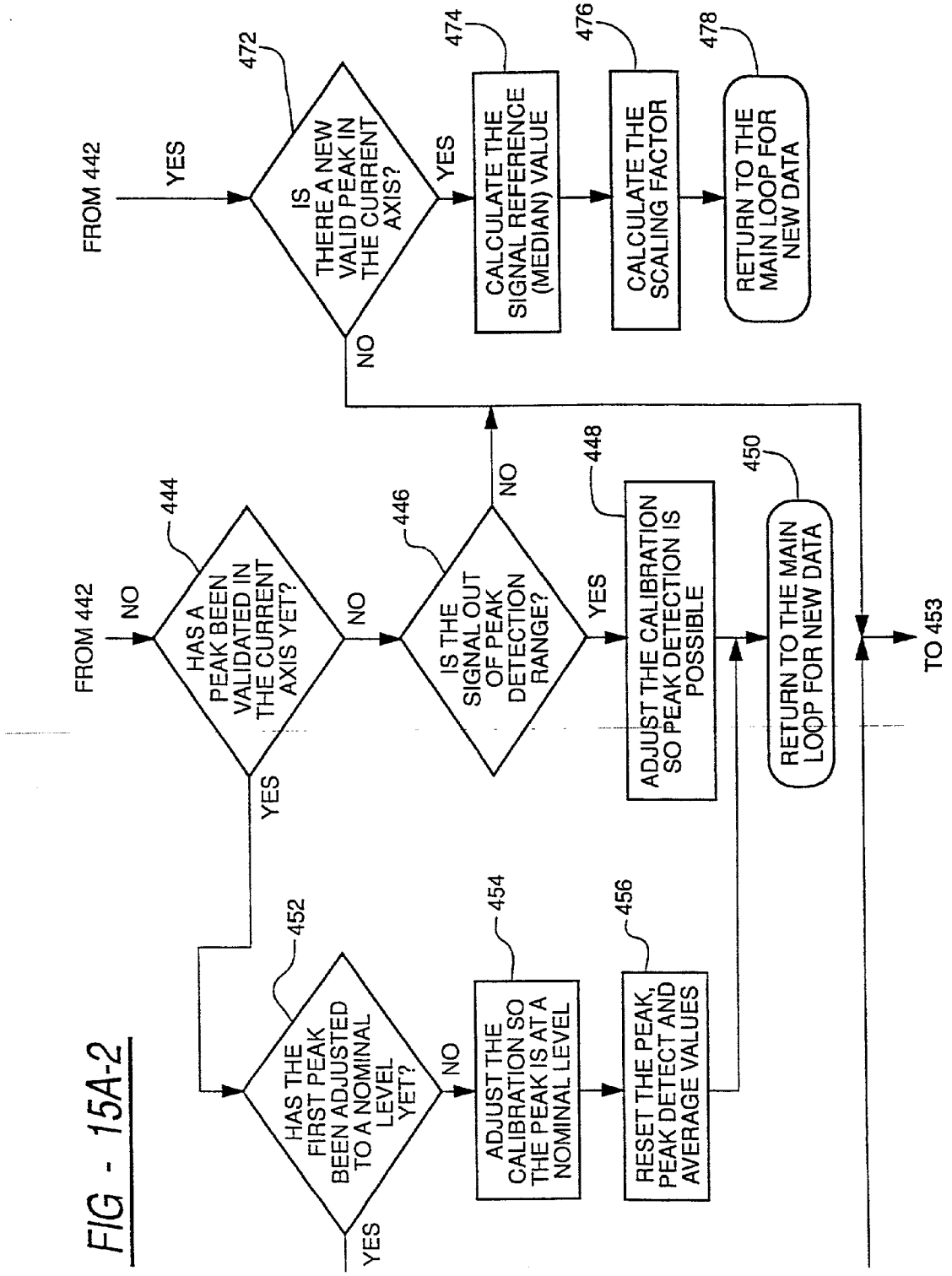

FROM 442
NO
HAS A PEAK BEEN VALIDATED IN THE CURRENT AXIS YET?
444
YES
NO
IS THE SIGNAL OUT OF PEAK DETECTION RANGE?
446
YES
NO
ADJUST THE CALIBRATION SO PEAK DETECTION IS POSSIBLE
448
RETURN TO THE MAIN LOOP FOR NEW DATA
450
TO 453
HAS THE FIRST PEAK BEEN ADJUSTED TO A NOMINAL LEVEL YET?
452
YES
NO
ADJUST THE CALIBRATION SO THE PEAK IS AT A NOMINAL LEVEL
454
RESET THE PEAK, PEAK DETECT AND AVERAGE VALUES
456
FROM 442
YES
IS THERE A NEW VALID PEAK IN THE CURRENT AXIS?
472
YES
NO
CALCULATE THE SIGNAL REFERENCE (MEDIAN) VALUE
474
CALCULATE THE SCALING FACTOR
476
RETURN TO THE MAIN LOOP FOR NEW DATA
478

FIG - 15A-2

FIG - 15B

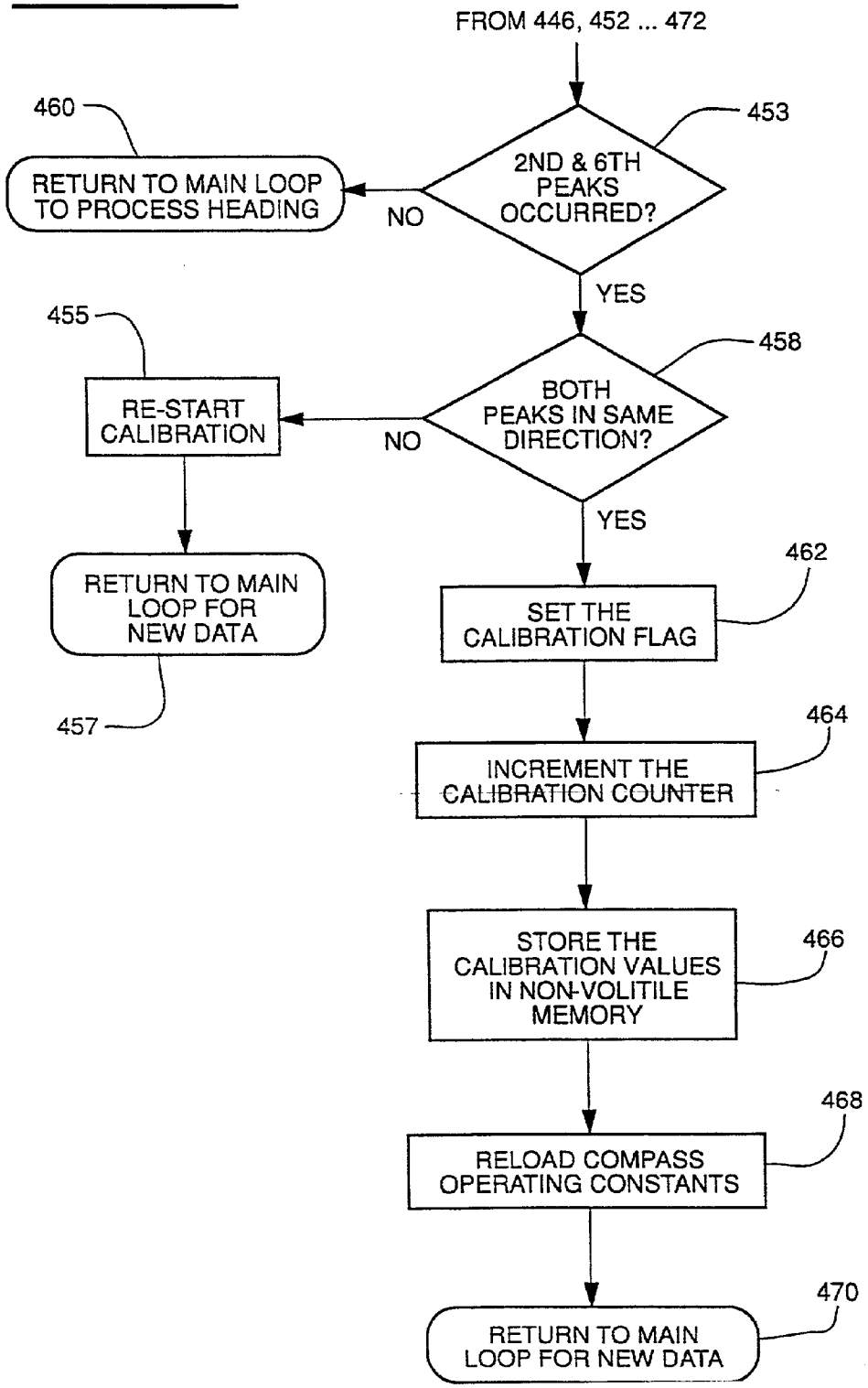
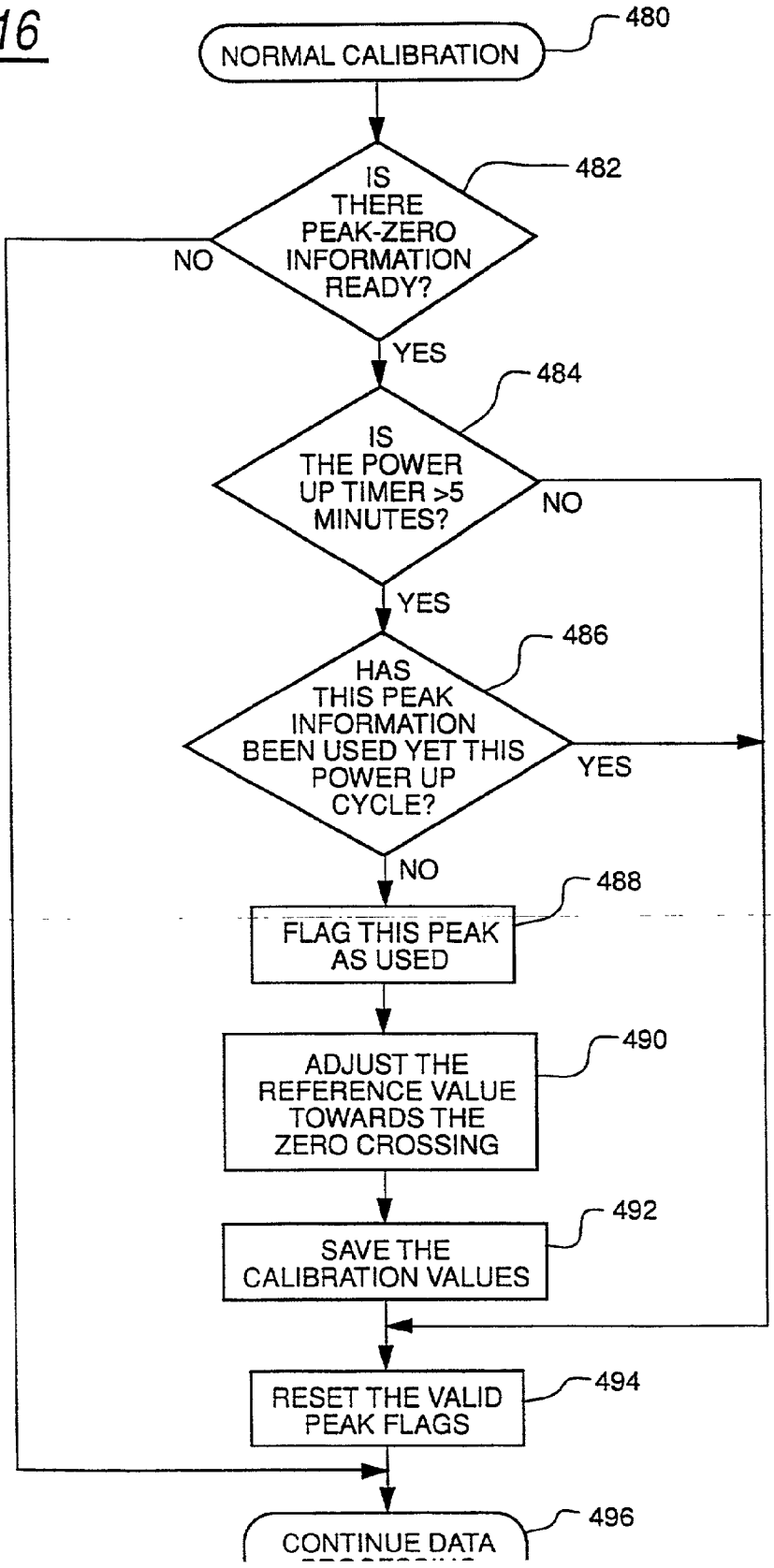

FROM 446, 452 ... 472
453
2ND & 6TH PEAKS OCCURRED?
NO
460
RETURN TO MAIN LOOP TO PROCESS HEADING
YES
458
BOTH PEAKS IN SAME DIRECTION?
NO
455
RE-START CALIBRATION
YES
462
SET THE CALIBRATION FLAG
464
INCREMENT THE CALIBRATION COUNTER
466
STORE THE CALIBRATION VALUES IN NON-VOLITILE MEMORY
468
RELOAD COMPASS OPERATING CONSTANTS
470
RETURN TO MAIN LOOP FOR NEW DATA
RETURN TO MAIN LOOP FOR NEW DATA
457

FIG - 16


NORMAL CALIBRATION
480
IS THERE PEAK-ZERO INFORMATION READY?
482
NO
YES
IS THE POWER UP TIMER >5 MINUTES?
484
NO
YES
HAS THIS PEAK INFORMATION BEEN USED YET THIS POWER UP CYCLE?
486
YES
NO
FLAG THIS PEAK AS USED
488
ADJUST THE REFERENCE VALUE TOWARDS THE ZERO CROSSING
490
SAVE THE CALIBRATION VALUES
492
RESET THE VALID PEAK FLAGS
494
CONTINUE DATA
496

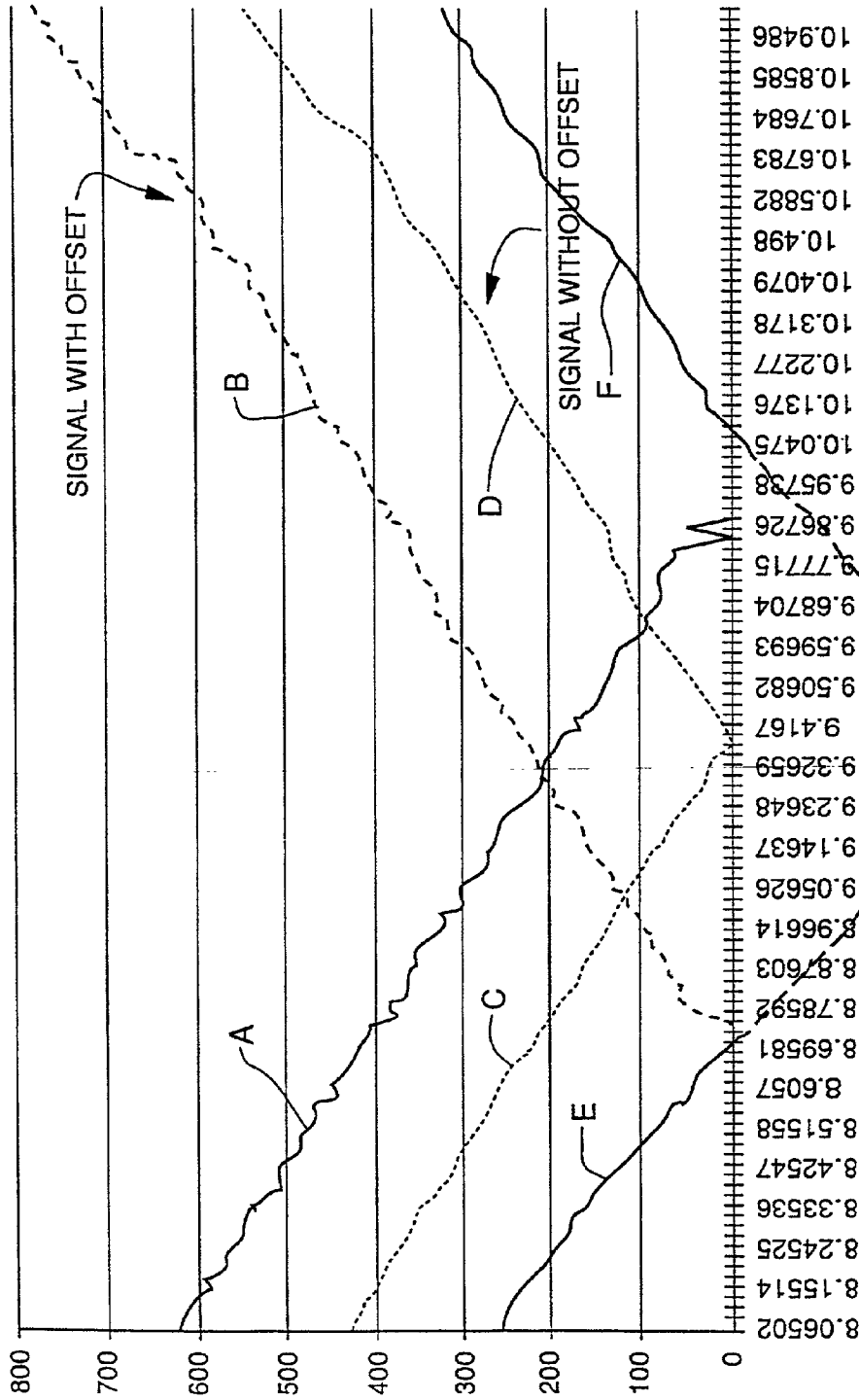

SIGNAL WITH OFFSET
SIGNAL WITHOUT OFFSET
A
B
C
D
E
F
800
700
600
500
400
300
200
100
0
8.06502
8.15514
8.24525
8.33536
8.42547
8.51558
8.6057
8.69581
8.78592
8.87603
8.96614
9.05626
9.14637
9.23648
9.32659
9.4167
9.50682
9.59693
9.68704
9.77715
9.86726
9.95738
10.0475
10.1376
10.2277
10.3178
10.4079
10.498
10.5882
10.6783
10.7684
10.8585
10.9486

FIG - 17

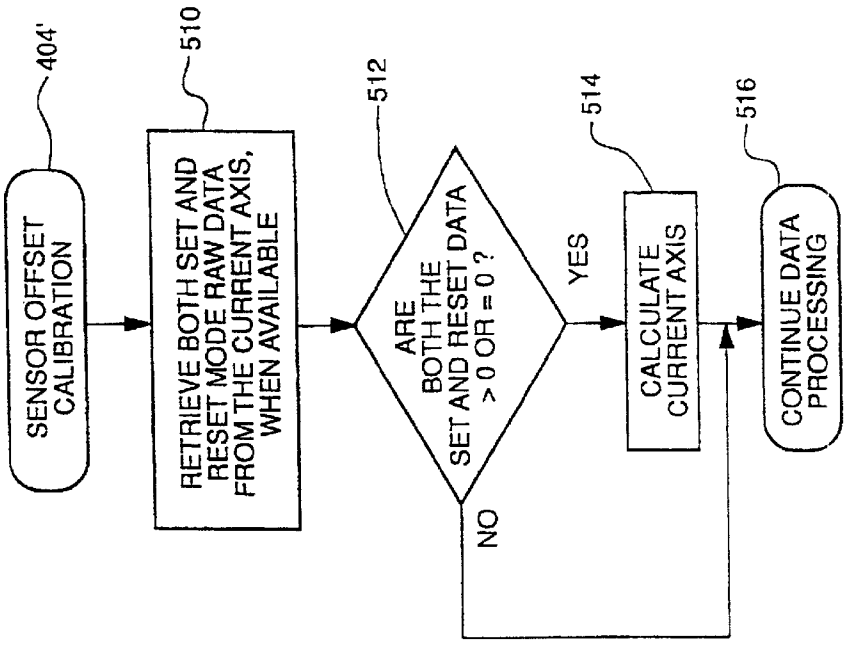


FIG - 18

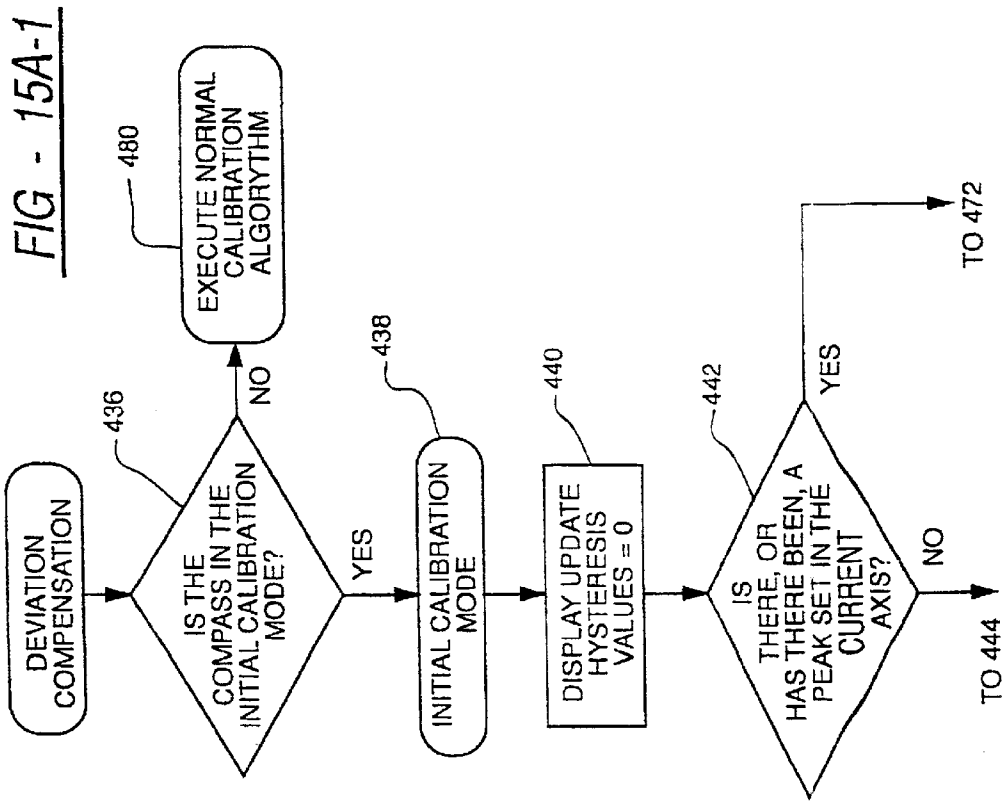


FIG - 15A-1

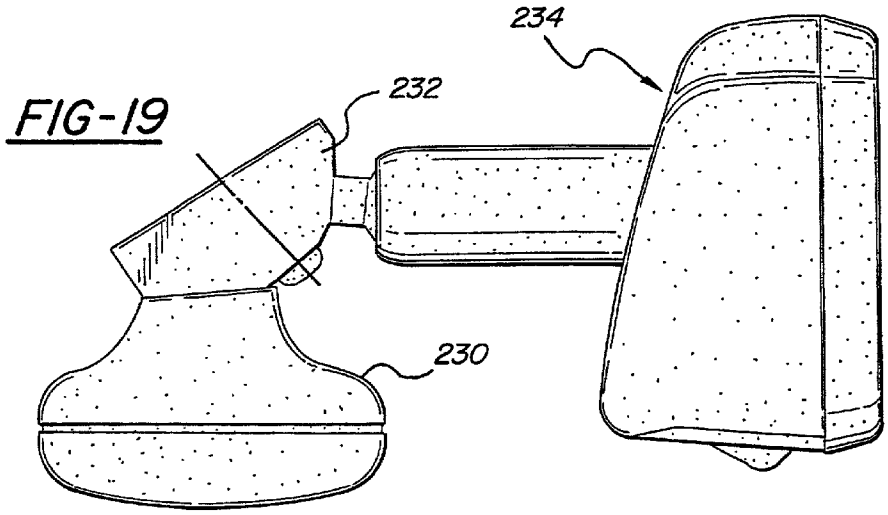


FIG-19

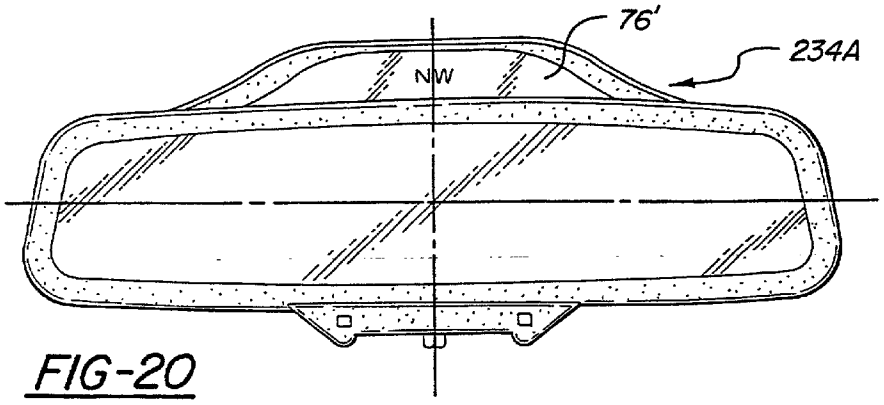


FIG-20

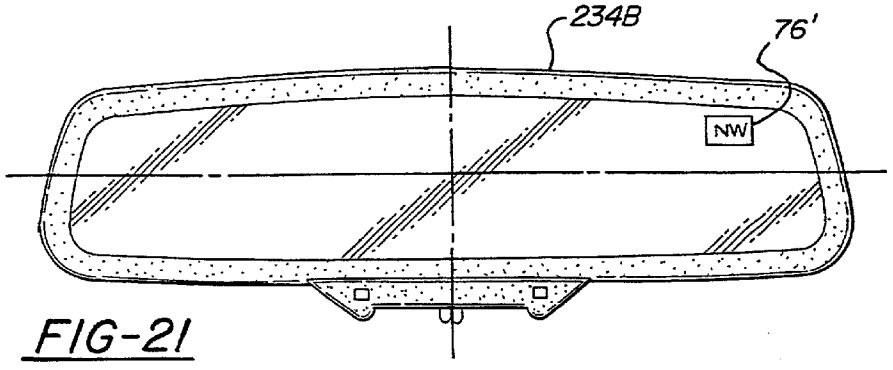


FIG-21

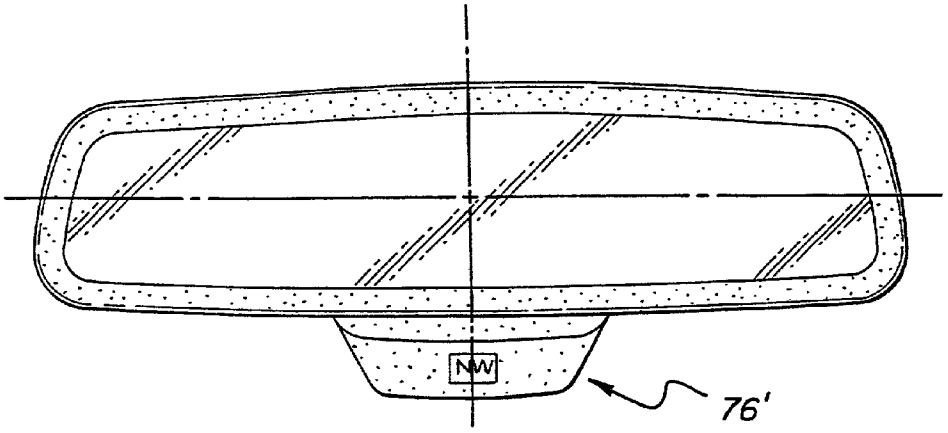


FIG-22A

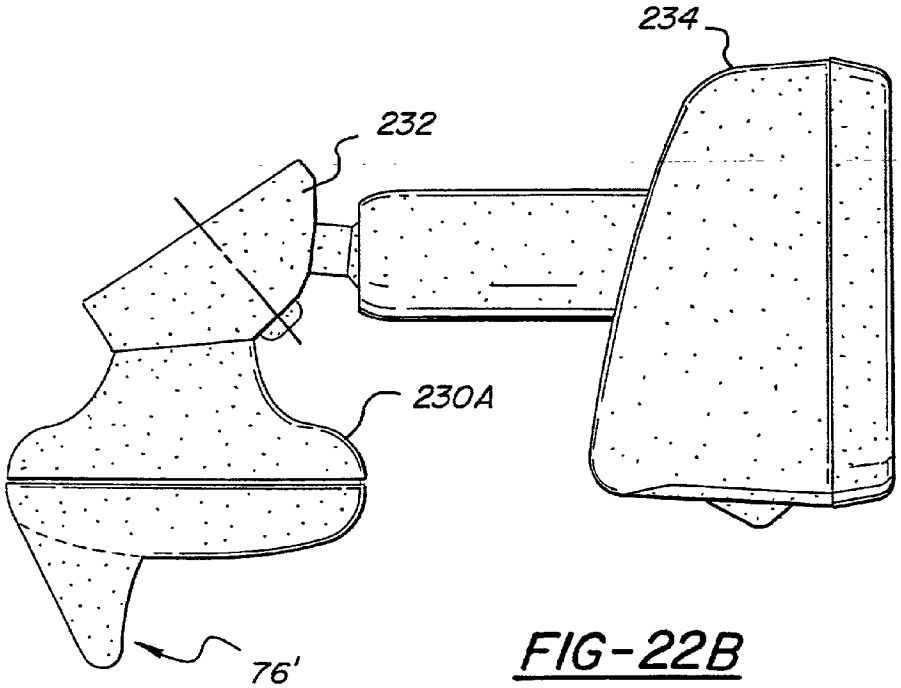


FIG-22B

COMPENSATION SYSTEM FOR ELECTRONIC COMPASS

FIELD OF THE INVENTION

[0001] This invention relates to magnetic compasses for vehicles. More particularly, it relates to compasses of the type which utilize an electronic magnetic field sensor.

BACKGROUND OF THE INVENTION

[0002] Magnetic compasses are commonly used in vehicles, including land vehicles, boats and aircraft, as an aid in direction finding and navigation. There is an increasing demand for magnetic compasses especially for use in passenger cars. In this field of use, there is an increasing requirement for a compass of low cost which exhibits a relatively high degree of accuracy with great reliability and which is of small size and weight.

[0003] Magnetic compasses for vehicles may be classified according to the type of the magnetic field sensor. One type is a magnetic rotor sensor which utilizes a magnetized element rotatably mounted to align itself with the ambient magnetic field. Examples of this type of vehicle compass are disclosed in Schierbeek et al U.S. Pat. No. 4,862,594 granted Sep. 5, 1989 and in co-pending application Ser. No. 07/597,854 filed Oct. 15, 1990 by Schierbeek et al now U.S. Pat. No. 5,131,154, granted Jul.21, 1992. Said patents are assigned to the same assignee as this application.

[0004] Another type is a flux gate sensor which utilizes a saturable magnetic core with excitation and sense windings for sensing the direction and field strength of an ambient magnetic field. Examples of vehicle compasses with flux gate sensors are represented by Baker et al U.S. Pat. No. 3,683,668 granted Aug. 15, 1972; Bower et al U.S. Pat. No. 4,733,179 granted Mar. 22, 1988; Hormel U.S. Pat. No. 4,720,992 granted Jan. 26, 1988; and Van Lente et al U.S. Pat. No. 4,953,305 granted Sep. 4, 1990.

[0005] There is a need, especially in vehicle compasses for passenger cars, for an improved magnetic field sensor to achieve the goals of accuracy, reliability, small size and weight and low cost. However, one of the problems in meeting these goals is that of providing deviation compensation for the compass, which is required to provide a high degree of accuracy, without a large cost penalty. It is known that a magnetic compass installed in a vehicle must be calibrated in the vehicle to account for the disturbing effect of the vehicle magnetic field. It is known that vehicles produce a magnetic field due to the presence of ferromagnetic materials, electric current carrying wires and the like and this magnetic field interferes with the earth field at locations within and adjacent the body of the vehicle. The magnetic field sensor of a compass responds to the localized magnetic field in which it is immersed for the purpose of direction finding with reference to the earth magnetic field. The magnetic field vector produced by the vehicle, herein referred to as the deviating magnetic field vector, combines with the earth magnetic field vector to produce a resultant or external magnetic field vector which, without calibration or compensation is unsuitable for reliable and accurate direction finding. Fully automatic deviation compensation is needed to meet present-day demands for passenger cars.

[0006] It is known to provide deviation compensation in a magnetic compass with a rotor type sensor by use of a pair of compensation coils which are energized with current to generate a magnetic field which is equal and opposite to the deviating magnetic field. This method of deviation compensation requires the vehicle to be oriented in certain cardinal directions relative to magnetic north and adjustments of coil current must be made. This adjustment may be carried out by the vehicle driver or it may be automated in a computer controlled compass. It results in inaccuracy unless the vehicle heading is accurately aligned relative to magnetic north. Deviation compensation of this type is disclosed in the above cited Schierbeek U.S. Pat. No. 4,862,594.

[0007] Another method of deviation compensation for vehicle compasses is referred to as the one hundred eighty degree compensation method. In this, the resultant magnetic field is measured with the vehicle in any selected orientation relative to the magnetic north and then the resultant field is measured with the vehicle in an orientation displaced one hundred eighty degrees from the first orientation. Using the measured values of the magnitude and directions of the resultant fields, the deviating field is calculated for both magnitude and direction. The calculated value is stored and subtracted from the magnetic field measurements subsequently taken by the compass in use for direction finding to thereby compensate it for deviation. The use of this method for a flux gate compass is disclosed in the above cited Bower U.S. Pat. No. 4,733,179, the Hormel U.S. Pat. No. 4,720,992 and the Baker et al U.S. Pat. No. 3,683,668.

[0008] Fully automatic deviation compensation systems for vehicle compasses have been proposed wherein no manual intervention is required. In the Tsushimo U.S. Pat. No. 4,445,279, granted May 1, 1984 an automatic system is disclosed using a flux gate sensor. An A-to-D converter and microprocessor are used to calculate an offset correction to compensate for the deviating field of the vehicle after driving the car in a full circle. A fully automatic compensation system is described in the Al-Attar U.S. Pat. No. 4,807,462 granted Feb. 28, 1989. In the system of this patent, a flux gate sensor measures three headings with the car moving, and using the headings, the coordinates are derived for the center of the earth field circle and the directional offset values are computed by using the coordinates. Another fully automatic deviation compensation system is described in the Van Lente U.S. Pat. No. 4,953,305 cited above. In this system, a flux gate sensor is used and the maximum and minimum signal values are recorded while the vehicle is driven through a closed loop. Then, the value of the deviating vehicle field is calculated from the recorded values. The compensating current is applied to the respective X and Y axis sense coils of the flux gate sensor to nullify the deviating field.

[0009] In the prior art, it is proposed to use magnetoresistive sensors in magnetic compasses. Such a compass is shown in the Picard U.S. Pat. No. 1,946,170 granted Feb. 13, 1934 wherein the magnetoresistive elements are connected in a bridge circuit. A compass using thin film magnetoresistive sensors is described in the Stucki et al U.S. Pat. No. 3,942,258 granted Mar. 9, 1976. In this system three magnetoresistive sensors are disposed in orthogonal relationship to develop a signal corresponding to the angular relationship between the compass platform and the magnetic north. The sensors are provided with a pumping coil and an output coil wound around the film at ninety degrees to each other. The pumping coil applies an alternating bias magnetic field to the

magnetoresistive film. The Sansom U.S. Pat. No. 4,525,671 granted Jun. 25, 1985 describes a magnetoresistive sensor with a single magnetoresistive element capable of sensing two components of a magnetic field. A current strap extends parallel to the magnetoresistive element and other current strap extends at right angles to the magnetoresistive element. One of the current straps carries current in alternate directions during a periodic cycle while the other strap carries current in a single direction. Another magnetic compass comprising a magnetoresistive thin film is disclosed in UK patent application 8707218 published Sep. 28, 1988. Two pairs of magnetoresistive thin films are arranged at right angles to each other. Means are provided to produce a biasing magnetic field and to measure a change in electric resistivity of the magnetoresistive material. The Boord et al U.S. Pat. No. 4,533,872 granted Aug. 6, 1985 describes a magnetoresistive thin film sensor of particular configuration for use as an electronic sensor in a compass.

[0010] As indicated above, the prior art is replete with vehicle compass technology in great detail. While the use of magnetoresistive sensors for compasses is suggested in the prior art, practical application requires an acceptable technique for fully automatic deviation compensation in a vehicle. Even though the prior art includes many different methods of deviation compensation for vehicle compasses, the art is lacking in respect to deviation compensation for magnetoresistive sensors.

[0011] A general object of this invention is to provide an improved vehicle compass using a magnetoresistive sensor which overcomes certain disadvantages of the prior art.

SUMMARY OF THE INVENTION

[0012] In accordance with this invention, a vehicle compass is provided which provides a high degree of accuracy and reliability with small size and weight and which is of low cost. This is accomplished using a thin film magnetoresistive sensor provided with a current conductor for providing switchable magnetic bias and a current conductor for nullifying a deviating field.

[0013] Further, in accordance with a first embodiment of this invention, an electronic compass is provided which employs a closed loop system to nullify deviating magnetic fields.

[0014] Further, in accordance with a second embodiment of this invention, an electronic compass is provided which automatically operates in an initial calibration mode to determine the initial compensation for the particular vehicle installation and in a normal calibration mode which is operative during normal compass operation for adjusting calibration as may be needed. In the initial calibration mode, the signal peak values are adjusted to a nominal earth field level by changing the offset current. compensating signal reference values for each axis are determined as each peak for that axis is determined. In the normal compensation mode, the sensor signals are sampled and stored during compass operation in its direction indicating mode. When a new peak is acquired for one axis, which should occur at the signal reference value in the orthogonal axis, an adjustment value is stored and later used to adjust the compensating signal reference value. The signal reference value for each axis is adjusted at least once for each peak of the orthogonal axis during the time interval between turn-on and turn-off of the vehicle ignition switch.

[0015] A complete understanding of this invention may be obtained from the detailed description that follows taken with the accompanying drawings.

DESCRIPTION OF TEE DRAWINGS

[0016] **FIG. 1** depicts a single-axis magnetoresistive sensor;

[0017] **FIG. 2** is a graphical representation of the operation of a single-axis magnetoresistive sensor;

[0018] **FIG. 3** is a diagram representing a typical relationship of the compass sensor and certain magnetic field vectors with the directional axis of a vehicle in which the compass of this invention is installed;

[0019] **FIG. 4** is a block diagram of a compass embodying this invention;

[0020] **FIGS. 5A and 5B** are a graphical representation of the operation of the compass of **FIG. 4**;

[0021] **FIG. 6** is a timing diagram to aid in explanation;

[0022] **FIG. 7** is a flow chart representing the program executed by the microcomputer of the compass;

[0023] **FIG. 8** is a schematic diagram of the Y-axis signal channel of the compass embodying this invention;

[0024] **FIG. 9** is a schematic diagram of the X-axis signal channel;

[0025] **FIGS. 10A and 10B** taken together form a schematic diagram of electronic circuits, including the microcomputer, which are coupled with the circuits of **FIGS. 8 and 9** of the compass;

[0026] **FIG. 11** is a schematic diagram of the bias current circuit for set and reset of the sensor; and

[0027] **FIGS. 12A and 12B** taken together constitute a schematic circuit of the electronic compass of a second embodiment of this invention;

[0028] **FIG. 13** is a modification of the electronic circuit;

[0029] **FIGS. 14A and 14B** taken together constitute a flow chart representing the main loop of the control program executed by the microcomputer;

[0030] **FIGS. 15A and 15B** taken together constitute a flow chart representing a program executed by the microcomputer for the initial calibration mode of operation;

[0031] **FIG. 16** is a flow chart representing the program executed by the microcomputer for the normal calibration mode of operation;

[0032] **FIG. 17** is a graph showing examples of sensor offset;

[0033] **FIG. 18** is a flow chart representing a program executed by the microcomputer for calculating sensor offset;

[0034] **FIG. 19** is a side elevation view of a vehicle inside the rearview mirror having the compass of this invention installed therein;

[0035] **FIG. 20** is a front elevation view of an inside rearview mirror showing a compass display above the mirror;

[0036] **FIG. 21** is a front elevation view of another inside rearview mirror with the compass display behind the mirror;

[0037] **FIG. 22A** is a front elevation view of an inside rearview mirror with an integrated compass module mounted on the mirror support bracket; and

[0038] **FIG. 22B** is side elevation view of the mirror and compass of **FIG. 22A**.

BEST MODE FOR CARRYING OUT THE INVENTION

[0039] Referring now to the drawings, there is shown an illustrative embodiment of the invention in a magnetic compass for vehicles which utilizes a magnetoresistive sensor. It will be appreciated as the description proceeds that the invention is useful in other applications and may be realized in different embodiments.

FIRST EMBODIMENT OF THE INVENTION

[0040] Magnetoresistive Sensor

[0041] Before describing the compass of this invention, it will be helpful to consider the magnetoresistive sensor used in the compass. A single-axis magnetoresistive sensor is illustrated schematically in **FIG. 1**. The sensor **10** comprises a bridge circuit **12** including a set of four magnetoresistive elements **14** connected in the bridge circuit. The magnetoresistive elements **14** are formed of a magnetic material which exhibits the magnetoresistive effect, such as permalloy, which changes its resistivity in the presence of an external magnetic field. The bridge circuit **12** is excited with a DC voltage across the input terminals and an output signal voltage V_0 is developed across the output terminals in response to an external magnetic field. The sensor **10** is provided with a bias current strap **16** which is energized by a set/reset voltage at its input terminal to produce a magnetic bias field M_B which is of reversible polarity in accordance with the input voltage. Also, the sensor **10** is provided with an offset current strap **18** which is energized by a reversible polarity offset voltage applied to its input terminals. The current strap **18** produces an offset magnetic field MO which is reversible polarity in accordance with the input signal voltage. The functions of the bias current strap **16** and the offset current strap **18** will be discussed subsequently.

[0042] Preferably, the sensor **10** is fabricated on a silicon substrate on which the magnetoresistive elements **14** are deposited as a thin film. In this construction, the bias current strap **16** is formed as a current conductive layer. It overlays a soft magnetic layer which in turn overlays the elements **14**. A pulse of current in one direction through the current strap **16** produces a magnetic field of sufficient strength to saturate the magnetic layer and provide a positive bias field. When the current is removed, the device remains in a biased condition under the influence of the magnetic layer. Similarly, a pulse of current in the opposite direction provides a negative bias. The offset current strap **18** is formed as a current conductive layer which overlays the magnetoresistive elements **14** and carries current in a direction perpendicular to the current carrying direction of the strap **16**. The offset magnetic field MO produced by the current strap **18** is effective to oppose an external magnetic field to which the magnetoresistive elements **14** are subjected. Magnetoresistive sensors constructed by the deposition of a thin film ferromagnetic material on a silicon substrate are well-known in the art, as indicated by the Boord U.S. Pat. No. 4,533,872.

[0043] The operation of the sensor **10** will be described with reference to the graph of **FIG. 2**. The curve V represents the output voltage of the sensor **10** as a function of magnetic field strength in a direction perpendicular to the current flow in the magnetoresistive elements **14**. When the field strength is zero, the output voltage V has a maximum value and as the field strength is increased from zero in either direction, the output voltage decreases symmetrically. (The terms 'positive' and 'negative' and the symbols therefor are used in a relative sense to denote opposite directions or polarity of magnetization.) The voltage curve near the peak is highly non-linear and tends to become substantially linear in a mid-range of the voltage variation. In order to obtain directional information regarding an external magnetic field, a bias field having a field strength alternating between $+M_B$ and $-M_B$ is applied to the magnetoresistive elements **14**. This is accomplished by the bias current strap **16** and the associated soft magnetic layer which is alternately driven into magnetic saturation by current pulses of alternate polarity through the current strap **16**. When a current pulse is applied in one direction the device will operate with a positive bias, $+M_B$, which herein is called the "set model" until the saturation of the soft iron magnetic layer is reversed. A current pulse in the opposite direction will reverse the direction of saturation and the device will operate with a negative bias, $-M_B$, herein called the "reset mode".

[0044] When the device is operated in the alternating set/reset modes and when subjected to zero field strength, the output voltage V will have a value V_R in the set mode and also in the reset mode so that the output voltage remains constant at the V_R level. When the sensor **10** is subjected to an external magnetic field M_e, the external field is combined with the bias field M_B. As shown in **FIG. 2**, if the external field is of positive polarity, i.e. $+M_e$, it will add to the bias field $+M_B$ to produce a resultant field strength M_B+M_e which results in an output voltage $-V_e$. In the reset mode, the external field $+M_e$ decreases the bias field $-M_B$ to produce a net field strength of $-M_B+M_e$. This produces an output voltage in the reset mode of $+V_e$. Thus, the output voltage of the sensor **10**, when subjected to an external magnetic field of $+M_e$, is an alternating square wave voltage of the same frequency as the alternating square wave voltage applied to the bias current strap **16**. The output voltage varies from a positive peak value of $+V_e$ in the reset mode to a negative peak value of $-V_e$ in the set mode. As indicated in **FIG. 2**, the peak-to-peak value of the output voltage V_0 represents the external field M_e. As will be discussed subsequently, the voltage V_R is an offset voltage which is removed from the output voltage V_0 by AC coupling. It is noted further that if the output voltage V_0 is positive in the reset mode, the external field M_e is positive and if the output voltage V_0 is positive in the set mode the external field is negative. It is only necessary to measure the positive portion of the output voltage V_0 to determine the magnitude of the external field and the direction of the external field M_e will be known from its polarity and whether it is in the set or reset mode.

[0045] Vehicle Compass System

[0046] Now consider the sensor **10** installed in a vehicle **26**, such as a passenger car, as depicted in **FIG. 3**. In order

to determine the direction of the external field M_e, it is necessary to use two single-axis sensors **10** and **10'** which are orthogonally oriented relative to each other. The sensor **10** is mounted in the vehicle with its sensitive axis SA parallel to the direction reference axis, i.e. the longitudinal axis Y-Y of the vehicle **26**. The sensor **10'** is of the same construction as sensor **10** and is mounted adjacent the sensor **10** with its sensitive axis extending parallel to the X-X axis of the vehicle. In such an installation, the sensors are subject to the earth magnetic field M_N which is stationary with reference to the earth and it is also subjected to the vehicle magnetic field M_v which is stationary with respect to the vehicle. The external field M_e to which the sensor **10** is subjected is the vector sum of the earth field and the vehicle field. Accordingly, the sensor **10** responds to the Y-axis component of the vehicle field and the sensor **10'** responds to the X-axis component. The vehicle field M_V remains constant regardless of the direction heading of the vehicle **26**. However, the external magnetic field Me includes a component due to the earth field M_N and the output voltages of the sensors **10** and **10'** vary with vehicle heading relative to the magnetic north direction, as will be discussed below.

[**0047**] The electronic compass of this invention is shown in block diagram in **FIG. 4**. In general, the compass comprises a two-axis sensor **32** and a multiplexer **34** which are mounted on a sensor circuit board **36**. A mother board **46** mounts a microcomputer **38**, an analog-to-digital converter **42** and a digital-to-analog converter **44** which controls a constant current source **48**. The circuits of **FIG. 4** are operative to measure the X and Y-axis output signals and to process the signals to eliminate the DC voltage offset and to nullify the effect of the vehicle deviating magnetic field to obtain deviation compensation of the compass. The microcomputer **38** is operated under a control program to process the signals to achieve deviation compensation and to compute the magnetic heading of the vehicle, as will be described subsequently.

[**0048**] The circuit of **FIG. 4** will now be described in greater detail. The two-axis sensor **32** comprises the Y-axis sensor **10** and the X-axis sensor **10'** mounted with respect to each other and the vehicle **26** as described above. The microcomputer **38** controls the switching of a sensor bias circuit **60** to bias the sensors alternately in the set and reset modes. A multiplexer **34** has an address select input **52** for selecting X or Y-axis output signals. The output signal of the Y-axis sensor **10** is applied to an input **56** of the multiplexer and the X-axis output signal of the sensor **10'** is applied to an input **54** of the multiplexer. The output signal of the multiplexer at output **58** is coupled through a capacitor **62** to the input **64** of the A/D converter **42**. The capacitor **62** provides AC coupling between the multiplexer output **58** and the A/D converter input **64** to block the DC offset voltage V_R discussed above with reference to **FIG. 2**. Thus, the amplitude of the output voltages of the sensors **10** and **10'** which must be measured by the A/D converter **42** is reduced by the value of the DC offset voltage.

[**0049**] The output of the A/D converter **42** is applied to inputs **63** of the microcomputer **38**. The microcomputer **38** processes the digital signal outputs of the A/D converter **42** in accordance with an algorithm for determining the nullifying magnetic field for the respective X-axis and Y-axis sensors **10'** and **10** to offset and nullify the effect of the deviating vehicle magnetic field on the sensors. This algorithm is embodied in the program (see **FIG. 7**) of the microcomputer **38** which will be described subsequently.

[**0050**] Deviation Compensation

[**0051**] The manner in which the compass is compensated for deviation due to the vehicle magnetic field will be described, in general, with reference to **FIGS. 5A and 5B**. With the compass represented in **FIG. 4** installed in the vehicle **26**, as described with reference to **FIG. 3**, the output signal of the sensor **10** as it is applied through AC coupling to the input of the A/D converter **42** is represented by the waveform V_{ey} in **FIG. 5A**. This signal V_{ey} has an offset component D_y, prior to deviation compensation, which is of constant value and produced by the Y-axis component of the vehicle field. The Y-axis output signal V_{ey} has an alternating component E_y which is produced by the earth magnetic field in accordance with the direction heading of the vehicle **26**. The component E_y varies in a sinusoidal manner as shown in **FIG. 5A** relative to the signal level D_y as the vehicle is driven through various directions relative to magnetic north. The waveform V_{ey} of the Y-axis output signal may be produced over a relatively short time period or a long time period; it is depicted in **FIG. 5A** without regard to time. The output signal, instead, is plotted as a function of vehicle direction. When the vehicle is headed in the direction of magnetic north, the output signal V_{ey} is at its maximum value V_{eymax} when it is headed in the magnetic south direction it is at a minimum value, V_{eymin}. When the heading is either west or east, the value of the Y-axis signal V_{ey} is at the value of the deviation component D_y which is half way between the maximum and minimum values.

[**0052**] It is required to determine the, current in the deviation offset strap **18** for nullifying the Y-axis component of the deviating magnetic field. For this purpose, the A/D converter **42** is set with a full-scale range of reading capability which is equal to or slightly greater than the maximum value of the earth field component E_y which occurs within the geographical range, such as the North American continent, in which the vehicle may be operated. This full scale range of the A/D converter **42** is represented by the signal voltage level designated A/D in **FIG. 5A**. The operation of the compass circuit to achieve the deviation offset current in strap **18** of the sensor **10** will be described subsequently.

[**0053**] In a manner analogous to that described above for the Y-axis output signal of sensor **10**, with reference **FIG. 5A**, the X-axis sensor **10'** produces an X-axis output signal V_{ex}as depicted in **FIG. 5B**. It is noted that this signal V_{ex} has a component D_x which is constant as a result of the X-axis component of the deviating vehicle field. It also has an alternating component E_X due to the earth field which varies in accordance with the direction heading of the vehicle. However, the alternating component, while varying in a sinusoidal manner, is ninety degrees out-of-phase with the variable component E_y in the output signal of the Y-axis sensor **10**. It is noted that the deviation component D_X of the output signal V_{ex} of the X-axis sensor lot is typically different in magnitude from the deviation component D_y of the output signal V_{ey} of the Y-axis sensor **10**; the relative magnitudes depend upon the direction of the vehicle magnetic field vector M_v and they are equal to each other only when the vector is at forty-five degrees or an odd multiple thereof relative to the longitudinal axis of the vehicle. On the other hand, the alternating component E_X in the X-axis

sensor output signal Vex has the same amplitude as the alternating component E_y in the output signal V_{EY} of the Y-axis sensor **10**. As indicated in **FIG. 5**B, the full scale range of the A/D converter **42**, designated by the signal level A/D, is the same for the sampling of both the Y-axis and X-axis output signals by the A/D converter **42**.

[**0054**] Compass Operation

[**0055**] The operation of the electronic compass will now be described with reference to **FIGS. 4, 5A, 5**B, **6** and **7**. An accurate determination of the vehicle magnetic heading can be made only if the influence of the deviating magnetic field of the vehicle is nullified. When such nullification is achieved, the Y-axis and X-axis output signals correspond only to the components of the earth magnetic field and can be combined in a known functional relationship to determine the direction of the magnetic north vector. The operation of the magnetic compass for achieving nullification of the deviating magnetic field, for deviation compensation of the compass, will now be described.

[**0056**] A timing diagram depicting the operation for nullification of the deviating vehicle magnetic field and measurement of the earth magnetic field is shown in **FIG. 6**. The sensors **10** and **10'** are alternately operated in the set mode and the reset mode simultaneously with each other under timing control signals from the microcomputer **38**. In particular, the bias current straps **16** and **16'** of sensors **10** and **10'**, respectively, are connected in series and are energized with the same current pulse in the reset direction for a reset period, say five milliseconds, and are energized with the same current pulse in the set direction for a set period, say five milliseconds. During the reset mode, as indicated in **FIG. 6**, the output signal of the X-axis sensor **10'** is measured by the A/D converter **42**. Initially, as indicated in **FIG. 5B** the amplitude of the output signal V_{ex} is greater than the full scale of the A/D converter. As a result of such measurement, the microcomputer **38** produces an output signal to the D/A converter **44** which causes it to produce an increment of deviation offset current having a polarity, in the deviation offset current strap **18'** of the sensor **10'**, such that it nullifies an increment of the X-axis component of the vehicle deviating field. Further, as shown in **FIG. 6**, during the set mode, the output signal of the Y-axis sensor **10** is measured by the A/D converter **42**. Initially, as indicated in **FIG. 5**A, the value of the output signal V_{ey} will be greater than the full scale of the A/D converter. As a result of this measurement, the microcomputer **38** will provide a control signal to the D/A converter **44** which causes the current source **48** to produce an increment of deviation offset current in the offset current strap **18** of the Y-axis sensor **10** with a polarity such that it nullifies an increment of the Y-axis component of the vehicle deviating field. Next, as indicated in **FIG. 6**, the output signal of the Y-axis sensor **10** is measured during the reset cycle. Following that, the output signal of the X-axis sensor **10'** is measured during the set mode and then it is measured during the reset mode. For each output signal measurement which determines that the signal magnitude is greater than the full scale of the A/D converter **42**, the current in the corresponding deviation offset current strap **18** or **18'** is incrementally increased. This process continues until the deviation offset current in the current strap **18** of the Y-axis sensor is at a level within the full scale of the A/D converter **42** which is of such value that the Y-axis component of the vehicle deviating field is substantially nullified. The same is done with respect to the X-axis sensor. In this condition, the values of the Y-axis output signal and the X-axis output signal correspond accurately to the earth magnetic field for the particular vehicle headings during which measurements are made. The deviation compensation process is continuous during vehicle operation; the first cycle of compensation is completed when the vehicle has turned through a full circle from any arbitrary starting point. Turning of a full circle is indicated by the occurrence of the peak values V_{eymax} and V_{eymin} corresponding to the maximum and minimum output signals of the Y-axis sensor and the occurrence of V_{exmax} and V_{exmin} corresponding to the maximum and minimum values of the output signals of the X-axis sensor.

[**0057**] **FIG. 7** is a flow chart representing the program of the microcomputer **38**. At block **100**, the execution of the program is started and it proceeds to block 102 which reads the output signal of the X-axis sensor **10'**. In block **104** the program determines whether the value of the X-axis signal is within the full scale range of the A/D converter **42**. If it is not, the program advances to block **106** which determines whether the value of X is greater than the full scale of the A/D converter **42**. If it is, block **108** increases the nullifying field in the -X direction and the program loops back to block **102**. If block **106** determines that X is not greater than the full scale, block **112** increases the nullifying field in the +X direction and the program loops back to block **102**.

[**0058**] If at block **104** it is determined that the measured value of X-axis output signal is within the full scale range of the A/D converter **42**, the program advances to block **144** which reads the measurement of the output signal of the Y-axis sensor **10**. Then, block **116** determines whether the value of the Y-axis signal is within the full scale range of the A/D converter **42**. If it is not, block **118** determines whether the value is greater than the full scale range. If it is, block **122** increases the nullifying field in the Y-axis sensor **10** in the -Y direction. Then, the program loops back to block **102**. If at block **118** it is determined that the output signal of the Y-axis sensor is not greater than the full scale range of the A/D converter, block **124** increases the nullifying field of the Y-axis sensor in the +Y direction and the program loops back to block **102**. This program execution is continued until at block **104** it is determined that the X-axis output signal is within the full scale range of the A/D converter **42** and further it is determined at block **116** that the output signal of the Y-axis sensor is within the full scale range. Then, the program advances to block **126** which determines whether the maximum value or positive peak of the output signal of the X-axis sensor **10'** has been identified. If it has not, the program loops back to block **102**. If it has, the program advances to block **128** which determines whether the minimum value or negative peak of the output signal of the X-axis sensor has been identified. If it has not, the program loops back to block **102**; if it has, the program advances to block **132**. Block **132** determines whether the maximum value or positive peak of the output signal of the Y-axis sensor has been identified. If it has not, the program loops back to block **102**. If it has, the program advances to block **134**. Block **134** determines whether the minimum value or negative peak of the output signal of the Y-axis sensor has been identified. If not, the program loops back to block **102**. If it has, it is determined that the deviation compensation procedure has completed a full cycle.

[0059] In this state, the X-axis and Y-axis output signals correspond substantially to the earth magnetic field and are suitable for computing the magnetic heading of the vehicle. It will be understood that the process described is repeated continuously and adjusts the deviation compensation in accordance with changes in the vehicle magnetic field that may occur and to continually enhance the accuracy of the heading indication. When the block **134** determines that a full cycle of deviation compensation has been executed, the program advances to block **136** which computes the magnetic heading of the vehicle. Then, block **138** adds a stored value of variation compensation to obtain the true heading of the vehicle. The true heading is displayed for the information of the vehicle driver by block **142**.

[0060] Electronic Circuit of the Compass

[0061] The circuit of the electronic compass is shown in the schematic diagrams of **FIGS. 8, 9, 10**A, **10**B and **11**. **FIG. 8** shows the Y-axis signal channel **70**Y for developing the output signal V_{ey} from the output sensor **10**. The bridge circuit of the sensor **10** is excited with a D/C voltage V_{cc}. The output of the bridge circuit is supplied to the input of a first stage amplifier **204** which provides a voltage gain of about ten or twelve. The amplified output is applied through an AC coupling capacitor **206** to the input of a second stage amplifier **208** which provides a gain of about twenty. The output of the amplifier **208** is applied through an AC coupling capacitor **212** to a terminal **214** for application of the signal V_{ey} to the circuit shown in **FIG. 10A** which will be described presently.

[0062] The X-axis channel **70**X for developing the output signal V_{ex} from the output sensor **10'** is shown in **FIG. 9** and is similar to that of **FIG. 8**. The bridge circuit of the sensor **10'** is excited with the DC voltage V_{cc}. The output of the bridge circuit is supplied to the input of a first stage amplifier **224** which provides a voltage gain of about ten or twelve. The amplified output is applied through an AC coupling capacitor **226** to the input of a second stage amplifier **228** which provides a gain of about twenty. The output of the amplifier **228** is applied through an AC coupling capacitor **232** to a terminal **234** for application of the signal V_{ex} to the circuit shown in **FIG. 10A** which will be described presently.

[0063] **FIGS. 10A and 10B** taken together form a schematic diagram of the electronic circuits, including the microcomputer **38**, which are coupled with the circuits of **FIGS. 8 and 9** described above and the circuit of **FIG. 11** which will be described below. The microcomputer **38** is, in the illustrative example, an eight bit microprocessor type COP881C is available from National SemiConductor, Inc. of Palo Alto, Calif. As shown in **FIG. 10**A, the microcomputer **38** is provided with a reset circuit **72** of conventional design coupled with the pins V_{cc}, Reset and Ground as indicated. The microcomputer is also provided with a clock circuit **70**, also of conventional design, and connected with the pins CK1 and CK**0**. As shown in **FIG. 10**B, the microcomputer **38** is coupled with an EEPROM **246** at pins G**1**, G**5**, G**4**, G**6**. The EEPROM **246** serves as a permanent memory for data to be stored when the power to the electronic circuit is interrupted. A compass heading display **76**, such as a vacuum fluorescent display, is coupled to pins G**5**, G**4** and G**6**. The display may be located in the vehicle at any location convenient for the driver remotely, if desired, from the location of the mother board **46**. Referring again to **FIG. 10A, a** manual switching circuit **252** is coupled with microcomputer pins **10, 11, 12** and **13**. A manual switch **254** is provided for use in connection with compensating the compass for variation. Also, a manual switch **255** is shown for changing the brightness of the display **248** but automatic means could be provided. The remaining circuits associated with the microcomputer **38**, which will be described presently, are operative to control the sensors **10** and **10'** and to process the output signals thereof to provide deviation compensation and to develop the heading direction signals. The heading is presented in alphanumeric form on the display **248** to indicate the cardinal and intercardinal compass points heading to the vehicle driver.

[0064] A driver circuit **282** for the set/reset current straps **16** and **16'** of the sensors **10** and **10'** is shown in **FIG. 11**. The switching signal for the driver circuit **282** is produced by the microcomputer **38** at output pin Do and applied to the input terminal **284**. The driver circuit **282** comprises a pair of Darlington transistors **286** and **288** which are alternately switched conductive and non-conductive in response to the switching signal on connector **284**. Accordingly, the current straps **16** and **16'** are energized with current pulses as shown in the timing diagram of **FIG. 6** and described above to provide the set and reset modes for the sensors **10** and **10'** for the measurement of the Y-axis sensor output signal and X-axis sensor output signal, respectively.

[0065] As shown in **FIG. 10**A, the multiplexer **52** receives the Y-axis sensor output signal at terminal **214** and receives the X-axis sensor output signal at terminal **234**. The multiplexer **34** is provided with an address signal from the data output pins D**1** and D**2** of the microcomputer **38** which is applied to pins A and B of the multiplexer **52**. Thus, output signals of the Y-axis and X-axis sensors **10** and **10'** are accessed alternately in timed relation with the set and reset modes as described with reference to **FIG. 6**. The sensor output signals are alternately outputted through pin **0/1** of the multiplexer to the A/D converter **42** shown in **FIG. 10A**. The A/D converter includes a comparator **256** which has its inverting input connected with the **0/1** output pin of the multiplexer **52**. The non-inverting input of the comparator **256** is connected with the output of a ramp generator **258** which receives a pulsed input from pin D**3** of the microcomputer **34**. A clamp circuit **262** is coupled with the ramp generator **258** and clamps the ramp generator output at a certain voltage level so that the output does not go all the way to ground after each ramp which would require a time delay on build-up to the ramp reference voltage. The comparator **256** is operated with a reference voltage, for example, of about 2.5 volts on the non-inverting input. The A/D converter has a full scale range of 2.0 volts above the reference and, for example, the clamp voltage is about 2.3 volts. The ramp voltage is incremented at the rate of one millivolt per microsecond and the pulse count required to reach the signal voltage level at comparator **256** is stored in a register and represents the measured value of the sensor voltage applied to the A/D converter at comparator **256**. The pulse count register indicates when the signal measurement is greater than the full scale range of the A/D converter **42**.

[0066] As shown in **FIG. 10**B, the D/A converter **44** is coupled with output pins L**0** through L**7**. The D/A converter **44** is a ladder network known as an R2R network and, for example, develops an output voltage of 2.5 volts at a register

count of **127**. The output of the D/A converter is applied through a voltage-to-current converter comprising amplifiers **262** and **266**. The current amplifier **266** develops the offset current supply at connector **268** for the offset current straps **18** and **181** which are shown in **FIG. 10A**. The offset current return circuit **272** of **FIG. 10A** comprises an amplifier **274** which has its non-inverting input coupled with pin **2** of the multiplexer **52**. The output of the amplifier **274** provides the offset current return at the terminal **276**. The operation of the A/D converter **42** and the D/A converter **44** for developing the offset current required to provide deviation compensation is described above with reference to FIGS. **5**A and SB.

SECOND EMBODIMENT OF THE INVENTION

[**0067**] A second embodiment of the invention will now be described with reference to **FIGS. 12 through 22**. The second embodiment provides deviation compensation of the compass to a high degree of accuracy on a long term basis. This is accomplished by operation in an initial calibration mode followed by operation in a long term or normal calibration mode.

[**0068**] In initial calibration mode, the sensor output signals for each axis are alternately adjusted until they are within the full scale or readable range of the A/D converter. This is done by changing the offset current for each sensor by relatively large increments, if necessary, to produce readable sensor signals. The sensor signals are also alternately adjusted by incrementally changing the sensor offset current to adjust each sensor signal peak value so that it is approximately equal to a predetermined nominal earth field value. The predetermined nominal earth field value is selected for each sensor to be that which corresponds to the nominal earth field which is to be encountered. Once the sensor signal peak values are adjusted to the nominal level, so that they are readable by the A/D, by the sensor offset current adjustment, a signal reference compensating value for each axis is determined using the maximum and minimum signal peak values as each peak is acquired for each axis. The signal reference value for each of the X-axis and Y-axis sensors is stored when it is determined.

[**0069**] The normal calibration mode is operative during normal compass operation, i.e. when the compass is being used in its operational mode for directional or heading information. During normal operation, since the sensors have already been adjusted to a nominal earth field value and the compensating signal reference values determined, the compensating signal reference values are adjusted for each axis by a fixed step size, preferably two counts, as each new peak is determined on the opposite or orthogonal axis. An axis can be calibrated upon the occurrence of every new peak. During normal compensation, the compensating signal reference values for each axis may be adjusted once, and preferably, twice, once for each new peak in the opposite axis during each ignition or power-up cycle of compass operation.

[**0070**] A complete description of the initial calibration mode and the normal operation calibration mode will be given below.

[**0071**] Electronic Circuit

[**0072**] Since certain portions of the electronic circuit of the Second Embodiment correspond to the First Embodiment described above, only a brief description will be given.

[**0073**] The compass electronic circuit, as shown in **FIGS. 12A and 12B**, comprises a microcomputer **38'** with support circuitry, a single slope A/D converter **42'**, an offset circuit **50'** including an eight bit D/A converter **44'** driving a constant current source **48'**, an EEPROM **46'**, a two-axis magnetoresistive (MR) sensor **32'**, sensor bias circuitry **60'**, and amplifier circuitry **70Y'** and **70X'** with a multiplexer **52'**. The microcomputer **381** is an eight bit COP881C microcomputer available from National SemiConductor, Inc., and is provided with a reset circuit **72'** coupled with the V_{cc}, Reset and Ground pins, and a clock circuit **741** connected with the pins CKI and CKO. The microcomputer **38'** is coupled to the non-volatile EEPROM memory **46'** for data storage. A compass heading display **76'**, such as a vacuum fluorescent display, is also be coupled to the microcomputer **38'**. The heading may be presented in alphanumeric format to display the octant (cardinal and intercardinal) compass headings to the vehicle operator. A calibrate switch **82** and a zone switch **84** described herein are also coupled with the microcomputer **38'** in a switching circuit **80**. The sensor set/reset driver circuit **60'** comprises a pair of Darlington transistors Q2 and Q3 which are switched alternately between conductive and non-conductive states by a microcomputer switching signal, and are used to bias the MR sensors, as is described below.

[**0074**] The two-axis sensor **32'** includes two magnetoresistive (MR) sensors **10** and **10'** (see **FIG. 4**) for determining the X (east/west) and Y (north/south) components of a sensed magnetic field. Each of the MR sensors has a bias strap **16** and a current strap **18** as previously described with reference to **FIGS. 1 and 4**. The bias strap **16** is used to apply a set/reset signal to bias the MR sensor in two states. Since the MR sensors are biased in two states, the A/D converter **42'**, which is a twelve bit converter, only has to read positive data. The readable A/D range is set to be slightly greater than the, maximum earth field of about 300 Mgauss. Only about 3,000 steps (i.e., 3,000 mv) of the twelve bit A/D are used as the readable A/D range. The current strap is used to adjust the MR sensor output signals to a nominal earth field level within the readable A/D range.

[**0075**] The X and Y sensor output signals are coupled through first and second stage amplifiers **302** and **304** to the inputs of the multiplexer **52'**, and thence the amplified X and Y outputs are coupled to a shared second stage amplifier **306** (having temperature compensation). The multiplexed X and Y sensor signals are then coupled through the shared A/D converter **42'** to the microcomputer **38'**. The microcomputer **38'** determines whether either of the X and Y sensor signals are outside the readable A/D range. If so, the signal is repeatedly increased or decreased by changing the value on the D/A converter **44'** until the sensor signal is within the readable range. If either the X or Y sensor signals is then not equal to the nominal earth field, the microcomputer determines the number of counts (steps) to apply to the D/A converter **44'** to decrease or increase the current supplied to the current straps **18** for each of the MR sensors so as to adjust the MR sensor signals to a nominal earth field level within the readable A/D range. The nominal earth field level may, for example, be about 200 Mgauss.

[**0076**] The compass is provided with a manually actuated calibrate switch **82** and a manually actuated zone switch **84**. The calibrate switch is used to enter the initial calibration mode by pressing and holding the calibrate button for a

predetermined time, say about a half second. Once activated, the legend "CAL" is displayed on display **76'** adjacent the location for display of the true vehicle heading to confirm to the operator that the calibrate switch actuation has put the compass in the initial calibration mode. The operator may then drive the vehicle in a suitable course to acquire sufficient peak (e.g., north) and peak set (e.g., north/south or east/west) information so that the microcomputer **38'** can update the calibration data as each peak set (for the north/south or east/west axis) is acquired. After the vehicle has been driven in such a course, for example through the approximately two circles, the microcomputer will have counted six peaks (e.g., north or south). When a predetermined initial calibration criteria has been met, as described below, the compass will then automatically exit the initial calibration mode and "CAL" is no longer displayed.

[**0077**] The initial calibration mentioned above is further described, as follows. If the measured Y-axis sensor signal is out of the twelve bit A/D range (using about 3000 steps), then the Y-axis sensor signal is repeatedly increased or decreased by changing the value on the D/A **44'** until the Y-axis sensor signal is within the readable A/D range. If the Y-axis sensor signal is not equal to the nominal earth field level, then the Y-axis sensor signal is again level shifted using the D/A **44'** until it is equal to the nominal earth field. When a north/south peak set for the Y-axis is obtained, the compensating signal reference value to correct the readable sensor signal is determined by averaging the north and south peak values. The above steps are repeated for the X-axis, so that the X-axis sensor signal is adjusted to the nominal earth field level, and then the compensating signal reference value is determined by averaging the east and west peaks. Finally, the compass determines a scaling factor for the axis having the lower maximum output signal to account for any output variances between the X-axis and Y-axis sensors. This completes the initial calibration mode.

[**0078**] The normal calibration mode is always operative whenever the compass is being operated in its direction indicating mode. For normal calibration, since the MR sensors have already been adjusted to a nominal earth field level and the initial compensating signal reference values determined, the compensating signal reference values are automatically adjusted or updated for each axis whenever a new peak is determined for the opposite or orthogonal axis. As the vehicle is being driven during normal compass operation, the X-axis and Y-axis sensor data are sampled and stored. When a Y-axis peak (e.g., north or south) is obtained, the opposing X-axis (east/west) signal reference value may be adjusted or updated since a Y-axis peak should correspond to the reference value on the X-axis. Thus, the north/south or east/west axis is compensated whenever a new peak is obtained for its opposing axis. This may be done once for each peak such that each axis may be adjusted or compensated twice during any ignition or power-up cycle.

[**0079**] The zone switch **84** is used to compensate for the angular difference between magnetic and true north. There are fifteen zones (zones 1 to 15), eleven of which cover the United States. The compass provides zones which vary about +28 degrees from a center zone (zone 8). Within the United States, the variation from the center zone ranges from about −12 degrees to +28 degrees (zones 1 to 11). The zone entry mode is entered by actuating and holding the zone switch **84** until the current zone setting appears in the display. The display may then be cycled through zones 1 to 15 by repeatedly actuating the zone switch **84**. When the desired zone is displayed, releasing the zone switch **84** will exit the zone entry mode and store the new zone setting in non-volatile memory.

[**0080**] To filter the MR sensor data, the compass is provided with a software filter in the form of a digital lag filter which will be described later. Additionally, to prevent the compass display from oscillating between two octants, such as "IN" and "NE", the display is time dampened so that a new heading will not be displayed until the same heading data persists for about 1½ seconds. The display damping technique of the present embodiment will be described later.

[**0081**] An alternate electronic circuit is shown in **FIG. 13**. This circuit incorporates much of the support circuitry into an application-specification integrated circuit (ASIC). The drawing of **FIG. 13** is self-explanatory.

[**0082**] Operation of the Second Embodiment

[**0083**] The operation of the second embodiment will now be described with reference to **FIGS. 14 through 18**. For convenience of explanation and understanding, the main loop of the control program will be described first with reference to **FIGS. 14A and 14B**. The initial calibration mode is depicted as a routine in the flow charts of **FIGS. 15A and 15B**. The normal calibration mode is depicted in the flow chart of **FIG. 16**. Additionally, a sensor offset voltage calculation is explained with reference to **FIG. 17** and is shown in the flow chart of **FIG. 18**.

[**0084**] Main Loop Operation

[**0085**] Referring now to **FIGS. 14A and 14B**, the compass operation will be described with reference to the main loop of the control program of the microcomputer **38'**. The program starts at the start block **400**. The microcomputer is reset at block **402** when the ignition switch is turned on and the microcomputer is initialized for execution of the control program. The microcomputer will interpret any user inputs, as described herein, in block **403**. The program advances to the retrieve data block **404** which causes the microcomputer to read the Y-axis and X-axis signals alternately at the output of the A/D converter **42'**. A sub-routine for calculating the sensor offset voltage is incorporated in the retrieve data block **404** and will be described below with reference to **FIG. 18**. The program advances to the test block **406** which determines whether the data was ready for retrieval. If not, the program loops back to block **403** as indicated. If data was ready for retrieval, the program advances to a test block **408** which determines whether the new signal data is outside the readable range of the A/D converter **42'**. If it is, the program advances to block **410**. If the compass is in the initial calibration mode, this causes an eight count change in the D/A converter **44'** setting to change the offset current through the current strap **18** of the corresponding Y-axis sensor or X-axis sensor to adjust the sensor signal such that it is within the readable range of the A/D converter. If the compass is in the normal operating mode, there is no operation in block **410**. Next, the program loops back to block **403**.

[**0086**] If at test block **408**, the sensor signal is not readable by the A/D converter **42'**, the program advances to block **412** which filters the data, suitably by a digital lag filter, for the

purpose of reducing noise in the sensor signal. In the embodiment as described, a digital lag filter having the form

$$X_F(t)=X_F(t\text{-}1)+K * (X_u(t)-X_F(t\text{-}1)),$$

[0087] where $X_F(t)$ is the filtered value at time (t), $X_F(t\text{-}1)$ is the filtered value-at time (t-1), $X_u(t)$ is the unfiltered value at time (t), and if the compass is in initial calibration mode,

$$\frac{1}{3+(X_u(t)-X_F(t-1))^2/8190}$$

[0088] or if the compass is in the normal operating mode,

$$\frac{1}{3+(X_u(t)-X_F(t-1))^2/4096}$$

[0089] Then, the program advances to block **414** which compensates the compass for deviation resulting from the vehicle magnetic field. Block **414** represents a sub-routine which is depicted in the flow charts of **FIGS. 15A, 15B** and **15**C which will be described in detail subsequently.

[0090] From block **414**, the program advances to the test block **416** which determines whether the deviation compensation procedure of block **414** changed the output of the D/A converter **44'** and hence the offset current in the current strap **18** of the sensor. If it did, the program loops back to block **403**. If it did not, the program advances to block **418** which scales the data for the Y-axis or X-axis signal having the lower maximum output by applying a scaling factor to account for the difference in magnitude between the peak values of the X-axis and Y-axis signals. At block **420**, new signal data is stored by copying data from the working registers to assigned locations in the random access memory (RAM) of the microcomputer **38'**. Then, the program advances to block **422** which causes the microcomputer to detect the peak values of the signal data for each axis as they occur by examining the signal trend on each axis and to detect the difference between the signal reference value and the actual signal value of the opposite axis to determine the sign of the two count reference adjustment. The peak value and signal reference adjustment value for each axis are then stored in RAM as they are determined. Next, the program proceeds to block **424** which causes the microcomputer to determine the heading angle of the vehicle by using a known functional relationship wherein the heading angle is expressed as an arctangent function of the X-axis and Y-axis signals. In block **426** the heading angle, expressed in units of degrees, is stored in the RAM.

[0091] After the heading angle is stored by block **426**, the program advances to the test block **428** which determines whether the compass is in the zone-setting mode. If it is, the program advances to block **403** which interprets the user input to control the display in accordance with such input. This permits the operator to select the geographical zone and the corresponding variation angle to compensate for the magnetic variation angle of the earth field from true north which depends upon the geographical location of the vehicle. If block **428** determines that the compass is not in the zone-setting mode, the program advances to block **432** which adds the variation compensation angle to the magnetic heading which was stored by block **426**. This allows the microcomputer to develop an output signal which corresponds to the true heading of the vehicle. The program then advances to block **434** which updates the true heading signal which is stored in the display memory. This block also converts the heading, as expressed in degrees, to a heading angle expressed in one of the eight principal compass points, i.e. the cardinal and intercardinal points. Changes in the compass display are dampened using a four level progressive damping technique. Each level utilizes a progressively larger time duration. Typical time durations for each level, one through four, are 1.3 seconds, 1.8 seconds, 2.2 seconds, and 2.8 seconds, respectively. The damping level used for a display update corresponds to the number of octants by which the new display differs from the existing display. From block **434**, the program loops back to block **403**.

Initial Calibration Mode of Deviation Compensation

[0092] The operation of the system in the initial calibration mode will now be described with reference to **FIGS. 15A and 15B**. As discussed above, in the initial calibration mode, the sensor offset current is first changed as needed to produce readable sensor signals which are within a predetermined measurement range. The signal peak values are also adjusted to a nominal earth field level by changing the sensor offset current. The compensating signal reference values are then determined for each axis, as the peak set values are determined, for the respective axis.

[0093] To enter the initial calibration mode, the calibrate switch **82** is actuated by the operator by pressing and holding it closed for a predetermined time, for example, about a half second. This causes the display to display "CAL" to confirm to the operator that the compass is in the initial calibration mode. The operator may then calibrate the compass by driving the vehicle in approximately two circles. As the vehicle traverses such a course, it acquires peak (e.g. north) and peak set (e.g. north/south or east/west) values. The microcomputer **38'** then determines the compensating signal reference value for each axis as each peak for that axis is determined. After the vehicle has been driven in two circles, the microcomputer will have counted six peaks (e.g. north or south) and, provided the second and sixth correspond directionally (e.g., north and south) it will then automatically exit the initial calibration mode and the "CAL" display is turned off.

[0094] The control program for performing deviation compensation (which is represented by the block **414** in **FIG. 14A**) will be described in more detail with reference to **FIGS. 15A and 15B**. The compensation routine starts with a test block **436** which determines whether the compass is in the initial calibration mode. If it is not, the program proceeds to operate in the normal calibration mode **480** which will be described subsequently with reference to **FIG. 16**. If the compass is in the initial calibration mode, the program advances to the routine for that mode indicated at block **438**. First, block **440** sets the time delay value to zero for the compass display. This disables the time delay which is used in normal compass operation to dampen changes in the displayed direction when only a momentary change has occurred.

[0095] Then, the program advances to the test block **442** which determines whether a peak set has occurred in the

current axis. (In this routine, the program is executed alternately for the X-axis and Y-axis signals. In the flow chart, the term "current" axis means the axis for which the program is being executed at the time.) If there has not been a peak set in the current axis, the program advances to a test block **444** which determines whether a peak has been validated in the current axis. If not, the test block **446** determines whether the signal is out of peak detection range. If it is, the microcomputer **38'** adjusts the D/A converter **44'** setting by eight counts to change the offset current in the current strap **18** so that the sensor signal is adjusted such that it is within the readable A/D range enough to permit peak detection. This is done at block **448**. Then, the program returns to the main loop for new data.

[**0096**] If at block **444**, it is determined that a peak has been validated in the current axis, the program branches to test block **452**. This determines whether the first peak has been. adjusted to the nominal earth field level. If it has not, the program advances to block **454** which adjusts the offset current for the sensor so that the peak is at a nominal level. (The nominal level, as stated above, is a signal corresponding to an earth field of about 200 mGauss.) Then, block **456** resets the peak, peak detect and average values and the program returns to the main loop for new data at block **450**.

[**0097**] If it is determined at test block **452** that the first peak had been adjusted to a nominal level, the program advances to test block **453** for a determination of whether the second and sixth peaks have both occurred. If not, at block **460** the program returns to the main loop at block **416** to process the heading. If both peaks have occurred, test block **458** determines whether they correspond directionally. If not, block **455** re-starts initial calibration and the program returns at block **457** to the main loop for new data. If both peaks correspond directionally, the initial calibration exit criteria has been met and the calibration flag is set at block **462**. Then, the calibration counter is incremented at block **464** to keep track of the number of times the compass has been calibrated. Next, the program advances to block **466** which stores the calibration values in the non-volatile memory. This includes the values on the D/A converter **44'**, the scaling factor, the compensating signal reference values, the peak values and the value of the register that stores the calibration flag. Then, the program advances to block **468** which reloads the compass operating constants. This step includes reloading the EEPROM and storing the calibration values in their respective storage locations including the calibration step-size (typically two counts) for normal calibration. Then, the program returns to the main loop for new data as indicated at block **470**.

[**0098**] If at test block **442**, it is determined that there has been a peak set in the current axis, the program advances to test block **472** which determines whether there is a new valid peak in the current axis. If the answer is no, the program proceeds to block **453** which was described above. If there is a new valid peak, the program advances to block **474** to determine the signal reference value by calculating the average of the peak set values. Then, the program advances to block **476** which calculates the scaling factor. The scaling factor is used to match the output of one of the X-axis and Y-axis sensors to the other and for this purpose, the signal from that axis which has the lower signal level is multiplied by the scaling factor to scale it to the sensor having the larger signal level. The scaling factor is calculated by dividing the peak value of the larger signal by the peak value of the lower signal. After block **476**, the program returns to the main loop for new data as indicated at block **478**.

[**0099**] Normal compensation Mode

[**0100**] It is desirable to provide the compass with long term calibration after the initial calibration in order to compensate for any changes that may occur on a long term basis in the ambient magnetic field. For this purpose, normal calibration is automatically performed whenever the compass is operated in its direction indicating mode. The compass operates in this mode at any time that the ignition switch is on and the initial calibration mode is not operative. In general, in the normal calibration mode, the X-axis and Y-axis sensor signals are sampled and stored. Whenever a new peak is acquired for one axis, which should occur at the signal reference value in the orthogonal axis, an adjustment value is stored and later used to adjust the compensating signal reference value. This is accomplished by adding the stored signal reference adjustment to the existing signal reference value. During normal compensation, the compensating signal reference values for each axis may be adjusted once, and preferably, twice, once for each new peak in the opposite axis during each ignition or power-up cycle of compass operation. Suitably, this compensation is effected upon the occurrence of the first peak in each of the X-axis and Y-axis after a warm-up delay as described below.

[**0101**] The operation in the normal calibration mode will be further described with reference to the flow chart of **FIG. 16**. The normal calibration mode is entered at block **480** and the test block **482** determines whether the peak and signal reference adjustment information is ready. If not, the program continues processing the data signals as indicated at block **496**. If peak and signal reference adjustment information is ready, the program advances to block **484** which determines whether the power-up timer of the microcomputer **38'** is greater than five minutes which has the effect of delaying normal calibration for a period of five minutes after the ignition switch is turned on. If the answer at block **484** is no, the program advances to block **494** which resets the valid peak flags and then the program continues data processing. If the timer is greater than five minutes, the program advances to test block **486** which determines whether the peak information that has been acquired has been used already in this power-up cycle. If it has, the program advances to reset the valid peak flags at block **494** and data processing is continued. If the peak information has not yet been used, the program advances to block **488** which sets a flag to indicate that this peak has been used in this power-up cycle. Then, at block **490**, the signal reference adjustment value is added to the compensating signal reference value. For example, in the case of an X-axis peak, if the Y-axis measured signal at the time of the X-axis peak is not equal to the Y-axis signal reference value, the signal reference value is adjusted by two counts towards the Y-axis measured value. Then, the program advances to block **492** which stores the compensating signal reference values, i.e. the new reference value for each of the axes. In block **494**, the valid peak flags are reset and the program then continues data processing as indicated in block **496**.

[**0102**] Sensor Offset Calculation

[**0103**] Each of the X-axis and Y-axis sensors may have a signal offset voltage which is inherent in the system which,

without proper correction may result in inaccurate or unusable sensor signals. The sensor offset voltage may arise in part from the internal characteristics of the particular sensor. Further, the sensor offset voltage may be induced, in part, from the signal path externally of the sensor and from software latency. The sensor offset voltage is independent of the offset arising from the vehicle magnetic field previously discussed.

[0104] Examples of sensor offset voltage are illustrated in **FIG. 17**. **FIG. 17** is a graphical representation of the signal voltage of the Y-axis sensor as a function of time as it is developed at the output of the A/D converter **42'**. Lines C and D represent a signal with no offset. The line C represents the signal voltage developed during the reset mode and the line D represents the signal voltage developed during the set mode. Line C, being from the reset mode, is indicative of the magnetic south component and line D, being from the set mode, is indicative of the magnetic north component. Lines C and D intersect at the reference value of the signal voltage which indicates the heading of east or west.

[0105] A signal with zero sensor offset voltage indicates a definite direction without ambiguity. The sensor does not have an output signal in both set and reset modes at the same time. There are certain conditions of sensor offset voltage in which the signals, during reset and set modes are of such values that accurate direction information may not be derived from them. One example of this condition is represented by a reset voltage corresponding to line E and a set voltage corresponding to line F. In this condition, the Y-axis sensor has a zero output voltage in both sensor modes. In the time interval between the zero values, no direction information can be derived. Another example is a condition in which the sensor has a positive signal in both sensor modes at the same time. This is represented by reset voltage shown by line A and a set voltage shown by line B. In order to remove such offset conditions, an offset voltage calibration value is calculated and added to the sensor signal to compensate for the offset. This offset calibration value is calculated as one-fourth the sum of the set data and reset data plus one-half of the previously calculated offset value.

[0106] The sensor offset voltage calculation routine is imbedded in the retrieve data block **404** of **FIG. 14A**. This routine **404'** entitled "SENSOR OFFSET VOLTAGE CALIBRATION" is represented by the flow chart of **FIG. 18**. In this program, the set and reset mode data is retrieved from the current axis at block **510**. Then, at test block **512**, it is determined whether both the set and reset data are greater than zero at the same time or whether they are equal to zero at the same time. If they are not, the program continues data processing as indicated at block **516**. If they are in block **514**, the sensor offset calibration value is calculated by adding one-fourth of the set data plus the reset data to one-half of the old calibration offset value.

[0107] As described, the sensor offset calibration value for each X-axis and Y-axis is used to compensate for the sensor offset in the program step indicated at block **404**. Accordingly, the signal data which is processed downstream of that block is corrected for sensor offset.

[0108] Compass And Vehicle Mirror Combination

[0109] According to this invention, the electronic compass is incorporated, in whole or in part, into the structure of a vehicle inside rearview mirror. In this application, the sensor board **36** (see **FIG. 4**) may be mounted on the inside rearview mirror assembly so that its position is fixed with respect to the vehicle or at a suitable remote location in the vehicle. The compass display .**76'** may be located in the mirror structure for convenient viewing by the vehicle driver. Several different arrangements will be described below.

[0110] As shown in **FIG. 19**, the compass circuit of **FIGS. 12A and 12B** is located in a compass module **230** secured below the mounting bracket **232** of the rearview mirror **234**.

[0111] As shown in **FIG. 20**, the module may communicate with a prismatic mirror or electrochromic mirror so that the vehicle heading may be displayed above the mirror. Alternatively, as shown in **FIG. 21**, the display **76'** may be located behind the mirror and viewable through a transparent area by all passengers in the vehicle.

[0112] **FIGS. 22A and 22B** depict an integrated compass module. In this arrangement, the compass module **230A** houses the electronic circuit of the compass (either that of **FIGS. 12A and 12B** or that of **FIG. 13**) and also the display. This module is supported on the mirror mounting bracket **232** such that the display **76'** is viewable below the mirror **234**.

[0113] A stand alone compass module may be mounted similarly and supply directional information to other vehicle systems for display or navigational purposes.

CONCLUSION

[0114] Although the description of this invention has been given with reference to particular embodiments, it is not to be construed in a limiting sense. Many variations and modifications will now occur to those skilled in the art. For a definition of the invention, reference is made to the appended claims.

What is claimed is:

1. A method for compensating for the effect of a deviating magnetic field in a vehicle compass, said compass comprising:

first and second magnetoresistive sensors responsive to an external magnetic field for developing electronic signals representative of said external magnetic field, said external magnetic field being a combination of the earth magnetic field and a deviating field of the vehicle,

said first and second sensors being oriented in a predetermined angular relation with each other, and being aligned in a predetermined angular relation with respective axes of said vehicle,

each of said sensors including means for nullifying at least part of a deviating magnetic field which impinges on it, said method comprising the steps of:

determining-whether the value of the sensor signal of each sensor is different from a nominal value which corresponds approximately to the value of the earth magnetic field,

if it is, using said nullifying means for adjusting the magnetic field impinging on each sensor to adjust the sensor signal to a value approximately equal to the nominal value,

determining the maximum and minimum peak values of each sensor signal,

determining the average of said peak values of each sensor signal,

and mathematically compensating the actual value of each sensor signal in accordance with the respective average value.

2. A method for compensating for the effect of a deviating magnetic field in a vehicle compass, said compass comprising:

first and second magnetoresistive sensors responsive to an external magnetic field for developing electronic signals representative of said external magnetic field, said external magnetic field being a combination of the earth magnetic field and a deviating field of the vehicle,

said first -and second sensors being oriented in a predetermined angular relation with each other, and being aligned in a predetermined angular relation with respective axes of said vehicle,

each of said sensors including means for nullifying at least part of a deviating magnetic field which impinges on it,

a digital electronic circuit including means for measuring said signals when said signals are within a predetermined measurement range,

said method comprising the steps of:

determining whether the value of the sensor signal of each sensor is within said measurement range,

if it is not, using said nullifying means for nullifying at least part of magnetic field impinging on said sensor to reduce the sensor signal to a value within said range.

3. A method as defined in claim 2 including the steps of:

determining whether the value of the sensor signal of each sensor is greater than a nominal value which is approximately equal to the earth magnetic field,

and if it is, using said nullifying means for adjusting at least part of the magnetic field impinging on each sensor to adjust the sensor signal to a value approximately equal to the nominal value.

4. A method as defined in claim 3 including the steps of:

determining the maximum and minimum peak values of each sensor signal,

determining a reference value for each sensor signal equal to the average of said peak values of each sensor signal,

and mathematically compensating the actual value of each sensor signal in accordance with the respective reference value.

5. A method for updating the deviation compensation of a vehicle compass comprising:

first and second sensors responsive to an external magnetic field for developing electronic signals representative of said external magnetic field, said external magnetic field being a combination of the earth magnetic field and a deviating field of the vehicle,

said first and second sensors being oriented in a predetermined angular relation with each other, and being aligned in a predetermined angular relation with respective axes of said vehicle,

and a memory which stores a reference value for each sensor signal, said reference value for each sensor being equal to an offset value for providing deviation compensation for the respective sensor at a previous time,

said method comprising the steps of:

detecting the occurrence of a peak in the sensor signal of one of the sensors,

measuring the value of the sensor signal of the other sensor which occurs at the same time as the occurrence of said peak,

and if there is a difference between the measured value and said reference value, adjusting the reference value in accordance with the difference.

6. A method as defined in claim 5 wherein said sensors are magnetoresistive sensors.

7. A method as defined in claim 5 wherein said compass is installed in a vehicle having a switch which is in one of two switch states when the vehicle is being driven;

and wherein said step of adjusting is executed a predetermined number of times during a time-interval that said switch is in said one state without being switched to another state.

8. A method of determining an offset calibration value for a magnetoresistive sensor in a magnetic compass, said compass including an electronic circuit and a microcomputer for processing an output signal from said sensor, said sensor being alternately biased between a reset mode and a set mode,

said method comprising the steps of:

determining whether both reset signal and the set signal are equal to or greater than zero at the same time,

if they are, calculate a sensor offset calibration value.

9. A method as defined in claim 8 wherein said step of calculating includes adding one-fourth of set signal value plus the reset signal value to one-half of a previous sensor offset calibration value which was calculated in the same way the last time the calibration value was calculated.

10. A method for compensating an electronic compass in a vehicle of the type comprising first and second sensors oriented in a predetermined angular relation with each other and with respective axes of the vehicle,

said method comprising the steps of:

determining a compensating reference signal value for each sensor,

detecting the occurrence of a peak in the sensor signal of one of the sensors,

measuring the value of the sensor signal of the other sensor which occurs at the same time as the occurrence of said peaks,

and, if there is a difference between the measured value and the reference value, adjusting the reference value in accordance with the difference.

11. In combination, for use in a vehicle,

an electronic compass comprising a magnetoresistive sensor for detecting the magnetic field of the earth,

an electronic circuit coupled with said sensor for developing signals indicative of the direction of said vehicle,

and electronic display coupled with said circuit for displaying said direction,

a rear view mirror,

said electronic display being disposed on said mirror for viewing by a driver of said vehicle.

12. The invention as defined by claim 11 wherein said sensor and said electronic circuit are mounted on said mirror.

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