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(54) MICRO INTEGRATED GLOBAL POSITIONING SYSTEM/INERTIAL MEASUREMENT UNIT SYSTEM

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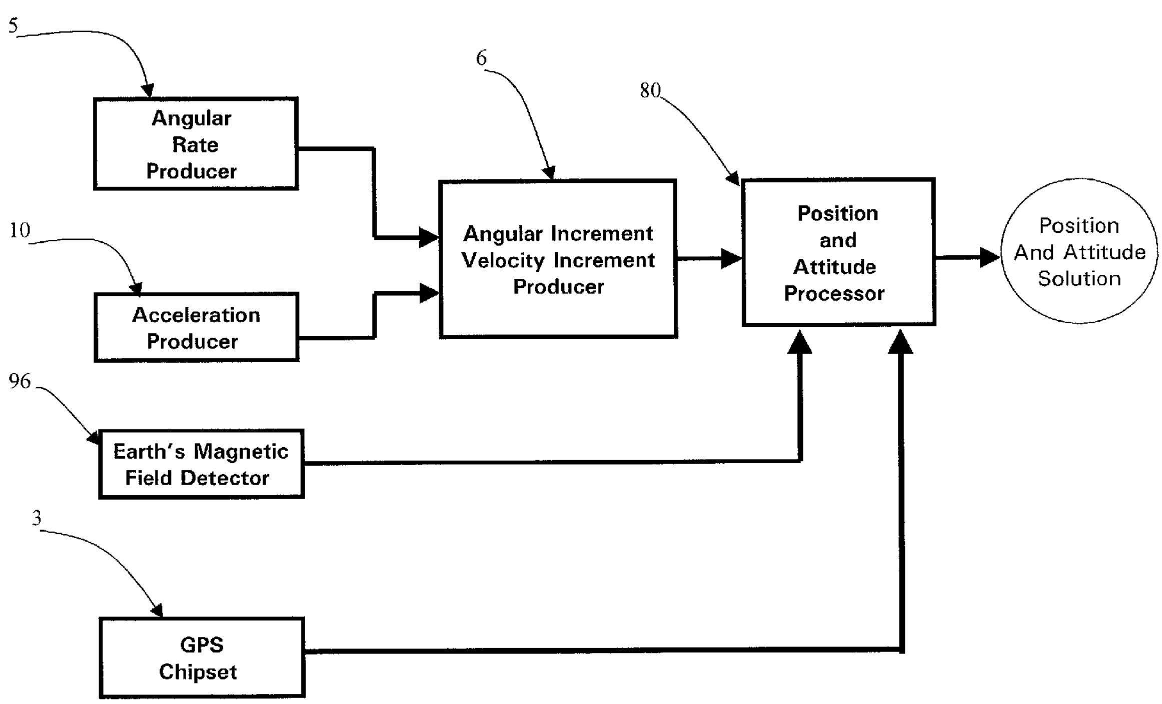
(52) **U.S. Cl.** **342/357.14**; 701/216

(57) **ABSTRACT**

A micro integrated Global Positioning System (GPS)/Inertial Measurement Unit (IMU) System, which is adapted to apply to output signals proportional to rotation and translational motion of a carrier and GPS measurements of the carrier, respectively from angular rate sensors, acceleration sensors, and GPS chipset, is employed with MEMS angular rate and acceleration sensors and GPS chipset. Compared with a conventional IMU/GPS system, the system of the present invention uses an integrated processing scheme by means of digital closed loop control of the dither driver signals for MEMS angular rate sensors, a feedforward open-loop signal processing scheme of the IMU, digital temperature control and compensation, the earth's magnetic field-based heading damping, robust error estimator, and compact sensor and circuit architecture and dramatically shrinks the size of mechanical and electronic hardware and power consumption, meanwhile, obtains highly accurate motion measurements.



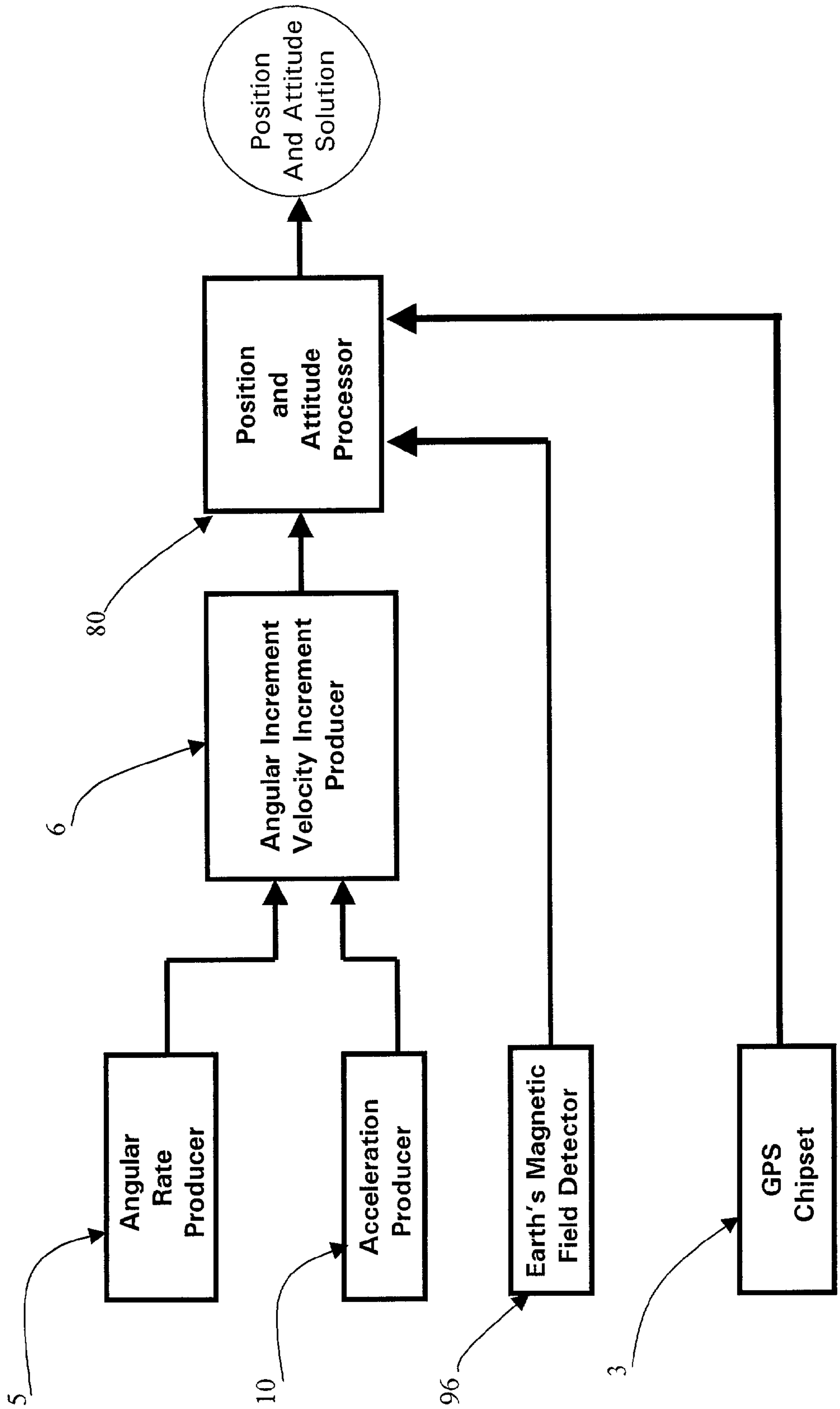

Position And Attitude Solution
Position and Attitude Processor
Angular Increment Velocity Increment Producer
Angular Rate Producer
Acceleration Producer
Earth's Magnetic Field Detector
GPS Chipset
80
6
5
10
96
3

Figure 1

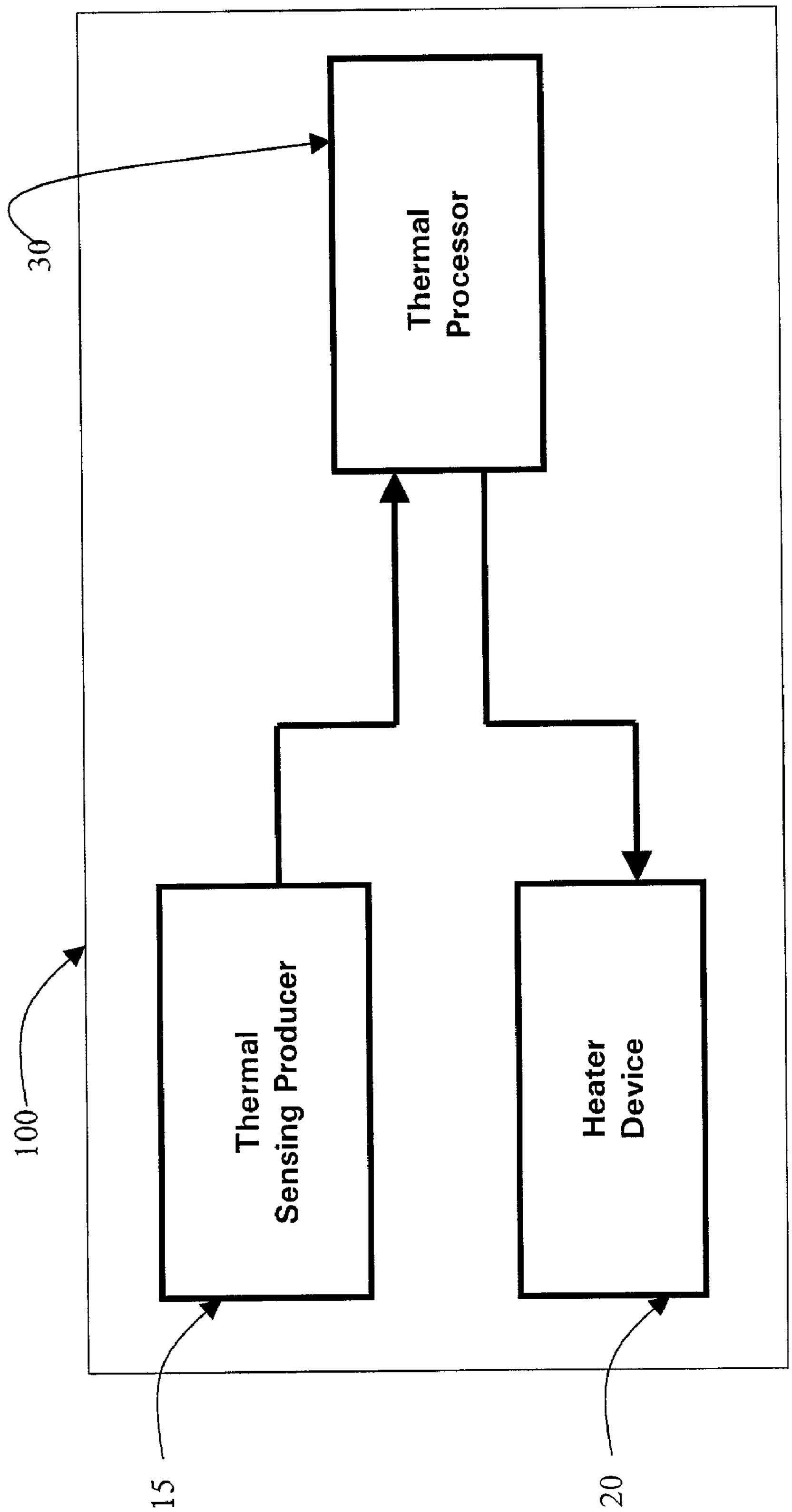

30
Thermal
Processor
100
Thermal
Sensing Producer
Heater
Device
15
20

Figure 2

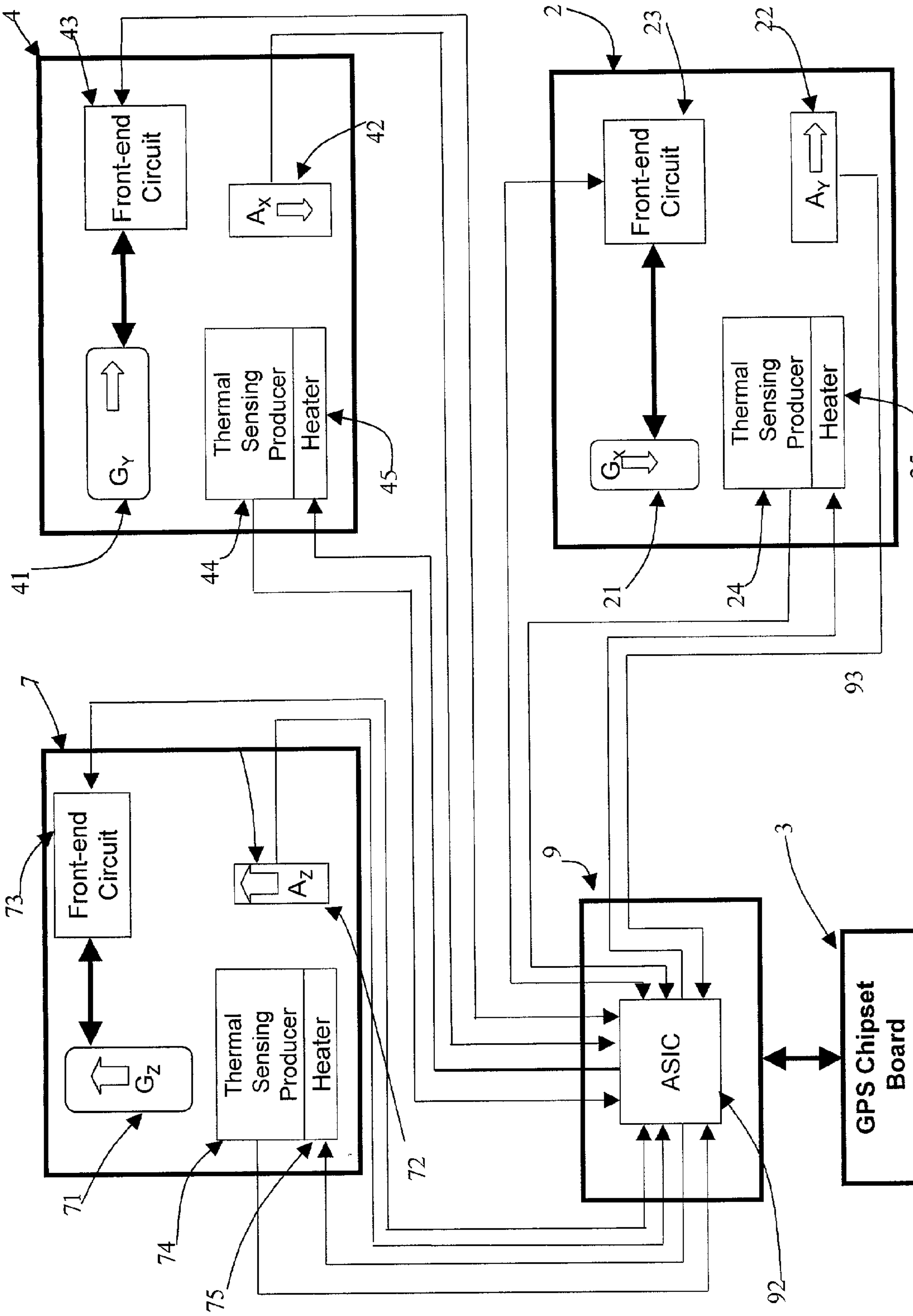

Front-end Circuit
Thermal Sensing Producer
Heater
ASIC
GPS Chipset Board
4
41
42
43
44
45
2
21
22
23
24
25
7
71
72
73
74
75
9
92
93
3

Figure 3

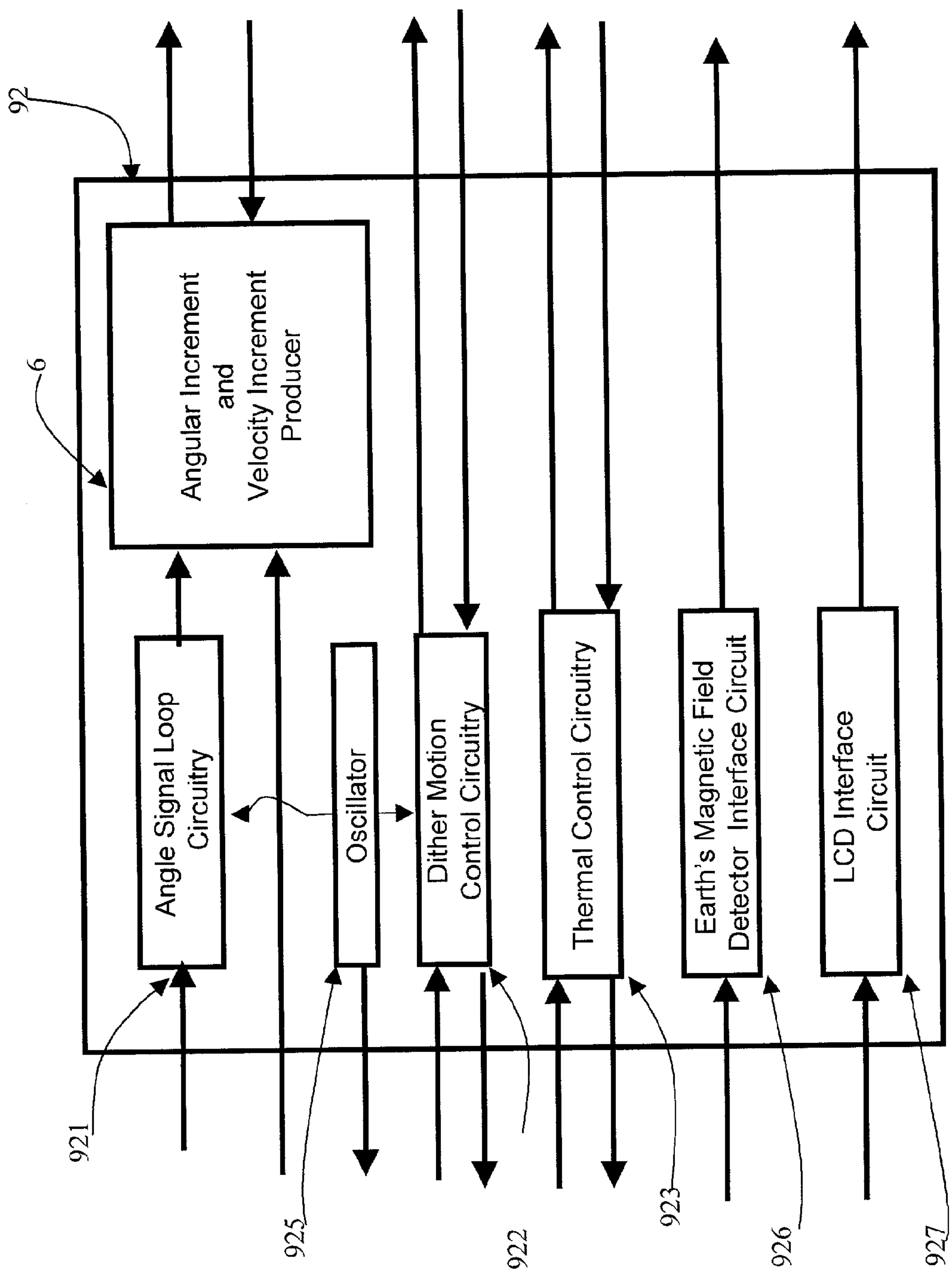
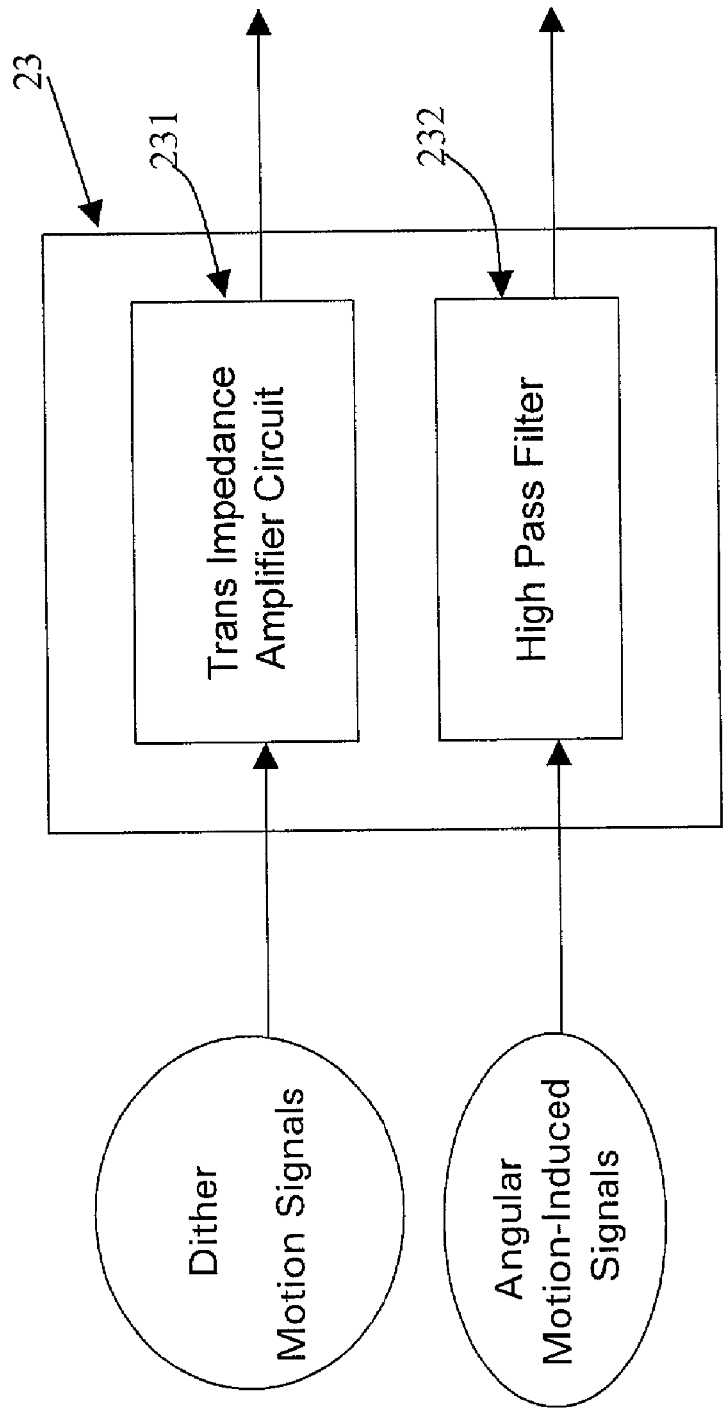

92
6
Angular Increment and Velocity Increment Producer
Angle Signal Loop Circuitry
Oscillator
Dither Motion Control Circuitry
Thermal Control Circuitry
Earth's Magnetic Field Detector Interface Circuit
LCD Interface Circuit
921
925
922
923
926
927

Figure 4



23
231
232
Trans Impedance Amplifier Circuit
High Pass Filter
Dither Motion Signals
Angular Motion-Induced Signals

Figure 5

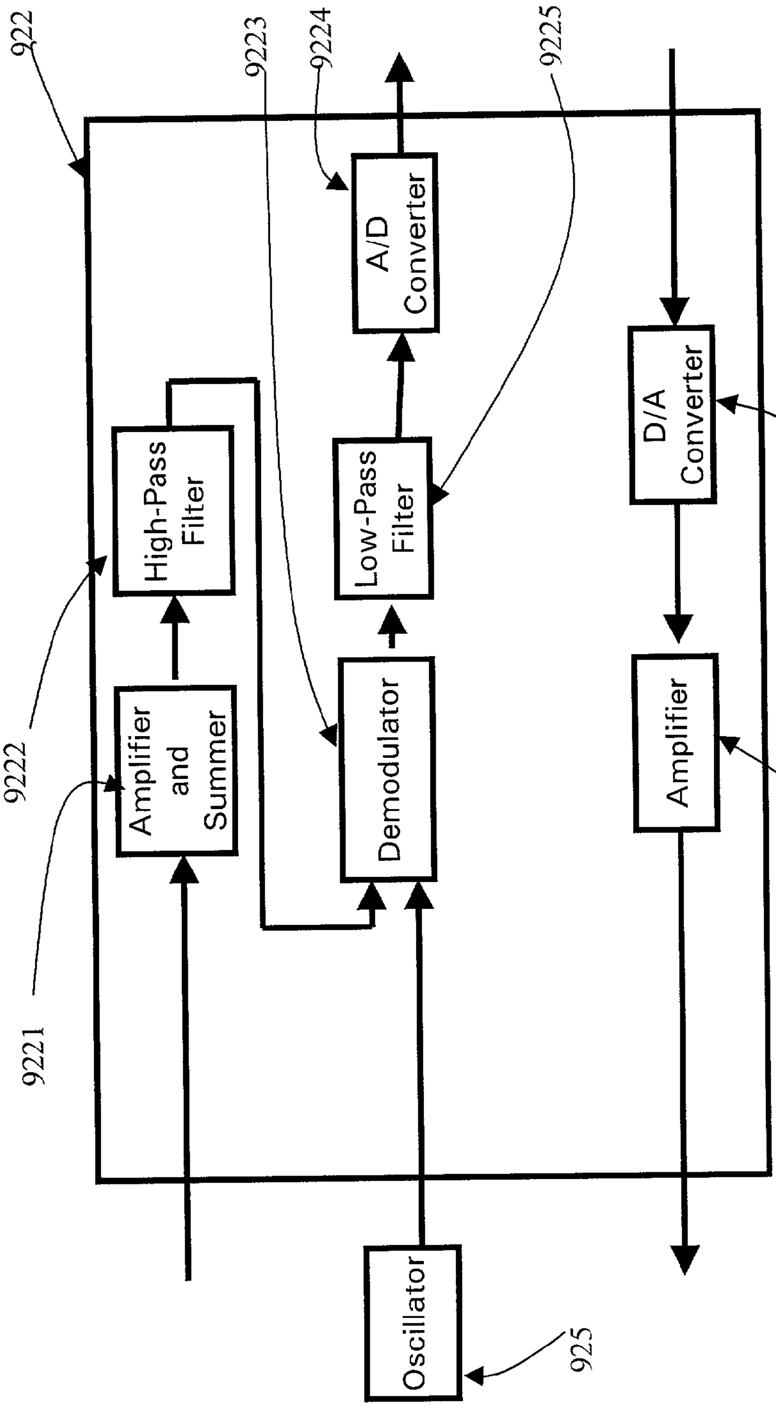

922
9223
9224
9225
A/D Converter
High-Pass Filter
Low-Pass Filter
D/A Converter
9222
Amplifier and Summer
Demodulator
Amplifier
9226
9221
9227
Oscillator
925

Figure 6

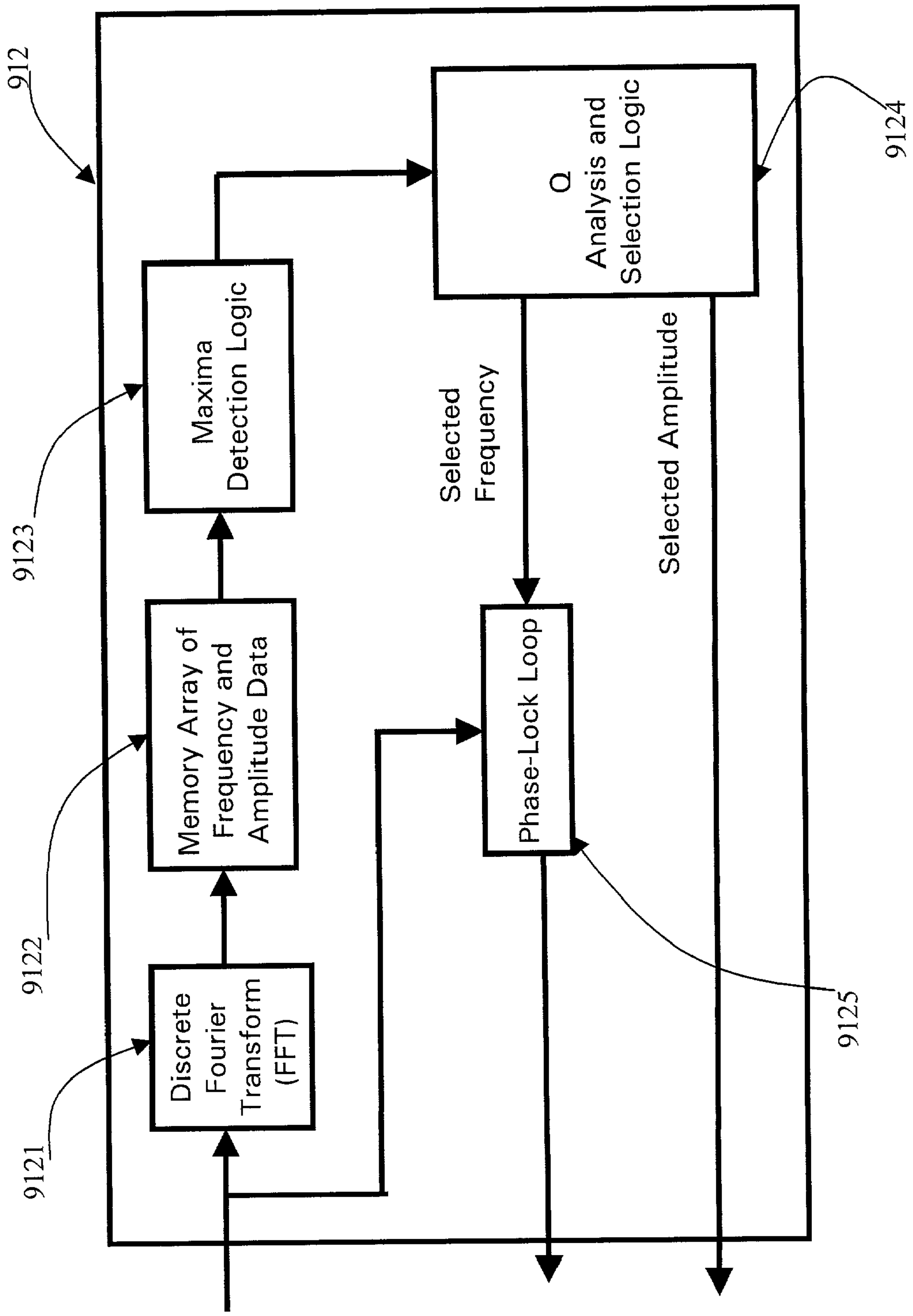

912
9121
Discrete Fourier Transform (FFT)
9122
Memory Array of Frequency and Amplitude Data
9123
Maxima Detection Logic
Q Analysis and Selection Logic
9124
Selected Frequency
Selected Amplitude
Phase-Lock Loop
9125

Figure 7

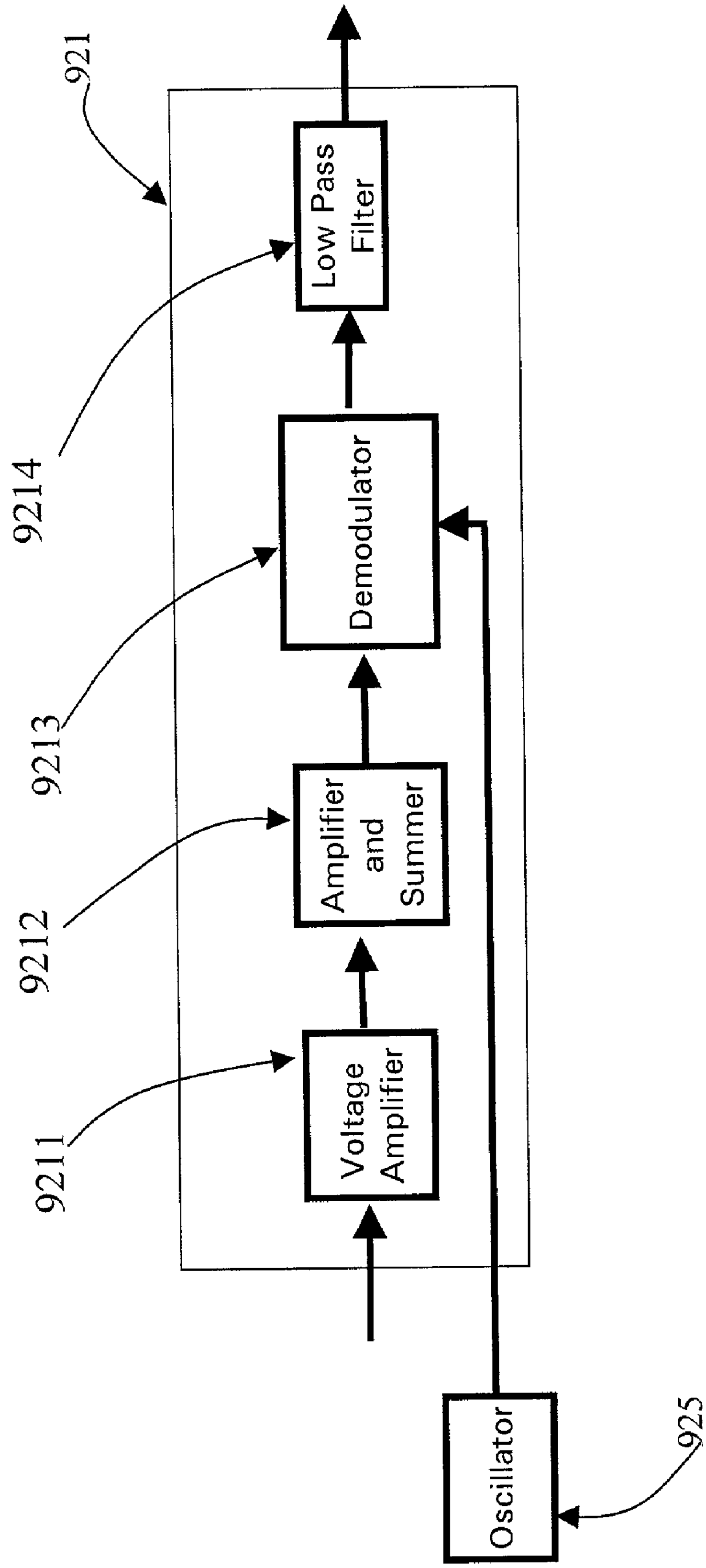
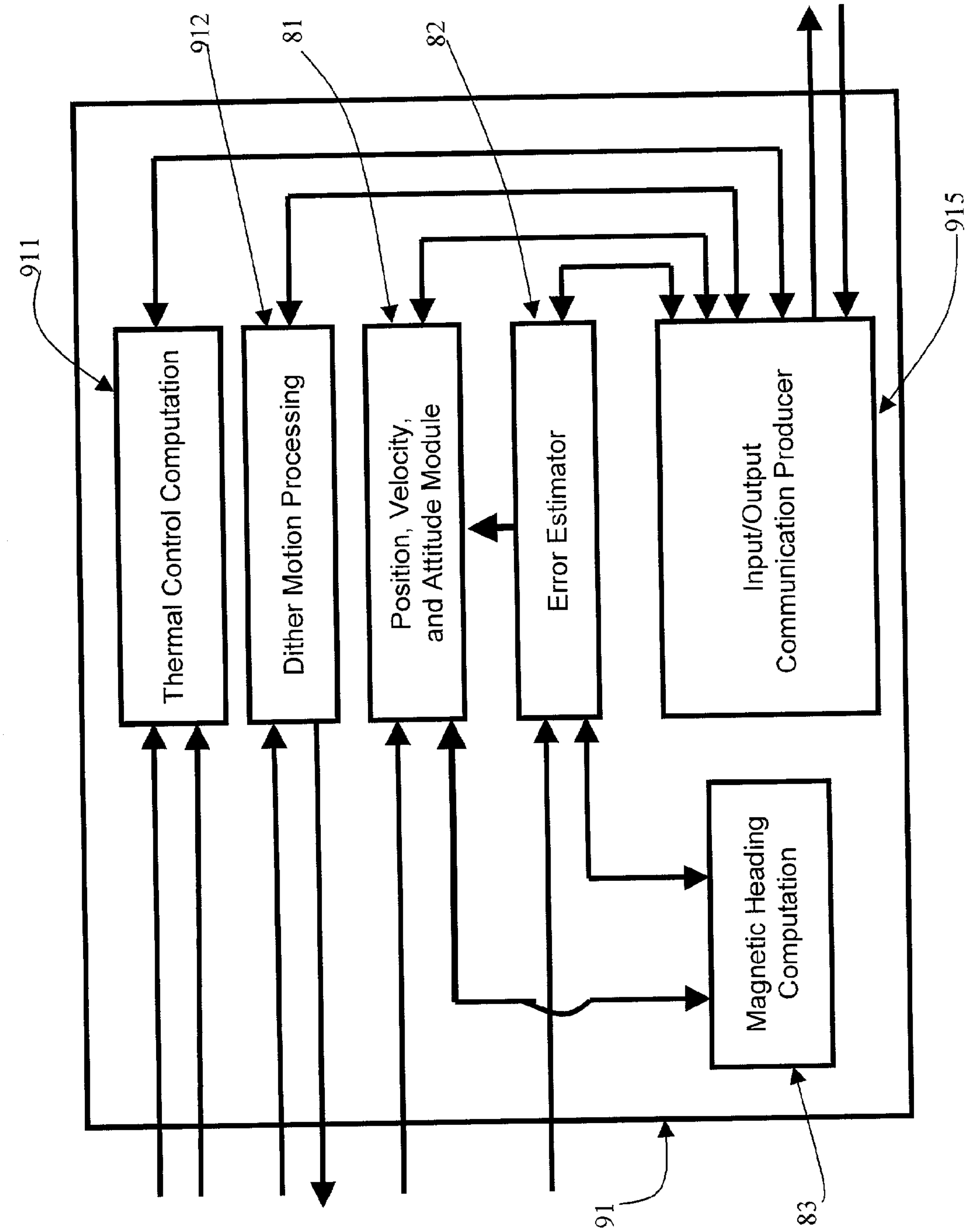

921
9214
9213
9212
9211
Low Pass Filter
Demodulator
Amplifier and Summer
Voltage Amplifier
Oscillator
925

Figure 8



Thermal Control Computation
Dither Motion Processing
Position, Velocity, and Attitude Module
Error Estimator
Input/Output Communication Producer
Magnetic Heading Computation
911
912
81
82
915
91
83

Figure 9

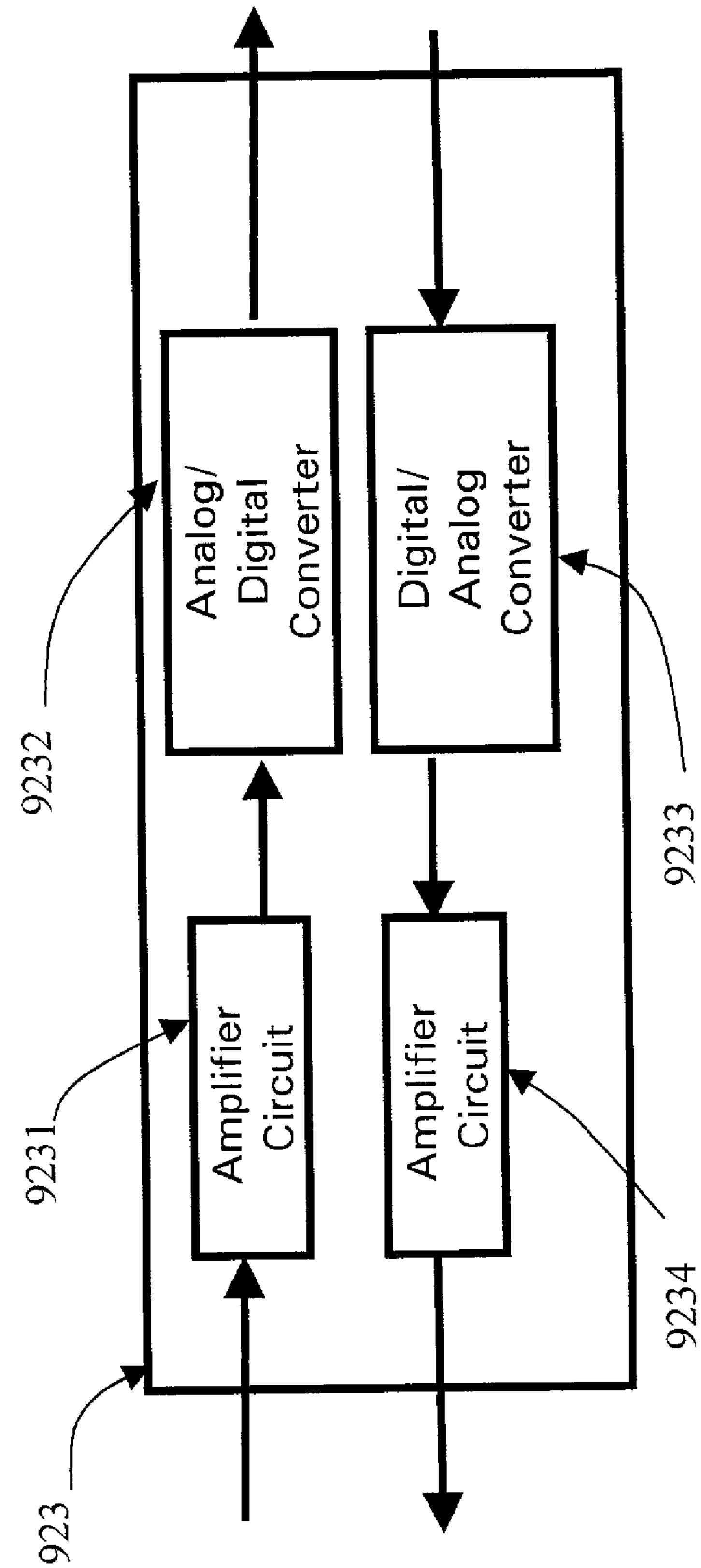

Analog/
Digital
Converter
Digital/
Analog
Converter
Amplifier
Circuit
Amplifier
Circuit
9232
9231
923
9233
9234

Figure 10

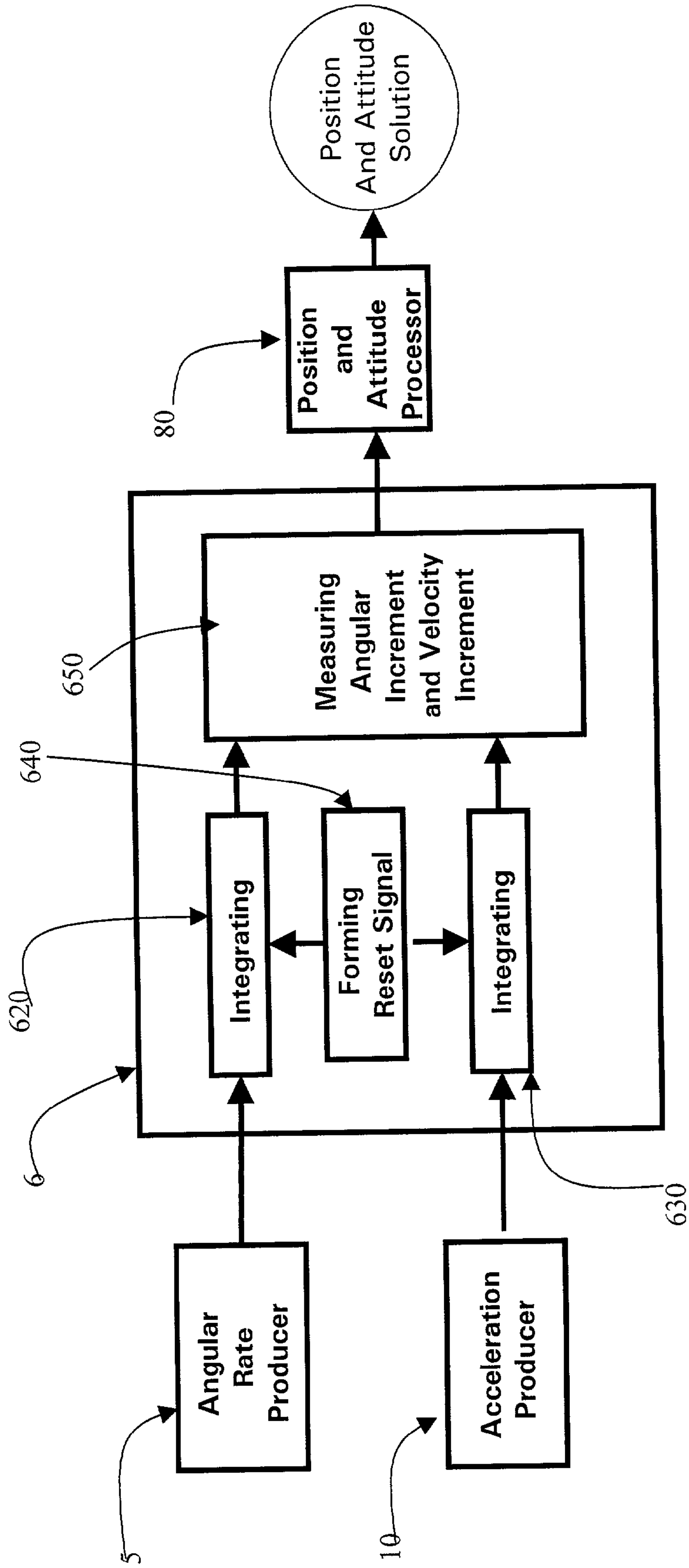

Position And Attitude Solution
Position and Attitude Processor
80
Measuring Angular Increment and Velocity Increment
650
640
Integrating
Forming Reset Signal
Integrating
620
6
630
Angular Rate Producer
Acceleration Producer
5
10

Figure 11

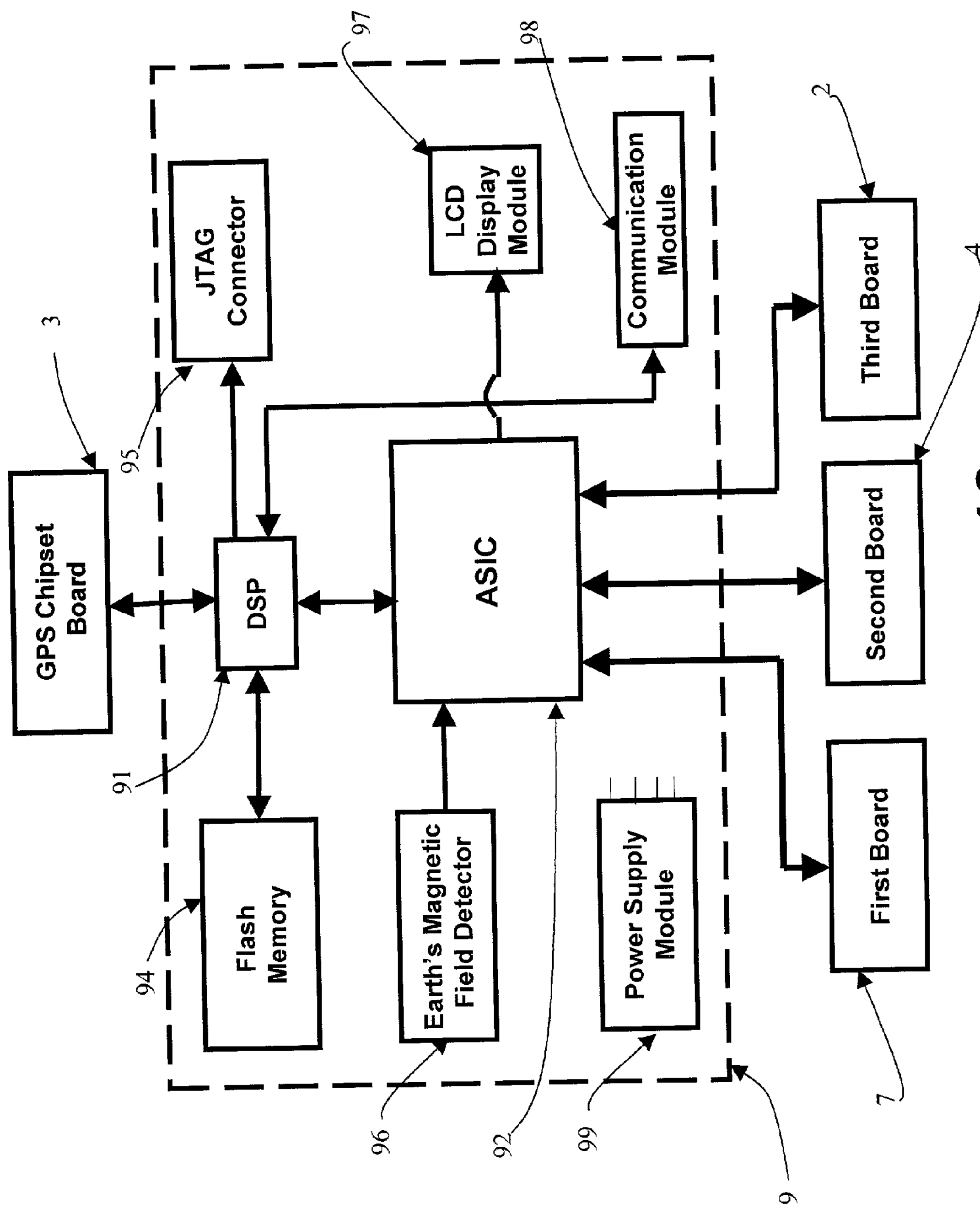

GPS Chipset Board
JTAG Connector
LCD Display Module
Communication Module
DSP
ASIC
Flash Memory
Earth's Magnetic Field Detector
Power Supply Module
Third Board
Second Board
First Board
3
95
97
98
2
4
91
94
96
92
99
9
7

Figure 12

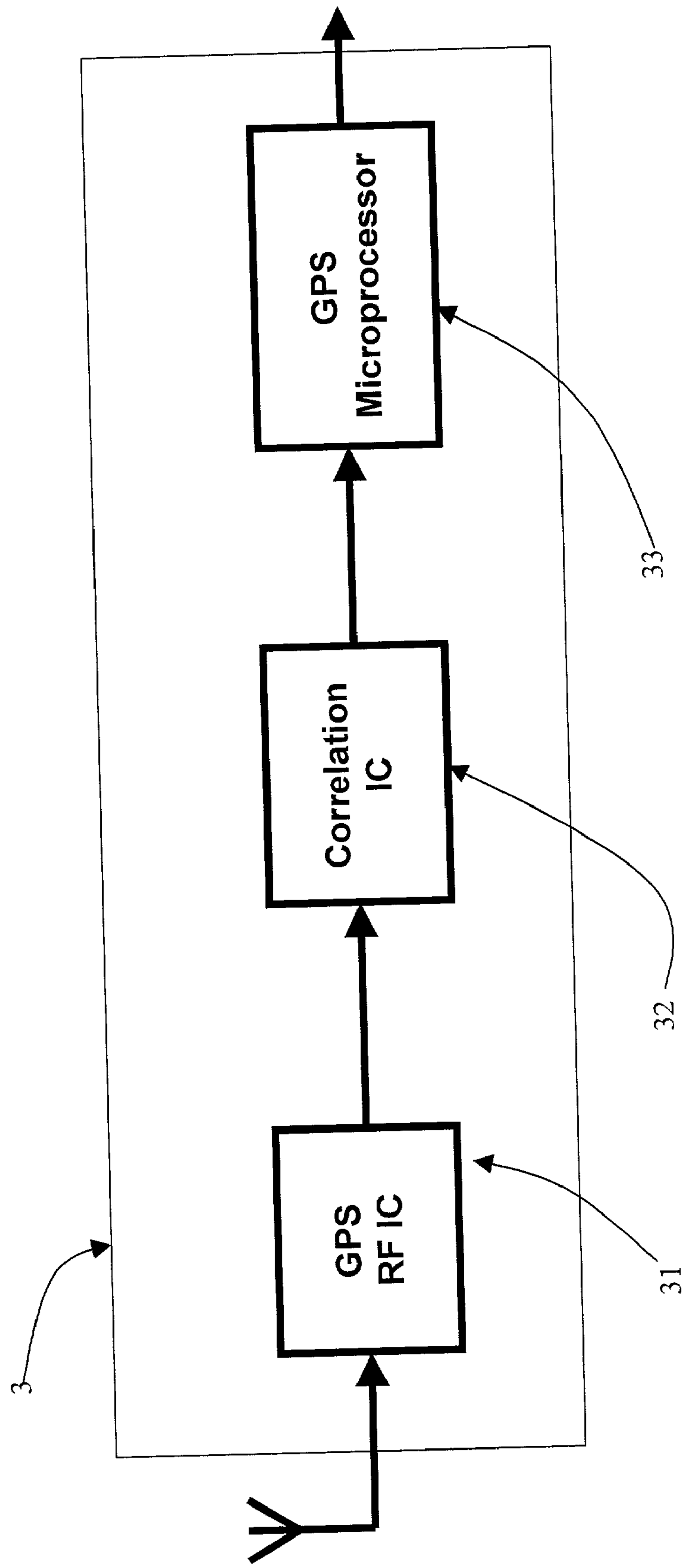


Figure 13

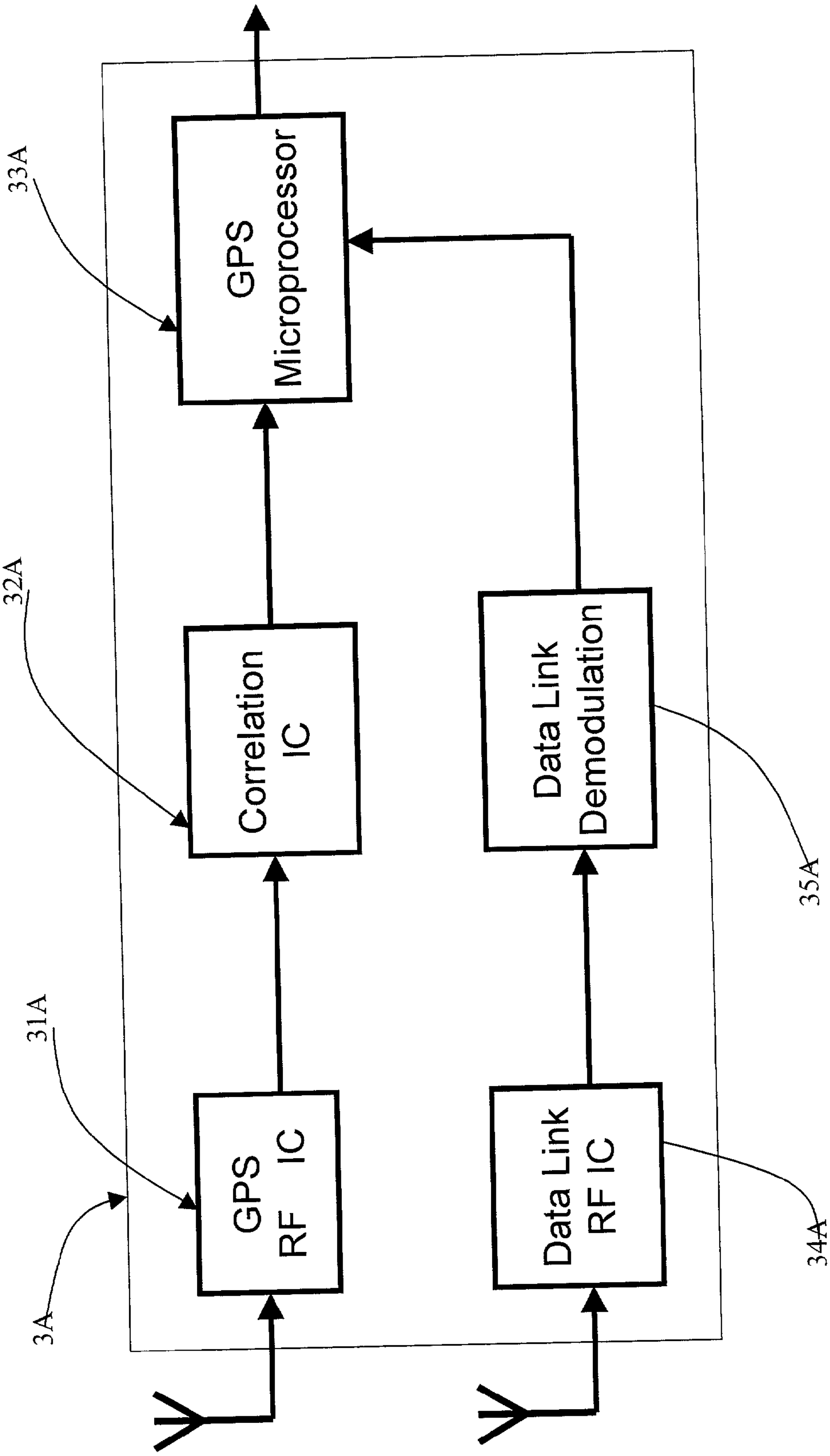

33A
GPS Microprocessor
32A
Correlation IC
Data Link Demodulation
35A
31A
GPS RF IC
Data Link RF IC
34A
3A

Figure 14

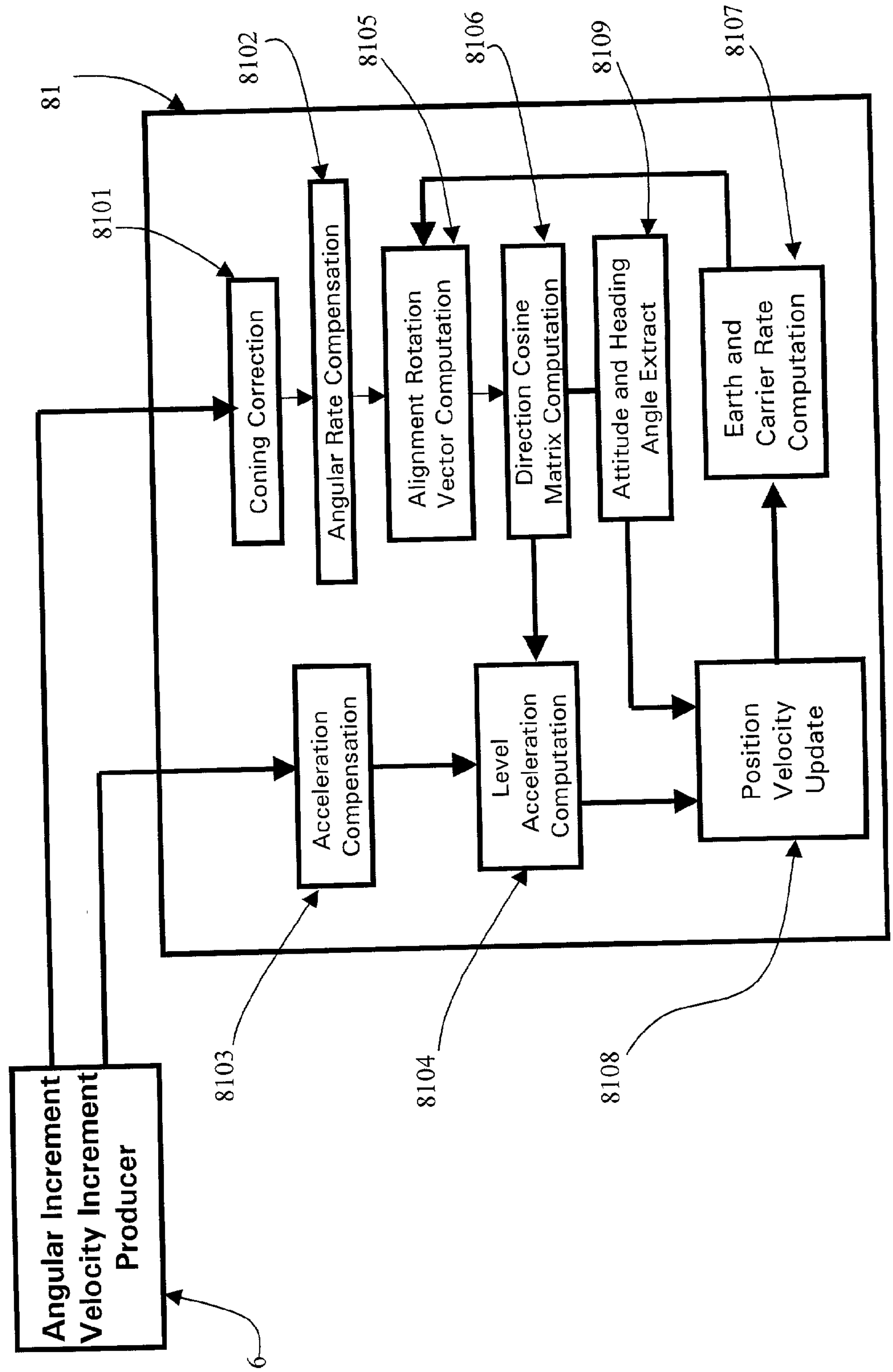

81
8101
8102
8105
8106
8109
8107
Coning Correction
Angular Rate Compensation
Alignment Rotation Vector Computation
Direction Cosine Matrix Computation
Attitude and Heading Angle Extract
Earth and Carrier Rate Computation
Acceleration Compensation
Level Acceleration Computation
Position Velocity Update
Angular Increment Velocity Increment Producer
8103
8104
8108
6

Figure 15

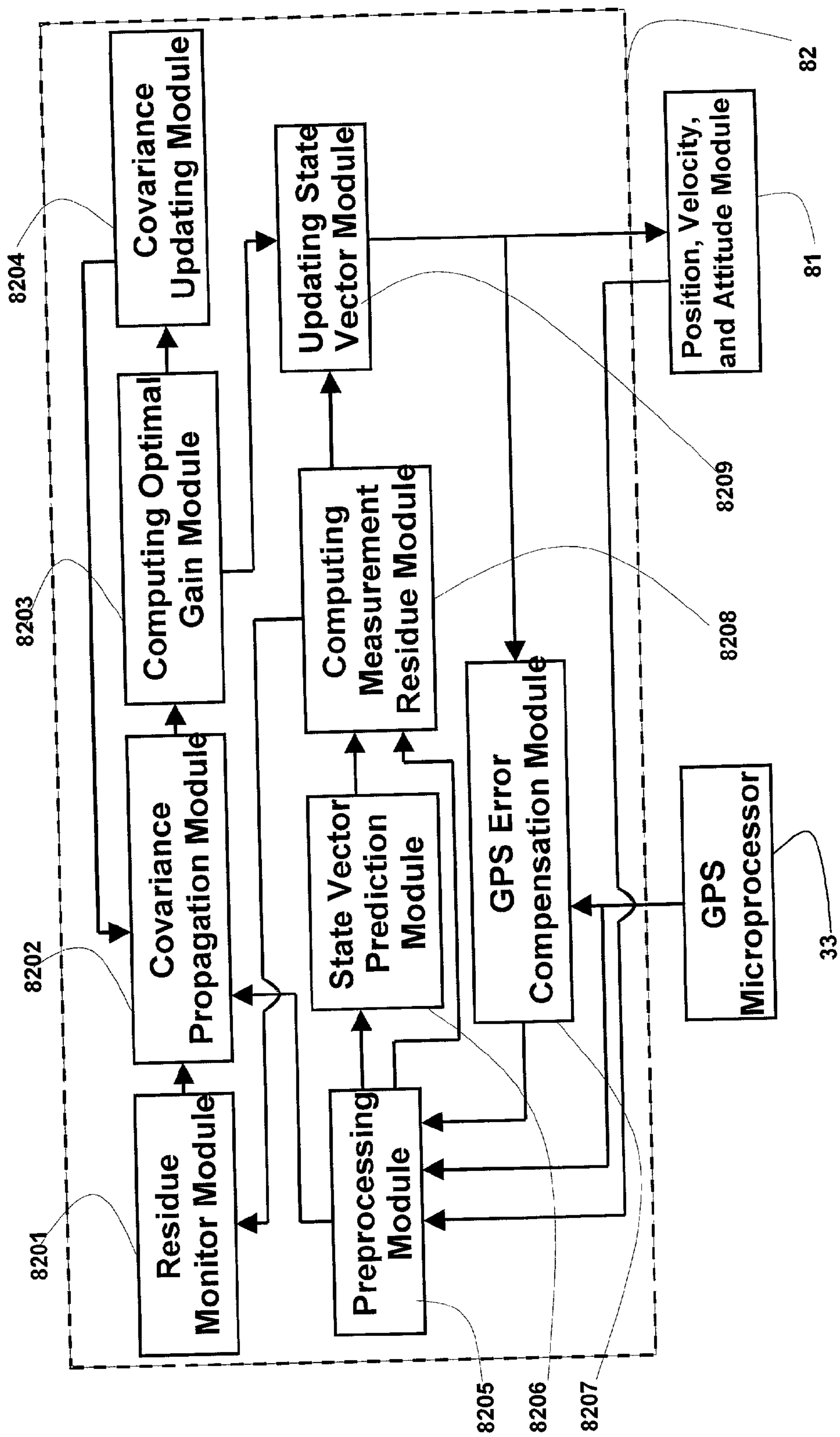

Covariance Updating Module
Computing Optimal Gain Module
Covariance Propagation Module
Residue Monitor Module
Updating State Vector Module
Computing Measurement Residue Module
State Vector Prediction Module
Preprocessing Module
GPS Error Compensation Module
Position, Velocity, and Attitude Module
GPS Microprocessor
8201
8202
8203
8204
8205
8206
8207
8208
8209
81
82
33

Figure 16

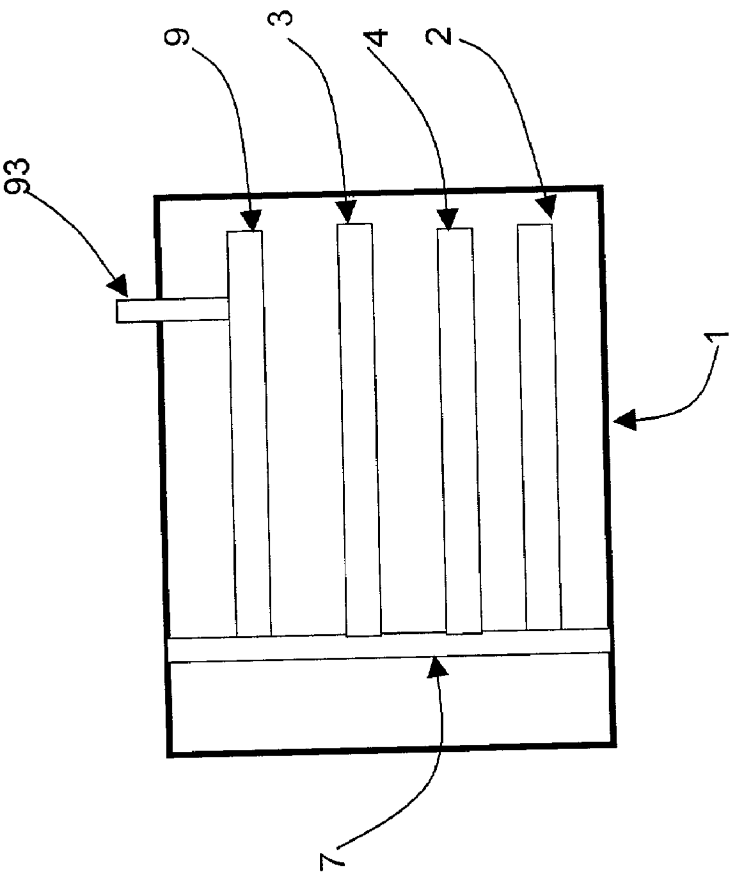


Figure 17

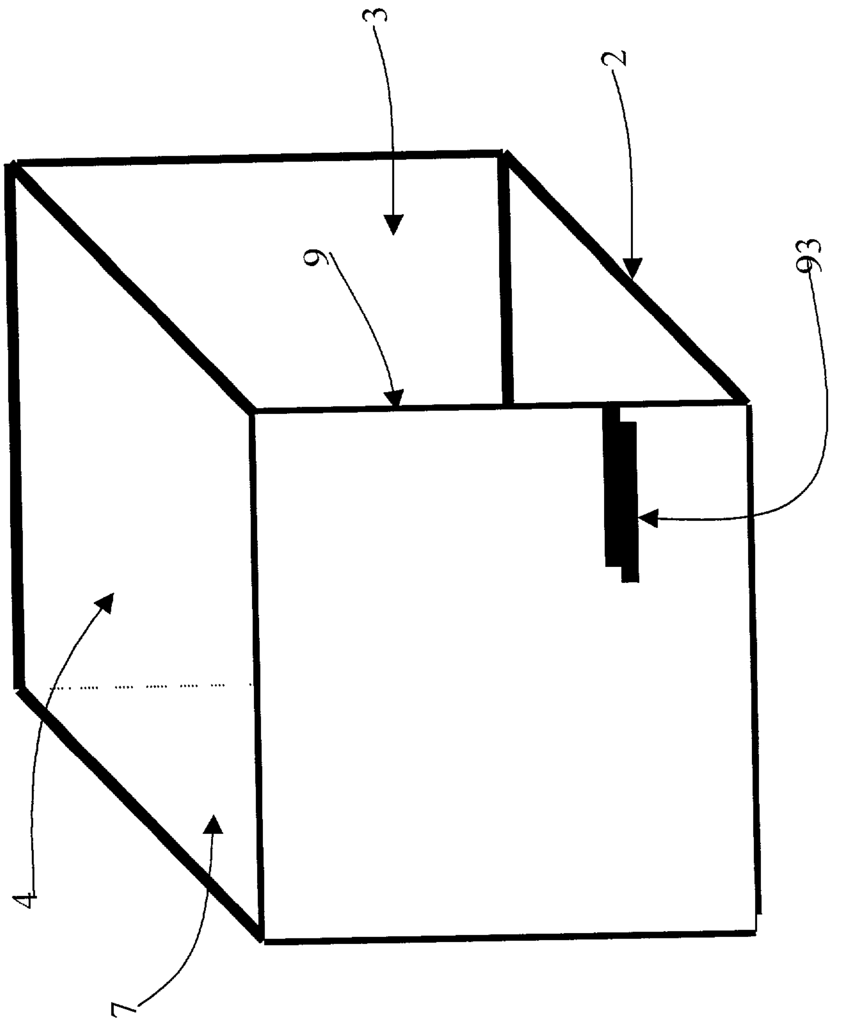


Figure 18

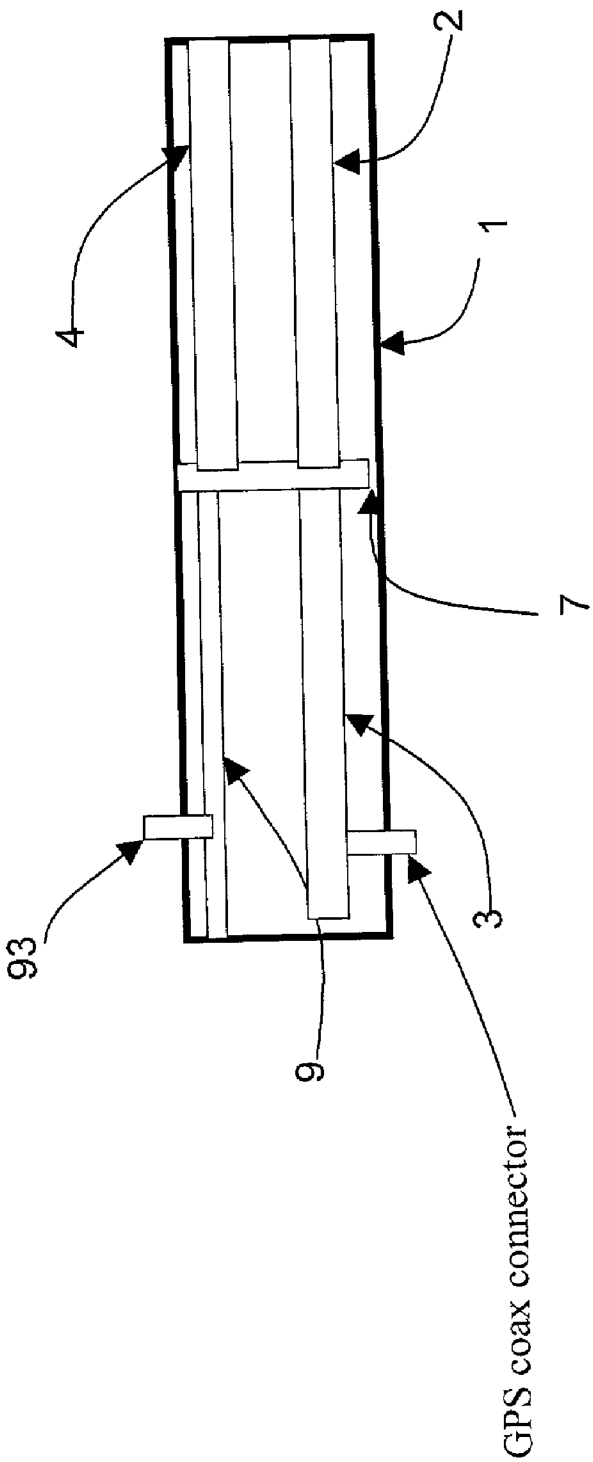


Figure 19

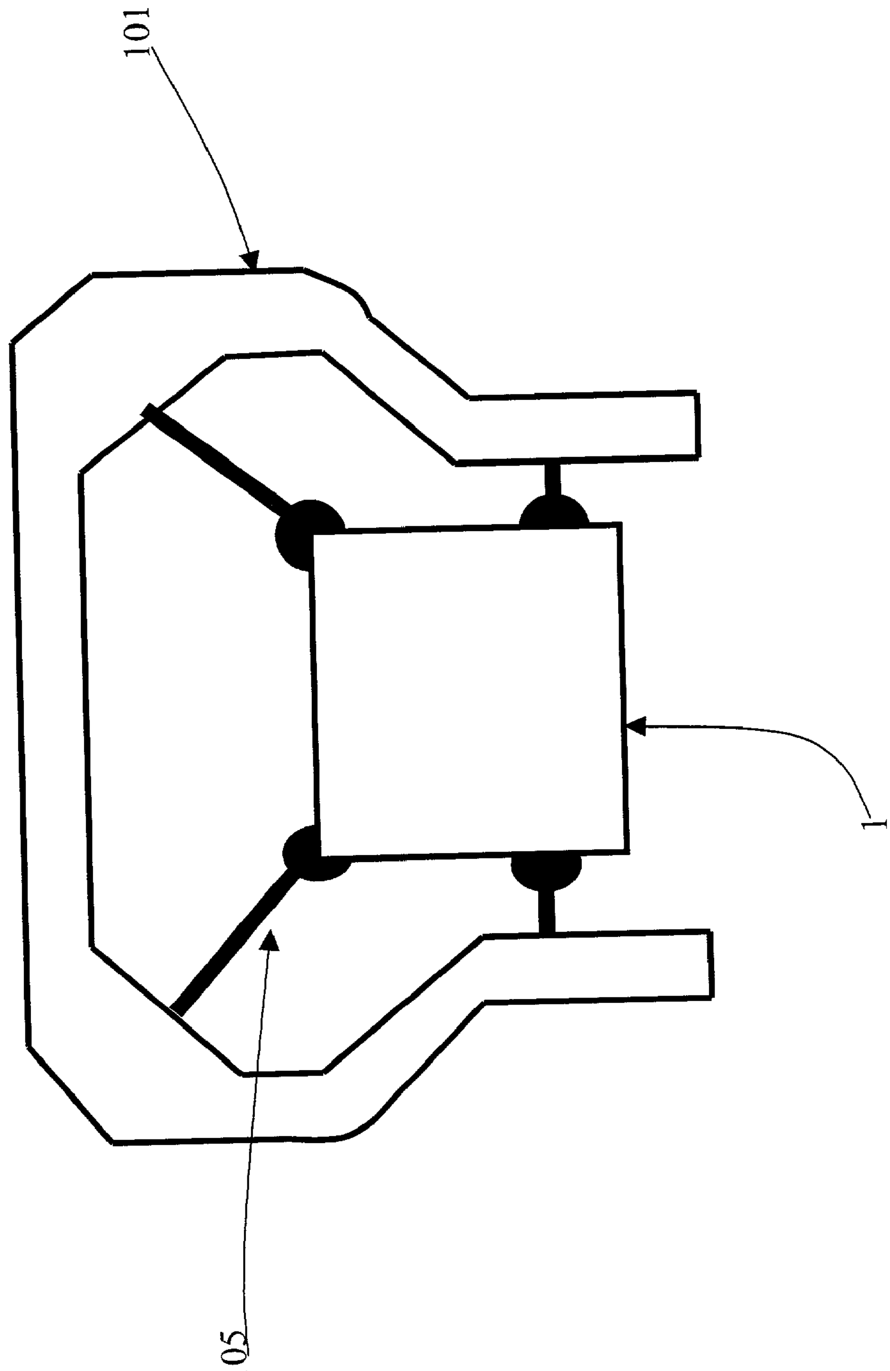


Figure 20

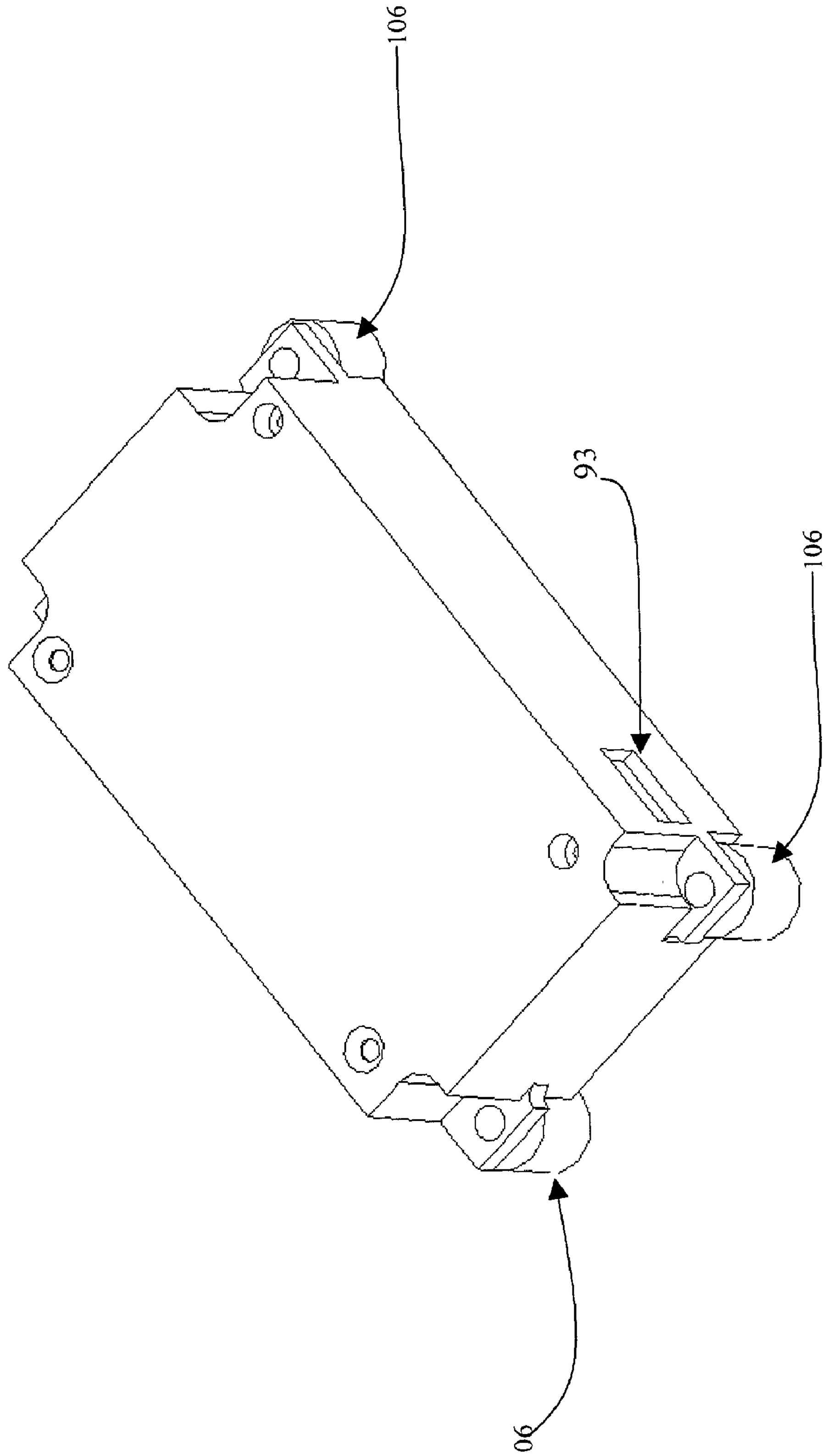


Figure 21

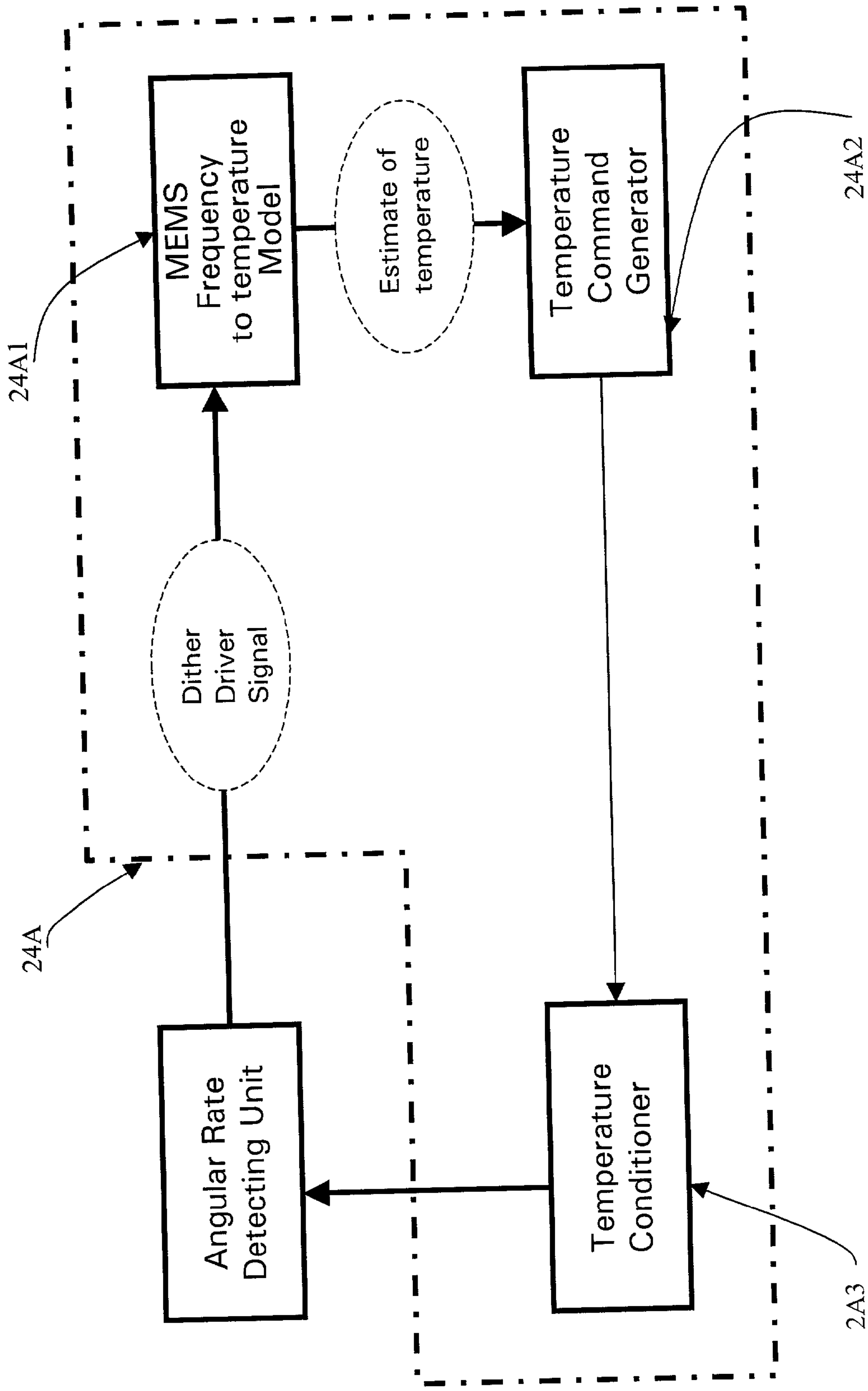

24A1
MEMS Frequency to temperature Model
Estimate of temperature
Temperature Command Generator
24A2
Dither Driver Signal
24A
Angular Rate Detecting Unit
Temperature Conditioner
2A3

Figure 22

MICRO INTEGRATED GLOBAL POSITIONING SYSTEM/INERTIAL MEASUREMENT UNIT SYSTEM

CROSS REFERENCE OF RELATED APPLICATIONS

[0001] This is a regular application of a provisional application having an application number of No. 60/219,957 and a filing date of Jul. 20, 2000.

BACKGROUND OF THE PRESENT INVENTION

[0002] 1. Field of the Present Invention

[0003] The present invention relates to a motion measurement system, and more particularly to an integrated Global Positioning System (GPS)/Inertial Measurement Unit (IMU) System in micro size, which can produce highly accurate, digital angular rate, acceleration, position, velocity, and attitude measurements of a carrier under dynamic environments.

[0004] 2. Description of the Related Arts

[0005] In the past decade, an IMU or GPS receiver is commonly employed to determine the motion measurement of a carrier.

[0006] The IMU is a key part of an inertial navigation system (INS). Generally, an INS consists of an IMU, a microprocessor and associated embedded navigation software. The components of the IMU include the inertial sensors (angular rate producer and acceleration producer, traditionally called gyros and accelerometers or angular rate sensor and acceleration sensor) and the associated hardware and electronics. Based on the carrier acceleration and rotation rate measurements obtained from the onboard inertial sensors, the position, velocity, and attitude measurements of a carrier are obtained by numerically solving Newton's equations of motion through the microprocessor.

[0007] In principle, an IMU relies on three orthogonally mounted inertial angular rate producers and three orthogonally mounted acceleration producers to produce three-axis angular rate and acceleration measurement signals. The three orthogonally mounted inertial angular rate producers and three orthogonally mounted acceleration producers with additional supporting mechanical structure and electronic devices are conventionally called the Inertial Measurement Unit (IMU). The conventional IMUs may be catalogued into Platform IMU and Strapdown IMU.

[0008] In the platform IMU, angular rate producers and acceleration producers are installed on a stabilized platform. Attitude measurements can be directly picked off from the platform structure. But attitude rate measurements can not be directly obtained from the platform. Moreover, highly accurate feedback control loops are required to implement the platform IMU.

[0009] Compared with the platform IMU, in a strapdown IMU, angular rate producers and acceleration producers are directly strapped down with the carrier and move with the carrier. The output signals of the strapdown angular rate producers and acceleration producers are angular rate and acceleration measurements expressed in the carrier body frame. The attitude measurements can be obtained by means of a series of computations.

[0010] A conventional IMU uses a variety of inertial angular rate producers and acceleration producers. Conventional inertial angular rate producers include iron spinning wheel gyros and optical gyros, such as Floated Integrating Gyros (FIG), Dynamically Tuned Gyros (DTG), Ring Laser Gyros (RLG), Fiber-Optic Gyros (FOG), Electrostatic Gyros (ESG), Josephson Junction Gyros (JJG), Hemisperical Resonating Gyros (HRG), etc. Conventional acceleration producers include Pulsed Integrating Pendulous Accelerometer (PIPA), Pendulous Integrating Gyro Accelerometer (PIGA), and etc.

[0011] The inertial navigation system, which uses a platform IMU, in general, is catalogued as a gimbaled inertial navigation system. The inertial navigation system which uses a strapdown IMU is, in general, catalogued as a strapdown inertial navigation system. In a gimbaled inertial navigation system, the angular rate producer and acceleration producer are mounted on a gimbaled platform to isolate the sensors from the rotations of the carrier so that the measurements and navigation calculations can be performed in a stabilized navigation coordinated frame. Generally, the motion of the carrier can be expressed in several navigation frames of reference, such as earth centered inertial (ECI), earth-centered earth-fixed (ECEF), locally level with axes in the directions of north-east-down (NED) or east-north-up (ENU) or north-west-up (NWU), and locally level with a wander azimuth. In a strapdown inertial navigation system, the inertial sensors are rigidly mounted to the carrier body frame. In order to perform the navigation computation in the stabilized navigation frame, a coordinate frame transformation matrix is established and updated in a high rate to transform the acceleration measurements from the body frame to the navigation frame.

[0012] In general, the motion measurements from the gimbaled inertial navigation system are more accurate than that from the strapdown inertial navigation system. Moreover, the gimbaled inertial navigation system is easier to be calibrated than the strapdown inertial navigation system. But, a gimbaled inertial navigation system is more complex and expensive than a strapdown inertial navigation system. The strapdown inertial navigation systems become the predominant mechanization due to their low cost, reliability, and small size.

[0013] An inertial navigation system is based on the output of inertial angular rate producer and acceleration producer of an IMU to provide the position, velocity, and attitude information of a carrier through a deadreckoning method. Inertial navigation systems, in principle, permit self-contained operation and output continuous position, velocity, and attitude data of a carrier after loading the starting position and performing an initial alignment procedure.

[0014] In addition to the self-contained operation, other advantages of an inertial navigation system include the full navigation solution and wide bandwidth.

[0015] However, an inertial navigation system is expensive and is degraded with drift in output (position, velocity, and attitude) over an extended period of time. It means that the position errors, velocity errors, and attitude errors increase with time. This error propagation characteristic is primarily caused by many error sources, such as, gyro drift, accelerometer bias, misalignment, gravity disturbance, initial position and velocity errors, and scale factor errors.

[0016] Generally, the ways of improving accuracy of inertial navigation systems include employing highly accurate inertial sensors and aiding the inertial navigation system using an external sensor.

[0017] However, current highly accurate inertial sensors are very expensive with big size and heavy weight.

[0018] A GPS receiver has been commonly used to aid an inertial navigation system recently. The GPS is a satellite-based, worldwide, all-weather radio positioning and timing system. The GPS system is originally designed to provide precise position, velocity, and timing information on a global common grid system to an unlimited number of adequately equipped users.

[0019] A specific GPS receiver is the key device for a user to access the global positioning system. A conventional, single antenna GPS receiver supplies world-wide, highly accurate three dimensional position, velocity, and timing information, but not attitude information, by processing so-called pseudo range and range rate measurements from the code tracking loops and the carrier tracking loops in the GPS receiver, respectively. In a benign radio environment, the GPS signal propagation errors and GPS satellite errors, including selective availability, serve as the bounds for positioning errors. However, the GPS signals may be intentionally or unintentionally jammed or spoofed, and the GPS receiver antenna may be obscured during carrier attitude maneuvering, and the performance degrades when the signal-to-noise ratio of the GPS signal is low and the carrier is undergoing highly dynamic maneuvers.

[0020] As both the cost and size of high performance GPS receivers are reduced in the past decade, a multiple-antenna GPS receiver can provide both position and attitude solution of a carrier, using interferometric techniques. This technology utilizes measurements of GPS carrier phase differences on the multiple-antenna to obtain highly accurate relative position measurements. Then, the relative position measurements are converted to the attitude solution. The advantages of this approach are long-term stability of the attitude solution and relatively low cost. However, this attitude measurement system retains the characterization of low bandwidth and is susceptible to shading and jamming, and requires at least 3 antennas configurations for a three-axis attitude solution, and requires antenna separation enough for high attitude resolution.

[0021] Because of the inherent drawbacks of a stand-alone inertial navigation system and a stand-alone GPS receiver, a stand-alone inertial navigation system or a stand-alone GPS receiver can not meet mission requirements under some constraints, such as low cost, long-term high accuracy, high rate output, interrupt-free, etc.

[0022] Performance characteristics of the mutually compensating stand-alone GPS receiver and the stand-alone inertial navigation system suggest that, in many applications, an integrated GPS/IMU system, combining the best properties of both systems, will provide superior accurate continuous navigation capability. This navigation capability is unattainable in either one of the two systems alone.

[0023] The benefits offered by an integrated GPS/IMU system are outlined as follows:

[0024] (1) The aiding of the GPS receiver's signal-tracking loop process with inertial data from the INS allows the effective bandwidth of the loops to be reduced, resulting in an improved tracking signal in a noisy and dynamic environment.

[0025] (2) An inertial navigation system not only provides navigation information when the GPS signal is lost temporarily, but also reduces the search time required to reacquire GPS signals.

[0026] (3) Inertial navigation system errors and inertial sensor errors can be calibrated while the GPS signal is available, so that the inertial navigation system can provide more accurate position information after the GPS signal is lost.

[0027] (4) The GPS enables and provides on-the-fly alignment of an inertial navigation system by means of maneuvering, eliminating the static initial self-alignment of the pre-mission requirements of the stand-alone inertial navigation system.

[0028] Conventional IMUs commonly have the following features:

[0029] (i) High cost,

[0030] (ii) Large bulk (volume, mass, large weight),

[0031] (iii) High power consumption,

[0032] (iv) Limited lifetime, and Long turn-on time.

[0033] Conventional GPS devices systems can be catalogued into two families:

[0034] (i) Full-functional GPS receivers, including display, I/O ports.

[0035] (ii) GPS OEM engine modules.

[0036] A conventional integrated GPS/IMU system also has the following features:

[0037] (i) High cost,

[0038] (ii) Large bulk (volume, mass, large weight),

[0039] (iii) High power consumption,

[0040] (iv) Limited lifetime, and Long turn-on time.

[0041] These present deficiencies of conventional integrated GPS/IMU systems prohibit them from being used in the emerging cost-sensitive commercial applications, such as control of phased array antennas for mobile communications, automotive navigation, and handheld equipment.

[0042] A micro IMU has been invented, referring to the U.S. patent application, entitled Micro Inertial Measurement Unit, application Ser. No. 09/477,151, of American GNC Corporation, the same patent owner of the present invention. The micro IMU employs MEMS (MicroElectronicMechanicalSystem) angular rate and acceleration producers. Compared with a conventional IMU, the micro IMU utilizes a feedforward open-loop signal processing scheme to obtain highly accurate motion measurements by means of signal digitizing, temperature control and compensation, sensor error and misalignment calibrations, attitude updating, and damping control loops, and dramatically shrinks the size of mechanical and electronic hardware and power consumption. Meanwhile, it obtains highly accurate motion measurements.

[0043] MEMS, or, as stated more simply, micromachines, are believed as the next logical step in the silicon revolution. It is forecasted that this coming step will be different, and more important than simply packing more transistors onto silicon. The hallmark of the next thirty years of the silicon revolution will be the incorporation of new types of functionality onto the chip structures, which will enable the chip to, not only think, but to sense, act, and communicate as well. MEMS inertial sensors offer tremendous cost, size, and reliability improvements for guidance, navigation, and control systems, compared with conventional inertial sensors.

[0044] Meanwhile, new horizons are opening up for GPS technology. A tiny, inexpensive GPS chip sets such as the Mitel GP2000 and the SiRFstar GRF1/LX Chip, which are small enough to fit into a cellular phone or hand-held computer but powerful enough to receive GPS satellite signals, are advanced now. Upcoming consumer electronics devices such as cellular phones are planed to use it.

[0045] Although the MEMS angular rate sensors and MEMS accelerometers and GPS chipsets are available commercially and have achieved micro chip-size and low power consumption, they are not yet technically equipped to construct a high performance, small size, and low power consumption integrated GPS/IMU systems based on the conventional technologies.

SUMMARY OF THE PRESENT INVENTION

[0046] A main objective of the present invention is to provide a micro integrated GPS/IMU system, which can produce highly accurate, position, velocity, attitude, and heading measurements of the carrier under dynamic environments.

[0047] Another objective of the present invention is to provide a micro integrated GPS/IMU system, which successfully incorporates the MEMS inertial sensors and GPS chipset technologies.

[0048] Another objective of the present invention is that three axes the Earth's magnetic field vector measurement from a tiny Earth's magnetic field detector, such as a magnetometer, is incorporated to stabilize the heading solution of the system of the present invention.

[0049] Another objective of the present invention is to use the inertial velocity and acceleration from a position and attitude processor, which are corrected by a Kalman filter, to aid the code and carrier phase tracking of the GPS satellite signals in a GPS receiver so as to enhance the performance of the integrated GP S/IIMU in heavy jamming and high dynamic environments.

[0050] Another objective of the present invention is to improve the accuracy of the GPS receiver position and velocity solution by using a differential GPS method. To accurately determine the GPS receiver's position and velocity at the centimeter level, the GPS carrier phase measurements are used and the differential GPS is employed.

[0051] Another objective of the present invention is that the self-contained INS extends the GPS solution as the GPS receiver loses lock on the GPS signals. Once the GPS receiver regains the signals and then estimates the receiver's position and velocity, the output (position and velocity) of the GPS receiver is used to correct the drifted position and velocity of the INS.

[0052] Another objective of the present invention is that a data link is used to transfer the differential GPS correction data, such as position, velocity, and raw measurement corrections (pseudorange, range rate, and carrier phase corrections), from a GPS reference site (wherein a GPS receiver is established with a known position) to the micro integrated GPS/IMU system. Using the differential GPS and carrier phase measurements, the accuracy of the GPS positioning is of the order of centimeter level after fixing the integer ambiguities, and, as a result, the micro integrated GPS/IMU system is applicable to highly accurate position requirements.

[0053] A further objective of the present invention is that the inertial navigation system can aid the resolution of the GPS carrier phase integer ambiguities by providing more accurate position information.

[0054] Another objective of the present invention is that the Kalman filter processes the GPS phase measurements as well as the GPS pseudorange and range rate measurements from the GPS receiver, so as to improve the accuracy of the integrated positioning solution.

[0055] Another objective of the present invention is that the Kalman filter is implemented in real time to optimally blend the GPS raw data and the INS solution to obtain the blended navigation solution.

[0056] A further objective of the present invention is that a robust Kalman filter is implemented in real time to eliminate the possible instability of the integration solution.

[0057] In order to accomplish the above objectives, the present invention provides a micro integrated GPS/IMU system of a carrier, which comprises a body frame, comprising:

[0058] an angular rate producer, producing orthogonal three-axis (X axis, Y axis and Z axis) electrical angular rate signals;

[0059] an acceleration producer, producing orthogonal three-axis (X-axis, Y axis and Z axis) electrical acceleration signals;

[0060] an angular increment and velocity increment producer, converting the three-axis electrical angular rate signals into digital angular increments and for converting the three-axis electrical acceleration signals into digital velocity increments;

[0061] a GPS chipset, receiving GPS RF (Radio Frequency) signals and providing GPS measurements, including GPS position and velocity data or GPS raw pseudorange, range rate, and carrier phase measurements and ephemeris and navigation message from GPS satellites;

[0062] an Earth's magnetic field detector, producing the Earth's magnetic field vector electrical measurement signals, including X, Y, Z axes signals of an Earth's magnetic field vector measurement in the body frame of the carrier; and

[0063] a position and attitude processor, computing position, attitude and heading angle measurements combining the three-axis digital angular increments and three-axis velocity increments, the GPS measurements, and the Earth magnetic field vector measurement in order to provide a rich and accurate motion measurement of the carrier to meet diverse needs.

BRIEF DESCRIPTION OF THE DRAWINGS

[0064] **FIG. 1** is a block diagram illustrating the processing module for the micro integrated GPS/IMU system according to a preferred embodiment of the present invention.

[0065] **FIG. 2** is a block diagram illustrating a thermal control means for the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention.

[0066] **FIG. 3** is a block diagram illustrating the connection among the five circuit boards inside the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention.

[0067] **FIG. 4** is the function block diagram of the ASIC (Application Specific Integrated Circuit) chip in the control board of the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention.

[0068] **FIG. 5** is a block diagram of the front-end circuit in each of the first, second, and third circuit boards of the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention.

[0069] **FIG. 6** is block diagram of the dither motion control circuitry of the ASIC chip in the control circuit board of the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention.

[0070] **FIG. 7** is a block diagram of the dither motion processing module running in the DSP chip in the control board of the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention.

[0071] **FIG. 8** is a block diagram of the angle signal loop circuitry of the ASIC chip in the control board of the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention.

[0072] **FIG. 9** is a functional block diagram illustrating processing modules running in the DSP chip in the control board of the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention.

[0073] **FIG. 10** is a block diagram illustrating another thermal processor for outputting analog voltage signals of the thermal sensing producer according to the above preferred embodiment of the present invention.

[0074] **FIG. 11** is a block diagram illustrating another angular increment and velocity increment producer for outputting voltage signals of an angular rate producer and acceleration producer according to the above preferred embodiment of the present invention.

[0075] **FIG. 12** is a block diagram illustrating the control board according to the above preferred embodiment of the present invention.

[0076] **FIG. 13** is a block diagram illustrating the first embodiment of the GPS chipset board according to the above preferred embodiment of the present invention.

[0077] **FIG. 14** is a block diagram illustrating the second embodiment of the GPS chipset board with differential GPS technology according to the above preferred embodiment of the present invention.

[0078] **FIG. 15** is a functional block diagram illustrating the position velocity attitude and heading module according to the above preferred embodiment of the present invention.

[0079] **FIG. 16** is a functional block diagram illustrating the error estimator according to the above preferred embodiment of the present invention

[0080] **FIG. 17** is a sectional side view of the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention

[0081] **FIG. 18** illustrates a second alternative mode of the inside mechanical structure and circuit board deployments in the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention.

[0082] **FIG. 19** illustrates a third alternative mode of the inside mechanical structure and circuit board deployments of the micro integrated GPS/IMU system to achieve a flat case according to the above preferred embodiment of the present invention.

[0083] **FIG. 20** shows the support bracket and shock mount installation configuration for the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention.

[0084] **FIG. 21** shows another preferred box and installation configuration for the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention.

[0085] **FIG. 22** shows another preferred thermal sensing producer for the micro integrated GPS/IMU system according to the above preferred embodiment of the present invention.

DETAIL DESCRIPTION OF THE PREFERRED EMBODIMENT

[0086] The present invention provides a micro integrated GPS/IMU system to blend raw motion measurements from the micro inertial measurement unit and a GPS chipset to improve the accuracy of the position, velocity, and attitude solution deduced from raw motion measurements for the micro inertial measurement unit only, in order to output highly accurate GPS/IMU mixed navigation solution.

[0087] Referring to **FIG. 1**, the micro integrated GPS/IMU system of a carrier, which comprises a body frame, comprises:

[0088] an angular rate producer **5**, producing orthogonal three-axis (X axis, Y axis and Z axis) electrical angular rate signals;

[0089] an acceleration producer **10**, producing orthogonal three-axis (X-axis, Y axis and Z axis) electrical acceleration signals;

[0090] an angular increment and velocity increment producer **6**, converting the three-axis electrical angular rate signals into digital angular increments and for converting the three-axis electrical acceleration signals into digital velocity increments;

[0091] a GPS chipset **3**, receiving GPS RF (Radio Frequency) signals and providing GPS measurements, including GPS position and velocity data or GPS raw pseudorange, range rate, and carrier phase measurements and ephemeris and navigation message from GPS satellites;

[0092] an Earth's magnetic field detector **96**, producing the Earth's magnetic field vector electrical measurement signals, including X, Y, Z axes signals of an Earth's magnetic field vector measurement in the body frame of the carrier; and

[0093] a position and attitude processor **80**, computing position, attitude and heading angle measurements combining the three-axis digital angular increments and three-axis velocity increments, the GPS measurements, and the Earth magnetic field vector measurement in order to provide a rich and accurate motion measurement of the carrier to meet diverse needs.

[0094] In general, the angular rate producer **5** and the acceleration producer **10** are very sensitive to a variety of temperature environments. In order to improve measurement accuracy, referring to **FIG. 2**, the present invention further comprises a thermal controlling means **100** for maintaining a predetermined operating temperature of the angular rate producer **5**, the acceleration producer **10**, and the angular increment and velocity increment producer **6**. It is worth to mention that if the angular rate producer **5**, the acceleration producer **10**, and the angular increment and velocity increment producer **6** are operated in an environment under perfect and constant thermal control, the thermal controlling means **100** can be omitted.

[0095] According to the preferred embodiment of the present invention, as shown in **FIG. 2**, the thermal controlling means **100** comprises a thermal sensing producer device **15**, a heater device **20**, and a thermal processor **30**.

[0096] The thermal sensing producer device **15** produces temperature signals, which are processed in parallel with the angular rate producer **5** and the acceleration producer **110** for maintaining a predetermined operating temperature of the angular rate producer **5**, the acceleration producer **10**, and angular increment and velocity increment producer **6**, wherein the predetermined operating temperature is a constant designated temperature selected between 150° F. and 185° F., preferably 176° F. (±0.1° F.).

[0097] The temperature signals produced from the thermal sensing producer device **15** are input to the thermal processor **30** for computing temperature control commands, using the temperature signals, a temperature scale factor, and a predetermined operating temperature of the angular rate producer **5** and the acceleration producer **10** and angular increment and velocity increment producer **6** to produce driving signals to the heater device **20** using the temperature control commands for controlling the heater device **20** to provide adequate heat for maintaining the predetermined operating temperature.

[0098] Generally, the X, Y, Z axes electrical signals of the Earth's magnetic field vector measurement expressed in the body frame of the carrier from the Earth's magnetic field detector **96** are analog voltage signals.

[0099] The system of the present invention can be further configured into different physical appearances. Referring to **FIGS. 3 and 17**, the micro integrated GPS/IMU system according to the preferred embodiment of the present invention physically and structurally comprises a first circuit board **2**, a second circuit board **4**, a third circuit board **7**, a GPS chipset board **3**, and a control circuit board **9** arranged inside a metal cubic case **1**, as shown in **FIG. 17**.

[0100] The first circuit board **2** is connected with the third circuit board **7** for producing the X axis angular rate sensing signal and the Y axis acceleration sensing signal to the control circuit board **9** through the third circuit board **7**.

[0101] The second circuit board **4** is connected with the third circuit board **7** for producing the Y axis angular rare sensing signal and the X axis acceleration sensing signal to the control circuit board **9** through the third circuit board **7**.

[0102] The third circuit board **7** is connected with the control circuit board **9** for producing the Z axis angular rate sensing signal and the Z axis acceleration sensing signals to the control circuit board **9**.

[0103] The GPS chipset board **3** is connected with the control circuit board **9** through the third circuit board **7** or directly for providing GPS position and velocity solution or GPS raw measurements including pseudorange, range rate, and carrier phase measurements to the control circuit board **9**.

[0104] The control circuit board **9** is connected with the first circuit board **2** and then the second circuit board **4** through the third circuit board **7**, and with the GPS chipset board **3** for processing: the X axis, Y axis and Z axis angular rate sensing signals, the X axis, Y axis and Z axis acceleration sensing signals which are output from the first, second and the third board respectively, the Earth magnetic field vector from Earth's magnetic field detector **96** arranged on the control circuit board **9** itself, and the GPS position and velocity solution or GPS raw measurements from the GPS board **3**, to produce digital angular increments and velocity increments, GPS/IMU mixed position, velocity, and attitude solution.

[0105] Referring to **FIGS. 3 and 12**, the control circuit board **9** basically comprises:

[0106] a Digital Signal Processor (DSP) chip **91** for all performing computation and control tasks of the system of the present invention, which are depicted in **FIG. 9**;

[0107] an Earth's magnetic field detector **96**, including a magnetometer, for producing electrical Earth's magnetic field vector measurement signals to the DSP chip **91**;

[0108] an Application Specific Integrated Circuit (ASIC) chip **92**, which includes analog and digital kind circuit (mixed signal IC), for performing signal processing in circuit hardware method and providing the data interface for the DSP chip **91**, referring to **FIG. 4**;

[0109] a communication module **98**, providing an input/output interface between the micro integrated GPS/IMU system of the present invention and an external user;

[0110] a connector **93**, connected with the communication module **98**, for providing proper pine configuration which is compatible with the external user; and

[0111] a power supply module **99**, receiving external power through the connector **93** and providing all voltages needed for the first, second, third, and GPS boards.

[0112] As shown in **FIGS. 1, 3, 4, 9,** and **12**, the angular producer **5** of the preferred embodiment of the present invention comprises:

[0113] an X axis vibrating type angular rate detecting unit **21** and a first front-end circuit **23** connected to the first circuit board **2**;

[0114] a Y axis vibrating type angular rate detecting unit **41** and a second front-end circuit **43** connected to the second circuit board **4**;

[0115] a Z axis vibrating type angular rate detecting unit **71** and a third front-end circuit **73** connected to the third circuit board **7**;

[0116] three angular signal loop circuitries **921**, which are provided in the ASIC chip **92** connected to the control circuit board **9**, for the first, second and third circuit boards **2, 4, 7** respectively;

[0117] three dither motion control circuitries **922**, which are provided in the ASIC chip **92** connected to the control circuit board **9**, for the first, second and third circuit boards **2, 4, 7** respectively;

[0118] an oscillator **925** providing reference pickoff signals for the X axis vibrating type angular rate detecting unit **21**, the Y axis vibrating type angular rate detecting unit **41**, the Z axis vibrating type angular rate detecting unit **71**, the angle signal loop circuitry **921**, and the dither motion control circuitry **922**; and

[0119] three dither motion processing modules **912**, which run in the DSP (Digital Signal Processor) chip **91** connected on the control circuit board **9**, for the first, second and third circuit boards **2, 4, 7** respectively.

[0120] Each of the X axis, Y axis and Z axis angular rate detecting units **21, 41,** and **71** is structurally identical except that the sensing axis of each angular rate detecting unit is placed in an orthogonal direction. The X axis angular rate detecting unit **21** is adapted to detect the angular rate of the carrier along the X axis. The Y axis angular rate detecting unit **21** is adapted to detect the angular rate of the carrier along the Y axis. The Z axis angular rate detecting unit **21** is adapted to detect the angular rate of the carrier along the Z axis.

[0121] Each of the X axis, Y axis and Z axis angular rate detecting units **21, 41** and **71** is a vibratory device, which comprises at least one set of vibrating inertial elements, including tuning forks, associated supporting structures and means, including capacitive readout means, and uses Coriolis effects to detect carrier angular rate.

[0122] Each of the X axis, Y axis and Z axis vibrating type angular rate detecting units **21, 41, 71** receives signals as follows:

[0123] 1) dither drive signals from the respective dither motion control circuitry **922**, keeping the inertial elements oscillating; and

[0124] 2) carrier reference oscillation signals from the oscillator **925**, including capacitive pickoff excitation signals.

[0125] Each of the X axis, Y axis and Z axis vibrating type angular rate detecting units **21, 41, 71** detects the angular motion in X axis, Y axis and Z axis respectively of a carrier in accordance with the dynamic theory (Coriolis force), and outputs signals as follows:

[0126] 1) angular motion-induced signals, including rate displacement signals which may be modulated carrier reference oscillation signals to the high-pass filters **232, 432,732** of the first, second, and third front-end circuits **23**; and

[0127] 2) inertial element dither motion signals thereof, including dither displacement signals, to trans Impedance amplifier circuits **231, 431, 731** of the first, second, and third front-end circuits **23**.

[0128] The Coriolis Effect is that, when an angular rate is applied to a translating or vibrating inertial element, a Coriolis force is generated. When this angular rate is applied to the axis of an oscillating inertial element, its tines receive a Coriolis force, which then produces torsional forces about the sensor axis. These forces are proportional to the applied angular rate, which then can be measured.

[0129] The force (or acceleration), Coriolis force (or Coriolis acceleration) or Coriolis effect, is originally named from a French physicist and mathematician, Gaspard de Coriolis (1792-1843), who postulated this acceleration in 1835 as a correction for the earth's rotation in ballistic trajectory calculations. The Coriolis acceleration acts on a body that is moving around a point with a fixed angular velocity and moving radially as well.

[0130] The basic equation defining Coriolis force can be expressed as follows:

$$\vec{F}_{Coriolis}=m\vec{a}_{Coriolis}=2m(\vec{\omega}\times\vec{V}_{Oscillation})$$

[0131] where $\vec{F}_{Coriolis}$ is the detected Coriolis force;

[0132] m is the mass of the inertial element;

[0133] $\vec{\alpha}_{Coriolis}$ is the generated Coriolis acceleration;

[0134] $\vec{\omega}$ is the applied (input) angular rotation rate;

[0135] $\vec{V}_{Oscillation}$ is the oscillation velocity in a rotating frame.

[0136] The Coriolis force produced is proportional to the product of the mass of the inertial element, the input rotation rate, and oscillation velocity of the inertial element that is perpendicular to the input rotation rate.

[0137] The first, second and third front-end circuits **23, 43, 73**, each of which is structurally identical and connected on the first, second and third circuit boards **2, 4, 7** respectively, are used to condition the output signal of the X axis, Y axis and Z axis vibrating type angular rate detecting units **21, 41, 71** respectively.

[0138] Referring to **FIG. 5**, each of the first, second and third front-end circuits **23**, **43**, **73**, further comprises:

[0139] a trans impedance amplifier circuit **231**, **431**, **731**, which is connected to the respective X axis, Y axis or Z axis vibrating type angular rate detecting unit **21**, **41**, **71** for changing the output impedance of the dither motion signals from a very high level, greater than 100 million ohms, to a low level, less than 100 ohms to achieve two dither displacement signals, which are A/C voltage signals representing the displacement between the inertial elements and the anchor combs. The two dither displacement signals are output to the dither motion control circuitry **922**; and

[0140] a high-pass filter circuit **232**, **432**, **732**, which is connected with the respective X axis, Y axis or Z axis vibrating type angular rate detecting units **21**, **41**, **71** for receiving the angular motion-induced signals and removing low frequency noise of the angular motion-induced signals, which are AC voltage signals output from vibrating type angular rate detecting unit **21**,**41**,**71**, to form filtered angular motion-induced signals to the angular signal loop circuitry **921**.

[0141] The three dither motion control circuitries **922** receive the inertial element dither motion signals from the X axis, Y axis and Z axis vibrating type angular rate detecting units **21**, **41**, **71**, through the trans impedance amplifier circuit **231**, **431**, **731** of the first, second and third front-end circuits **23**, **43**, **73** respectively, reference pickoff signals from the oscillator **925**, and produce digital inertial element displacement signals with known phase.

[0142] In order to convert the inertial element dither motion signals from the X axis, Y axis and Z axis vibrating type angular rate detecting units **21**, **41**, **71** to processible inertial element dither motion signals, referring to **FIG. 6**, each of the dither motion control circuitries **922** comprises:

[0143] an amplifier and summer circuit **9221** connected to the trans impedance amplifier circuit **231**, **431**, **731** of the respective first, second or third front-end circuit **23**, **43**, **73**, for amplifying the two dither displacement signals for more than ten times and enhancing the sensitivity for combining the two dither displacement signals to achieve a dither displacement differential signal by subtracting a center anchor comb signal with a side anchor comb signal;

[0144] a high-pass filter circuit **9222** connected to the amplifier and summer circuit **9221** for removing residual dither drive signals and noise from the dither displacement differential signal to form a filtered dither displacement differential signal;

[0145] a demodulator circuit **9223** connected to the high-pass filter circuit **2225** for receiving the capacitive pickoff excitation signals as phase reference signals from the oscillator **925** and the filtered dither displacement differential signal from the high-pass filter **9222** and extracting the in-phase portion of the filtered dither displacement differential signal to produce an inertial element displacement signal with known phase;

[0146] a low-pass filter **9225** connected to the demodulator circuit **9223** for removing high frequency noise from the inertial element displacement signal input thereto to form a low frequency inertial element displacement signal;

[0147] an analog/digital converter **9224** connected to the low-pass filter **9225** for converting the low frequency inertial element displacement analog signal to produce a digitized low frequency inertial element displacement signal to the dither motion processing module **912** (disclosed in the following text) running the DSP chip **91**;

[0148] a digital/analog converter **9226** processing the selected amplitude from the dither motion processing module **912** to form a dither drive signal with the correct amplitude; and

[0149] an amplifier **9227** which generates and amplifies the dither drive signal to the respective X axis, Y axis or Z axis vibrating type angular rate detecting unit **21**, **41**, **71** based on the dither drive signal with the selected frequency and correct amplitude from the digital/analog converter **9226**.

[0150] The oscillation of the inertial elements residing inside each of the X axis, Y axis and Z axis vibrating type angular rate detecting units **21**, **41**, **71** is generally driven by a high frequency sinusoidal signal with precise amplitude. It is critical to provide the X axis, Y axis and Z axis vibrating type angular rate detecting units **21**, **41**, **71** with high performance dither drive signals to achieve keen sensitivity and stability of X-axis, Y-axis and Z axis angular rate measurements.

[0151] The dither motion processing module **912** receives digital inertial element displacement signals with known phase from the analog/digital converter **9224** of the dither motion control circuitry **922** for:

[0152] (1) finding the frequencies which have the highest Quality Factor (Q) Values,

[0153] (2) locking the frequency, and

[0154] (3) locking the amplitude to produce a dither drive signal, including high frequency sinusoidal signals with a precise amplitude, to the respective X axis, Y axis or Z axis vibrating type angular rate detecting unit **21**, **41**, **71** to keep the inertial elements oscillating at the pre-determined resonant frequency.

[0155] The three dither motion processing modules **912** are used to search and lock the vibrating frequency and amplitude of the inertial elements of the respective X axis, Y axis or Z axis vibrating type angular rate detecting unit **21**, **41**, **71**. Therefore, the digitized low frequency inertial element displacement signal is first represented in terms of its spectral content by using discrete Fast Fourier Transform (FFT).

[0156] A phase-locked loop and digital/analog converter is further used to control and stabilize the selected frequency and amplitude.

[0157] Referring to **FIG. 7**, the dither motion processing module **912** further includes a discrete Fast Fourier Transform (FFT) module **9121**, a memory array of frequency and amplitude data module **9122**, a maxima detection logic module **9123**, and a Q analysis and selection logic module **9124** to find the frequencies which have the highest Quality Factor (Q) Values.

[**0158**] The discrete Fast Fourier Transform (FFT) module **9121** is arranged for transforming a digitized low frequency inertial element displacement signal from the analog/digital converter **9224** of the dither motion control circuitry **922** to form amplitude data with the frequency spectrum of the input inertial element displacement signal.

[**0159**] The memory array of frequency and amplitude data module **9122** receives the amplitude data with frequency spectrum to form an array of amplitude data with frequency spectrum.

[**0160**] The maxima detection logic module **9123** is adapted for partitioning the frequency spectrum from the array of the amplitude data with frequency into plural spectrum segments, and choosing those frequencies with the largest amplitudes in the local segments of the frequency spectrum.

[**0161**] The Q analysis and selection logic module **9124** is adapted for performing Q analysis on the chosen frequencies to select frequency and amplitude by computing the ratio of amplitude/bandwidth, wherein the range for computing bandwidth is between +–½ of the peek for each maximum frequency point.

[**0162**] Moreover, the dither motion processing module **912** further includes a phase-lock loop **9125** to reject noise of the selected frequency to form a dither drive signal with the selected frequency, which serves as a very narrow bandpass filter, locking the frequency.

[**0163**] Referring to **FIG. 8**, the three angle signal loop circuitries **921** receive the angular motion-induced signals from the X axis, Y axis and Z axis vibrating type angular rate detecting units **21, 41, 71** through the high-pass filter circuit **232, 432, 732** of the first, second and third front-end circuits **23, 43, 73**, respectively, reference pickoff signals from the oscillator **925**, and transform the angular motion-induced signals into angular rate signals. Referring to **FIG. 8**, each of the angle signal loop circuitries **921** for the respective first, second or third circuit board **2, 4, 7** comprises:

[**0164**] a voltage amplifier circuit **9211**, which amplifies the filtered angular motion-induced signals from the high-pass filter circuit **232** of the respective first, second or third front-end circuit **23, 43, 73** to an extent of at least 100 milivolts to form amplified angular motion-induced signals;

[**0165**] an amplifier and summer circuit **9212**, which subtracts a difference between the angle rates of the amplified angular motion-induced signals to produce a differential angle rate signal;

[**0166**] a demodulator **9213**, which is connected to the amplifier and summer circuit **9212**, extracting an amplitude of the in-phase differential angle rate signal from the differential angle rate signal and capacitive pickoff excitation signals from the oscillator **925**; and

[**0167**] a low-pass filter **9214**, which is connected to the demodulator **9213**, removing the high frequency noise of the amplitude signal of the in-phase differential angle rate signal to form the angular rate signal output to the angular increment and velocity increment producer **6**.

[**0168**] Referring to **FIG. 3**, the acceleration producer **10** according to the preferred embodiment of the present invention comprises:

[**0169**] an X axis accelerometer **42**, which is provided on the second circuit board **4** and connected with the angular increment and velocity increment producer **6** provided in the AISC chip **92** of the control circuit board **9**;

[**0170**] a Y axis accelerometer **22**, which is provided on the first circuit board **2** and connected with angular increment and velocity increment producer **6** provided in the AISC chip **92** of the control circuit board **9**; and

[**0171**] a Z axis accelerometer **72**, which is provided on the third circuit board **7** and connected with angular increment and velocity increment producer **6** provided in the AISC chip **92** of the control circuit board **9**.

[**0172**] Referring to **FIGS. 1, 4,** and **12**, a position and attitude processor **80** basically comprises the magnetometer interface circuit **926**, the DSP chip **91**, the communication module **98**, a connector **93**, and a power supply module **99**.

[**0173**] Referring to **FIGS. 2 and 3**, the thermal sensing producer device **15** of the preferred embodiment of the present invention further comprises:

[**0174**] a first thermal sensing producing unit **24** for sensing the temperature of the X axis angular rate detecting unit **21** and the Y axis accelerometer **22**;

[**0175**] a second thermal sensing producer **44** for sensing the temperature of the Y axis angular rate detecting unit **41** and the X axis accelerometer **42**; and

[**0176**] a third thermal sensing producer **74** for sensing the temperature of the Z axis angular rate detecting unit **71** and the Z axis accelerometer **72**.

[**0177**] Referring to **FIGS. 2 and 3**, the heater device **20** of the preferred embodiment of the present invention further comprises:

[**0178**] a first heater **25**, which is connected to the X axis angular rate detecting unit **21**, the Y axis accelerometer **22**, and the first front-end circuit **23**, for maintaining a predetermined operational temperature of the X axis angular rate detecting unit **21**, the Y axis accelerometer **22**, and the first front-end circuit **23**;

[**0179**] a second heater **45**, which is connected to the Y axis angular rate detecting unit **41**, the X axis accelerometer **42**, and the second front-end circuit **43**, for maintaining a predetermined operational temperature of the X axis angular rate detecting unit **41**, the X axis accelerometer **42**, and the second front-end circuit **43**; and

[**0180**] a third heater **75**, which is connected to the Z axis angular rate detecting unit **71**, the Z axis accelerometer **72**, and the third front-end circuit **73**, for maintaining a predetermined operational temperature of the Z axis angular rate detecting unit **71**, the Z axis accelerometer **72**, and the third front-end circuit **73**.

[**0181**] Referred to **FIGS. 2, 4** and **9**, the thermal processor **30** of the preferred embodiment of the present invention further comprises three identical thermal control circuitries **923** in the ASIC chip **92** and the thermal control computation modules **911** running in the DSP chip **91**.

[**0182**] As shown in **FIG. 10**, each of the thermal control circuitries **923** further comprises:

[**0183**] a first amplifier circuit **9231**, which is connected with the respective X axis, Y axis or Z axis thermal sensing producer **24**, **44**, **74**, for amplifying the signals and suppressing the noise residing in the temperature voltage signals from the respective X axis, Y axis or Z axis thermal sensing producer **24**, **44**, **74** and improving the signal-to-noise ratio;

[**0184**] an analog/digital converter **9232**, which is connected with the amplifier circuit **9231**, for sampling the temperature voltage signals and digitizing the sampled temperature voltage signals to digital signals, which are output to the thermal control computation module **911**;

[**0185**] a digital/analog converter **9233** which converts the digital temperature commands input from the thermal control computation module **911** into analog signals; and

[**0186**] a second amplifier circuit **9234**, which receives the analog signals from the digital/analog converter **9233**, amplifying the input analog signals from the digital/analog converter **9233** for driving the respective first, second or third heater **25**, **45**, **75**, and closing the temperature controlling loop.

[**0187**] The thermal control computation module **911** computes digital temperature commands using the digital temperature voltage signals from the analog/digital converter **9232**, the temperature sensor scale factor, and the predetermined operating temperature of the angular rate producer and acceleration producer, wherein the digital temperature commands are connected to the digital/analog converter **9233**.

[**0188**] Referring to **FIG. 11**, the angular increment and velocity increment producer **6** comprises an angular integrating means **620**, an acceleration integrating means **630**, a resetting means **640**, and an angular increment and velocity increment measurement means **650**.

[**0189**] The angular integrating means **620** and the acceleration integrating means **630** are adapted for respectively integrating the three-axis analog angular rate voltage signals and the three-axis analog acceleration voltage signals for a predetermined time interval to accumulate the three-axis analog angular rate voltage signals and the three-axis analog acceleration voltage signals as an uncompensated three-axis angular increment and an uncompensated three-axis velocity increment for the predetermined time interval to achieve accumulated angular increments and accumulated velocity increments. The integration is performed to remove noise signals that are non-directly proportional to the carrier angular rate and acceleration within the three-axis analog angular rate voltage signals and the three-axis analog acceleration voltage signals, to improve signal-to-noise ratio, and to remove the high frequency signals in the three-axis analog angular rate voltage signals and the three-axis analog acceleration voltage signals. The signals are directly proportional to the carrier angular rate and acceleration within the three-axis analog angular rate voltage signals and the three-axis analog acceleration voltage signals.

[**0190**] The resetting means forms an angular reset voltage pulse and a velocity reset voltage pulse as an angular scale and a velocity scale which are input into the angular integrating means **620** and the acceleration integrating means **630** respectively.

[**0191**] The angular increment and velocity increment measurement means **650** is adapted for measuring the voltage values of the three-axis accumulated angular increments and the three-axis accumulated velocity increments with the angular reset voltage pulse and the velocity reset voltage pulse respectively to acquire angular increment counts and velocity increment counts as a digital form of the angular increment and velocity increment measurements respectively.

[**0192**] The Earth's magnetic field detector **96**, connected with the Earth's magnetic field detector interface circuit **926**, which is a magnetometer interface circuit, of the ASIC chip **92**, is used for producing the Earth's magnetic field vector measurements to provide additional heading information for the micro integrated GPS/IMU system of the present invention.

[**0193**] Referred to **FIGS. 1 and 4**, the Earth's magnetic field detector interface circuit **926**, which is arranged on the ASIC chip **92** of the control board **9**, is used to condition the output signal of the Earth's magnetic field detector **96**, digitize the output signal of the Earth's magnetic field detector **96**, and input the digital Earth's magnetic field vector to the DSP chip **91**.

[**0194**] Referring to **FIG. 9**, the DSP chip **91** arranged on the control board **9** performs:

[**0195**] (1) a thermal control computation **911**, for closing the control loop of the thermal control means **100**;

[**0196**] (2) a dither motion processing **912**, for closing the control loop of the dither drive signals for the angular rate producer **5**;

[**0197**] (3) a position, velocity and attitude module **81** to process the digital angular increment and velocity increment to obtain inertial position, velocity, and attitude data and performing error correction using optimal estimates of inertial position, velocity, and attitude errors from an error estimator module **82** to obtain highly accurate GPS/IMU mixed position, velocity, and attitude data;

[**0198**] (4) an error estimator module **82** to process the position, velocity, and attitude solution from the position, velocity and attitude module **81**, the GPS measurements from the GPS chipset board **3**, magnetic heading data from a magnetic heading computation **83** to produce optimal estimates of inertial position, velocity, and attitude errors, which are fed back to the position, velocity and attitude module **81**;

[0199] (5) a magnetic heading computation **83**, receiving the three-axis digital Earth's magnetic field vector data from the Earth's magnetic field detector interface circuit **926** of the ASIC chip **92** and the pitch and roll angle data from the position, velocity, and attitude module **81** and computing magnetic heading data to error estimator module **82**; and

[0200] (6) an input and output data management with external users by means of an input/output communication producer **915**;

[0201] In order to make the output of the micro integrated GPS/IMU system more accessible, referred to **FIG. 12**, the position and attitude processor **80** further comprises:

[0202] a LCD display module **97**, arranged on the control board **9** and connected with the LCD interface circuit **927** of the ASIC chip **92** for providing a display of the motion measurements of the system of the present patent in a compact way, such as number or curve or map display of the position, velocity, and attitude data;

[0203] a flash memory **94**, connected with the DSP chip **91**, for providing a storage means of the executable software code of the control and computation tasks, as shown in **FIG. 9**, when the micro integrated GPS/IMU system is powered off; and

[0204] a JTAG connector **95**, connected with the DSP chip **91**, for providing an onboard programming function of the flash memory **94** of the control circuit board **9**A, wherein the on-board programming function is that the flash memory **94** can be programmed on board through a JATG connector.

[0205] Conventionally, an EPROM (Erasable Programmable Read-Only Memory) or a flash memory needs to be programmed off-board with a hardware programmer and is installed on the board through a socket.

[0206] The Joint Test Action Group (JTAG), was formed in 1985, by key electronic manufacturers to create a PCB (printed-circuit boards) and IC (integrated circuit) test standard. The JTAG proposal was approved in 1990 by IEEE Standard 1149.1~1990 Test Access Port and Boundary Scan Architecture. In the present invention, the JTAG connector is used to perform the on-board programming.

[0207] Flash memories are a type of non-volatile memory (NVM). NVMs are so named because they can retain information even when their power supply is removed. It has a distinct advantage over EPROM in that certain types of flash memory can be erased and reprogrammed inside any system with no special voltage needed.

[0208] Correspondingly, the LCD interface circuit **927** interfacing the LCD display module **97** with the DSP chip **91**A is arranged in the ASIC chip **92** on the control board **9**.

[0209] The Earth's magnetic field detector interface circuit **926**, connected between the Earth's magnetic field detector **96** and the DSP chip **91**, performs:

[0210] (1) sensing the electronic analog magnetic field signals, proportional to the Earth's magnetic field from the Earth's magnetic field detector **96**;

[0211] (2) amplifying the analog magnetic field signals to suppress noise in the electronic analog signal, which is not proportional to the Earth's magnetic field;

[0212] (3) converting the amplified signals to form three-axis digital Earth's magnetic field data, which are input to the DSP chip **91**; and

[0213] (4) providing data/address/control bus connection and producing an address decode function, so that the DSP chip **91** can access the Earth's magnetic field detector interface circuit **926** and pickup the three-axis digital Earth's magnetic field data.

[0214] The LCD interface circuit **927**, connected between the DSP chip **91** and an LCD display module **97**, is arranged in the ASIC chip **92** on the control board **9** to provide data/address/control bus connection and produce an address decode function, so that the DSP chip **91** can access the LCD display module **97** and output the motion measurements of the core IMU of the present patent, such as the position, velocity, and attitude data.

[0215] Referred to **FIG. 13**, the preferred embodiment of the GPS chipset board **3** comprises a GPS RF (Radio Frequency) IC (Integrated Circuit) **31**, a correlation IC **32** and a GPS microprocessor **33**.

[0216] The GPS RF (Radio Frequency) IC (Integrated Circuit) **31** is adapted for receiving the GPS RF signals from a GPS antenna, downconverting and sampling the incoming RF GPS signal, and providing Sign and Magnitude digital output to the Correlation IC **32**.

[0217] The correlation IC **32** is adapted for correlating the Sign and Magnitude digital stream with the appropriate local carrier and code to de-spread the GPS signals to output I and Q (in-phase and quadraphase) samples to the GPS microprocessor **33**.

[0218] The GPS microprocessor **33** is adapted for processing the I and Q samples to close the GPS signal tracking loops and to derive the GPS raw measurements and navigation solution.

[0219] Referred to **FIG. 14**, an alternative mode of the GPS chipset board **3A** comprises a GPS RF (Radio Frequency) IC (Integrated Circuit) **31A**, a correlation IC **32A**, a data link IC **34A**, a data demodulation module **35A**, and a GPS microprocessor **33**.

[0220] The GPS RF (Radio Frequency) IC (Integrated Circuit) **31A** is adapted for receiving the GPS RF signals from an antenna, downconverting and sampling the incoming RF GPS signal, and providing Sign and Magnitude digital output to the Correlation IC **32A**.

[0221] The correlation IC **32A** is adapted for inputting the for correlating the Sign and Magnitude digital stream with the appropriate carrier and code to de-spread the GPS signals to output I and Q (in-phase and quadraphase) samples to the GPS microprocessor **33**. The data link IC **34A** is adapted for receiving the data link RF signal from a differential GPS site and downconverting the data link RF signal to Data link IF (Intermediate Frequency IF) signal to the Data link demodulation module **35A**.

[0222] The data demodulation module **35A** is adapted for demodulating the data link IF signal to output GPS differential correction data to the GPS microprocessor **33A**.

[0223] The GPS microprocessor **33A** is adapted for processing the I and Q samples and the GPS differential data to close the GPS signal tracking loops and to derive the GPS navigation solution.

[0224] Furthermore, the inertial velocity and acceleration from a position and attitude processor, which are corrected by the error estimator **82**, can be fed back to the GPS microprocessor **33** to aid the code and carrier phase tracking of the GPS satellite signals, so as to enhance the performance of the integrated GPS/IMU in heavy jamming and high dynamic environments.

[0225] Referring to **FIG. 15**, the position, velocity and attitude module **81** comprises a coning correction module **8101**, an angular rate compensation module **8102**, an acceleration compensation module **8103**, a level acceleration computation module **8104**, an alignment rotation vector computation module **8105**, a direction cosine matrix computation module **8106**, an earth and carrier rate computation module **8107**, a position and velocity update module **8108**, and an attitude and heading angle extract module **8109**.

[0226] The coning correction module **8101** is adapted for accepting the digital three-axis angular increment values from the angular increment and velocity increment producer **6** and coarse angular rate bias obtained from an angular rate producer and acceleration producer calibration procedure at a high data rate (short interval) and for computing coning effect errors using the input digital three-axis angular increment values and coarse angular rate bias, and outputting three-axis coning effect data and three-axis angular increment data at a reduced data rate (long interval), which are called three-axis long-interval angular increment values and output into the angular rate compensation module **8102**.

[0227] The angular rate compensation module **8102** is adapted for receiving the coning effect errors and three-axis long-interval angular increment values from the coning correction module **8101**, the angular rate device misalignment parameters and the fine angular rate bias from the angular rate producer and the acceleration producer calibration procedure and for compensating definite errors in the three-axis long-interval angular increment values using the coning effect errors, the angular rate device misalignment parameters, the fine angular rate bias, and the coning correction scale factor in the three-axis long-interval angular increments and outputting the real three-axis angular increments to the alignment rotation vector computation module **8105**.

[0228] The alignment rotation vector computation module **8105** is adapted for receiving the compensated three-axis angular increments from the angular rate compensation module **8102** and the rotation rate vector of the local navigation frame (n frame) of the carrier relative to the inertial frame (i frame) from the earth and carrier rate computation module **8107** and updating a quaternion, which is a vector representing rotation angle of the carrier and outputting the updated quaternion is connected to the direction cosine matrix computation module **8106**.

[0229] The direction cosine matrix computation module **8106** is adapted for computing the direction cosine matrix by using the updated quaternion and receiving the optimal estimates of the attitude errors from the error estimator **82** to correct the direction cosine matrix.

[0230] The acceleration compensation module **8103** is adapted for compensating the definite errors in three-axis velocity increments using the acceleration device misalignment and accelerometer bias, wherein the compensated three-axis velocity increments are connected to the level acceleration computation module **8104**.

[0231] The level acceleration computation module **8104** is adapted for receiving the compensated three-axis velocity increments and computing level velocity increments using the compensated three-axis velocity increments from the acceleration compensation module **8104** and the direction cosine matrix from the direction cosine matrix computation module **8106**.

[0232] The attitude and heading angle extract module **8109** is adapted for extracting GPS/IMU mixed attitude and heading angle using the corrected direction cosine matrix.

[0233] The position and velocity update module **8108** accepts level velocity increments from a level acceleration computation module **8204** and computes position and velocity solution and receiving the optimal estimates of the position and velocity errors from error estimator **82** to compensate the errors in the position and velocity solution to form GPS/IMU mixed position and velocity data;

[0234] The earth and carrier rate computation module **8107** accepts the position and velocity solution from the position and a velocity update module **8208** and computes the rotation rate vector of the local navigation frame (n frame) of the carrier relative to the inertial frame (i frame), which is connected to an alignment rotation vector computation module **8205**.

[0235] The error estimator **82** establishes an INS error model and GPS error model as a state vector and processes the position, velocity and attitude solution from the position, velocity and attitude module **81**, GPS measurements from the GPS microprocessor **33**, and magnetic heading data from the magnetic heading computation to provide the optimal estimate of the errors of the position, velocity, and attitude from the position, velocity and attitude module **81** and GPS errors.

[0236] The error estimator is embodied as a Kalman filter. It is well known that the Kalman filter produces optimal estimates of a system state vector with well known statistical properties of the system and measurement. The estimates are unbiased and they have minimum variance within the class of linear unbiased estimates. The quality of the estimates is however only guaranteed as long as the assumptions underlying the mathematical model hold. Any misspecification in the system and measurement model may invalidate the results of filtering and thus also any conclusion based on them.

[0237] Therefore, the error estimator is further embodied as a robust Kalman filter. The robust Kalman filter is stable enough to operate in more than one dynamic environment. If the dynamics change drastically, or if a sensor failure occurs, for example, a GPS satellite signal failure or an inertial sensor signal failure, the robust Kalman filter must detect, rectify and isolate the failure situation.

[0238] The robust Kalman robust filter has the characteristic that it provides near-optimum performance over a large class of process and measurement models. The pure Kalman filter is not robust since it is optimal for only one particular system and measurement model. If the filter's model is not correct, the filter covariance may report accuracy which is different from what can actually be achieved. The purpose of filter integrity is to ensure that the predicted performance from the error covariance matrix is close to the actual estimation error statistics. In addition, filter divergence is usually caused by a changing system and measurement model, or a sensor failure.

[0239] This present invention uses a residual monitoring method to obtain the robust Kalman filter which is used to blend the GPS data and the inertial sensor measurements. When the proper redundancy is available, residual monitoring schemes can efficiently detect hard and soft failures and filter divergence. One benefit of the residual monitoring approach is that when the filter model is correct, the statistical distribution of the residual sequence is known. Thus, it is easy to generate a measurement editing and divergence detection scheme using a test-of-distribution on the measurement residuals. The same statistics can be used to assess the filter tuning and adjust the size of the covariance when divergence is detected. **FIG. 16** gives the implementation of this robust Kalman filter including a residual monitoring function.

[0240] As shown in **FIG. 16, a** GPS error compensation module **8207** gathers the GPS measurements from the GPS microprocessor **33**, and performs GPS measurement compensation by using the optimal estimates of GPS error variables from an updating state vector module **8209** to perform GPS error compensation. The corrected GPS measurements are sent to a preprocessing module **8205**.

[0241] The preprocessing module **8205** receives the GPS satellite ephemeris from the GPS microprocessor **33**, the corrected GPS measurements from the GPS error compensation module **8207**, and INS solutions from the position, velocity and attitude module **81**. The preprocessing module **8205** performs the calculation of the state transition matrix and sends it as well as the previous state vector to a state vector prediction module **8206**. The calculated state transit matrix is also sent to a covariance propagation module **8802**. The preprocessing module **8205** calculates the measurement matrix and the current measurement vector according to the computed measurement matrix and the measurement model. The measurement matrix and the computed current measurement vector are passed to a computing measurement residue module **8208**.

[0242] The state vector prediction module **8206** receives the state transition matrix and the previous state vector from the preprocessing module **8205** to perform state prediction of the current epoch. The predicted current state vector is passed to the computing measurement residue module **8208**.

[0243] The computing measurement residue module **8208** receives the predicted current state vector from the state vector prediction module **8206** and the measurement matrix and the current measurement vector from the preprocessing module **8205**. The computing measurement residue module **8208** calculates the measurement residues by subtracting the multiplication of the measurement matrix and the predicted current state vector from the current measurement vector. The measurement residues are sent to a residue monitor module **331** as well as the updating state vector module **8209**.

[0244] The residue monitor module **8201** performs a discrimination on the measurement residues received from the computing measurement residue module **8208**. The discrimination law is whether the square of the measurement residues divided by the residual variance is larger than a given threshold. If the square of the measurement residues divided by the residual variance is larger than this given threshold, the current measurement may lead to the divergence of the Kalman filter. When it occurs, the residue monitor module **331** calculates a new covariance of the system process or rejects the current measurement. If the square of the measurement residues divided by the residual variance is less than this given threshold, the current measurement can be used by the Kalman filter without changing the current covariance of system process to obtain the current navigation solution. The covariance of the system process is sent to the covariance propagation module **8202**.

[0245] The covariance propagation module **8202** gathers the covariance of the system process from the residue monitor module **8201**, the state transition matrix from the preprocessing module **8205**, and the previous covariance of estimated error to calculate the current covariance of the estimated error. The computed current covariance of the estimated error is sent to a computing optimal gain module **8203**.

[0246] The computing optimal gain module **8203** receives the current covariance of the estimated error from the covariance computing module **3202** to compute the optimal gain. This optimal gain is passed to a covariance updating module **8204** as well as the updating state vector module **339**. The covariance updating module **8204** updates the covariance of the estimated error and sends it to the covariance propagation module **8202**.

[0247] The updating state vector module **8209** receives the optimal gain from the computing optimal gain module **8203** and the measurement residues from the computing measurement residue module **8208**. The updating state vector module **8209** calculates the current estimate of state vector including position, velocity and attitude errors and GPS errors, and sends them to the GPS error compensation module **8207** and the position velocity and attitude module **81**.

[0248] The magnetic heading computation module **83** receives the three-axis digital Earth's magnetic field signals from the Earth's magnetic field detector interface circuit **926** of the ASIC chip **92** and the pitch and roll angle data from the attitude and heading module **81** or the position, velocity, and attitude module **82** and computes magnetic heading data. The magnetic heading computation module **83** further performs:

[0249] (1) loading the calibration parameters of the Earth's magnetic field detector **96** from the flash memory **94** to form a calibration vector;

[0250] (2) receiving the three-axis digital Earth's magnetic field signals from the Earth's magnetic field detector interface circuit **926** of the ASIC chip **92**, which is expressed in the body frame, to form a measurement vector;

[0251] (3) receiving the pitch and roll angle data from the attitude and heading module **81** or the position, velocity, and attitude module **82** to form a transformation matrix from the body frame to level frame;

[0252] (4) compensating the measurement vector with the calibration vector;

[0253] (5) transforming the compensated measurement vector from the body frame to the level frame to form a measurement vector, which is expressed in the level frame;

[0254] (6) computing magnetic heading data using the measurement vector expressed in the level frame, which is output to error estimator **82**.

[0255] As mentioned above, the first circuit board **2**, the second circuit board **4**, the third circuit board **7**, the GPS chipset board **3**, and the control circuit board **9** are arranged inside the metal cubic case **1**, as shown in **FIG. 17**, which are a preferred perspective view and a sectional view of the micro integrated GPS/IMU system of the present invention as shown in the block diagram of **FIG. 1**.

[0256] According to a first alternative mode of the physical structure of the present invention, the first circuit board **2**, the second circuit board **4**, the third circuit board **7**, the GPS chipset board **3**, and the control circuit board **9** are spatially arranged inside the metal cubic case **1** respectively, as shown in **FIG. 18**. In those configurations, the first circuit board **2** and the second circuit board **4** are assembled in the top and bottom. The third circuit board **7** and the GPS chipset board **3** are assembled in the right or left side to be connected with the first circuit board **2** and the second circuit board **4** in an orthogonal way to achieve three sensing axis of the angular rate producer and acceleration producer. The control circuit board **9** can be assembled in the front or back side to be connected with the first circuit board **2**, the second circuit board **4**, the third circuit board **7** and the GPS chipset board **3**.

[0257] In the above disclosed spatial configuration of the first circuit board **2**, the second circuit board **4**, the third circuit board **7**, the GPS chipset board **3**, and the control circuit board **9**, the first circuit board **2**, the second circuit board **4**, the third circuit board **7**, the GPS chipset board **3**, and the control circuit board **9** are arranged inside the metal cubic case **1**. In some applications, spatial configuration of the first circuit board **2**, the second circuit board **4**, the third circuit board **7**, the GPS chipset board **3**, and the control circuit board **9** of the core IMU of the present patent can be alternatively arranged to achieve a flat metal case **1**. Referred to **FIG. 19**, the third circuit board **7** is assembled vertically in the flat metal case **1**. The first circuit board **2**, the second circuit board **4**, the GPS chipset board **3**, and the control circuit board **9** are scattered in both sides of the third circuit board **7**.

[0258] The above disclosed embodiment of the present invention is installed in a carrier to provide the motion measurements. The extreme vibration and shock may induce the additional unexpected error in the output of the micro integrated GPS/IMU system. Referring to **FIG. 20, a** support bracket **101** and a shock mount **105** are designed to minimize the effect of the extreme vibration and shock on the output performance of the micro integrated GPS/IMU system. The support bracket **101** is directly strapped down on the carrier. The micro integrated GPS/IMU system is fixed through the four shock mounts **105** with the support bracket **101**.

[0259] Referring to **FIG. 21**, the micro integrated GPS/IMU system can be installed in a carrier through the four vibration isolators **106**.

[0260] Referring to **FIGS. 3 and 22**, a preferred thermal sensing producer **24A**, **44A**, **74A** further performs:

[0261] (A) receiving dither driver signal from the angular rate detecting unit **21**, **41**, **71**;

[0262] (B) extracting the dither frequency of the inertial element of the angular rate detecting unit **21**, **41**, **71**;

[0263] (C) estimating the operational temperature of the angular rate detecting unit **21**, **41**, **71** by means of accessing a MEMS frequency to temperature model using the dither frequency of the inertial element of the angular rate detecting unit **21**, **41**, **71**, wherein the MEMS frequency to temperature model is pre-determined through multiple tests of the angular rate detecting unit **21**, **41**, **71**;

[0264] (D) sending the operational temperature through the thermal control circuitry **923** of the ASIC chip **92** to the DSP chip **91**.

What is claimed is:

1. A micro integrated GPS/IMU system for a carrier, comprising:

an angular rate producer, producing X axis, Y axis and Z axis electrical angular rate signals;

an acceleration producer, producing X axis, Y axis and Z axis electrical acceleration signals;

an angular increment and velocity increment producer, converting said X axis, Y axis and Z axis electrical angular rate signals into digital angular increments and converting said X axis, Y axis and Z axis electrical acceleration signals into digital velocity increments;

a GPS chipset, providing GPS measurements from at least a GPS satellite;

an Earth's magnetic field detector, producing Earth's magnetic field vector electrical measurement signals, including X, Y, Z axes signals of an Earth's magnetic field vector measurement for said carrier; and

a position and attitude processor, computing position, attitude and heading angle measurements using said digital angular increments, said digital velocity increments, said GPS measurements, and said Earth magnetic field vector measurement.

2. The micro integrated GPS/IMU system, as recited in claim 1, wherein said GPS chipset comprises a GPS RF (Radio Frequency) IC (Integrated Circuit), a correlation IC and a GPS microprocessor,

said GPS RF (Radio Frequency) IC (Integrated Circuit) receiving GPS RF signals from a GPS antenna, down-converting and sampling said RF GPS signals, and providing Sign and Magnitude digital output to said correlation IC, said correlation IC correlating said Sign and Magnitude digital output with a appropriate local carrier and code to de-spread to output I and Q (in-phase and quadraphase) samples to said GPS microprocessor,

said GPS microprocessor processing said I and Q samples to close GPS signal tracking loops and to derive GPS raw measurements and a navigation solution.

3. The micro integrated GPS/IMU system, as recited in claim 1, wherein said GPS chipset comprises a GPS RF (Radio Frequency) IC (Integrated Circuit), a correlation IC, a data link IC, a data demodulation module, a GPS microprocessor,

said GPS RF (Radio Frequency) IC (Integrated Circuit) receiving GPS RF signals from an antenna, downconverting and sampling said RF GPS signal, and providing Sign and Magnitude digital output to said Correlation IC,

said correlation IC correlating said Sign and Magnitude digital output with a appropriate carrier and code to de-spread to output I and Q (in-phase and quadraphase) samples to said GPS microprocessor,

said data link IC receiving a RF signal from a differential GPS site and downconverting said RF signal to an IF (Intermediate Frequency IF) signal to said Data link demodulation module,

said data demodulation module demodulating said IF signal to output GPS differential correction data to said GPS microprocessor,

said GPS microprocessor processing said I and Q samples and said GPS differential correction data to close GPS signal tracking loops and to derive a GPS navigation solution.

4. The micro integrated GPS/IMU system, as recited in claim 1, wherein said position and attitude processor comprises:

an ASIC chip comprising an Earth's magnetic field detector interface circuit to condition said Earth's magnetic field vector electrical measurement signals of said Earth's magnetic field detector and digitize said Earth's magnetic field vector electrical measurement of said Earth's magnetic field detector to output digital Earth's magnetic field vector data;

a DSP chip receiving said digital Earth's magnetic field vector data from said Earth's magnetic field detector interface circuit and performing computation and control tasks for said micro integrated GPS/IMU system;

a power supply module for receiving an external power to provide required voltages.

5. The micro integrated GPS/IMU system, as recited in claim 4, wherein said position and attitude processor further comprises:

a communication module providing an input/output interface between said micro integrated GPS/IMU system and an external user, and

a connector which is connected with said communication module and provides proper pine configuration which is compatible with said external user, moreover said external power is received in said power supply module through said connector.

6. The micro integrated GPS/IMU system, as recited in claim 2, wherein said position and attitude processor comprises:

an ASIC chip comprising an Earth's magnetic field detector interface circuit to condition said Earth's magnetic field vector electrical measurement signals of said Earth's magnetic field detector and digitize said Earth's magnetic field vector electrical measurement of said Earth's magnetic field detector to output digital Earth's magnetic field vector data;

a DSP chip receiving said digital Earth's magnetic field vector data from said Earth's magnetic field detector interface circuit and performing computation and control tasks for said micro integrated GPS/IMU system;

a power supply module for receiving an external power to provide required voltages.

7. The micro integrated GPS/IMU system, as recited in claim 6, wherein said position and attitude processor further comprises:

a communication module providing an input/output interface between said micro integrated GPS/IMU system and an external user, and

a connector which is connected with said communication module and provides proper pine configuration which is compatible with said external user, moreover said external power is received in said power supply module through said connector.

8. The micro integrated GPS/IMU system, as recited in claim 3, wherein said position and attitude processor comprises:

an ASIC chip comprising an Earth's magnetic field detector interface circuit to condition said Earth's magnetic field vector electrical measurement signals of said Earth's magnetic field detector and digitize said Earth's magnetic field vector electrical measurement of said Earth's magnetic field detector to output digital Earth's magnetic field vector data;

a DSP chip receiving said digital Earth's magnetic field vector data from said Earth's magnetic field detector interface circuit and performing computation and control tasks for said micro integrated GPS/IMU system;

a power supply module for receiving an external power to provide required voltages.

9. The micro integrated GPS/IMU system, as recited in claim 8, wherein said position and attitude processor further comprises:

a communication module providing an input/output interface between said micro integrated GPS/IMU system and an external user, and

a connector which is connected with said communication module and provides proper pine configuration which is compatible with said external user, moreover said external power is received in said power supply module through said connector.

10. The micro integrated GPS/IMU system, as recited in claim 4, wherein said DSP chip comprises:

means for executing a thermal control computation for closing a control loop of a thermal control means;

means for performing a dither motion processing for closing said control loop of dither drive signals for said angular rate producer;

a position, velocity and attitude module for processing said digital angular increment and said digital velocity increment to obtain inertial position, velocity and attitude data and performing error correction using optimal estimates of inertial position, velocity and attitude errors to obtain position, velocity, and attitude solution data;

an error estimator module for processing said position, velocity, and attitude solution data from said position, velocity and attitude module, said GPS measurements from said GPS chipset, computing magnetic heading data to said error estimator module to produce optimal estimates of inertial position, velocity, and attitude errors;

an input/output communication producer, managing input and output data with external users; and

a magnetic heading computation module, receiving said digital Earth's magnetic field vector data from said Earth's magnetic field detector interface circuit of said ASIC chip and pitch and roll angle data from said position, velocity and attitude module and computing magnetic heading data to said error estimator module.

11. The micro integrated GPS/IMU system, as recited in claim 6, wherein said DSP chip comprises:

means for executing a thermal control computation for closing a control loop of a thermal control means;

means for performing a dither motion processing for closing said control loop of dither drive signals for said angular rate producer;

a position, velocity and attitude module for processing said digital angular increment and said digital velocity increment to obtain inertial position, velocity and attitude data and performing error correction using optimal estimates of inertial position, velocity and attitude errors to obtain position, velocity, and attitude solution data;

an error estimator module for processing said position, velocity, and attitude solution data from said position, velocity and attitude module, said GPS measurements from said GPS chipset, computing magnetic heading data to said error estimator module to produce optimal estimates of inertial position, velocity, and attitude errors;

an input/output communication producer, managing input and output data with external users; and

a magnetic heading computation module, receiving said digital Earth's magnetic field vector data from said Earth's magnetic field detector interface circuit of said ASIC chip and pitch and roll angle data from said position, velocity and attitude module and computing magnetic heading data to said error estimator module.

12. The micro integrated GPS/IMU system, as recited in claim 8, wherein said DSP chip comprises:

means for executing a thermal control computation for closing a control loop of a thermal control means;

means for performing a dither motion processing for closing said control loop of dither drive signals for said angular rate producer;

a position, velocity and attitude module for processing said digital angular increment and said digital velocity increment to obtain inertial position, velocity and attitude data and performing error correction using optimal estimates of inertial position, velocity and attitude errors to obtain position, velocity, and attitude solution data;

an error estimator module for processing said position, velocity, and attitude solution data from said position, velocity and attitude module, said GPS measurements from said GPS chipset, computing magnetic heading data to said error estimator module to produce optimal estimates of inertial position, velocity, and attitude errors;

an input/output communication producer, managing input and output data with external users; and

a magnetic heading computation module, receiving said digital Earth's magnetic field vector data from said Earth's magnetic field detector interface circuit of said ASIC chip and pitch and roll angle data from said position, velocity and attitude module and computing magnetic heading data to said error estimator module.

13. The micro integrated GPS/IMU system, as recited in claim 4, wherein said Earth's magnetic field detector interface circuit is connected between said Earth's magnetic field detector and said DSP chip, said Earth's magnetic field detector interface circuit:

acquiring electronic analog signals proportional to an Earth's magnetic field from said Earth's magnetic field detector;

amplifying said electronic analog signals to suppress noise in said electronic analog signal, which is not proportional to said Earth's magnetic field, to form amplified signals;

converting said amplified signals to form three-axis digital Earth's magnetic field data, which are input to said DSP chip;

providing data/address/control bus connection and producing an address decode function, wherein said DSP chip accesses said Earth's magnetic field detector interface circuit and pickups said three-axis digital Earth's magnetic field data.

14. The micro integrated GPS/IMU system, as recited in claim 6, wherein said Earth's magnetic field detector interface circuit is connected between said Earth's magnetic field detector and said DSP chip, said Earth's magnetic field detector interface circuit:

acquiring electronic analog signals proportional to an Earth's magnetic field from said Earth's magnetic field detector;

amplifying said electronic analog signals to suppress noise in said electronic analog signal, which is not proportional to said Earth's magnetic field, to form amplified signals;

converting said amplified signals to form three-axis digital Earth's magnetic field data, which are input to said DSP chip;

providing data/address/control bus connection and producing an address decode function, wherein said DSP chip accesses said Earth's magnetic field detector interface circuit and pickups said three-axis digital Earth's magnetic field data.

15. The micro integrated GPS/IMU system, as recited in claim 8, wherein said Earth's magnetic field detector interface circuit is connected between said Earth's magnetic field detector and said DSP chip, said Earth's magnetic field detector interface circuit:

acquiring electronic analog signals proportional to an Earth's magnetic field from said Earth's magnetic field detector;

amplifying said electronic analog signals to suppress noise in said electronic analog signal, which is not proportional to said Earth's magnetic field, to form amplified signals;

converting said amplified signals to form three-axis digital Earth's magnetic field data, which are input to said DSP chip;

providing data/address/control bus connection and producing an address decode function, wherein said DSP chip accesses said Earth's magnetic field detector interface circuit and pickups said three-axis digital Earth's magnetic field data.

16. The micro integrated GPS/IMU system, as recited in claim 10, wherein said Earth's magnetic field detector interface circuit is connected between said Earth's magnetic field detector and said DSP chip, said Earth's magnetic field detector interface circuit:

acquiring electronic analog signals proportional to an Earth's magnetic field from said Earth's magnetic field detector;

amplifying said electronic analog signals to suppress noise in said electronic analog signal, which is not proportional to said Earth's magnetic field, to form amplified signals;

converting said amplified signals to form three-axis digital Earth's magnetic field data, which are input to said DSP chip;

providing data/address/control bus connection and producing an address decode function, wherein said DSP chip accesses said Earth's magnetic field detector interface circuit and pickups said three-axis digital Earth's magnetic field data.

17. The micro integrated GPS/IMU system, as recited in claim 11, wherein said Earth's magnetic field detector interface circuit is connected between said Earth's magnetic field detector and said DSP chip, said Earth's magnetic field detector interface circuit:

acquiring electronic analog signals proportional to an Earth's magnetic field from said Earth's magnetic field detector;

amplifying said electronic analog signals to suppress noise in said electronic analog signal, which is not proportional to said Earth's magnetic field, to form amplified signals;

converting said amplified signals to form three-axis digital Earth's magnetic field data, which are input to said DSP chip;

providing data/address/control bus connection and producing an address decode function, wherein said DSP chip accesses said Earth's magnetic field detector interface circuit and pickups said three-axis digital Earth's magnetic field data.

18. The micro integrated GPS/IMU system, as recited in claim 12, wherein said Earth's magnetic field detector interface circuit is connected between said Earth's magnetic field detector and said DSP chip, said Earth's magnetic field detector interface circuit:

acquiring electronic analog signals proportional to an Earth's magnetic field from said Earth's magnetic field detector;

amplifying said electronic analog signals to suppress noise in said electronic analog signal, which is not proportional to said Earth's magnetic field, to form amplified signals;

converting said amplified signals to form three-axis digital Earth's magnetic field data, which are input to said DSP chip;

providing data/address/control bus connection and producing an address decode function, wherein said DSP chip accesses said Earth's magnetic field detector interface circuit and pickups said three-axis digital Earth's magnetic field data.

19. The micro integrated GPS/IMU system, as recited in claim 10, wherein said position, velocity, and attitude module comprises:

a coning correction module for accepting said digital angular increments from said angular increment and velocity increment producer and coarse angular rate bias obtained from an angular rate producer and acceleration producer calibration procedure at a high data rate in short interval and for computing coning effect errors using said digital angular increment and coarse angular rate bias, and outputting coning effect data and angular increment data at a reduced data rate in long interval, which are long-interval angular increment values;

an angular rate compensation module, receiving said coning effect errors and said long-interval angular increment values from said coning correction module and angular rate device misalignment parameters and fine angular rate bias from said angular rate producer and acceleration producer calibration procedure, and compensating definite errors in said long-interval angular increment values using said coning effect errors, angular rate device misalignment parameters, fine angular rate bias, and coning correction scale factor in said long-interval angular increments and outputting real angular increments;

an alignment rotation vector computation module, receiving said real angular increments from said angular rate compensation module and said rotation rate vector of said local navigation frame (n frame) of said carrier relative to said inertial frame (i frame) from an earth and carrier rate computation module and updating a quaternion, which is a vector representing rotation angle of said carrier and outputting said updated quaternion;

a direction cosine matrix computation module, which is connected to said updated quaternion, for computing said direction cosine matrix by using said updated quaternion and receiving said optimal estimates of said attitude errors from error estimator to correct said direction cosine matrix;

an acceleration compensation module, compensating said definite errors in said velocity increments using said acceleration device misalignment, accelerometer bias, wherein said compensated velocity increments are connected to said level acceleration computation module;

a level acceleration computation module, receiving said compensated velocity increments and computing level velocity increments using said compensated velocity increments from said acceleration compensation module and said direction cosine matrix from said direction cosine matrix computation module;

an attitude and heading angle extract module, extracting attitude and heading angle using said corrected direction cosine matrix;

a position and velocity update module, accepting said level velocity increments from said level acceleration computation module and computing a position and velocity solution and receiving said optimal estimates of said position and velocity errors from error estimator to compensate said errors in said position and velocity solution; and

an earth and carrier rate computation module, accepting said position and velocity solution from said position and velocity update module and computing said rotation rate vector of said local navigation frame (n frame) of said carrier relative to said inertial frame (i frame), which is connected to said alignment rotation vector computation module.

20. The micro integrated GPS/IMU system, as recited in claim 11, wherein said position, velocity, and attitude module comprises:

a coning correction module for accepting said digital angular increments from said angular increment and velocity increment producer and coarse angular rate bias obtained from an angular rate producer and acceleration producer calibration procedure at a high data rate in short interval and for computing coning effect errors using said digital angular increment and coarse angular rate bias, and outputting coning effect data and angular increment data at a reduced data rate in long interval, which are long-interval angular increment values;

an angular rate compensation module, receiving said coning effect errors and said long-interval angular increment values from said coning correction module and angular rate device misalignment parameters and fine angular rate bias from said angular rate producer and acceleration producer calibration procedure, and compensating definite errors in said long-interval angular increment values using said coning effect errors, angular rate device misalignment parameters, fine angular rate bias, and coning correction scale factor in said long-interval angular increments and outputting real angular increments;

an alignment rotation vector computation module, receiving said real angular increments from said angular rate compensation module and said rotation rate vector of said local navigation frame (n frame) of said carrier relative to said inertial frame (i frame) from an earth and carrier rate computation module and updating a quaternion, which is a vector representing rotation angle of said carrier and outputting said updated quaternion;

a direction cosine matrix computation module, which is connected to said updated quaternion, for computing said direction cosine matrix by using said updated quaternion and receiving said optimal estimates of said attitude errors from error estimator to correct said direction cosine matrix;

an acceleration compensation module, compensating said definite errors in said velocity increments using said acceleration device misalignment, accelerometer bias, wherein said compensated velocity increments are connected to said level acceleration computation module;

a level acceleration computation module, receiving said compensated velocity increments and computing level velocity increments using said compensated velocity increments from said acceleration compensation module and said direction cosine matrix from said direction cosine matrix computation module;

an attitude and heading angle extract module, extracting attitude and heading angle using said corrected direction cosine matrix;

a position and velocity update module, accepting said level velocity increments from said level acceleration computation module and computing a position and velocity solution and receiving said optimal estimates of said position and velocity errors from error estimator to compensate said errors in said position and velocity solution; and

an earth and carrier rate computation module, accepting said position and velocity solution from said position and velocity update module and computing said rotation rate vector of said local navigation frame (n frame) of said carrier relative to said inertial frame (i frame), which is connected to said alignment rotation vector computation module.

21. The micro integrated GPS/IMU system, as recited in claim 12, wherein said position, velocity, and attitude module comprises:

a coning correction module for accepting said digital angular increments from said angular increment and velocity increment producer and coarse angular rate bias obtained from an angular rate producer and acceleration producer calibration procedure at a high data rate in short interval and for computing coning effect errors using said digital angular increment and coarse angular rate bias, and outputting coning effect data and angular increment data at a reduced data rate in long interval, which are long-interval angular increment values;

an angular rate compensation module, receiving said coning effect errors and said long-interval angular increment values from said coning correction module and angular rate device misalignment parameters and fine angular rate bias from said angular rate producer and acceleration producer calibration procedure, and compensating definite errors in said long-interval angular increment values using said coning effect errors, angular rate device misalignment parameters, fine angular rate bias, and coning correction scale factor in said long-interval angular increments and outputting real angular increments;

an alignment rotation vector computation module, receiving said real angular increments from said angular rate compensation module and said rotation rate vector of said local navigation frame (n frame) of said carrier relative to said inertial frame (i frame) from an earth and carrier rate computation module and updating a quaternion, which is a vector representing rotation angle of said carrier and outputting said updated quaternion;

a direction cosine matrix computation module, which is connected to said updated quaternion, for computing said direction cosine matrix by using said updated quaternion and receiving said optimal estimates of said attitude errors from error estimator to correct said direction cosine matrix;

an acceleration compensation module, compensating said definite errors in said velocity increments using said acceleration device misalignment, accelerometer bias, wherein said compensated velocity increments are connected to said level acceleration computation module;

a level acceleration computation module, receiving said compensated velocity increments and computing level velocity increments using said compensated velocity increments from said acceleration compensation module and said direction cosine matrix from said direction cosine matrix computation module;

an attitude and heading angle extract module, extracting attitude and heading angle using said corrected direction cosine matrix;

a position and velocity update module, accepting said level velocity increments from said level acceleration computation module and computing a position and velocity solution and receiving said optimal estimates of said position and velocity errors from error estimator to compensate said errors in said position and velocity solution; and

an earth and carrier rate computation module, accepting said position and velocity solution from said position and velocity update module and computing said rotation rate vector of said local navigation frame (n frame) of said carrier relative to said inertial frame (i frame), which is connected to said alignment rotation vector computation module.

22. The micro integrated GPS/IMU system, as recited in claim 10, wherein said error estimator comprises a Kalman filter which comprises:

a GPS error compensation module, gathering said GPS measurements from said GPS microprocessor, which is alternatively corrected with said differential GPS data, and said position and velocity corrections from an updating state vector module to perform GPS error compensation;

a preprocessing module, receiving said GPS satellite ephemeris from said GPS microprocessor, said corrected GPS raw data from said GPS error compensation module, and INS solutions from said position, velocity and attitude module, wherein said preprocessing module performs a calculation of said state transition matrix which is sent with said previous state vector to a state vector prediction module. Said calculated state transit matrix is also sent to a covariance propagation module. Said preprocessing module calculates said measurement matrix and said current measurement vector according to said computed measurement matrix and said measurement model, wherein said measurement matrix and said computed current measurement vector are passed to a computing measurement residue module; wherein

said state vector prediction module receives said state transition matrix and said previous state vector from said preprocessing module to perform state prediction of said current epoch, wherein said predicted current state vector is passed to said computing measurement residue module;

said computing measurement residue module receives said predicted current state vector from said state vector prediction module and said measurement matrix and said current measurement vector from said preprocessing module, wherein said computing measurement residue module calculates said measurement residues by subtracting said multiplication of said measurement matrix and said predicted current state vector from said current measurement vector, wherein said measurement residues are sent to a residue monitor module as well as said updating state vector module;

said residue monitor module performs a discrimination on said measurement residues received from said computing measurement residue module, wherein said discrimination law is whether a square of said measurement residues divided by said residual variance larger than a given threshold, wherein when said square of said measurement residues divided by said residual variance is larger than said given threshold, said current measurement leads to a divergence of said Kalman filter and then said residue monitor module selectively calculates a new covariance of said system process and rejects said current measurement, wherein when said square of said measurement residues divided by said residual variance is less than said given threshold, said current measurement is used by said Kalman filter without changing said current covariance of system process to obtain a current navigation solution, wherein said covariance of said system process is sent to said covariance propagation module;

said covariance propagation module gathers said covariance of said system process from said residue monitor module, said state transition matrix from said preprocessing module, and said previous covariance of estimated error to calculate said current covariance of said estimated error, wherein said computed current covariance of said estimated error is sent to a computing optimal gain module;

said computing optimal gain module receives said current covariance of said estimated error from said covariance computing module to compute an optimal gain which is passed to a covariance updating module as well as said updating state vector module, wherein said covariance updating module updates said covariance of said estimated error to send to said covariance propagation module;

said updating state vector module receives said optimal gain from said computing optimal gain module and said measurement residues from said computing measurement residue module, wherein said updating state vector module calculates said current estimate of state vector including position, velocity and attitude errors and sends to said GPS error compensation module and said position velocity and attitude module.

23. The micro integrated GPS/IMU system, as recited in claim 11, wherein said error estimator comprises a Kalman filter which comprises:

a GPS error compensation module, gathering said GPS measurements from said GPS microprocessor, which is alternatively corrected with said differential GPS data, and said position and velocity corrections from an updating state vector module to perform GPS error compensation;

a preprocessing module, receiving said GPS satellite ephemeris from said GPS microprocessor, said corrected GPS raw data from said GPS error compensation module, and INS solutions from said position, velocity and attitude module, wherein said preprocessing module performs a calculation of said state transition matrix which is sent with said previous state vector to a state vector prediction module. Said calculated state transit matrix is also sent to a covariance propagation module. Said preprocessing module calculates said measurement matrix and said current measurement vector according to said computed measurement matrix and said measurement model, wherein said measurement matrix and said computed current measurement vector are passed to a computing measurement residue module; wherein

said state vector prediction module receives said state transition matrix and said previous state vector from said preprocessing module to perform state prediction of said current epoch, wherein said predicted current state vector is passed to said computing measurement residue module;

said computing measurement residue module receives said predicted current state vector from said state vector prediction module and said measurement matrix and said current measurement vector from said preprocessing module, wherein said computing measurement residue module calculates said measurement residues by subtracting said multiplication of said measurement matrix and said predicted current state vector from said current measurement vector, wherein said measurement residues are sent to a residue monitor module as well as said updating state vector module;

said residue monitor module performs a discrimination on said measurement residues received from said computing measurement residue module, wherein said discrimination law is whether a square of said measurement residues divided by said residual variance larger than a given threshold, wherein when said square of said measurement residues divided by said residual variance is larger than said given threshold, said current measurement leads to a divergence of said Kalman filter and then said residue monitor module selectively calculates a new covariance of said system process and rejects said current measurement, wherein when said square of said measurement residues divided by said residual variance is less than said given threshold, said current measurement is used by said Kalman filter without changing said current covariance of system process to obtain a current navigation solution, wherein said covariance of said system process is sent to said covariance propagation module;

said covariance propagation module gathers said covariance of said system process from said residue monitor module, said state transition matrix from said preprocessing module, and said previous covariance of estimated error to calculate said current covariance of said estimated error, wherein said computed current covariance of said estimated error is sent to a computing optimal gain module;

said computing optimal gain module receives said current covariance of said estimated error from said covariance computing module to compute an optimal gain which is passed to a covariance updating module as well as said updating state vector module, wherein said covariance updating module updates said covariance of said estimated error to send to said covariance propagation module;

said updating state vector module receives said optimal gain from said computing optimal gain module and said measurement residues from said computing measurement residue module, wherein said updating state vector module calculates said current estimate of state vector including position, velocity and attitude errors and sends to said GPS error compensation module and said position velocity and attitude module.

24. The micro integrated GPS/IMU system, as recited in claim 12, wherein said error estimator comprises a Kalman filter which comprises:

a GPS error compensation module, gathering said GPS measurements from said GPS microprocessor, which is alternatively corrected with said differential GPS data, and said position and velocity corrections from an updating state vector module to perform GPS error compensation;

a preprocessing module, receiving said GPS satellite ephemeris from said GPS microprocessor, said corrected GPS raw data from said GPS error compensation module, and INS solutions from said position, velocity and attitude module, wherein said preprocessing module performs a calculation of said state transition matrix which is sent with said previous state vector to a state vector prediction module. Said calculated state transit matrix is also sent to a covariance propagation module. Said preprocessing module calculates said measurement matrix and said current measurement vector according to said computed measurement matrix and said measurement model, wherein said measurement matrix and said computed current measurement vector are passed to a computing measurement residue module; wherein

said state vector prediction module receives said state transition matrix and said previous state vector from said preprocessing module to perform state prediction of said current epoch, wherein said predicted current state vector is passed to said computing measurement residue module;

said computing measurement residue module receives said predicted current state vector from said state vector prediction module and said measurement matrix and said current measurement vector from said preprocessing module, wherein said computing measurement residue module calculates said measurement residues by subtracting said multiplication of said measurement matrix and said predicted current state vector from said current measurement vector, wherein said measurement residues are sent to a residue monitor module as well as said updating state vector module;

said residue monitor module performs a discrimination on said measurement residues received from said computing measurement residue module, wherein said discrimination law is whether a square of said measurement residues divided by said residual variance larger than a given threshold, wherein when said square of said measurement residues divided by said residual variance is larger than said given threshold, said current measurement leads to a divergence of said Kalman filter and then said residue monitor module selectively calculates a new covariance of said system process and rejects said current measurement, wherein when said square of said measurement residues divided by said residual variance is less than said given threshold, said current measurement is used by said Kalman filter without changing said current covariance of system process to obtain a current navigation solution, wherein said covariance of said system process is sent to said covariance propagation module;

said covariance propagation module gathers said covariance of said system process from said residue monitor module, said state transition matrix from said preprocessing module, and said previous covariance of estimated error to calculate said current covariance of said estimated error, wherein said computed current covariance of said estimated error is sent to a computing optimal gain module;

said computing optimal gain module receives said current covariance of said estimated error from said covariance computing module to compute an optimal gain which is passed to a covariance updating module as well as said updating state vector module, wherein said covariance updating module updates said covariance of said estimated error to send to said covariance propagation module;

said updating state vector module receives said optimal gain from said computing optimal gain module and said measurement residues from said computing measurement residue module, wherein said updating state vector module calculates said current estimate of state vector including position, velocity and attitude errors and sends to said GPS error compensation module and said position velocity and attitude module.

25. The micro integrated GPS/IMU system, as recited in claim 19, wherein said error estimator comprises a Kalman filter which comprises:

a GPS error compensation module, gathering said GPS measurements from said GPS microprocessor, which is alternatively corrected with said differential GPS data, and said position and velocity corrections from an updating state vector module to perform GPS error compensation;

a preprocessing module, receiving said GPS satellite ephemeris from said GPS microprocessor, said corrected GPS raw data from said GPS error compensation module, and INS solutions from said position, velocity and attitude module, wherein said preprocessing module performs a calculation of said state transition matrix which is sent with said previous state vector to a state vector prediction module. Said calculated state transit matrix is also sent to a covariance propagation module. Said preprocessing module calculates said measurement matrix and said current measurement vector according to said computed measurement matrix and said measurement model, wherein said measurement matrix and said computed current measurement vector are passed to a computing measurement residue module; wherein

said state vector prediction module receives said state transition matrix and said previous state vector from said preprocessing module to perform state prediction of said current epoch, wherein said predicted current state vector is passed to said computing measurement residue module;

said computing measurement residue module receives said predicted current state vector from said state vector prediction module and said measurement matrix and said current measurement vector from said preprocessing module, wherein said computing measurement residue module calculates said measurement residues by subtracting said multiplication of said measurement matrix and said predicted current state vector from said current measurement vector, wherein said measurement residues are sent to a residue monitor module as well as said updating state vector module;

said residue monitor module performs a discrimination on said measurement residues received from said computing measurement residue module, wherein said discrimination law is whether a square of said measurement residues divided by said residual variance larger than a given threshold, wherein when said square of said measurement residues divided by said residual variance is larger than said given threshold, said current measurement leads to a divergence of said Kalman filter and then said residue monitor module selectively calculates a new covariance of said system process and rejects said current measurement, wherein when said square of said measurement residues divided by said residual variance is less than said given threshold, said current measurement is used by said Kalman filter without changing said current covariance of system process to obtain a current navigation solution, wherein said covariance of said system process is sent to said covariance propagation module;

said covariance propagation module gathers said covariance of said system process from said residue monitor module, said state transition matrix from said preprocessing module, and said previous covariance of estimated error to calculate said current covariance of said estimated error, wherein said computed current covariance of said estimated error is sent to a computing optimal gain module;

said computing optimal gain module receives said current covariance of said estimated error from said covariance computing module to compute an optimal gain which is passed to a covariance updating module as well as said updating state vector module, wherein said covariance updating module updates said covariance of said estimated error to send to said covariance propagation module;

said updating state vector module receives said optimal gain from said computing optimal gain module and said measurement residues from said computing measurement residue module, wherein said updating state vector module calculates said current estimate of state vector including position, velocity and attitude errors and sends to said GPS error compensation module and said position velocity and attitude module.

26. The micro integrated GPS/IMU system, as recited in claim 20, wherein said error estimator comprises a Kalman filter which comprises:

a GPS error compensation module, gathering said GPS measurements from said GPS microprocessor, which is alternatively corrected with said differential GPS data, and said position and velocity corrections from an updating state vector module to perform GPS error compensation;

a preprocessing module, receiving said GPS satellite ephemeris from said GPS microprocessor, said corrected GPS raw data from said GPS error compensation module, and INS solutions from said position, velocity and attitude module, wherein said preprocessing module performs a calculation of said state transition matrix which is sent with said previous state vector to a state vector prediction module. Said calculated state transit matrix is also sent to a covariance propagation module. Said preprocessing module calculates said measurement matrix and said current measurement vector according to said computed measurement matrix and said measurement model, wherein said measurement matrix and said computed current measurement vector are passed to a computing measurement residue module; wherein

said state vector prediction module receives said state transition matrix and said previous state vector from said preprocessing module to perform state prediction of said current epoch, wherein said predicted current state vector is passed to said computing measurement residue module;

said computing measurement residue module receives said predicted current state vector from said state vector prediction module and said measurement matrix and said current measurement vector from said preprocessing module, wherein said computing measurement residue module calculates said measurement residues by subtracting said multiplication of said measurement matrix and said predicted current state vector from said current measurement vector, wherein said measurement residues are sent to a residue monitor module as well as said updating state vector module;

said residue monitor module performs a discrimination on said measurement residues received from said computing measurement residue module, wherein said discrimination law is whether a square of said measurement residues divided by said residual variance larger than a given threshold, wherein when said square of said measurement residues divided by said residual variance is larger than said given threshold, said current measurement leads to a divergence of said Kalman filter and then said residue monitor module selectively calculates a new covariance of said system process and rejects said current measurement, wherein when said square of said measurement residues divided by said residual variance is less than said given threshold, said current measurement is used by said Kalman filter without changing said current covariance of system process to obtain a current navigation solution, wherein said covariance of said system process is sent to said covariance propagation module;

said covariance propagation module gathers said covariance of said system process from said residue monitor module, said state transition matrix from said preprocessing module, and said previous covariance of estimated error to calculate said current covariance of said estimated error, wherein said computed current covariance of said estimated error is sent to a computing optimal gain module;

said computing optimal gain module receives said current covariance of said estimated error from said covariance computing module to compute an optimal gain which is passed to a covariance updating module as well as said updating state vector module, wherein said covariance updating module updates said covariance of said estimated error to send to said covariance propagation module;

said updating state vector module receives said optimal gain from said computing optimal gain module and said measurement residues from said computing measurement residue module, wherein said updating state vector module calculates said current estimate of state vector including position, velocity and attitude errors and sends to said GPS error compensation module and said position velocity and attitude module.

27. The micro integrated GPS/IMU system, as recited in claim 21, wherein said error estimator comprises a Kalman filter which comprises:

a GPS error compensation module, gathering said GPS measurements from said GPS microprocessor, which is alternatively corrected with said differential GPS data, and said position and velocity corrections from an updating state vector module to perform GPS error compensation;

a preprocessing module, receiving said GPS satellite ephemeris from said GPS microprocessor, said corrected GPS raw data from said GPS error compensation module, and INS solutions from said position, velocity and attitude module, wherein said preprocessing module performs a calculation of said state transition matrix which is sent with said previous state vector to a state vector prediction module. Said calculated state transit matrix is also sent to a covariance propagation module. Said preprocessing module calculates said measurement matrix and said current measurement vector according to said computed measurement matrix and said measurement model, wherein said measurement matrix and said computed current measurement vector are passed to a computing measurement residue module; wherein

said state vector prediction module receives said state transition matrix and said previous state vector from said preprocessing module to perform state prediction of said current epoch, wherein said predicted current state vector is passed to said computing measurement residue module;

said computing measurement residue module receives said predicted current state vector from said state vector prediction module and said measurement matrix and said current measurement vector from said preprocessing module, wherein said computing measurement residue module calculates said measurement residues by subtracting said multiplication of said measurement matrix and said predicted current state vector from said current measurement vector, wherein said measurement residues are sent to a residue monitor module as well as said updating state vector module;

said residue monitor module performs a discrimination on said measurement residues received from said computing measurement residue module, wherein said discrimination law is whether a square of said measurement residues divided by said residual variance larger than a given threshold, wherein when said square of said measurement residues divided by said residual variance is larger than said given threshold, said current measurement leads to a divergence of said Kalman filter and then said residue monitor module selectively calculates a new covariance of said system process and rejects said current measurement, wherein when said square of said measurement residues divided by said residual variance is less than said given threshold, said current measurement is used by said Kalman filter without changing said current covariance of system process to obtain a current navigation solution, wherein said covariance of said system process is sent to said covariance propagation module;

said covariance propagation module gathers said covariance of said system process from said residue monitor module, said state transition matrix from said preprocessing module, and said previous covariance of estimated error to calculate said current covariance of said estimated error, wherein said computed current covariance of said estimated error is sent to a computing optimal gain module;

said computing optimal gain module receives said current covariance of said estimated error from said covariance computing module to compute an optimal gain which is passed to a covariance updating module as well as said updating state vector module, wherein said covariance updating module updates said covariance of said estimated error to send to said covariance propagation module;

said updating state vector module receives said optimal gain from said computing optimal gain module and said measurement residues from said computing measurement residue module, wherein said updating state vector module calculates said current estimate of state vector including position, velocity and attitude errors and sends to said GPS error compensation module and said position velocity and attitude module.

28. The micro integrated GPS/IMU system, as recited in claim 10, wherein said magnetic heading computation module:

loads said calibration parameters of said Earth's magnetic field detector from flash memory to form a calibration vector;

receives said three-axis digital Earth's magnetic field signals from said Earth's magnetic field detector interface circuit of said ASIC chip, which is expressed in said body frame, to form a measurement vector;

receives said pitch and roll angle data from said attitude and heading module or said position, velocity, and attitude module to form a transformation matrix from said body frame to level frame;

compensates said measurement vector with said calibration vector;

transforms said compensated measurement vector from said body frame to said level frame to form a measurement vector, which is expressed in said level frame; and

computes magnetic heading data using said measurement vector expressed in said level frame, which is output to error estimator.

29. The micro integrated GPS/IMU system, as recited in claim 11, wherein said magnetic heading computation module:

loads said calibration parameters of said Earth's magnetic field detector from flash memory to form a calibration vector;

receives said three-axis digital Earth's magnetic field signals from said Earth's magnetic field detector interface circuit of said ASIC chip, which is expressed in said body frame, to form a measurement vector;

receives said pitch and roll angle data from said attitude and heading module or said position, velocity, and attitude module to form a transformation matrix from said body frame to level frame;

compensates said measurement vector with said calibration vector;

transforms said compensated measurement vector from said body frame to said level frame to form a measurement vector, which is expressed in said level frame; and

computes magnetic heading data using said measurement vector expressed in said level frame, which is output to error estimator.

30. The micro integrated GPS/IMU system, as recited in claim 12, wherein said magnetic heading computation module:

loads said calibration parameters of said Earth's magnetic field detector from flash memory to form a calibration vector;

receives said three-axis digital Earth's magnetic field signals from said Earth's magnetic field detector interface circuit of said ASIC chip, which is expressed in said body frame, to form a measurement vector;

receives said pitch and roll angle data from said attitude and heading module or said position, velocity, and attitude module to form a transformation matrix from said body frame to level frame;

compensates said measurement vector with said calibration vector;

transforms said compensated measurement vector from said body frame to said level frame to form a measurement vector, which is expressed in said level frame; and

computes magnetic heading data using said measurement vector expressed in said level frame, which is output to error estimator.

31. The micro integrated GPS/IMU system, as recited in claim 25, wherein said magnetic heading computation module:

loads said calibration parameters of said Earth's magnetic field detector from flash memory to form a calibration vector;

receives said three-axis digital Earth's magnetic field signals from said Earth's magnetic field detector interface circuit of said ASIC chip, which is expressed in said body frame, to form a measurement vector;

receives said pitch and roll angle data from said attitude and heading module or said position, velocity, and attitude module to form a transformation matrix from said body frame to level frame;

compensates said measurement vector with said calibration vector;

transforms said compensated measurement vector from said body frame to said level frame to form a measurement vector, which is expressed in said level frame; and

computes magnetic heading data using said measurement vector expressed in said level frame, which is output to error estimator.

32. The micro integrated GPS/IMU system, as recited in claim 26, wherein said magnetic heading computation module:

loads said calibration parameters of said Earth's magnetic field detector from flash memory to form a calibration vector;

receives said three-axis digital Earth's magnetic field signals from said Earth's magnetic field detector interface circuit of said ASIC chip, which is expressed in said body frame, to form a measurement vector;

receives said pitch and roll angle data from said attitude and heading module or said position, velocity, and attitude module to form a transformation matrix from said body frame to level frame;

compensates said measurement vector with said calibration vector;

transforms said compensated measurement vector from said body frame to said level frame to form a measurement vector, which is expressed in said level frame; and

computes magnetic heading data using said measurement vector expressed in said level frame, which is output to error estimator.

33. The micro integrated GPS/IMU system, as recited in claim 27, wherein said magnetic heading computation module:

loads said calibration parameters of said Earth's magnetic field detector from flash memory to form a calibration vector;

receives said three-axis digital Earth's magnetic field signals from said Earth's magnetic field detector interface circuit of said ASIC chip, which is expressed in said body frame, to form a measurement vector;

receives said pitch and roll angle data from said attitude and heading module or said position, velocity, and attitude module to form a transformation matrix from said body frame to level frame;

compensates said measurement vector with said calibration vector;

transforms said compensated measurement vector from said body frame to said level frame to form a measurement vector, which is expressed in said level frame; and

computes magnetic heading data using said measurement vector expressed in said level frame, which is output to error estimator.

34. The micro integrated GPS/IMU system, as recited in claim 1, 2, **3**, **4**, **10**, **13**, **16**, **19**, **22**, **25**, **28**, or **31**, further comprising a thermal controlling means for maintaining a predetermined operating temperature of said angular rate producer, said acceleration producer and said angular increment and velocity increment producer.

35. The micro integrated GPS/IMU system, as recited in claim 34, wherein said thermal controlling means comprises a thermal sensing producer device, a heater device and a thermal processor, wherein said thermal sensing producer device, which produces temperature signals, is processed in parallel with said angular rate producer and said acceleration producer for maintaining said predetermined operating temperature of said angular rate producer, said acceleration producer and said angular increment and velocity increment producer, wherein said predetermined operating temperature is a constant designated temperature selected between 150° F. and 185° F., wherein said temperature signals produced from said thermal sensing producer device are input to said thermal processor for computing temperature control commands using said temperature signals, a temperature scale factor, and said predetermined operating temperature of said angular rate producer and said acceleration producer, and producing driving signals to said heater device using said temperature control commands for controlling said heater device to provide adequate heat for maintaining said predetermined operating temperature in said micro inertial measurement unit.

36. The micro integrated GPS/IMU system, as recited in claim 1, 2, **3**, **4**, **10**, **13**, **16**, **19**, **22**, **25**, **28**, or **31**, wherein said X axis, Y axis and Z axis electrical angular rate signals produced from said angular producer are analog angular rate voltage signals directly proportional to angular rates of said carrier carrying said micro inertial measurement unit, wherein said X axis, Y axis and Z axis electrical acceleration signals produced from said acceleration producer are analog acceleration voltage signals directly proportional to accelerations of said vehicle, wherein said X, Y, Z axes electrical signals of Earth's magnetic field vector measurement in a body frame of said carrier are analog voltage signals.

37. The micro integrated GPS/IMU system, as recited in claim 34, wherein said X axis, Y axis and Z axis electrical angular rate signals produced from said angular producer are analog angular rate voltage signals directly proportional to angular rates of said carrier carrying said micro inertial measurement unit, wherein said X axis, Y axis and Z axis electrical acceleration signals produced from said acceleration producer are analog acceleration voltage signals directly proportional to accelerations of said vehicle, wherein said X, Y, Z axes electrical signals of Earth's magnetic field vector measurement in a body frame of said carrier are analog voltage signals.

38. The micro integrated GPS/IMU system, as recited in claim 36, wherein said angular increment and velocity increment producer comprises:

an angular integrating means and an acceleration integrating means, which are adapted for respectively integrating said X axis, Y axis and Z axis analog angular rate voltage signals and said X axis, Y axis and Z axis analog acceleration voltage signals for a predetermined time interval to accumulate said X axis, Y axis and Z axis analog angular rate voltage signals and said X axis, Y axis and Z axis analog acceleration voltage signals as a raw X axis, Y axis and Z axis angular increment and a raw X axis, Y axis and Z axis velocity increment for a predetermined time interval to achieve accumulated angular increments and accumulated velocity increments, wherein said integration is performed to remove noise signals that are non-directly proportional to said carrier angular rate and acceleration within said X axis, Y axis and Z axis analog angular rate voltage signals and said X axis, Y axis and Z axis analog acceleration voltage signals, to improve signal-to-noise ratio, and to remove said high frequency signals in said X axis, Y axis and Z axis analog angular rate voltage signals and said X axis, Y axis and Z axis analog acceleration voltage signals;

a resetting means which forms an angular reset voltage pulse and a velocity reset voltage pulse as an angular scale and a velocity scale which are input into said angular integrating means and said acceleration integrating means respectively; and

an angular increment and velocity increment measurement means which is adapted for measuring said voltage values of said X axis, Y axis and Z axis accumulated angular increments and said X axis, Y axis and Z axis accumulated velocity increments with said angular reset voltage pulse and said velocity reset voltage pulse respectively to acquire angular increment counts and velocity increment counts as a digital form of angular increment and velocity increment measurements respectively.

39. The micro integrated GPS/IMU system, as recited in claim 1, 2 or **3**, wherein said micro integrated GPS/IMU system comprises a first circuit board, a second circuit board, a third circuit board, a GPS chipset board, and a control circuit board arranged inside a case, said first circuit board being connected with said third circuit board for producing X axis angular sensing signal and Y axis acceleration sensing signal to said control circuit board, said second circuit board being connected with said third circuit board for producing Y axis angular sensing signal and X axis acceleration sensing signal to said control circuit board, said third circuit board being connected with said control circuit board for producing Z axis angular sensing signal and Z axis acceleration sensing signals to said control circuit board, said GPS chipset board being connected with said control circuit board for providing said GPS measurements to said control circuit board, wherein said control circuit board is connected with said first circuit board, said second circuit board, and said GPS chipset board through said third circuit board for processing said X axis, Y axis and Z axis angular sensing signals and said X axis, Y axis and Z axis acceleration sensing signals from said first, second and third board respectively.

40. The micro integrated GPS/IMU system, as recited in claim 4, 10, **13**, **16**, **19**, **22**, **25**, **28**, or **31**, wherein said micro integrated GPS/IMU system comprises a first circuit board, a second circuit board, a third circuit board, a GPS chipset board, and a control circuit board arranged inside a case, said first circuit board being connected with said third circuit board for producing X axis angular sensing signal and Y axis acceleration sensing signal to said control circuit board, said second circuit board being connected with said third circuit board for producing Y axis angular sensing signal and X axis acceleration sensing signal to said control circuit board, said third circuit board being connected with said control circuit board for producing Z axis angular sensing signal and Z axis acceleration sensing signals to said control circuit board, said GPS chipset board being connected with said control circuit board for providing said GPS measurements to said control circuit board, wherein said control circuit board is connected with said first circuit board, said second circuit board, and said GPS chipset board through said third circuit board for processing said X axis, Y axis and Z axis angular sensing signals and said X axis, Y axis and Z axis acceleration sensing signals from said first, second and third board respectively.

41. The micro integrated GPS/IMU system, as recited in claim 40, wherein said DSP chip, said Earth's magnetic field detector, said ASIC chip, said power supply module are provided on said control circuit board, and said GPS chipset is provided on said GPS chipset board.

42. The micro integrated GPS/IMU system, as recited in claim 41, wherein said angular producer comprises:

a X axis vibrating type angular rate detecting unit and a first front-end circuit connected on said first circuit board;

a Y axis vibrating type angular rate detecting unit and a second front-end circuit connected on said second circuit board;

a Z axis vibrating type angular rate detecting unit and a third front-end circuit connected on said third circuit board;

three angular signal loop circuitries which are provided on said control circuit board for said first, second and third circuit boards respectively;

three dither motion control circuitries which are provided on in said control circuit board for said first, second and third circuit boards respectively;

an oscillator adapted for providing reference pickoff signals for said X axis vibrating type angular rate detecting unit, said Y axis vibrating type angular rate detecting unit, said Z axis vibrating type angular rate detecting unit, said angle signal loop circuitry, and said dither motion control circuitry; and

three dither motion processing modules provided on said control circuit board, for said first, second and third circuit boards respectively.

43. The micro integrated GPS/IMU system, as recited in claim 42, wherein said acceleration producer comprises:

a X axis accelerometer, which is provided on said second circuit board and connected with said angular increment and velocity increment producer provided on said control circuit board;

a Y axis accelerometer, which is provided on said first circuit board and connected with angular increment and velocity increment producer provided on said control circuit board; and

a Z axis accelerometer, which is provided on said third circuit board and connected with angular increment and velocity increment producer provided on said control circuit board.

44. The micro integrated GPS/IMU system, as recited in claim 43, wherein said first, second and third front-end circuits are used to condition said output signal of said X axis, Y axis and Z axis vibrating type angular rate detecting units respectively and each further comprises:

a trans impedance amplifier circuit, which is connected to said respective X axis, Y axis or Z axis vibrating type angular rate detecting unit for changing said output impedance of said dither motion signals from a very high level, greater than 100 million ohms, to a low level, less than 100 ohms to achieve two dither displacement signals, which are A/C voltage signals representing said displacement between said inertial elements and said anchor combs, wherein said two dither displacement signals are output to said dither motion control circuitry; and

a high-pass filter circuit, which is connected with said respective X axis, Y axis or Z axis vibrating type angular rate detecting units for receiving said angular motion-induced signals and removing low frequency noise of the angular motion-induced signals, which are AC voltage signals output from said vibrating type angular rate detecting unit to form filtered angular motion-induced signals to said angular signal loop circuitry.

45. The micro integrated GPS/IMU system, as recited in claim 43, wherein each of said X axis, Y axis and Z axis angular rate detecting units is a vibratory device, which comprises at least one set of vibrating inertial elements, including tuning forks, and associated supporting structures and means, including capacitive readout means, and uses Coriolis effects to detect angular rates of said carrier, wherein each of said X axis, Y axis and Z axis vibrating type angular rate detecting units receives dither drive signals from said respective dither motion control circuitry, keeping said inertial elements oscillating; and carrier reference oscillation signals from said oscillator, including capacitive pickoff excitation signals, wherein each of said X axis, Y axis and Z axis vibrating type angular rate detecting units detects said angular motion in X axis, Y axis and Z axis respectively of said carrier in accordance with said dynamic theory, wherein each of said X axis, Y axis and Z axis vibrating type angular rate detecting units outputs angular motion-induced signals, including rate displacement signals which may be modulated carrier reference oscillation signals to said trans Impedance amplifier circuit of said respective first, second or third front-end circuits; and inertial element dither motion signals thereof, including dither displacement signals, to said high-pass filter of said respective first, second or third front-end circuit.

46. The micro integrated GPS/IMU system, as recited in claim 43, wherein said three dither motion control circuitries receive said inertial element dither motion signals from said X axis, Y axis and Z axis vibrating type angular rate detecting units respectively, reference pickoff signals from said oscillator, and produce digital inertial element displacement signals with known phase, wherein each said dither motion control circuitries comprises:

an amplifier and summer circuit connected to said trans impedance amplifier circuit of said respective first, second or third front-end circuit for amplifying said two dither displacement signals for more than ten times and enhancing said sensitivity for combining said two dither displacement signals to achieve a dither displacement differential signal by subtracting a center anchor comb signal with a side anchor comb signal;

a high-pass filter circuit connected to said amplifier and summer circuit for removing residual dither drive signals and noise from said dither displacement differential signal to form a filtered dither displacement differential signal;

a demodulator circuit connected to said high-pass filter circuit for receiving said capacitive pickoff excitation signals as phase reference signals from said oscillator and said filtered dither displacement differential signal from said high-pass filter and extracting said in-phase portion of said filtered dither displacement differential signal to produce an inertial element displacement signal with known phase;

a low-pass filter connected to said demodulator circuit for removing high frequency noise from said inertial element displacement signal input thereto to form a low frequency inertial element displacement signal;

an analog/digital converter connected to said low-pass filter for converting said low frequency inertial element displacement signal that is an analog signal to produce a digitized low frequency inertial element displacement signal to said respective dither motion processing module;

a digital/analog converter processing said selected amplitude from said respective dither motion processing module to form a dither drive signal with correct amplitude; and

an amplifier which generates and amplifies said dither drive signal to said respective X axis, Y axis or Z axis vibrating type angular rate detecting unit based on said dither drive signal with said selected frequency and correct amplitude.

47. The micro integrated GPS/IMU system, as recited in claim 43, wherein said dither motion processing module further includes a discrete Fast Fourier Transform (FFT) module, a memory array of frequency and amplitude data module, a maxima detection logic module, and a Q analysis and selection logic module to find said frequencies which have highest Quality Factor (Q) Values;

wherein said discrete Fast Fourier Transform (FFT) module is arranged for transforming said digitized low frequency inertial element displacement signal from said analog/digital converter of said dither motion control circuitry to form amplitude data with said frequency spectrum of said input inertial element displacement signal;

wherein said memory array of frequency and amplitude data module receives said amplitude data with frequency spectrum to form an array of amplitude data with frequency spectrum;

wherein said maxima detection logic module is adapted for partitioning said frequency spectrum from said array of said amplitude data with frequency into plural spectrum segments, and choosing said frequencies with said largest amplitudes in said local segments of said frequency spectrum; and

wherein said Q analysis and selection logic module is adapted for performing Q analysis on said chosen frequencies to select frequency and amplitude by computing said ratio of amplitude/bandwidth, wherein a range for computing bandwidth is between +−½ of said peek for each maximum frequency point.

48. The micro integrated GPS/IMU system, as recited in claim 43, wherein said dither motion processing module further includes a phase-lock loop to reject noise of said selected frequency to form a dither drive signal with said selected frequency by, which serves as a very narrow bandpass filter, locking said frequency;

wherein said angle signal loop circuitries receive said angular motion-induced signals from said X axis, Y axis and Z axis vibrating type angular rate detecting units respectively, reference pickoff signals from said oscillator, and transform said angular motion-induced signals into angular rate signals, wherein each of said angle signal loop circuitries for said respective first, second or third circuit board comprises:

a voltage amplifier circuit, which amplifies said filtered angular motion-induced signals from said high-pass filter circuit of said respective first, second or third front-end circuit to an extent of at least 100 milivolts to form amplified angular motion-induced signals;

an amplifier and summer circuit, which subtracts said difference between said angle rates of said amplified angular motion-induced signals to produce a differential angle rate signal;

a demodulator, which is connected to said amplifier and summer circuit, extracting said amplitude of said in-phase differential angle rate signal from said differential angle rate signal and said capacitive pickoff excitation signals from said oscillator;

a low-pass filter, which is connected to said demodulator, removing said high frequency noise of said amplitude signal of said in-phase differential angle rate signal to form said angular rate signal output to said angular increment and velocity increment producer.

49. The micro integrated GPS/IMU system, as recited in claim 43, further comprising a thermal controlling means for maintaining a predetermined operating temperature of said angular rate producer, said acceleration producer and said angular increment and velocity increment producer, wherein said thermal controlling means comprises:

a thermal sensing producer device, comprising:

a first thermal sensing producing unit for sensing said temperature of said X axis angular rate detecting unit and said Y axis accelerometer,

a second thermal sensing producer for sensing said temperature of said Y axis angular rate detecting unit and said X axis accelerometer, and

a third thermal sensing producer for sensing said temperature of said Z axis angular rate detecting unit and said Z axis accelerometer;

a heater device, comprising:

a first heater, which is connected with said X axis angular rate detecting unit, said Y axis accelerometer, and said first front-end circuit, for maintaining said predetermined operational temperature of said X axis angular rate detecting unit, said Y axis accelerometer, and said first front-end circuit,

a second heater, which is connected with said Y axis angular rate detecting unit, said X axis accelerometer, and said second front-end circuit, for maintaining said predetermined operational temperature of said X axis angular rate detecting unit, said X axis accelerometer, and said second front-end circuit, and

a third heater, which is connected with said Z axis angular rate detecting unit, said Z axis accelerometer, and said third front-end circuit, for maintaining said predetermined operational temperature of said Z axis angular rate detecting unit, said Z axis accelerometer, and said third front-end circuit; and

a thermal processor which comprises three identical thermal control circuitries and said thermal control computation module provided on said control circuit board, wherein

each of said thermal control circuitries further comprises:

a first amplifier circuit, which is connected with said respective X axis, Y axis or Z axis thermal sensing producer, for amplifying said signals and suppressing said noise residing in said temperature voltage signals from said respective X axis, Y axis or Z axis thermal sensing producer and improving said signal-to-noise ratio, an analog/digital converter, which is connected with said amplifier circuit, for sampling said temperature voltage signals and digitizing said sampled temperature voltage signals to digital signals, which are output to said thermal control computation module,

a digital/analog converter which converts said digital temperature commands input from said thermal control computation module into analog signals, and

a second amplifier circuit, which receives said analog signals from said digital/analog converter, amplifying said input analog signals from said digital/analog converter for driving said respective first, second or third heater; and closing said temperature controlling loop,

wherein said thermal control computation module computes digital temperature commands using said digital temperature voltage signals from said analog/digital converter, said temperature sensor scale factor, and said pre-determined operating temperature of said angular rate producer and acceleration producer, wherein said digital temperature commands are fed back to said digital/analog converter.

50. The micro integrated GPS/IMU system, as recited in claim 43, wherein said third circuit board is bonded to a supporting structure by means of a conductive epoxy, and said first circuit board, said second circuit board, GPS chipset board, and said control circuit board are arranged parallelly to bond to said third circuit board perpendicularly by a non conductive epoxy, wherein said first circuit board, said second circuit board, and said control circuit board are soldered to said third circuit board in such a manner as to use said third circuit board as an interconnect board.

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