US005923286A

United States Patent [19]

Divakaruni

[11] **Patent Number: 5,923,286**

[45] **Date of Patent: Jul. 13, 1999**

[54] **GPS/IRS GLOBAL POSITION DETERMINATION METHOD AND APPARATUS WITH INTEGRITY LOSS PROVISIONS**

[75] Inventor: **Sudhakar P. Divakaruni**, Scottsdale, Ariz.

[73] Assignee: **Honeywell Inc.**, Minneapolis, Minn.

[21] Appl. No.: **08/735,764**

[22] Filed: **Oct. 23, 1996**

[51] **Int. Cl.**[6] **G01S 5/02**; H04B 7/185

[52] **U.S. Cl.** **342/357**; 701/213

[58] **Field of Search** 342/357, 450, 342/457; 701/213, 214

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,806,940	2/1989	Harral et al.	342/451
5,394,333	2/1995	Kao	364/450
5,461,388	10/1995	Applegate et al.	342/357
5,504,482	4/1996	Schreder	340/995
5,504,492	4/1996	Class et al.	342/357
5,512,903	4/1996	Schmidke	312/357
5,543,804	8/1996	Buchler et al.	342/357
5,583,774	12/1996	Diesel	364/443
5,606,506	2/1997	Kyrtsos	364/449.1
5,657,025	8/1997	Ebner et al.	342/357

FOREIGN PATENT DOCUMENTS

0 629 877	12/1994	European Pat. Off. .
95 34850	12/1995	WIPO .

OTHER PUBLICATIONS

Article entitled Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS), document No. RTCA/DO–208, Jul. 1991, prepared by: SC–159, pp. 19–22.

Appendix F entitled "Least–Squares Residuals RAIM Method" from document No. RTCA/DO–208, Jul. 1991, prepared by SC–159, pp. 1–4.

Article entitled "Implementation of a RAIM Monitor and a GPS Receiver and an Integrated GPS/IRS" by Mats Brenner, in the proceedings of ION GPS–90, Third International Technical Meeting of the Satellite Division of the Institute of Navigation, Sep. 19–21, 1990, located at p. 397.

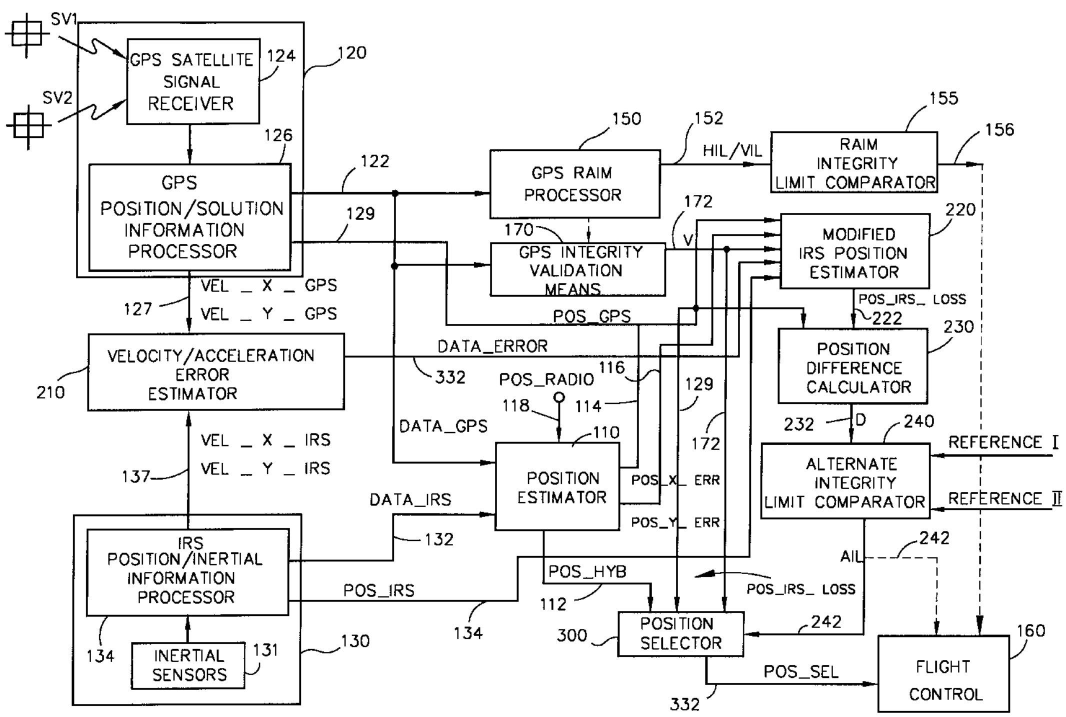
Patent Abstracts of Japan, vol. 013, No. 135 (p–851), Apr. 5, 1989.

Primary Examiner—Thomas Tarcza
Assistant Examiner—Dao L. Pham
Attorney, Agent, or Firm—Charles J. Ungemach; Ronald E. Champion

[57] **ABSTRACT**

A system for use with an inertial reference system and a global position receiver for calculating a position error after a loss of integrity by utilizing the global position system values for position and velocity at a time just before the loss of integrity and by utilizing the inertial reference system position modified by the known error in inertial reference system position as it varies with time and the position error as calculated by the global position system velocity extrapolated over the time since integrity loss.

19 Claims, 3 Drawing Sheets



DOCKET ALARM
Find authenticated court documents without watermarks at docketalarm.com.

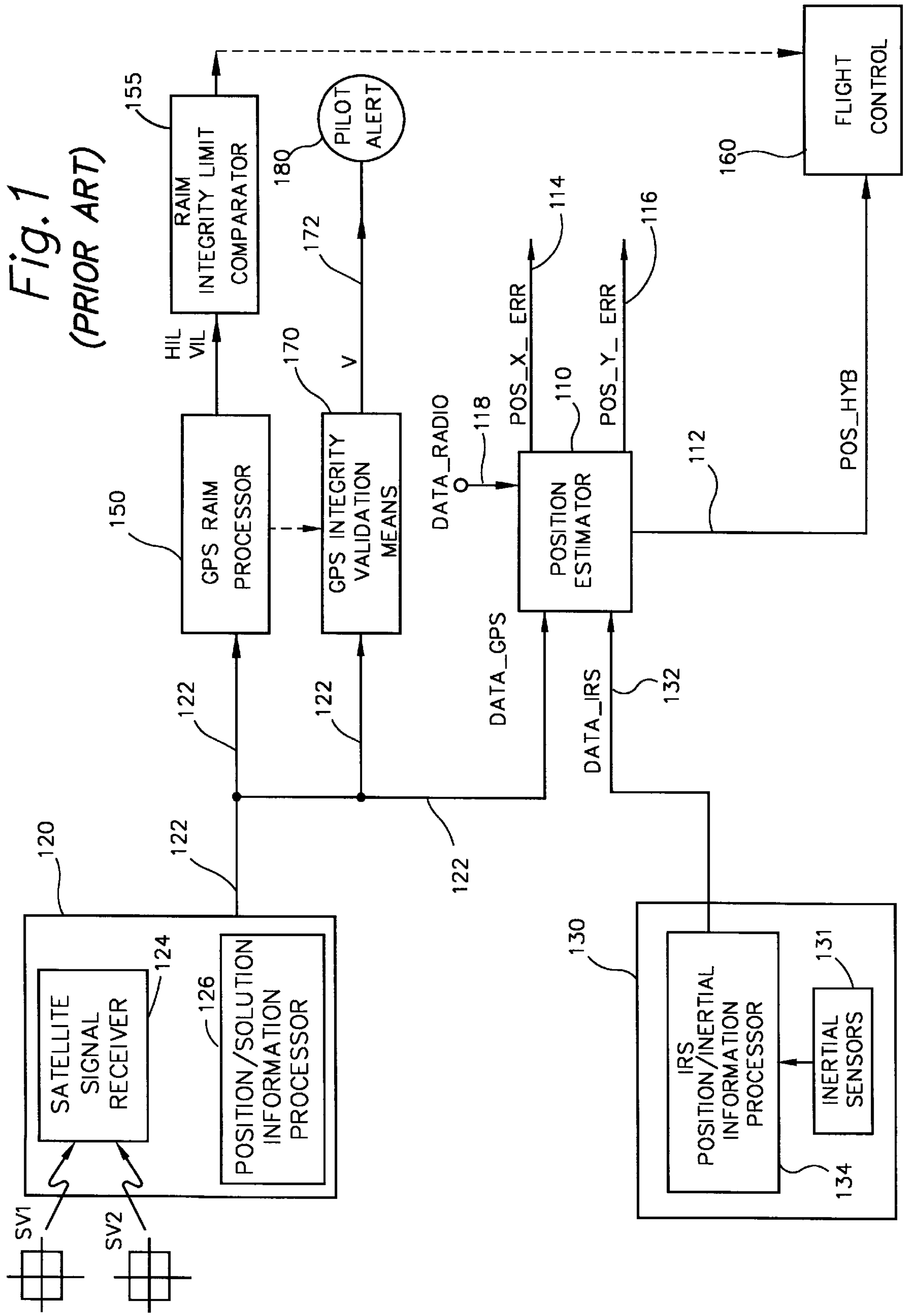


Fig. 1 (PRIOR ART)

DOCKET ALARM Find authenticated court documents without watermarks at docketalarm.com.

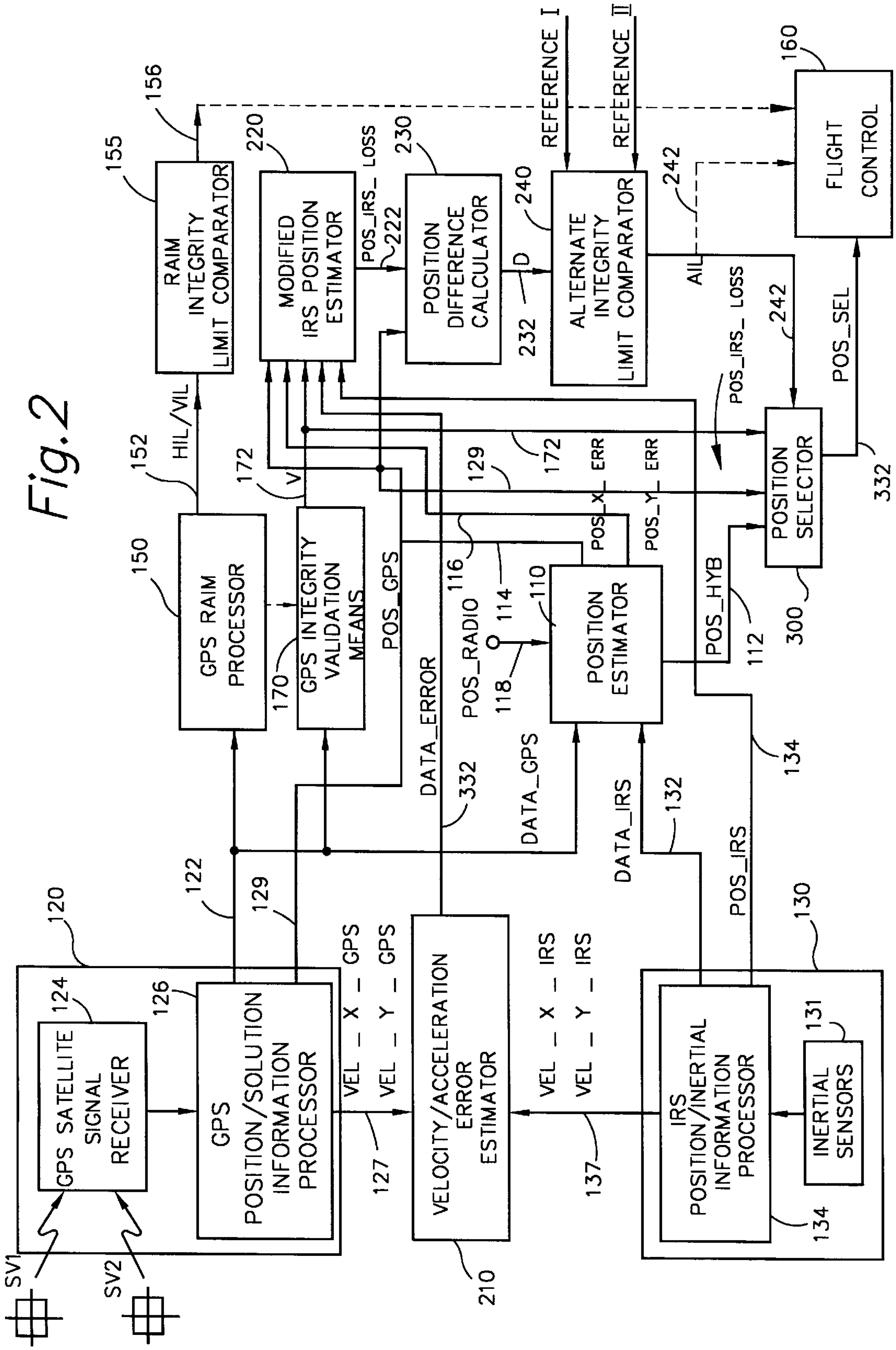


Fig. 2

DOCKET ALARM
Find authenticated court documents without watermarks at docketalarm.com.

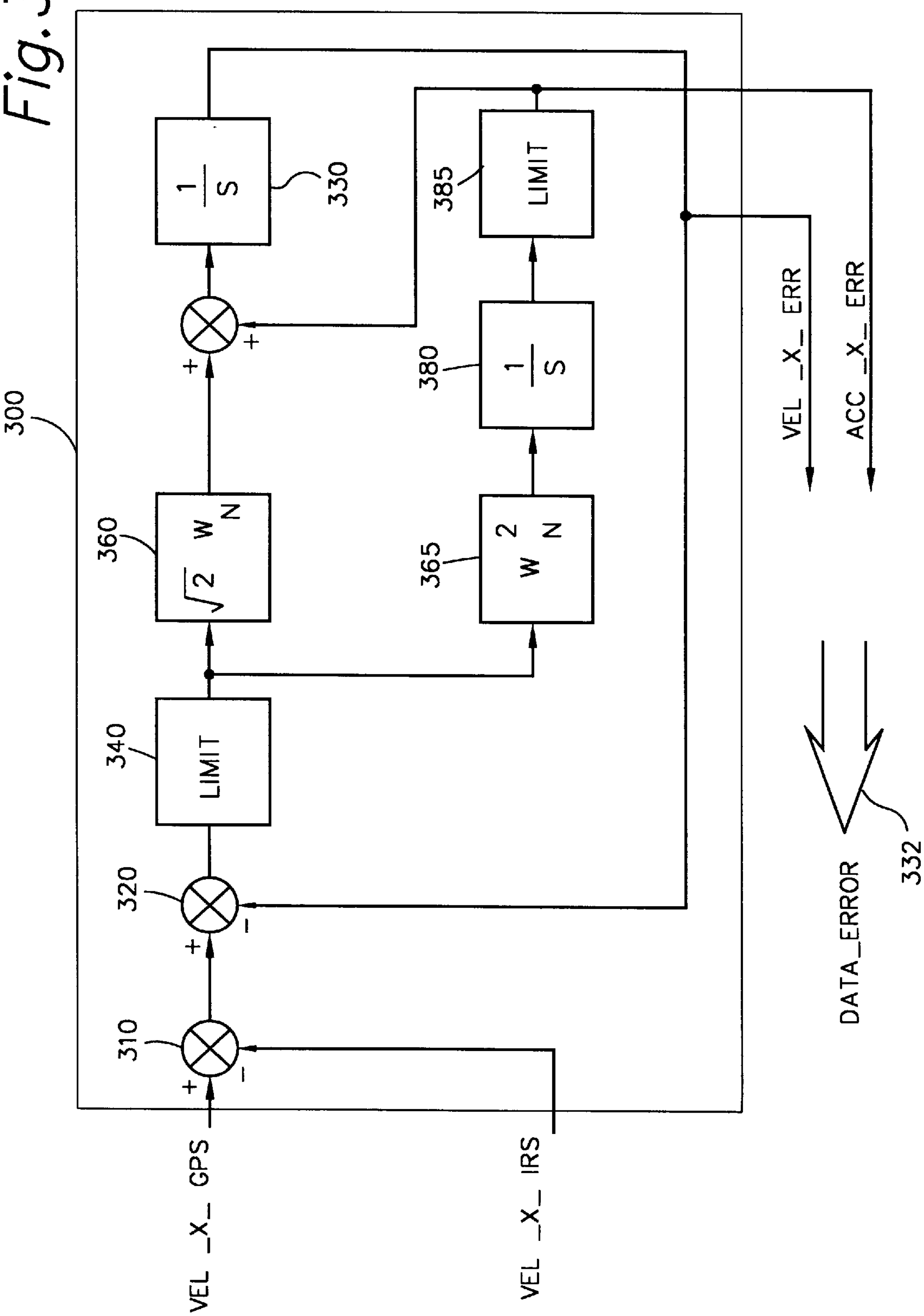

300
310
320
330
340
360
365
380
385
332
LIMIT
LIMIT
1/S
1/S
$\sqrt{2}$ WN
W_N^2
VEL_X_GPS
VEL_X_IRS
VEL_X_ERR
ACC_X_ERR
DATA_ERROR

Fig. 3

GPS/IRS GLOBAL POSITION DETERMINATION METHOD AND APPARATUS WITH INTEGRITY LOSS PROVISIONS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention pertains to a system employed for determining the global position of a mobile unit by employment of both an inertial reference system (IRS) and a satellite positioning system (GPS), and more specifically, a system which employs a provision for determining the mobile unit's global position and corresponding integrity during those periods of time in which the GPS satellite constellation is insufficient for establishing GPS integrity limit values by employment of RAIM.

2. Description of the Related Art

Satellite positioning systems are now well-known in the art. Such systems, for example, NAVSTAR-GPS, are rapidly being employed for a determination of the geocentric position of mobile units, such as water and land vehicles, space and aircraft, and survey equipment, to name a few.

In aircraft, GPS systems are being utilized for navigation, flight control, and airspace control. These GPS systems may operate independently or in combination with inertial reference systems or attitude heading reference systems in order to provide information particularly during a flight mission.

Global positioning systems, hereinafter referred to as "GPS", similar to NAVSTAR, commonly use a GPS receiver, located on a mobile unit, for receiving satellite information signals transmitted from a plurality of satellites. Each GPS satellite transmits a satellite information signal containing data that allows a user to determine the range or distance between selected GPS satellites and the antenna associated with the mobile unit's GPS receiver. These distances are then used to compute the geocentric position coordinates of the receiver unit using known triangulation techniques. The computed geocentric position coordinates may, in turn, be translated to earth latitude and longitude coordinates.

In order to determine the position of the GPS receiver, a minimum of four unique satellite information signals are required, rather than the expected three (three position, unknown coordinates). This is so, since the GPS receiver generally includes a receiver clock which is not as accurate as the atomic clock normally associated with each of the satellites. Therefore, receiving satellite information signals from four different satellites provides a complete solution which permits the correction of any receiver clock error as is well-understood in the art. Herein, the GPS receiver position derived by the triangulation technique using data from multiple satellites is referred to as the "GPS estimated position", identified as POS_GPS. The accuracy of this estimated GPS position is dependent upon many factors, including, among others, atmospheric conditions, selective satellite availability, and the relevant position of the satellites with respect to the line of sight view of the satellites.

Associated with a GPS estimated position is a "position error bound" as particularly defined by accepted GPS systems standards which have been developed by the Radio Technical Commission for Aeronautics (RTCA), in association with aeronautical organizations of the United States from both government and industry. The RTCA has defined the phrase "GPS system integrity" as the ability of a GPS system to provide timely warnings to users when the GPS system should not be used for navigation. "System integrity" is particularly identified in a document entitled "Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)", document number RTCA/DO-208, July 1991, prepared by: SC-159, beginning at section 1.5. As described therein, GPS is complicated in that it is a four-dimensional system involving three components of position and one time component. As also described in the aforesaid RTCA publication, the signal-in-space error transforms into a horizontal position error via a relatively complex function of a satellite constellation geometry at any given moment. The GPS integrity system must interpret the information it has about the received GPS signals and error terms in terms of the induced horizontal position error, commonly referred to as the "position error bound", and then make a decision as to whether the position error bound is outside the allowable radial error, specified for a particular phase of the flight mission in progress. The allowable error is referred to as the "alarm limit", herein referred to as the "integrity alarm limit". If the horizontal position error bound is found to exceed the integrity alarm limit, a timely warning must be issued by the GPS receiver or subsystem to notify the pilot that the GPS estimated position should not be relied upon.

Two rather distinct methods of assuring GPS integrity have evolved as civilian use of GPS has progressed. One is the Receiver Autonomous Integrity Monitoring (RAIM) concept, and the other is the ground monitoring approach that goes under the "GPS Integrity Channel" (GIC). The intent of both of these methods is the calculation of the position error bound with regard to the current GPS estimated position so that it may be compared with the alarm limit associated with a particular phase of a flight mission.

The receiver autonomous integrity monitoring system (RAIM) employs a self-consistency check among the measurements, more specifically, GPS pseudo range measurements. Satellite redundancy is required to perform a self-consistency check on an instantaneous basis. Thus, five satellites must be in view, i.e., five satellite information signals received and pseudo range measurements calculated by a GPS receiver. If fewer than five satellites are in view, the value of the predicted position error bound will be infinite. Also, constraints are placed on the satellite constellation geometry that must be met if the self-consistency check is to be effective in the presence of noise, e.g., azimuth angle of the satellite relative to user position. Generally, a satellite constellation with many satellites in view permits a robust integrity monitoring system. Conversely, a satellite constellation having only a few satellites in view, may limit the availability of an integrity monitoring system. Thus, there may be short periods when a good consistency check is not possible (less than five satellites in view). The main feature of RAIM is that it is completely self-contained and relatively easy to implement in software.

Examples of RAIM may be found in the aforementioned RTCA publication, Appendix F, and also in an article entitled "Implementation of a RAIM Monitor and a GPS Receiver and an Integrated GPS/IRS" by Mats Brenner, located at page 397, in the proceedings of ION GPS-90, Third International Technical Meeting of the Satellite Division of the Institute of Navigation, Sep. 19–21, 1990.

GPS systems which incorporate RAIM output a position error bound value which represents the probabilistic radial errors of the navigation solution, namely, the GPS estimated position of the receiver unit. Currently, RAIM may generate several numbers, including, a horizontal position error bound value (sometimes referred to as HIL—Horizontal

DOCKET ALARM
Find authenticated court documents without watermarks at docketalarm.com.

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming inter-face) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | **sales@docketalarm.com** | **1-866-77-FASTCASE**

fastcase®
Smarter legal research.