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Canadian Intellectual Property Office

CA 2978844 A1 2018/05/01

(21) **2 978 844**

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) **A1**

(22) **Date de dépôt/Filing Date**: 2017/09/08

(41) **Mise à la disp. pub./Open to Public Insp.**: 2018/05/01

(30) **Priorité/Priority**: 2016/11/01 (US15/340,318)

(51) **Cl.Int./Int.Cl.** *G08G 5/02* (2006.01),
B64C 13/20 (2006.01), *B64D 43/00* (2006.01),
B64D 45/04 (2006.01), *G01C 23/00* (2006.01),
G01S 13/91 (2006.01)

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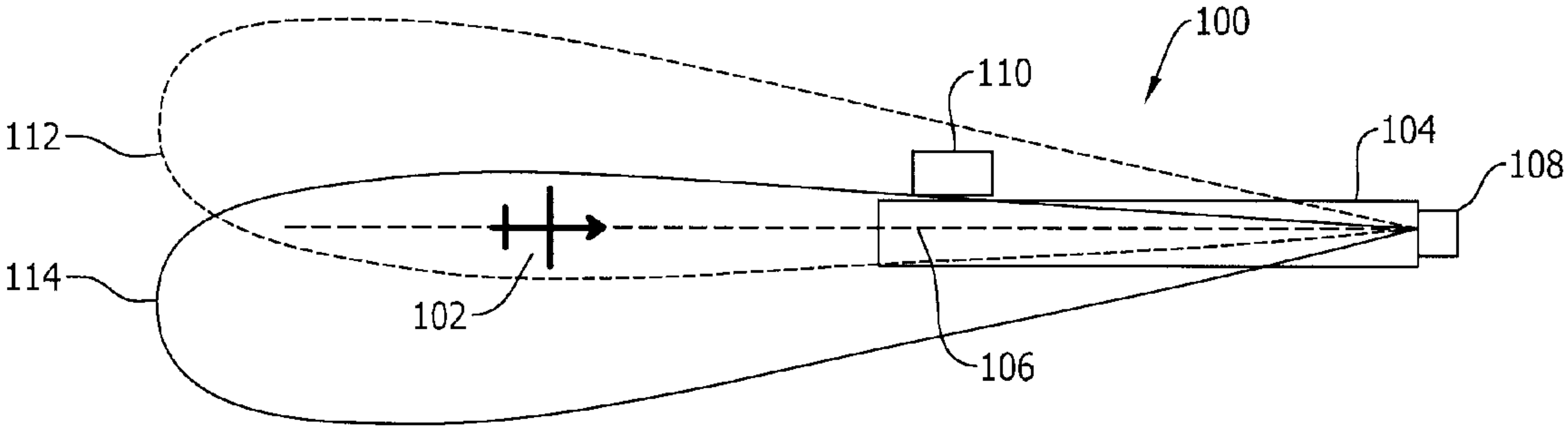
(54) Titre : SYSTEME DE COMMANDE DE VOL A DEVIATION DE LOCALISATEUR INTERCONNECTE SYNTHETIQUE ET METHODE D'UTILISATION

(54) Title: FLIGHT CONTROL SYSTEM WITH SYNTHETIC INTERTIAL LOCALIZER DEVIATION AND METHOD OF USE



(57) **Abrégé/Abstract:**

A flight control module for computing localizer deviation during landing of an aircraft is provided. The flight control module includes a communication interface and a processor. The communication interface is configured to receive inertial data for the aircraft. The processor is coupled to the communication interface and is configured to compute an inertial localizer deviation based on the inertial data.

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ABSTRACT

A flight control module for computing localizer deviation during landing of an aircraft is provided. The flight control module includes a communication interface and a processor. The communication interface is configured to receive inertial data for the aircraft. The processor is coupled to the communication interface and is configured to compute an inertial localizer deviation based on the inertial data.

FLIGHT CONTROL SYSTEM WITH SYNTHETIC INTERTIAL LOCALIZER DEVIATION AND METHOD OF USE

BACKGROUND

The field of the disclosure relates generally to flight control systems and, more specifically, to a flight control module utilizing a synthetic inertial localizer deviation.

Many known aircraft feature an automated landing system that controls the aircraft during landing. Automated landing systems have become increasingly more common and are frequently relied on for both instrument landings under instrument flight rules (IFR) and landings performed under visual flight rules (VFR). Known automated landing systems utilize various receivers, such as multi-mode receivers (MMRs), for example, to receive guidance signals transmitted from the ground. Such guidance signals may include, for example, instrument landing system (ILS) signals, global positioning service (GPS) landing system (GLS) signals, and/or microwave landing system (MLS) signals. The guidance signals inform the aircraft of its position relative to a desired vertical and lateral path to the runway and through roll-out after touchdown. The desired vertical path is referred to as the glideslope and the lateral path is referred to as the localizer. The glideslope is typically defined as a **3**° descent with a desired intercept with the ground at **1000** feet beyond the runway threshold. The localizer guides the aircraft to the runway centerline.

The guidance signals transmitted from the ground are received by an on-board antenna and routed to redundant MMRs. Each MMR computes a localizer deviation and a glideslope deviation that are routed to a flight control module that includes the automated landing system. The localizer deviation is an indication of the aircraft's position relative to the desired path to the runway centerline. For example, the localizer deviation may indicate the aircraft is approximately **2**° left of the runway centerline. The glideslope deviation is an indication of the aircraft's position relative to the desired glideslope to the runway. For example, the glideslope deviation may indicate the aircraft is **1**° below the desired glideslope. The flight control module uses the localizer deviation and the glideslope deviation to adjust the automated landing system and to command control surfaces of the aircraft.

Many known automated landing systems require three independently computed localizer and glideslope deviations. Such redundancy ensures that if one localizer deviation or one glideslope deviation fails, the automated landing system still has two good signals to control the aircraft. The redundant equipment necessary for independently computing three localizer and glideslope deviations adds cost and weight to the aircraft. If the available localizer deviation and glideslope deviations disagree beyond a predetermined threshold, the automated landing system forfeits control of the aircraft to the pilot. The availability of reliable, i.e., "good," localizer deviation and glideslope deviation signals is particularly important when the aircraft descends below **200** feet, because the margins for error are tighter and errant control by the automated landing system may result in the aircraft missing the runway. Accordingly, when failures or erroneous localizer or glideslope signals are detected, the flight control system relies on the good localizer and glideslope signals or forfeits control to the pilot.

BRIEF DESCRIPTION

According to one aspect of the present disclosure, a flight control module for computing localizer deviation during landing of an aircraft is provided. The flight control module includes a communication interface and a processor. The communication interface is configured to receive inertial data for the aircraft. The processor is coupled to the communication interface and is configured to compute an inertial localizer deviation based on the inertial data.

According to another aspect of the present disclosure, a flight control system for landing an aircraft is provided. The flight control system includes a communication bus, first and second multi-mode receivers (MMRs), and a flight control module. The first and second MMRs are coupled to the communication bus and are configured to compute first and second localizer deviations based on received localizer signals. The first and second MMRs are further configured to transmit first and second localizer deviation signals indicative of the first and second localizer deviations onto the communication bus. The flight control module is coupled to the communication bus and is configured to receive inertial data for the aircraft and the first and second localizer deviation signals over the communication bus. The flight control module is further configured to compute an inertial localizer deviation based on the inertial data. The flight control module is further configured to select one localizer deviation from among the first and second localizer deviations and the inertial localizer deviation. The flight control module is further configured to transmit the one localizer deviation to an automated landing system for the aircraft.

According to yet another aspect of the present disclosure, a method of detecting a localizer deviation for an aircraft during landing is provided. The method includes receiving instrument landing system (ILS) localizer signals. The method further includes computing MMR localizer deviations based on the ILS localizer signals. The method further includes filtering the MMR localizer deviations. The method further includes initializing an inertial localizer deviation computation based on a filtered MMR localizer deviation. The method further includes integrating inertial data, generated by an inertial reference unit (IRU) for the aircraft, from the filtered MMR localizer deviation to generate an inertial localizer deviation at the IRU. The method further includes translating the inertial localizer deviation at the IRU to a guidance control point (GCP).

The features, functions, and advantages that have been discussed can be achieved independently in various embodiments or may be combined in yet other embodiments further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top perspective diagram of an exemplary instrument landing system (ILS) for use in landing an aircraft;

FIG. **2** is a side perspective diagram of the exemplary ILS shown in FIG. **1**;

FIG. **3** is a top perspective diagram of the aircraft shown in FIGS. **1** and **2** during landing;

FIG. **4** is block diagram of an exemplary flight control system for the aircraft shown in FIGS. **1-3**;

FIG. **5** is a functional block diagram of an exemplary flight control module for use in the flight control system shown in FIG. **4**; and

FIG. **6** is a flow diagram of an exemplary method of detecting a localizer deviation for use in the flight control system shown in FIG. **4**.

DETAILED DESCRIPTION

As used herein, an element or step recited in the singular and proceeded with the word “a” or “an” should be understood as not excluding plural elements or steps unless such exclusion is explicitly recited. Furthermore, references to “one embodiment” of the present invention or the “exemplary embodiment” are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

FIG. **1** is a perspective diagram, from a top-view, of an exemplary instrument landing system (ILS) **100** for use in landing an aircraft **102**. FIG. **2** is another perspective diagram, from a side view, of ILS **100**. Aircraft **102** is illustrated during approach for landing on a runway **104**. Runway **104** is characterized by a runway centerline **106** that extends towards and beyond aircraft **102** for illustrative purposes.

Referring to FIG. **1**, in the exemplary embodiment, ILS **100** includes a localizer transmitter **108** and a glideslope transmitter **110**. Localizer transmitter **108** transmits a first localizer beam **112** and a second localizer beam **114** towards aircraft **102**. First localizer beam **112** and second localizer beam **114** cooperate define an ILS localizer signal that is received by aircraft **102** and processed to generate localizer deviations indicative of the lateral position of aircraft **102** relative to runway centerline **106**. The localizer signals are typically used to control aircraft **102** through landing and rollout, i.e., deceleration along runway prior to taxi.

Referring to FIG. **2**, aircraft **102** approaches runway **104** along a predefined glideslope **116** that intercepts runway **104** at a predefined distance beyond a runway threshold for runway **104**. The predefined distance is typically, for example, at least **1000** feet from the runway threshold, which is typically the site of glideslope transmitter **110**. Glideslope **116** is defined by a glideslope angle **118** measured between glideslope **116** and runway **104**. A typical glideslope, for example, is defined by glideslope angle **118** being equal to approximately **3**°. Glideslope transmitter **110** transmits a first glideslope beam **120** and a second glideslope beam **122** towards aircraft **102**. First glideslope beam **120** and second glideslope beam **122** define an ILS glideslope signal that is received by aircraft **102** and that is processed to generate glideslope deviations indicative of the vertical position of aircraft **102** relative to glideslope **116**. The glideslope signals are typically used to control aircraft **102** until it reaches a flare altitude, i.e., an altitude when the nose of aircraft **102** pitches up prior to landing, which typically occurs between **50** and **75** feet. When the flare altitude is reached, aircraft **102** typically switches to a radio altimeter to guide aircraft **102** to runway **104** for landing. In alternative embodiments, flare altitude may be greater than **75** feet or, in some embodiments, below **50** feet.

FIG. **3** is a perspective diagram of aircraft **102** during landing. FIG. **3** illustrates a top-view of aircraft **102** landing on runway **104**. Aircraft **102** includes a guidance control point (GCP) **302** to which all flight control commands for aircraft

102 are referenced. GCP **302** is typically located at the nose of aircraft **102**. Aircraft **102** also includes an inertial reference unit (IRU) **304** that includes various sensors for detecting linear and angular accelerations of aircraft **102**, which are translatable to accelerations, velocities, and attitude of aircraft **102** along three axis, i.e., pitch, roll, and yaw. IRU **304** is typically located at or near the center of aircraft **102**, which is illustrated in FIG. **3** as the intersection of the wings **305** and fuselage **307** of aircraft **102**. Accordingly, GCP **302** and IRU **304** are typically separated by a distance **306** extending along a portion of the length of fuselage **307** of aircraft **102**.

Runway **104** includes runway centerline **106** characterized by a runway heading **308** relative to magnetic North (N). Runway heading **308** is generally known by aircraft **102** and its navigations systems, and is sometimes referred to as a magnetic runway heading. During landing, aircraft **102** travels at a ground speed **310** along a track angle, or simply track **312**, relative to North. Ground speed **310** and track **312** are measurable by IRU **304**. Moreover, aircraft **102** travels with an aircraft heading **314** relative to North, which is generally defined as the direction the nose of aircraft **102** is pointing. Aircraft heading **314** is also measurable by IRU **304**. Notably, under certain circumstances, such as cross-winds, for example, track **312** and aircraft heading **314** may be different.

FIG. **3** illustrates aircraft **102** at an orientation with a localizer deviation **316** measured from runway centerline **106** to IRU **304**. Given inertial accelerations measured by IRU **304** and runway heading **308**, aircraft **102** may compute an inertial cross-runway velocity **318** that, over time, increases or decreases localizer deviation **316** and that can be translated to GCP **302**.

FIG. **4** is block diagram of an exemplary flight control system **400** for aircraft **102**, shown in FIGS. **1-3**. Flight control system **400** includes a flight control module **402** that controls aircraft **102** by transmitting commands to an actuator control module **404**. Flight control module **402** communicates with actuator control module **404** over a communication bus **406**. Actuator control module **404** controls one or more actuators **408** that are attached to various flight control surfaces of aircraft **102**. Actuator control module **404** communicates with actuators **408** over a communication bus **410**.

Aircraft **102** includes various sensors **412** that measure flight parameters and generate data that is transmitted onto a communication bus **414**. Flight control module **402** is communicably coupled to communication bus **414** through communication interface **415** and gains access to the data.

Sensors **412** include various accelerometers and gyroscopes located at IRU **304** that provide cross-runway acceleration **416**, ground speed **310**, track angle **312**, and aircraft heading **314**. Communication bus **414** is configured to be coupled to IRU **304**, which provides the inertial data. Communication bus **414** is further coupled to various other data sources, such as a navigation system (not shown) that provides runway heading **308** and a radar altimeter **418** that provides altitude for aircraft **102**. Communication bus **414** is further coupled to a left MMR **420** and a right MMR **422**. Left MMR **420** provides a left MMR localizer deviation **424**. Right MMR **422** provides a right MMR localizer deviation **426**.

Communication interface **415** receives first and second localizer deviation signals indicative of respective localizer deviations, such as left MMR localizer deviation **424** and right MMR localizer deviation **426**, computed based on the localizer transmission received by aircraft **102**.

Flight control module **402** includes an automated landing system **428**. Flight control module **402** receives and processes data from communication bus **414** to produce a localizer deviation signal that is used by automated landing system **428** to generate commands for actuator control module **404**. Flight control module **402** receives left MMR localizer deviation **424** and right MMR localizer deviation **426** expressed in difference in the depth of modulation (ddm). Flight control module **402** includes amplifiers **430** and **432** that each apply a gain, $K_{ddm\text{-}degrees}$, to the ddm values to convert left MMR localizer deviation **424** and right MMR localizer deviation **426** to degrees.

Flight control module **402** includes a synthetic inertial localizer deviation module (SILD) processor **434** that computes an inertial localizer deviation **436**, also referred to as a SILD, based on data received over communication bus **414**. Inertial localizer deviation **436** is converted from feet to degrees by an amplifier **438** that applies a gain, $K_{\text{feet-degrees}}$. Flight control module **402** selects which localizer signal to use to command actuator control module **404** using a signal selection fault detection (SSFD) algorithm. Flight control module **402** includes a mid-value selector **440** for carrying out SSFD. Mid-value selector **440** is sometimes referred to as an SSFD module, which is configured to select one localizer deviation from among MMR localizer deviations **424** and **426**, and inertial localizer deviation **436** for use in controlling automated landing system **428** of aircraft **102**. Mid-value selector **440** selects a middle value from among left MMR localizer deviation **424**, right MMR localizer deviation **426**, and inertial localizer deviation **436**. The selected localizer deviation **444** is converted from degrees to feet by an amplifier **442** and fed back to SILD processor **434**. SILD processor **434** complementary-filters the selected localizer deviation and generates a complementary-filtered localizer deviation **446**.

The addition of inertial localizer deviation **436** enables continued use of automated landing system **428** in the event of an undetected failure in one of left MMR **420** and right MMR **422** below an alert height, or altitude. Typically, the alert height is **200** feet. If one of left MMR localizer deviation **424** and right MMR localizer deviation **426** fails and is not respectively detected by left MMR **420** or right MMR **422**, mid-value selector **440** detects the failure as the failed signal will be different from the two good signals. Generally, known systems utilize three MMRs, which add weight and cost to aircraft **102**. When the two remaining good localizer deviation signals mis-compare, automated landing system **428** disengages and forfeits control of aircraft **102** to the pilot. Other known systems utilize two self-monitoring MMRs. In the event of an undetected failure in left MMR localizer deviation **424** or right MMR localizer deviation **426**, the two signals mis-compare, but no third signal is available. Such a failure results in automated landing system **428** disengaging. Inertial localizer deviation **436** introduces a third localizer signal that enables flight control module **402** to withstand an undetected failure in one of left MMR localizer deviation **424** or right MMR localizer deviation **426**.

Flight control module **402** may be embodied on one or more processors. Likewise, SILD processor **434**, mid-value selector **440**, and automated landing system **428** may be embodied on one or more processors configured to carry out the functionality described above.

FIG. **5** is a functional block diagram of flight control module **402** and, more specifically, SILD processor **434**, shown in FIG. **4**. SILD processor **434** includes a complementary filter **502**, a runway heading correction block **504**, an inertial cross-runway velocity block **506**, and a translation-to-GCP block **508**.

Complementary filter **502** blends high-frequency content of inertial data from IRU **304** with low-frequency content of left MMR localizer deviation **424** and right MMR localizer deviation **426** to produce a smooth, complementary-filtered localizer deviation **446**. Complementary filter **502** generally operates in terms of feet. Complementary-filtered localizer deviation **446**, expressed in feet, is fed back and subtracted **510** from selected localizer deviation **444** to produce a localizer deviation error value. Mid-value selector **440** operates in terms of degrees or radians. Accordingly, selected localizer deviation **444** is converted to feet by gain **442** prior to use by complementary filter **502** to compute the localizer deviation error value. The localizer deviation error value is gained by K_3 and integrated **512**. The result of integration **512** is added **514** to cross-runway acceleration **416**, and then added **516** to the localizer deviation error value gained **518** by K_2. The result of summing **516** is integrated **520** and added **522** to the localizer deviation error value gained **524** by K_1. The result of summation **522** is a localizer deviation rate **526** that is integrated

528 to generate complementary-filtered localizer deviation **446**. Complementary filter **502** is further characterized by, but not limited to the following equation, where D_{CF} is complementary-filtered localizer deviation **446** as a function of time, *t*, and expressed in feet, D_{sel} is selected localizer deviation **444** as a function of time, *t*, and expressed in feet, and A_{CR} is cross-runway acceleration **416** as a function of time, *t*.

$$D_{CF} = \left[\frac{K_1S^2+K_2S+K_3}{S^3+K_1S^2+K_2S+K_3}\right] \times D_{sel} + \left[\frac{S}{S^3+K_1S^2+K_2S+K_3}\right] \times A_{CR} \qquad \text{EQ. } \mathbf{1}$$

When aircraft **102** descends, as measured by radar altimeter **418**, below an altitude threshold **530**, complementary-filtered localizer deviation **446** is latched **532** as an initial condition for integration **534** of inertial cross-runway velocity **318**. Aircraft altitude from radar altimeter **418** is compared **536** to altitude threshold **530**, e.g., **200** feet, to trigger latch **532**.

Inertial cross-runway velocity block **506** computes inertial cross-runway velocity **318** as a function of an adjusted runway heading **538**, ground speed **310**, and track **312**. Inertial cross-runway velocity **318** is a projection of ground speed **310** along track **312** onto a cross-runway vector; computed as ground speed **310** multiplied **540** by the sine **542** of the difference **544** between track **312** and adjusted runway heading **538**. Inertial cross-runway velocity block **506** is further characterized by, but not limited to, the following equation, where V_{CR} is cross-runway velocity **318** as a function of time, *t*, S_{GND} is ground speed **310** as a function of time, *t*, T is track **312** as a function of time, *t*, and $H_{run,adj}$ is adjusted runway heading **538** as a function of time, *t*, and expressed in radians.

$$V_{CR}(t) = S_{GND}(t) \times sin\left(T(t) - H_{run,adj}(t)\right) \qquad \text{EQ. } \mathbf{2}$$

Runway heading correction block **504** computes adjusted runway heading **538** to correct for errors in magnetic runway heading **308** available on aircraft **102**. Adjusted runway heading **538** represents actual runway azimuth relative to North for use in inertial cross-runway velocity block **506** and translation-to-GCP block **508**.

Adjusted runway heading **538** is computed as a function of magnetic runway heading **308**, ground speed **310**, track **312**, and localizer deviation rate **526** from complementary filter **502**. Localizer deviation rate **526** is derived from EQ. **1**, above, and is a component of complementary-filtered localizer deviation **446**. Localizer deviation rate **526** is a derivative of complementary-filtered localizer deviation **446**, i.e., $S \times D_{CF}(t)$, and is represented by the following equation, where D_{rate} is localizer deviation rate **526** as a function of time, *t*.

$$D_{rate} = \left[\frac{K_1S^3+K_2S^2+K_3S}{S^3+K_1S^2+K_2S+K_3}\right] \times D_{sel} + \left[\frac{S^2}{S^3+K_1S^2+K_2S+K_3}\right] \times A_{CR} \qquad \text{EQ. 3}$$

In runway heading correction block **504**, localizer deviation rate **526** is divided **546** by ground speed **310** and subtracted **548**, along with magnetic runway heading **308**, from track **312**. The result of subtraction **548** is lag-filtered **550**, i.e., low-pass filtered, with a time constant, τ. The result of lag-filtering **550** is added **552** to magnetic runway heading **308** to generate adjusted runway heading **538**. Runway heading correction block **504** is further characterized, but not limited to, the following equation, where H_{run} is magnetic runway heading **308**.

$$H_{run,adj} = \frac{\tau S}{\tau S+1} \times H_{run} + \frac{1}{\tau S+1} \times T - \frac{1}{\tau S+1} \times \frac{D_{rate}}{S_{GND}} \qquad \text{EQ. 4}$$

Integration **534** integrates cross-runway velocity **318** from an initial condition at altitude threshold **530**, which is latched at complementary-filtered localizer deviation **446** with respect to GCP **302**. Integration **534** produces inertial localizer deviation **436** with respect to IRU **304**. A compensation **554** is added **556** to inertial localizer deviation **436** to correct for the difference between inertial localizer deviation **436** at IRU **304** and inertial localizer deviation **436** at GCP **302**. For example, GCP **302**, at the nose of aircraft **102**, is at a different cross-runway position than IRU **304** during "crabbed" approaches for cross-wind landings. Compensation **554** accounts for changes in aircraft heading **314** that occur below altitude threshold **530**, because integration **534** is initialized, at altitude threshold **530**, to complimentary-filtered localizer deviation **446**, which is computed with respect to GCP **302**.

Translation-to-GCP block **508** computes compensation **554** as a function of aircraft heading **314**, adjusted runway heading **538**, and distance **306** along the fuselage of aircraft **102** between IRU **304** and GCP **302**. Distance **306** is multiplied **558** by the sine **560** of a difference **562** between aircraft heading **314** and adjusted runway heading **538**, yielding compensation **554** as a function of time, *t*. When aircraft **102** descends to altitude threshold **530**, a hold value **564** of compensation **554** is latched **532**. Hold value **564** represents the portion of compensation **554** already incorporated into inertial localizer deviation **436** via the initial condition of complementary-filtered localizer deviation **446** latched **532** at altitude threshold **530**. Hold value **564** is subtracted **566** from compensation **554** to capture only the changes in aircraft heading **314** that occur below altitude threshold **530**. Translation-to-GCP block **508** is further characterized, but not limited to, the following equation, where C is compensation **554** as a function of time, t, $L_{IRU-GCP}$ is distance **306** along the fuselage of aircraft **102** between IRU **304** and GCP **302**, H_{ac} is aircraft heading **314** as a function of time, t, and t_{200} is the time at which aircraft **102** descends to altitude threshold **530**.

$$C(t) = L_{IRU-GCP}\left[sin\left(H_{ac}(t) - H_{run,adj}(t)\right) - sin\left(H_{ac}(t_{200}) - H_{run,adj}(t_{200})\right)\right]$$

EQ. **5**

FIG. **6** is a flow diagram of an exemplary method **600** of detecting a localizer deviation for use in flight control system **400**, shown in FIG. **4**, of aircraft **102**, shown in FIGS. **1-3**. Method **600** begins with aircraft **102** receiving **610** ILS localizer signals defined by first and second localizer beams **112** and **114**. An antenna for receiving first and second localizer beams **112** and **114** is typically located in the nose of aircraft **102**. The received signals are then passed to left MMR **420** and right MMR **422**. Left MMR **420** and right MMR **422** respectively compute **620** MMR localizer deviations **424** and **426** based on the received ILS localizer signals. MMR localizer deviations **424** and **426** are transmitted onto a communication bus **414**, such as an ARINC-**429** bus, for example.

Flight control module **402** gains access to MMR localizer deviations **424** and **426** on communication bus **414** through communication interface **415**, which may include an ARINC-**429** interface circuit card configured to communicate within flight control module **402** using peripheral component interconnect (PCI), PCI Express, PC/**104**, Ethernet, compact PCI, or other suitable protocol. SILD processor **434** receives MMR localizer deviations **424** and **426** and filters **630** them using complementary filter **502** to produce complementary-filtered localizer deviation **446**.

When aircraft **102** descends to altitude threshold **530**, the inertial localizer deviation computation is initialized **640** based on complementary-filtered localizer deviation **446**, which provides the initial condition for integration **534** of cross-runway velocity **318**. Inertial data is integrated **650** to generate inertial localizer deviation **436** with respect to IRU **304**. Inertial data includes cross-runway acceleration **416**, track angle **312**, ground speed **310**, and aircraft heading **314**, which are all determinable based on measurements at IRU **304**.

Inertial localizer deviation **436** is translated **660** from IRU **304** to GCP **302** using translation-to-GCP block **508**, which accounts for changes in aircraft heading **314** that occur below altitude threshold **530**.

The above described embodiments of flight control systems for use by an aircraft during landing provide an inertial localizer deviation that is considered in combination with MMR localizer deviation signals when commanding an automated landing system. More specifically, the inertial localizer deviation provides assurance the automated landing system can continue an automated landing in the event of an undetected MMR localizer deviation failure. The flight control systems described herein and, more specifically, flight control modules, generate the inertial localizer deviation by integrating inertial data from the aircraft's IRU from an initial condition established based on the MMR localizer deviations.

Exemplary embodiments of methods, systems, and apparatus for flight control systems are not limited to the specific embodiments described herein, but rather, components of systems and/or steps of the methods may be utilized independently and separately from other components and/or steps described herein. For example, the methods may also be used in combination with other non-conventional flight control systems, and are not limited to practice with only the systems and methods as described herein. Rather, the exemplary embodiment can be implemented and utilized in connection with many other applications, equipment, and systems that may benefit from increased efficiency, reduced operational cost, and reduced capital expenditure.

An exemplary technical effect of the methods, systems, and apparatus described herein includes at least one of: (a) generation of a SILD for consideration in SSFD processes; (b) controlling an automated landing system based on a SILD; (c) improving reliability of automated landing systems through addition of an inertial localizer deviation; (d) improving failure detection in MMR localizer deviation signals; (e) reducing cost and weight of producing triple-redundant localizer deviation for automated landing systems through elimination of a third MMR device; and (f) improving localizer accuracy for automated landing systems.

Some embodiments involve the use of one or more electronic or computing devices. Such devices typically include a processor, processing device, or controller, such as a general purpose central processing unit (CPU), a graphics processing unit (GPU), a microcontroller, a reduced instruction set computer (RISC) processor, an application specific integrated circuit (ASIC), a programmable logic circuit (PLC), a field programmable gate array (FPGA), a digital signal processing (DSP) device, and/or any other circuit or processing device capable of executing the functions described herein. The methods described herein may be encoded as executable instructions embodied in a computer readable medium, including, without limitation, a storage device and/or a memory device. Such instructions, when executed by a processing device, cause the processing device to perform at least a portion of the methods described herein. The above examples are exemplary only, and thus are not intended to limit in any way the definition and/or meaning of the terms processor, processing device, and controller.

In the embodiments described herein, memory may include, but is not limited to, a computer-readable medium, such as a random access memory (RAM), and a computer-readable non-volatile medium, such as flash memory. Alternatively, a floppy disk, a compact disc – read only memory (CD-ROM), a magneto-optical disk (MOD), and/or a digital versatile disc (DVD) may also be used. Also, in the embodiments described herein, additional input channels may be, but are not limited to, computer peripherals associated with an operator interface such as a mouse and a keyboard. Alternatively, other computer peripherals may also be used that may include, for example, but not be limited to, a scanner. Furthermore, in the exemplary embodiment, additional output channels may include, but not be limited to, an operator interface monitor.

This written description uses examples to disclose various embodiments, which include the best mode, to enable any person skilled in the art to practice those embodiments, including making and using any devices or systems and performing any incorporated methods. The patentable scope is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A flight control module for computing localizer deviation during landing of an aircraft, comprising:

a communication interface configured to receive inertial data for said aircraft;

a processor coupled to said communication interface and configured to compute an inertial localizer deviation based on the inertial data.

2. The flight control module of Claim **1**, wherein said communication interface is further configured to receive first and second localizer deviation signals indicative of respective localizer deviations computed based on a localizer transmission received by said aircraft.

3. The flight control module of Claim **2** further comprising a signal selection fault detection (SSFD) module configured to select one localizer deviation from among the respective localizer deviations and the inertial localizer deviation for use in controlling an automated landing system of said aircraft.

4. The flight control module of Claim **3**, wherein said SSFD module comprises a mid-value selector configured to select a middle value from among the respective localizer deviations and the inertial localizer deviation.

5. The flight control module of any one of Claims **1**-**4**, wherein said processor comprises a complementary filter configured to generate a filtered localizer deviation based on a localizer deviation signal received through said communication interface and the inertial data, including a cross-runway acceleration.

6. The flight control module of Claim **5**, wherein said communication interface is configured to be coupled to an inertial reference unit (IRU) through a communication bus, the IRU comprising a ground speed sensor, a track angle sensor, and an aircraft heading sensor, and wherein the inertial data includes a ground speed, a track angle, and an aircraft heading.

7. The flight control module of Claim **6**, wherein said communication interface is further configured to receive a magnetic runway heading, and wherein said processor is further configured to compute an adjusted runway heading based on the magnetic runway heading, the ground speed, and a localizer deviation rate computed by said complementary filter.

8. The flight control module of Claim **7**, wherein said processor is further configured to:

compute an inertial cross-runway velocity at the IRU based on the ground speed, the track angle, and the adjusted runway heading; and

apply a correction to the inertial localizer deviation, the correction computed based on the adjusted runway heading, the aircraft heading, and a distance between the IRU and a guidance control point of said aircraft.

9. A flight control system for landing an aircraft, said flight control system comprising:

a communication bus;

first and second multi-mode receivers (MMRs) coupled to said communication bus and configured to:

compute first and second localizer deviations based on received localizer signals, and transmit first and second localizer deviation signals indicative of the first and second localizer deviations onto said communication bus; and

a flight control module coupled to said communication bus and configured to:

receive inertial data for the aircraft and the first and second localizer deviation signals over said communication bus,

compute an inertial localizer deviation based on the inertial data,

select one localizer deviation from among the first and second localizer deviations and the inertial localizer deviation, and

transmit the one localizer deviation to an automated landing system for said aircraft.

10. The flight control system of Claim **9** further comprising an actuator control module coupled to said automated landing system through a second communication bus, said actuator control module communicably coupled to a flight control actuator, said automated landing system configured to instruct said actuator control module according to the one localizer deviation.

11. The flight control system of any one of Claims **9-10** further comprising a radar altimeter configured to detect an altitude of said aircraft, said radar altimeter coupled to said communication bus, wherein said flight control module is further configured to compute the inertial localizer deviation when the altitude falls below a predetermined threshold.

12. The flight control system of Claim **11**, wherein said flight control module is further configured to compute the inertial localizer deviation when the altitude falls below the predetermined threshold of **200** feet.

13. The flight control system of any one of Claims **11**-**12**, wherein said flight control module is further configured to select a mid-value from among the first and second localizer deviations and the inertial localizer deviation as the one localizer deviation for transmission to said automated landing system.

14. The flight control system of any one of Claims **11**-**13**, wherein said flight control module is further configured to initialize computation of the inertial localizer deviation based on the first and second localizer deviation signals when said aircraft descends below **200** feet in altitude, wherein the first and second localizer deviation signals are complementary-filtered prior to initialization.

15. A method of detecting a localizer deviation for an aircraft during landing, said method comprising:

receiving instrument landing system (ILS) localizer signals;

computing multi-mode receiver (MMR) localizer deviations based on the ILS localizer signals;

filtering the MMR localizer deviations;

initializing an inertial localizer deviation computation based on a filtered MMR localizer deviation;

integrating inertial data, generated by an inertial reference unit (IRU) for the aircraft, from the filtered MMR localizer deviation to generate an inertial localizer deviation at the IRU; and

translating the inertial localizer deviation at the IRU to a guidance control point (GCP).

16. The method of Claim **15**, wherein filtering the MMR localizer deviations comprises blending a cross-runway acceleration measured by the IRU, with the MMR localizer deviations using a complementary filter.

17. The method of any one of Claims **15**-**16**, wherein integrating the inertial data generated by the IRU comprises:

computing inertial cross-runway velocity based on ground speed and track angle measured by the IRU, and a runway heading; and

integrating the inertial cross-runway velocity from the filtered MMR localizer deviation to generate the inertial localizer deviation at the IRU.

18. The method of Claim **17**, wherein integrating the inertial data generated by the IRU further comprises:

computing an error correction for runway heading based on the ground speed, the track angle, and a localizer deviation rate, the localizer deviation rate computed based on the MMR localizer deviations; and

applying the error correction to a magnetic runway heading to generate an adjusted runway heading for use in computing the inertial cross-runway velocity and in translating the inertial localizer deviation at the IRU to the GCP.

19. The method of any one of Claims **15**-**18**, wherein translating the inertial localizer deviation at the IRU to the GCP comprises:

computing a cross-runway position difference between the IRU and the GCP based on an aircraft heading measured by the IRU and a runway heading; and adding the cross-runway position difference to the inertial localizer deviation at the IRU to generate an inertial localizer deviation at the GCP.

20. The method of any one of Claims **15**-**19**, wherein initializing the inertial localizer deviation computation comprises latching the filtered MMR localizer deviation upon an altitude of the aircraft falling below a predetermined threshold.

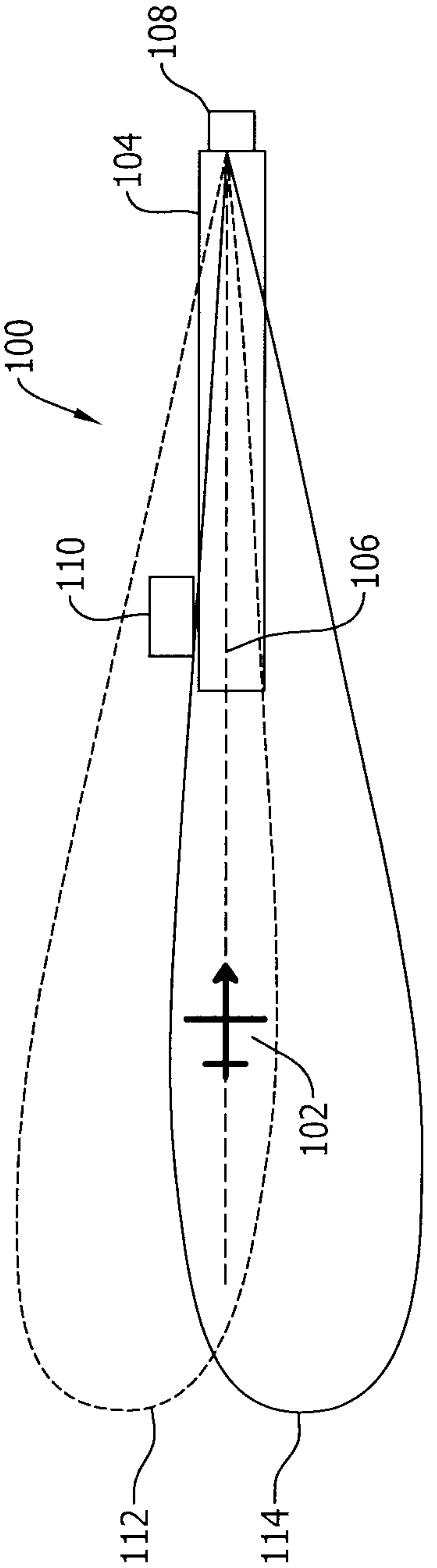
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FIG. 1

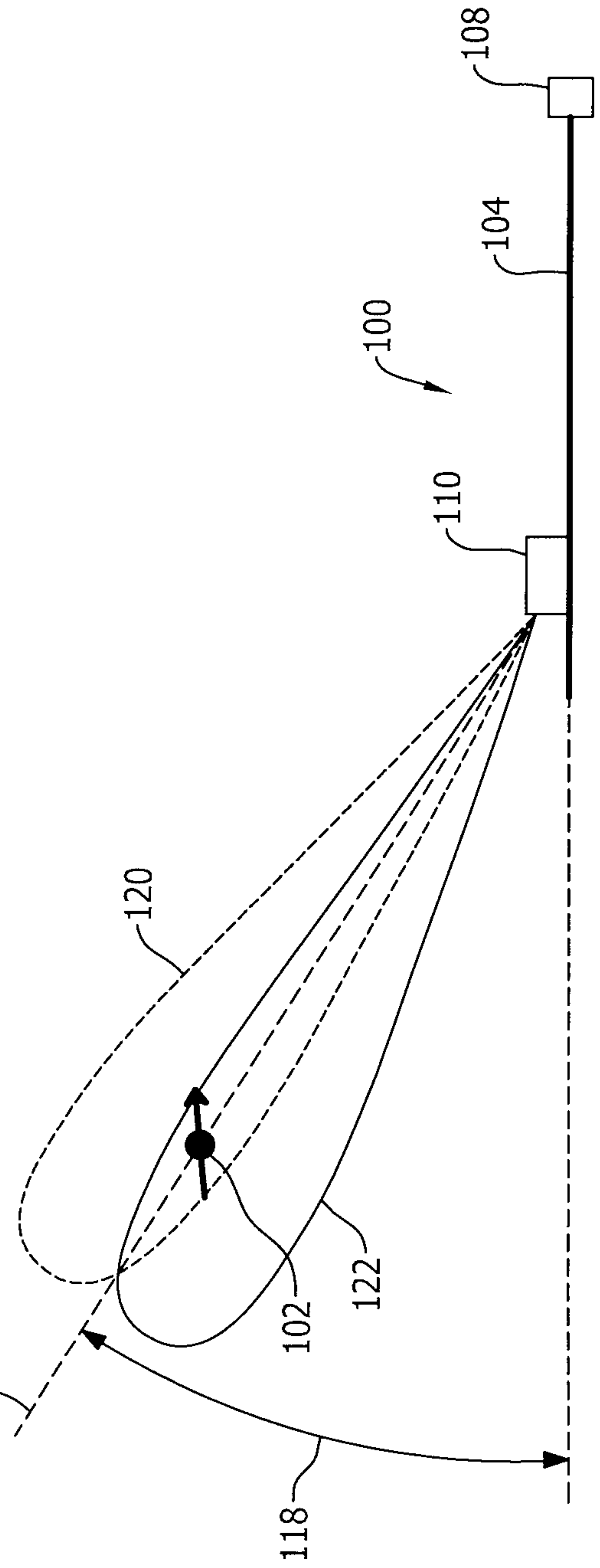
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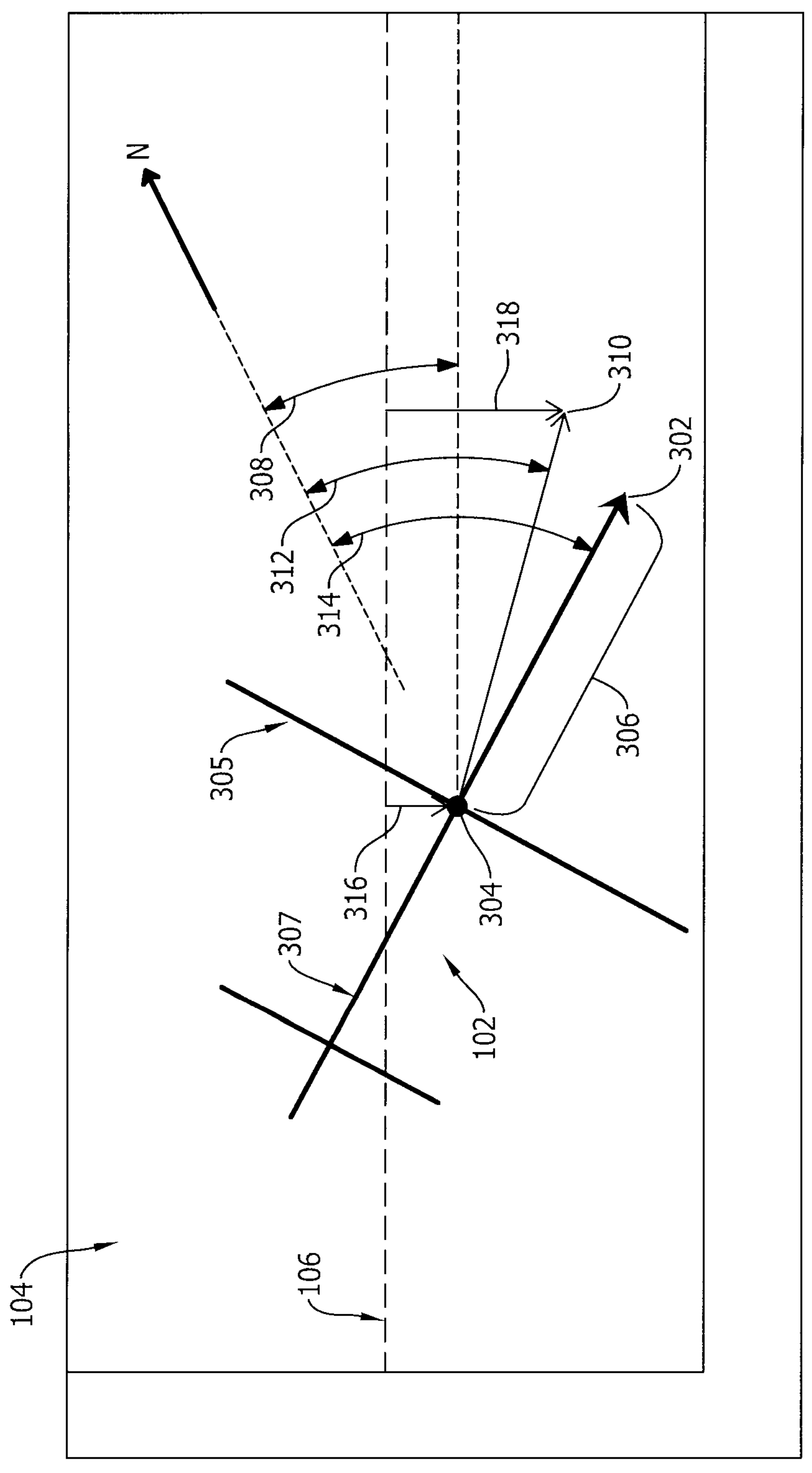
FIG. 2



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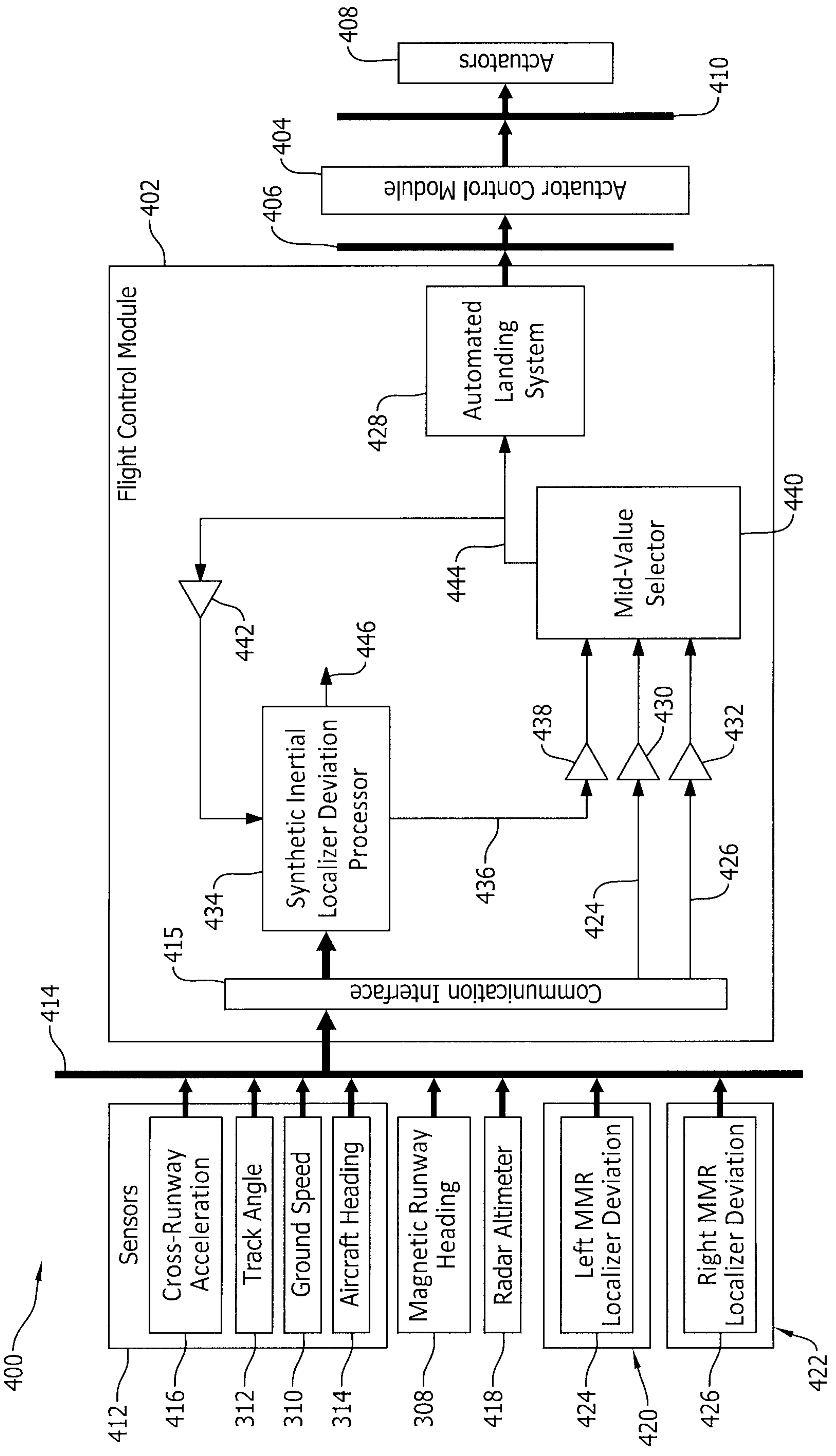
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Sensors
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Cross-Runway Acceleration
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Track Angle
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Ground Speed
314
Aircraft Heading
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Magnetic Runway Heading
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Radar Altimeter
424
Left MMR Localizer Deviation
420
426
Right MMR Localizer Deviation
422
414
402
Flight Control Module
415
Communication Interface
434
Synthetic Inertial Localizer Deviation Processor
446
436
424
426
438
430
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Mid-Value Selector
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Automated Landing System
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Actuator Control Module
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Actuators

FIG. 4

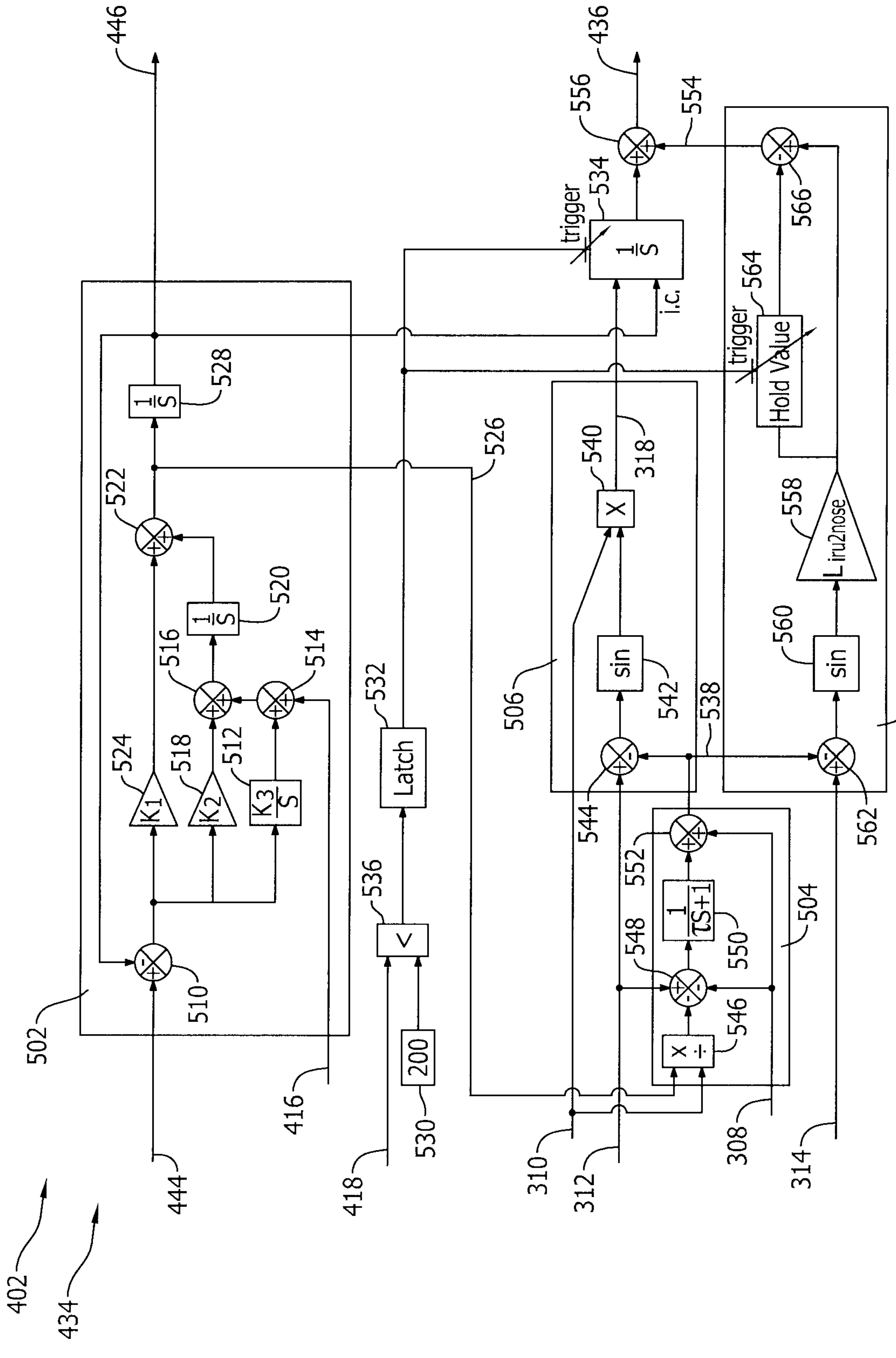
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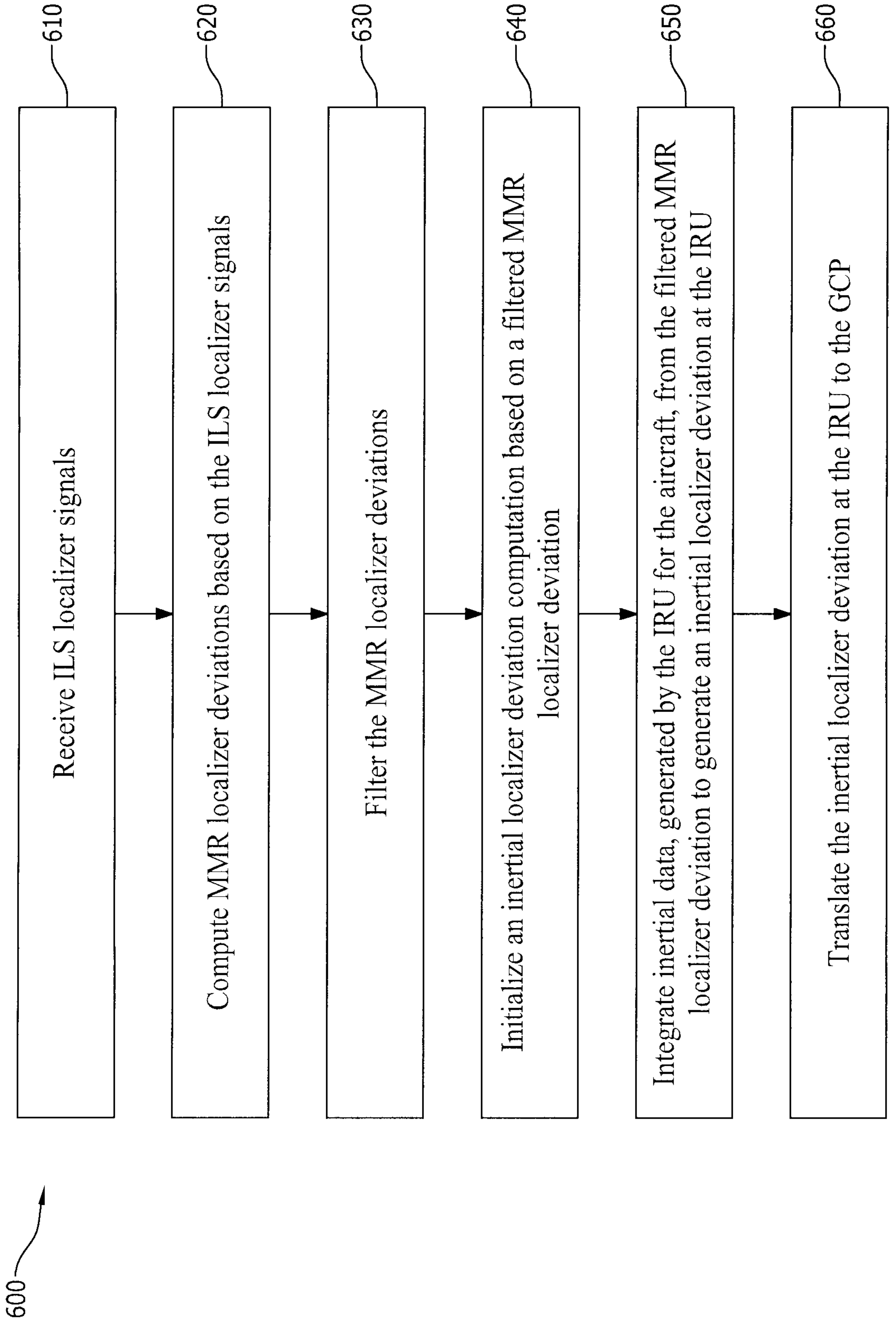
FIG. 5


600
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Receive ILS localizer signals
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Compute MMR localizer deviations based on the ILS localizer signals
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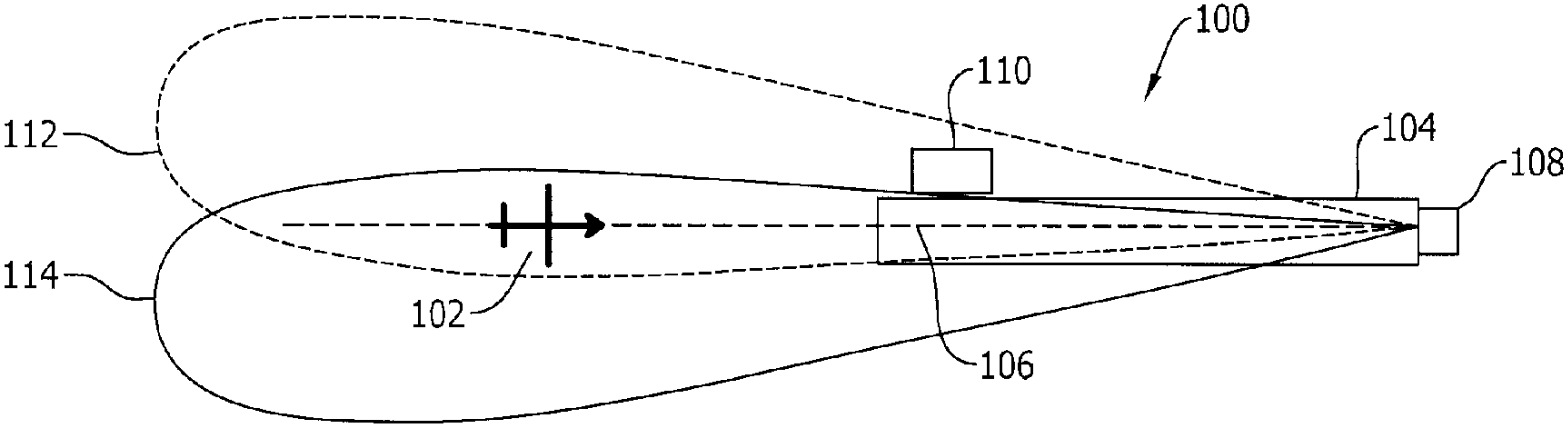
Filter the MMR localizer deviations
640
Initialize an inertial localizer deviation computation based on a filtered MMR localizer deviation
650
Integrate inertial data, generated by the IRU for the aircraft, from the filtered MMR localizer deviation to generate an inertial localizer deviation at the IRU
660
Translate the inertial localizer deviation at the IRU to the GCP

FIG. 6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