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Jacobs et al.

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(54) **RADAR REGISTRATION USING TARGETS OF OPPORTUNITY**

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(51) **Int. Cl.**
G01S 13/74 (2006.01)

(52) **U.S. Cl.** **342/29**; 342/32; 342/36; 342/37; 342/59

(58) **Field of Classification Search** 342/29–32, 342/36–38, 59, 107, 113, 133, 139–140, 342/146–147

See application file for complete search history.

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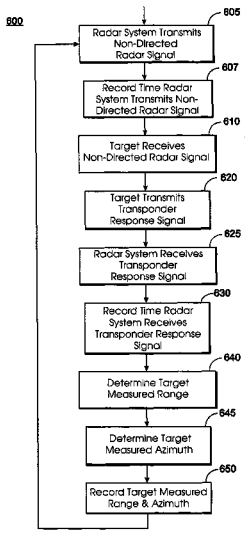
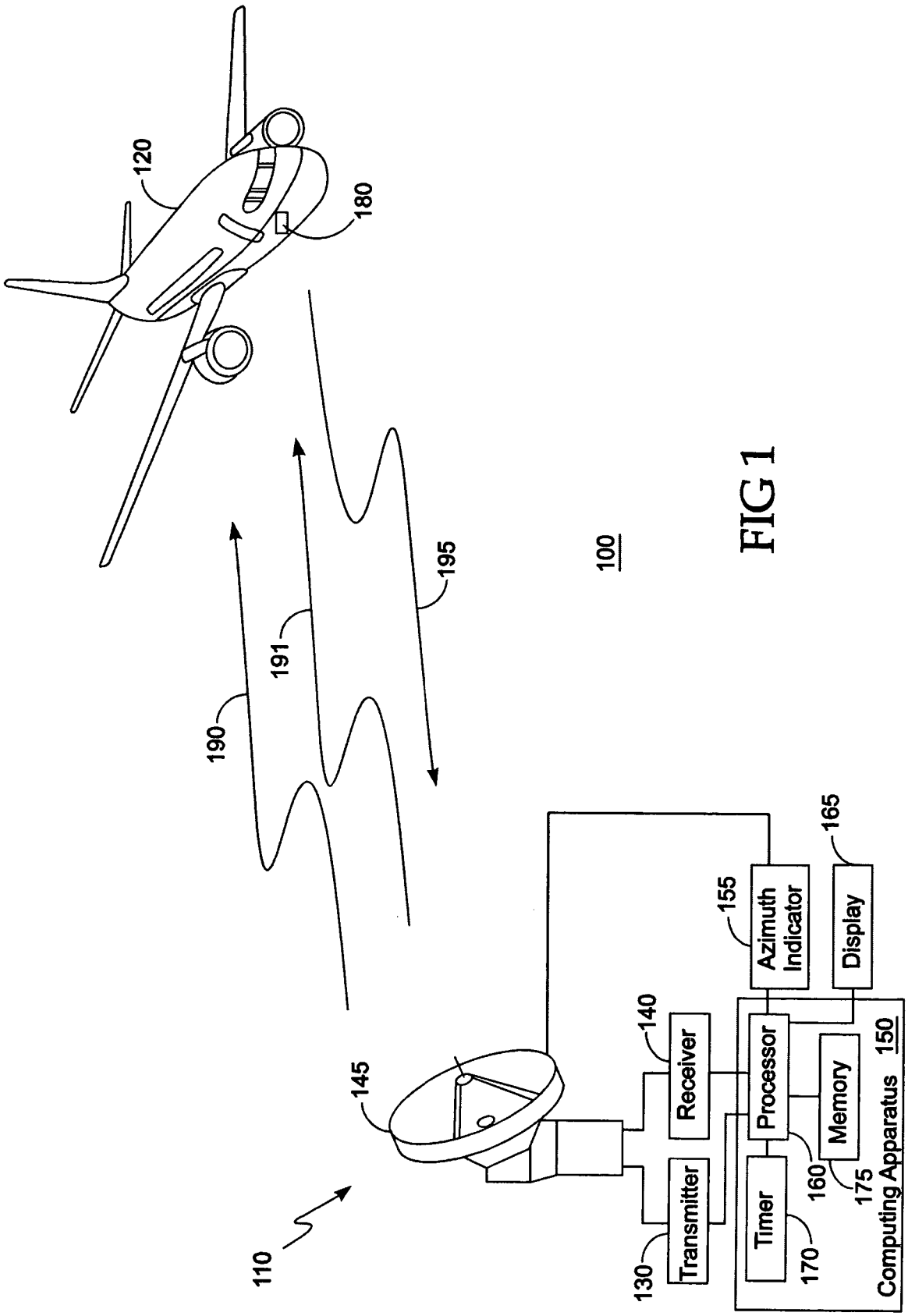
(57) **ABSTRACT**

A method for registering a radar system. The method includes obtaining first values for a location of a target relative to the radar system using radar system initiated signals, obtaining geo-referenced location data for and from the target, obtaining second values for the location of the target relative to the radar system using the geo-referenced location data, computing location registration bias errors for the radar system using the first and second values, and registering the radar system using the computed location registration bias errors.

31 Claims, 11 Drawing Sheets

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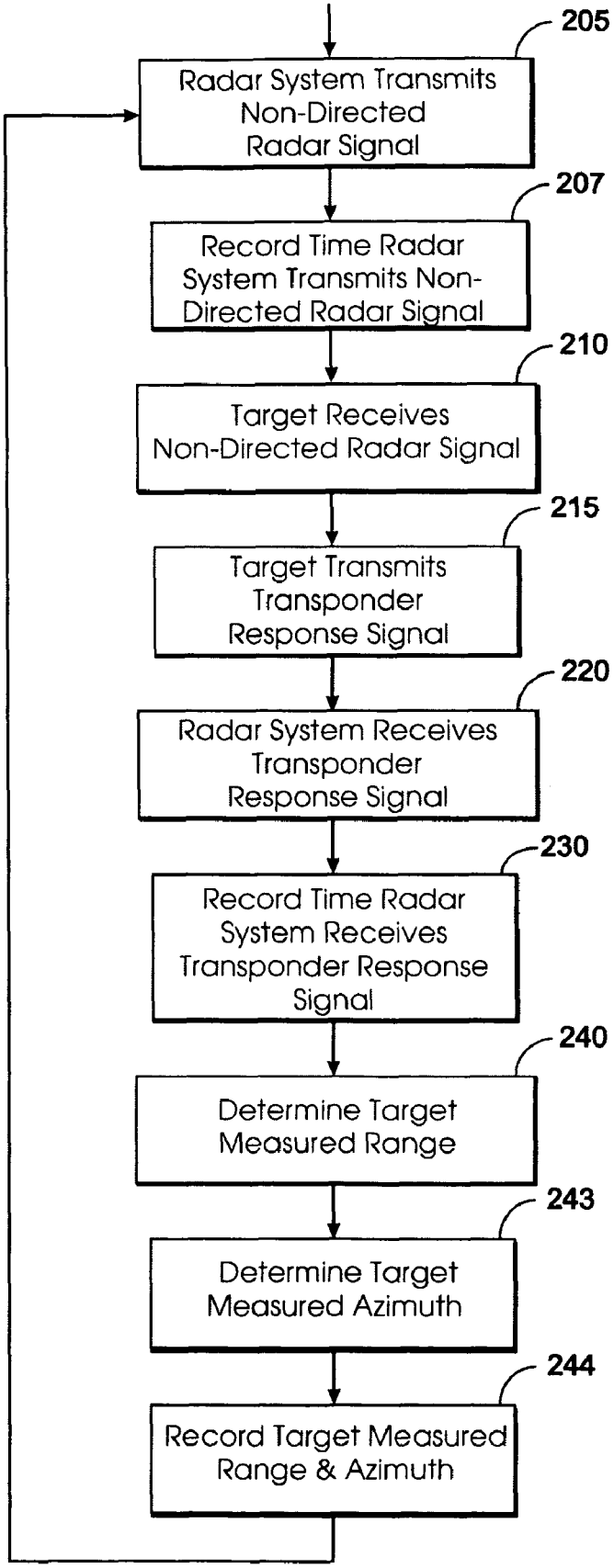
180
195
191
190
100
110
145
140
Receiver
Transmitter
130
155
Azimuth Indicator
165
Display
Processor
Memory
160
175
Timer
170
Computing Apparatus 150

FIG 1


205
Radar System Transmits Non-Directed Radar Signal
207
Record Time Radar System Transmits Non-Directed Radar Signal
210
Target Receives Non-Directed Radar Signal
215
Target Transmits Transponder Response Signal
220
Radar System Receives Transponder Response Signal
230
Record Time Radar System Receives Transponder Response Signal
240
Determine Target Measured Range
243
Determine Target Measured Azimuth
244
Record Target Measured Range & Azimuth

201

FIG 2A

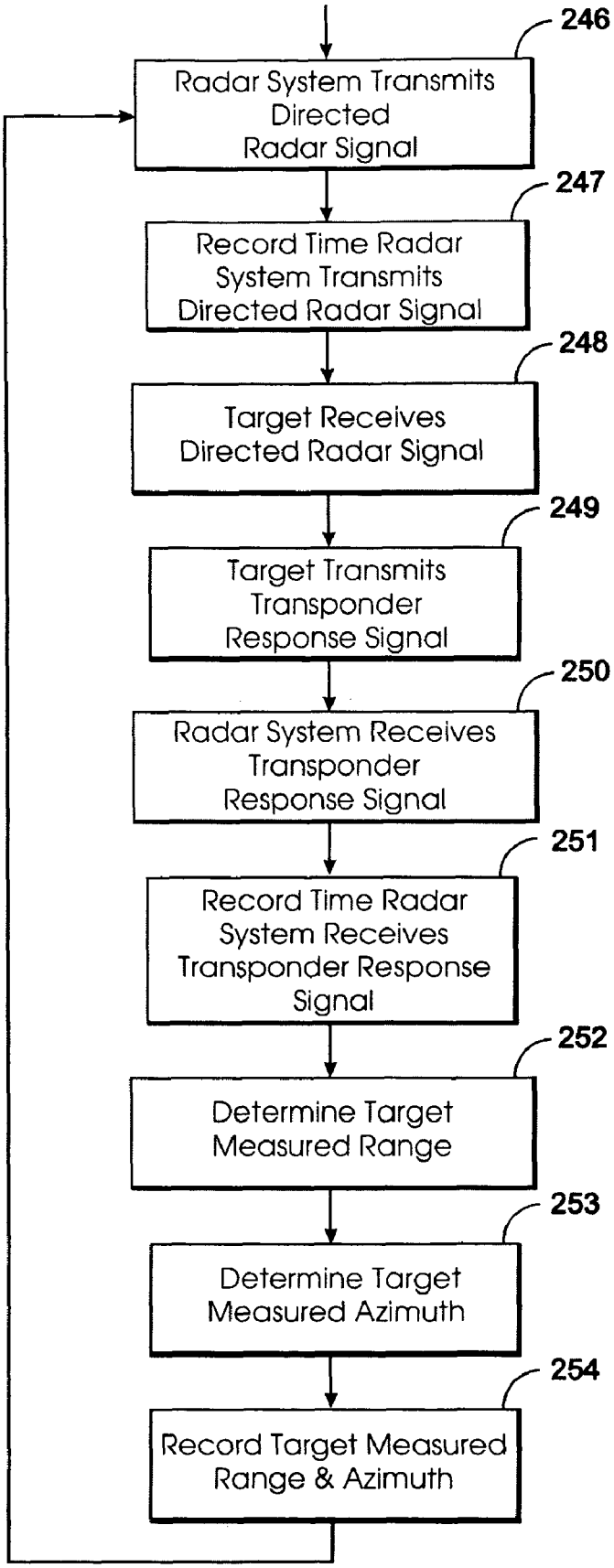

246
Radar System Transmits Directed Radar Signal
247
Record Time Radar System Transmits Directed Radar Signal
248
Target Receives Directed Radar Signal
249
Target Transmits Transponder Response Signal
250
Radar System Receives Transponder Response Signal
251
Record Time Radar System Receives Transponder Response Signal
252
Determine Target Measured Range
253
Determine Target Measured Azimuth
254
Record Target Measured Range & Azimuth
202

FIG 2B

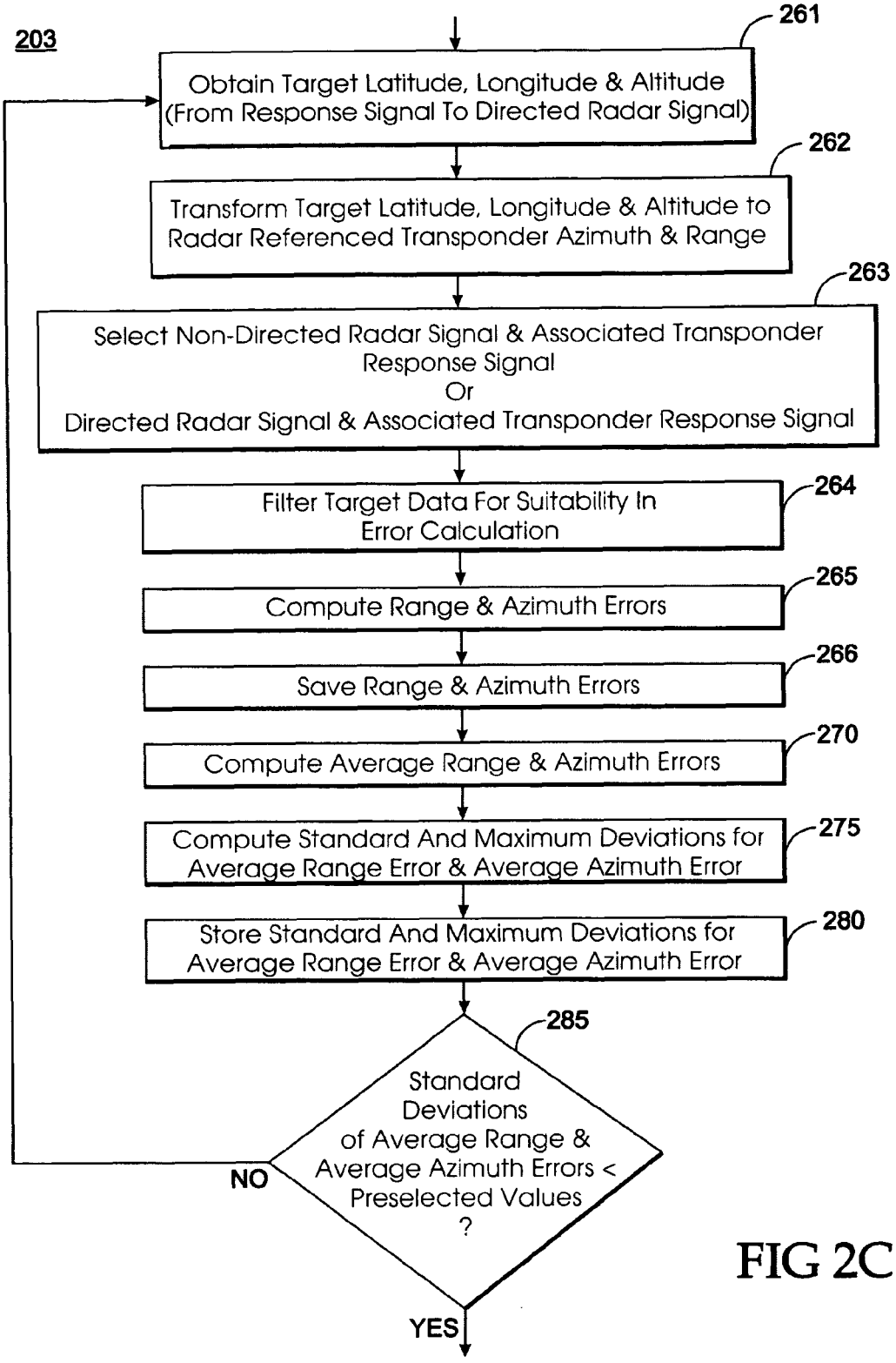

203
261
Obtain Target Latitude, Longitude & Altitude (From Response Signal To Directed Radar Signal)
262
Transform Target Latitude, Longitude & Altitude to Radar Referenced Transponder Azimuth & Range
263
Select Non-Directed Radar Signal & Associated Transponder Response Signal
Or
Directed Radar Signal & Associated Transponder Response Signal
264
Filter Target Data For Suitability In Error Calculation
265
Compute Range & Azimuth Errors
266
Save Range & Azimuth Errors
270
Compute Average Range & Azimuth Errors
275
Compute Standard And Maximum Deviations for Average Range Error & Average Azimuth Error
280
Store Standard And Maximum Deviations for Average Range Error & Average Azimuth Error
285
Standard Deviations of Average Range & Average Azimuth Errors < Preselected Values ?
NO
YES

FIG 2C

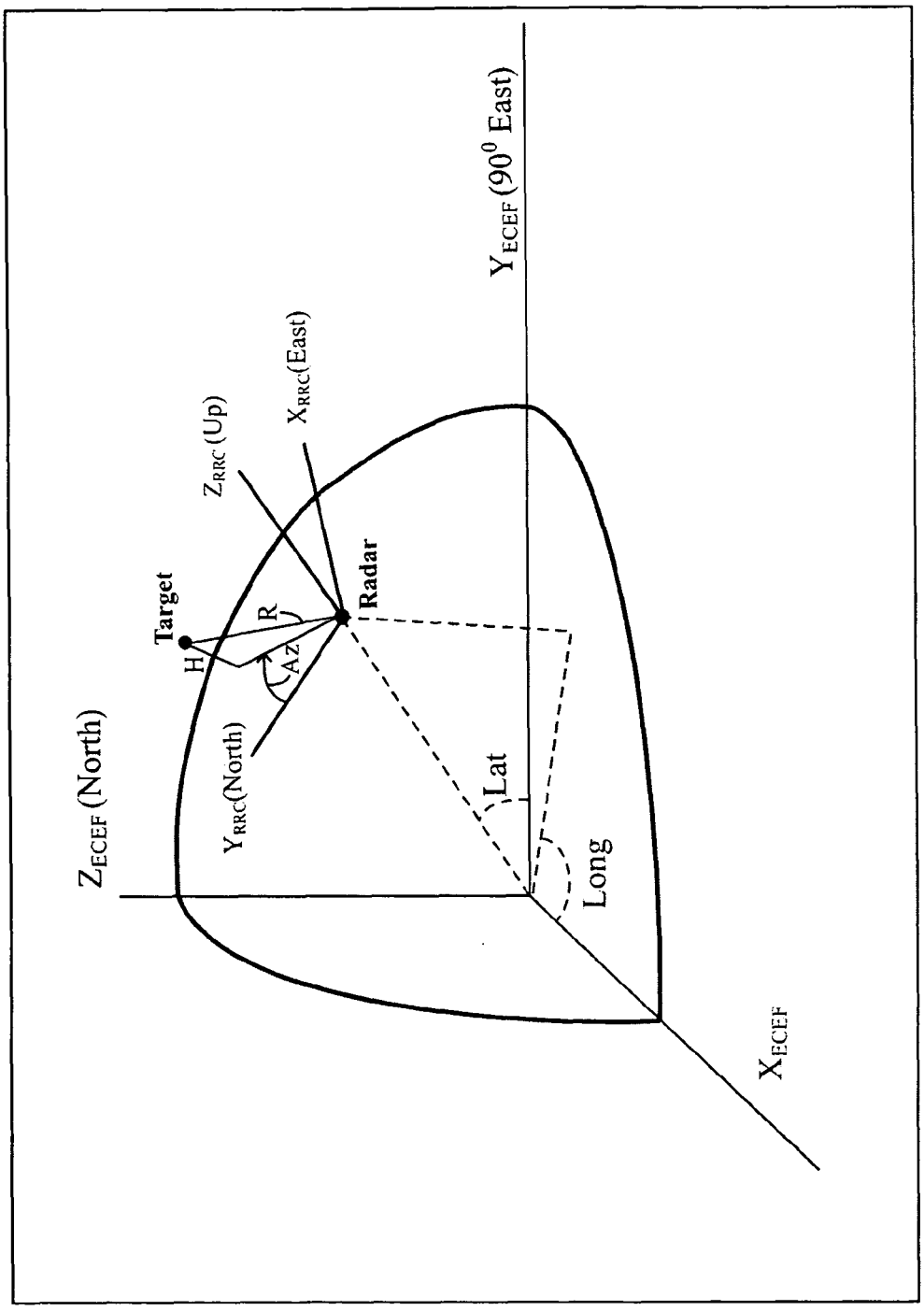

Y_{ECEF} (90^0 East)
Z_{RRC} (Up)
X_{RRC}(East)
Target
Radar
R
H
AZ
Y_{RRC}(North)
Z_{ECEF} (North)
Lat
Long
X_{ECEF}

FIG 3

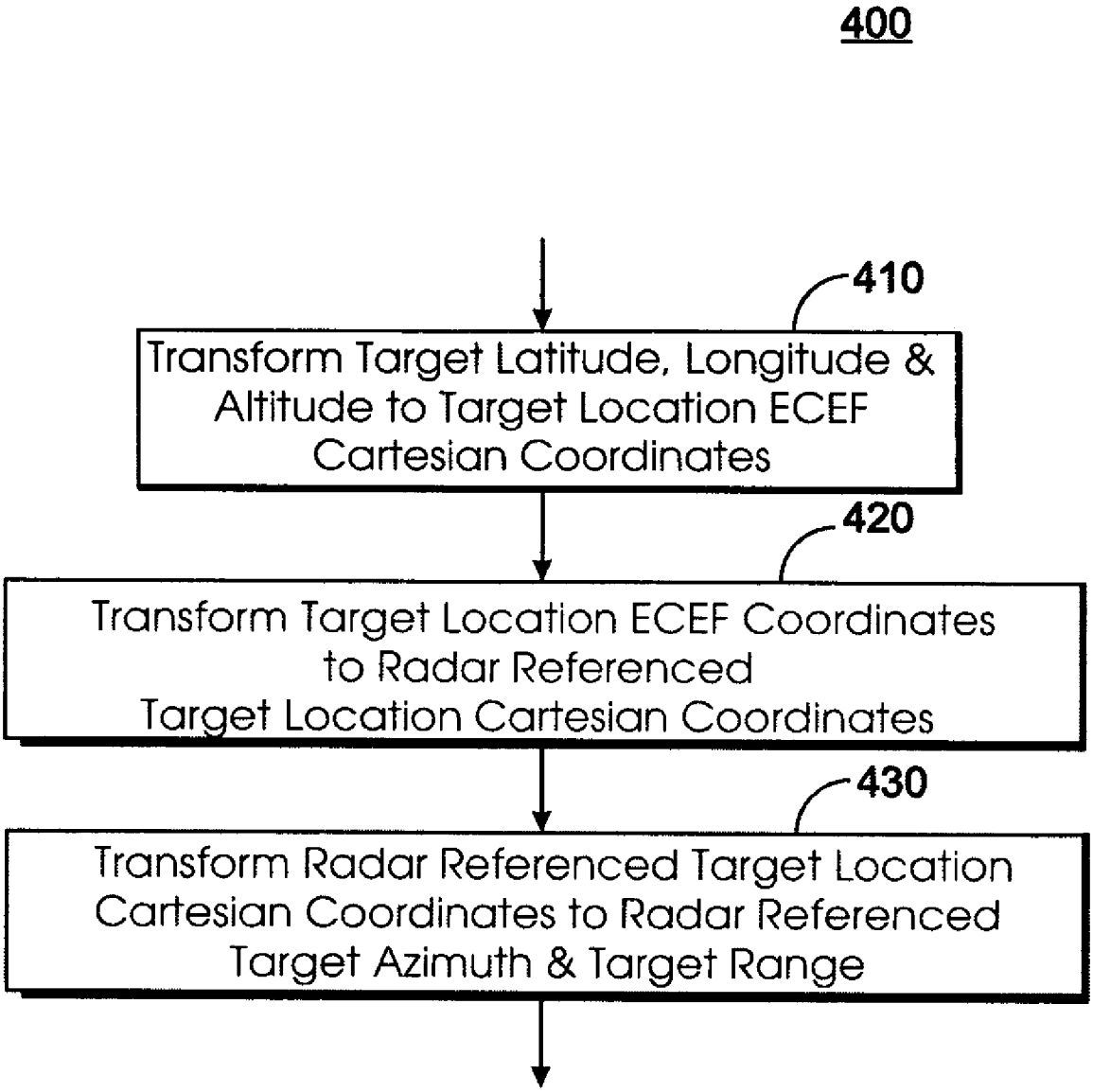

400
410
Transform Target Latitude, Longitude & Altitude to Target Location ECEF Cartesian Coordinates
420
Transform Target Location ECEF Coordinates to Radar Referenced Target Location Cartesian Coordinates
430
Transform Radar Referenced Target Location Cartesian Coordinates to Radar Referenced Target Azimuth & Target Range

FIG 4

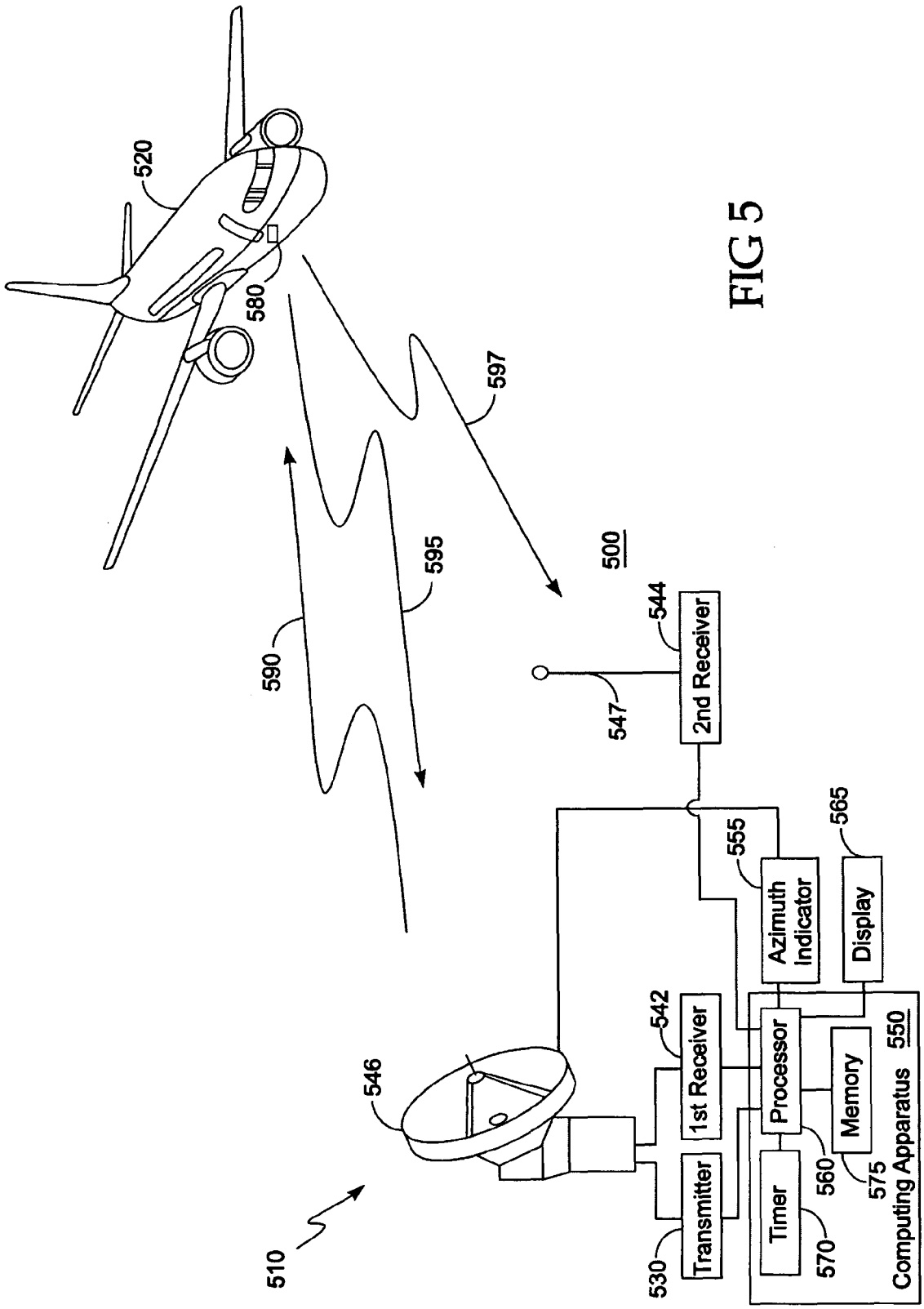

520
580
597
595
590
500
544
2nd Receiver
547
555
Azimuth Indicator
565
Display
542
1st Receiver
546
Processor
Memory
560
575
Timer
570
Transmitter
530
Computing Apparatus 550
510

FIG 5

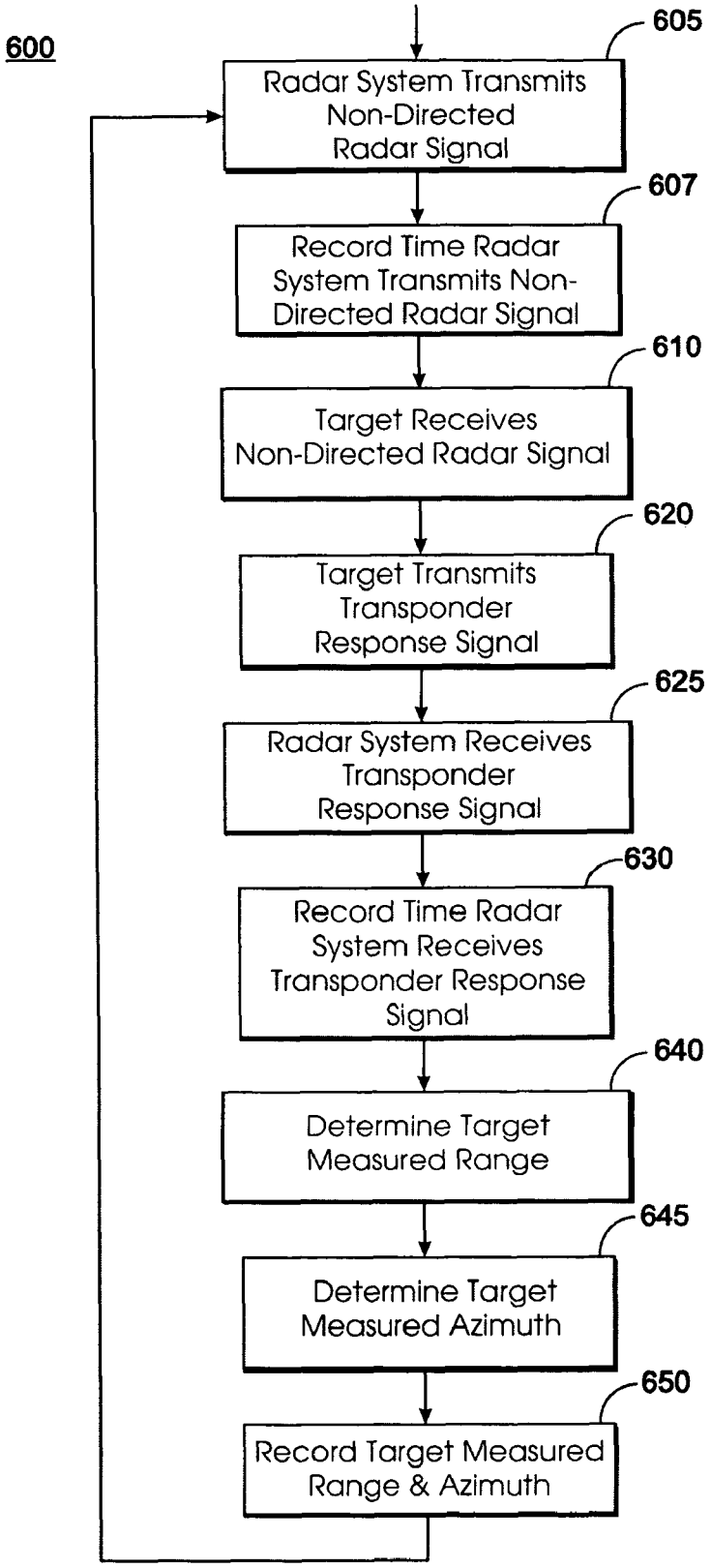

600
605
Radar System Transmits Non-Directed Radar Signal
607
Record Time Radar System Transmits Non-Directed Radar Signal
610
Target Receives Non-Directed Radar Signal
620
Target Transmits Transponder Response Signal
625
Radar System Receives Transponder Response Signal
630
Record Time Radar System Receives Transponder Response Signal
640
Determine Target Measured Range
645
Determine Target Measured Azimuth
650
Record Target Measured Range & Azimuth

FIG 6

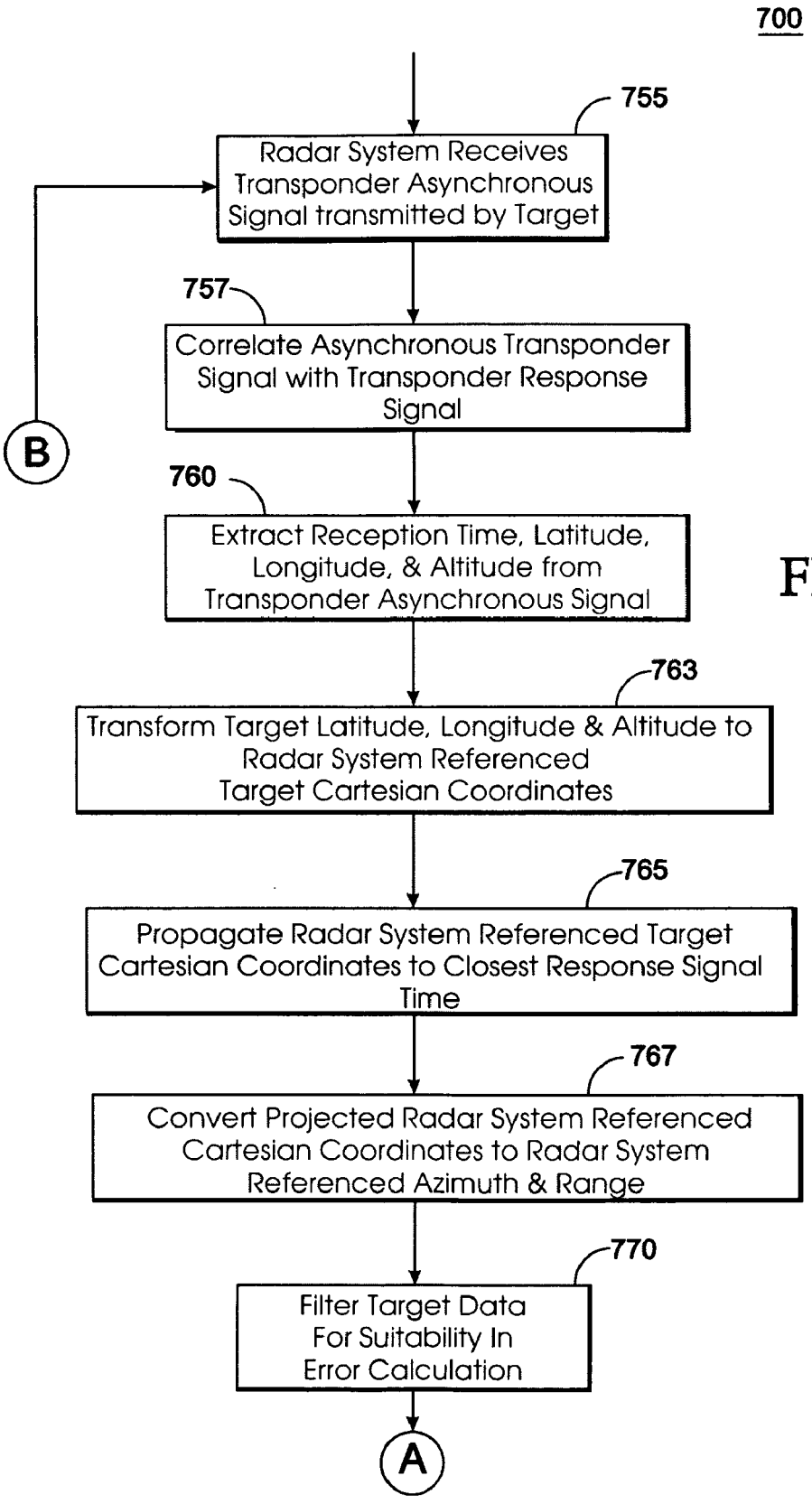

700
755
Radar System Receives Transponder Asynchronous Signal transmitted by Target
757
Correlate Asynchronous Transponder Signal with Transponder Response Signal
B
760
Extract Reception Time, Latitude, Longitude, & Altitude from Transponder Asynchronous Signal
763
Transform Target Latitude, Longitude & Altitude to Radar System Referenced Target Cartesian Coordinates
765
Propagate Radar System Referenced Target Cartesian Coordinates to Closest Response Signal Time
767
Convert Projected Radar System Referenced Cartesian Coordinates to Radar System Referenced Azimuth & Range
770
Filter Target Data For Suitability In Error Calculation
A

FIG 7

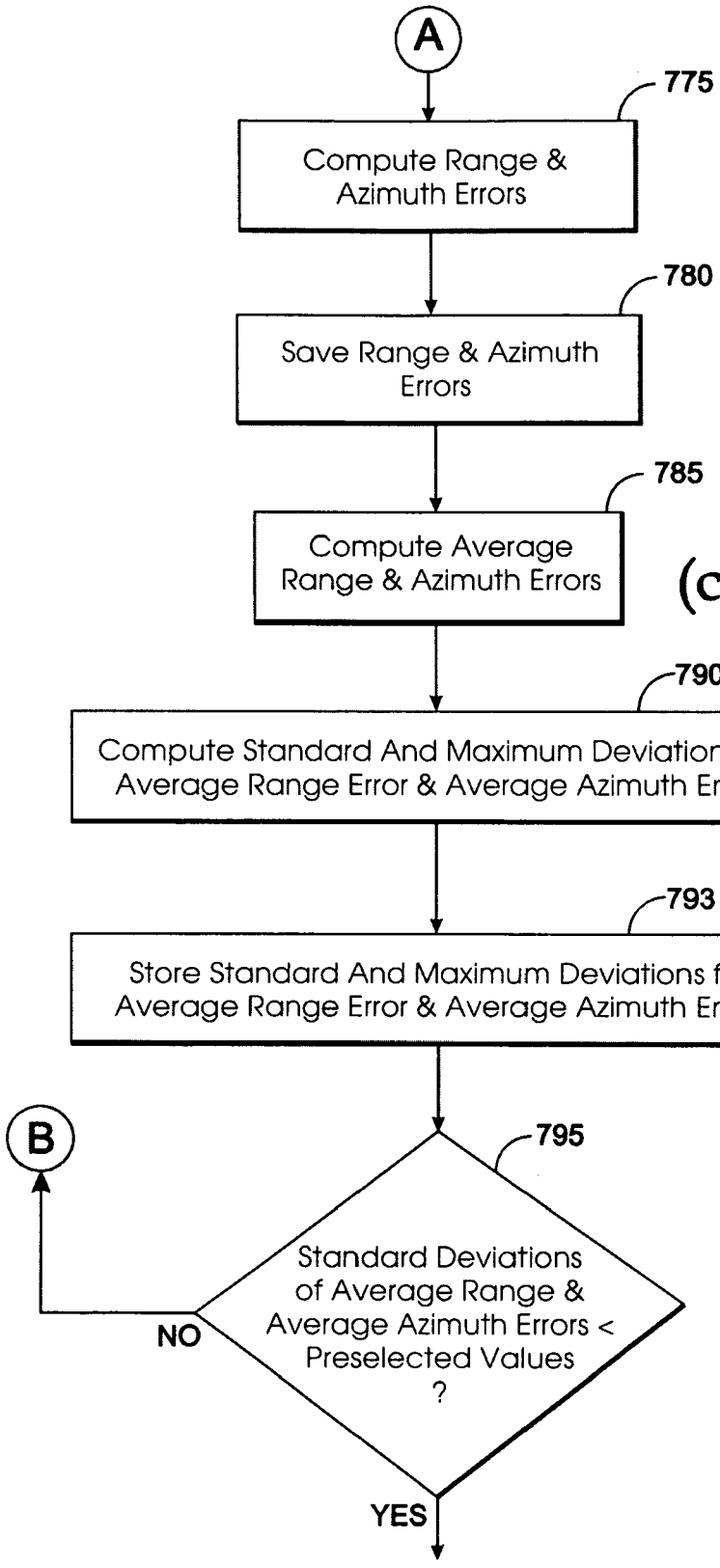


FIG 7 (continued)

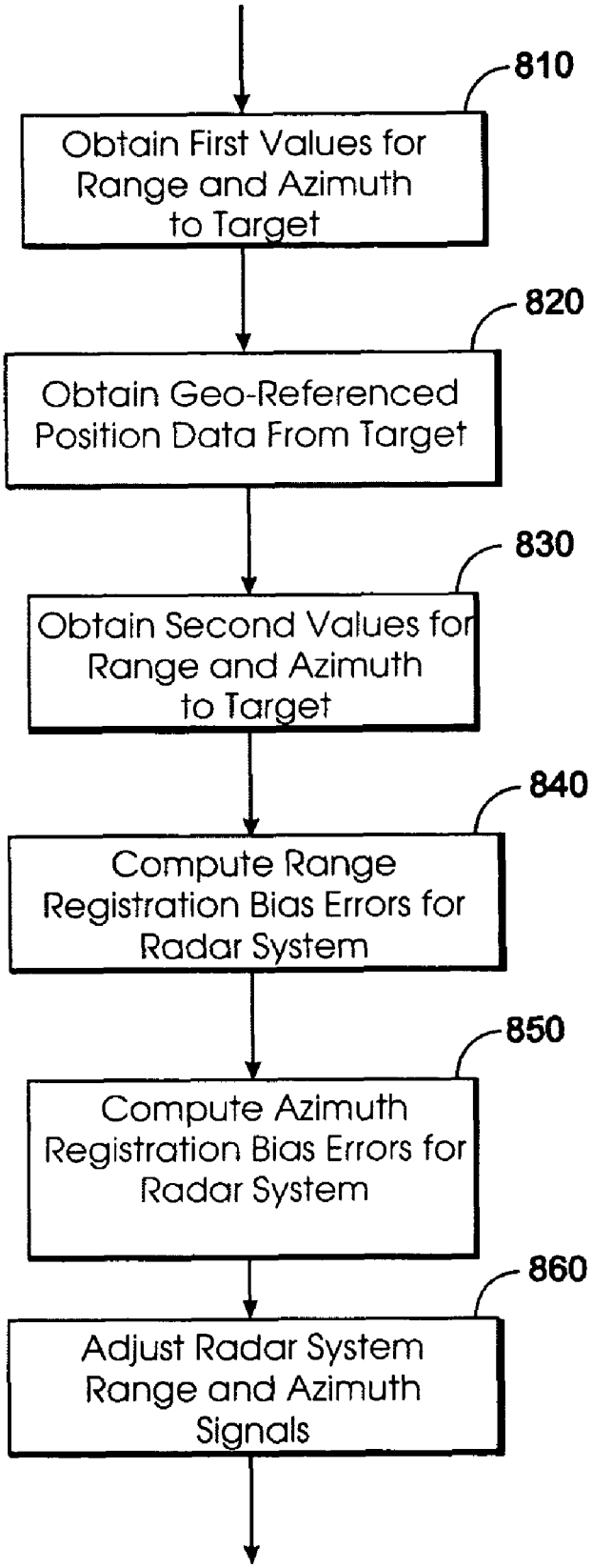

800
810
Obtain First Values for Range and Azimuth to Target
820
Obtain Geo-Referenced Position Data From Target
830
Obtain Second Values for Range and Azimuth to Target
840
Compute Range Registration Bias Errors for Radar System
850
Compute Azimuth Registration Bias Errors for Radar System
860
Adjust Radar System Range and Azimuth Signals

FIG 8

RADAR REGISTRATION USING TARGETS OF OPPORTUNITY

BACKGROUND

The ability to accurately locate the position of an aircraft detected by a radar system is an important capability of such systems. In particular, due to the speed at which modern aircraft operate, it is especially important for mid-air collision avoidance and in the control of landing approaches in inclement weather. The control of aircraft in a specified region of air space is referred to as air traffic control (ATC).

ATC systems often utilize a system referred to as the air traffic control radar beacon system (ATCRBS) which is used by ATC to enhance surveillance radar monitoring and separation of air traffic. ATCRBS assists ATC surveillance radars by acquiring information about the aircraft being monitored and providing this information to the radar controllers. The controllers can then use the information to identify radar returns from aircraft which are referred to as targets and to distinguish those returns from ground clutter. The aircraft's information is contained in the returned signal from a transponder located on the aircraft.

An ATC ground station usually includes two radar systems. The first is the primary surveillance radar (PSR). The second is the secondary surveillance radar (SSR). The primary surveillance radar operates by transmitting radio pulses, listening for any reflections from aircraft in its detection zone, and measuring the time between those transmitted pulses and their reflected pulses. The SSR depends on a cooperating transponder installed on an aircraft being tracked. The transponder emits a signal when it receives a signal from the secondary radar. The transponder can send encoded information about the aircraft, such as identity and altitude.

Errors in the locations of targets by radar systems such as ATC systems are compensated for by registration techniques. Current processes for accurately registering a radar system use an accurately surveyed transponder, referred to as a Position Adjustable Range Reference Orientation Transponder (PARROT). By comparing measured PARROT range and azimuth values to values derived from the surveyed position of the PARROT and the surveyed position of the radar, a bias or offset error in the radar system between the two can be calculated and then compensated for. The process involves measuring the PARROT range and azimuth data over multiple scans and applying proper filtering to achieve the required registration accuracy.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings provide visual representations which will be used to more fully describe various representative embodiments and can be used by those skilled in the art to better understand the representative embodiments disclosed herein and their inherent advantages. In these drawings, like reference numerals identify corresponding elements.

FIG. **1** is a drawing of a registration system for a directed mode registration of a radar system using a target of opportunity as described in various representative embodiments.

FIG. **2**A is a flowchart of a method for obtaining measured target range and azimuth data for the directed mode registration of the radar system using the target of opportunity of FIG. **1**.

FIG. **2**B is a flowchart of another method for obtaining measured target range and azimuth data for the directed mode registration of the radar system using the target of opportunity of FIG. **1**.

FIG. **2**C is a flowchart of a method for the directed mode registration of a radar system using the target of opportunity of FIG. **1**.

FIG. **3** is a drawing of various coordinate systems used in computing the target range and azimuth obtained from the response signal from the target transponder as described in various representative embodiments.

FIG. **4** is a flowchart of a method for transforming the target range and azimuth as described in various representative embodiments.

FIG. **5** is a drawing of a registration system for an asynchronous mode registration of a radar system using a target of opportunity as described in various representative embodiments.

FIG. **6** is a flowchart of a method for obtaining measured range and azimuth data for the asynchronous mode registration of a radar system using the target of opportunity of FIG. **5**.

FIG. **7** is a flowchart of a method for the asynchronous mode registration of a radar system using the target of opportunity of FIG. **5**.

FIG. **8** is a flowchart of a method for registering a radar system as described in various representative embodiments.

DETAILED DESCRIPTION

As shown in the drawings for purposes of illustration, novel techniques are disclosed herein for accurate radar registration using targets of opportunity that are detected by the radar. Previously, to obtain sufficiently accurate range and azimuth bias data an accurately located Position Adjustable Range Reference Orientation Transponder (PARROT) was used. Techniques disclosed herein eliminate the need for the PARROT in the registration process. This elimination results in reduced radar installation costs and provides registration capability in tactical situations where a PARROT may not be available or cannot be optimally sited.

In particular, the de-facto standard for Monopulse Secondary Surveillance Radar (MSSR) range and accuracy bias performance is found in Eurocontrol Mode S Station Functional Specification (SUR/MODES/EMS/SPE-01). This document specifies a Range Accuracy of $1/128$ NM (~47 ft) and an Azimuth Accuracy of 0.022 degrees. Mode S which stands for "mode select" is a discrete selective interrogation radar rather than a general broadcast system. Mode S transponders on the aircraft ignore interrogations not addressed with their unique identity code which reduces channel congestion.

While the present invention is susceptible of embodiment in many different forms, there is shown in the drawings and will herein be described in detail one or more specific embodiments, with the understanding that the present disclosure is to be considered as exemplary of the principles of the invention and not intended to limit the invention to the specific embodiments shown and described. In the following description and in the several figures of the drawings, like reference numerals are used to describe the same, similar or corresponding parts in the several views of the drawings.

Targets of opportunity can be employed for the radar system registration process when using Mode S. Monopulse Secondary Surveillance Radar (MSSR) has the capability to receive aircraft latitude, longitude and altitude information, either through a directed interrogation or via an Automatic Dependent Surveillance Broadcast (ADS-B). By converting

the target reported latitude/longitude geographical data to radar system polar coordinates, the error between the measured (range and azimuth) and target reported (latitude/longitude) positions can be calculated and the registration correction value extracted. However, both radar system measured and target reported position data samples can contain significant random errors. By taking multiple samples over a number of scans for all qualified targets of opportunity, and by applying proper filtering, the random error is significantly reduced yielding range and azimuth registration correction values that can meet accuracy requirements.

A list of the advantages and disadvantages of the directed interrogation method for the registration of a radar system is shown in Table 1.

TABLE 1

Advantages and Disadvantages of the Directed Interrogation Method

Advantages	Disadvantages
Simpler system configuration No separate ADS-B antenna/receiver required	Higher interrogation rate Additional interrogations required to acquire target Lat/Long
Greater accuracy No correlation of Lat/Long data to radar-measured range/azimuth required No time alignment required Faster Fewer corrupted samples due to directional antenna being less susceptible to FRUIT than ADS-B Omni antenna	

In the directed Mode S Ground-initiated Comm-B (GICB) interrogation mode, target position data is transferred to its transponder from its on-board global positioning satellite/inertial navigation system (GPS/INS system) and stored in Comm-B Data Selector (BDS) registers 0,5 and/or 5,1 and 5,2. Comm-B is a Mode S standard length (56-bit) communication protocol which is used to transmit data from the transponder to the interrogator. Once the interrogator acquires the aircraft and establishes it on its Mode S roll call schedule, it requests a downlink of the Latitude and Longitude data contained in the desired register(s).

The target latitude, longitude and altitude data is associated with the measured range and azimuth position. However, both data sources may provide erroneous information. The SSR data may contain registration bias errors and random measurement errors. The GICB data may contain errors due to lack of GPS data, INS drift, and/or latency in reporting.

To compensate for the errors associated with each individual sample, the target latitude/longitude position is converted to radar system referenced polar coordinates where it is compared to the radar system measured position. This comparison yields separate range and azimuth error estimates. These estimates are filtered/averaged over time providing increasingly accurate range and azimuth corrections that, when applied to the target position, can meet accuracy requirements.

In a representative example, upon receipt of the proper Mode S interrogation signal (standard or Comm-A requesting information in transponder BDS registers 0,5 and/or 5,1 and 5,2), the aircraft, if capable, will respond with Comm-B messages that contain the compact position report (CPR) position found in BDS 0,5 or coarse target position found in Comm-B Data Selector (BDS) 5,1 and fine target position found in BDS 5,2. Concurrently, the MSSR will measure and store the target's range and azimuth. The format of the data contained in the message MB fields for BDS register 0,5 is shown in Table 2 and for BDS registers 5,1 and 5,2 in Table 3. The minimum data update rate for register 0,5 is 0.2 seconds. The minimum update rate for registers 5,1 and 5,2 is 0.5 seconds (reference ICAO Annex 10, Volume III, pg 5-64 and 5-65).

TABLE 2

BDS 0,5 Message Format

BDS Register	Bits	Data Type	Remarks
0,5	1 to 5	Format Type Code (MSB to LSB)	0: No position information 1-4: Identification (N/A) 5-8: Surface Position (N/A) 9: $\mu < 3$ m 10: 3 m $\leqq \mu <$10 m, Baro altitude 11: 10 m $\leqq \mu <$ 0.05 NM, Baro altitude 12: 0.05 NM $\leqq \mu <$ 0.1 NM, Baro altitude 13: 0.1 NM $\leqq \mu <$ 0.25 NM, Baro altitude 14: 0.25 NM $\leqq \mu <$ 0.5 NM, Baro altitude 15: 0.5 NM $\leqq \mu <$ 1.0 NM, Baro altitude 16: 1.0 NM $\leqq \mu <$ 5.0 NM, Baro altitude 17: 5.0 NM $\leqq \mu <$ 10.0 NM, Baro altitude 18: $\mu \geqq$ 10.0 NM 19: Velocity (N/A) 20: $\mu <$ 3 m, GNSS Height 21: $\mu <$ 10 m, GNSS Height 22: $\mu \geqq$ 25 m, GNSS Height 23-31: Reserved μ = 95% containment radius, horizontal position error
	6 to 7	Surveillance Status	0: No condition information 1: Permanent alert (emergency condition) 2: Temp alert 3: SPI condition
	8	Single Antenna Flag	0: dual transmit antenna system 1: single transmit antenna
	9 to 20	Altitude	Specified by format type code: Altitude code as specified in 3.1.2.6.5.4 of ICAO Annex 10 Vol. IV, with M-bit removed. GNSS height
	21	Time	Valid for Format codes 9, 10, 20 and 21 only. 0: time of applicability not synchronized to UTC 1: time of applicability synchronized to UTC
	22	CPR Format	Indicated CPR formatting type 0: even format CPR coding 1: odd format CPR coding
	23 to 39	Encoded Latitude	CPR airborne format
	40 to 56	Encoded Longitude	CPR airborne format

TABLE 3

BDS 5,1 and 5,2 Message Formats

BDS Register	Bits	Data Type	Remarks
5,1	1	Status	Set to 0 if any of the three parameters reported are invalid.
	2	Latitude Sign	0 = North, 1 = South.

TABLE 3-continued

BDS 5,1 and 5,2 Message Formats

BDS Register	Bits	Data Type	Remarks
	3 to 21	Coarse Latitude (MSB to LSB)	Range −180 to +180, MSB 90 degrees, LSB 360/1048576 degrees. 2's compliment. (Only +90 to −90 are actually used)
	22	Longitude Sign	0 = East, 1 = West.
	23 to 41	Coarse Longitude (MSB to LSB)	Range −180 to +180, MSB 90 degrees, LSB 360/1048576 degrees. 2's compliment.
	42	Altitude sign	0 = positive, 1 = negative
	43 to 56	Pressure Altitude (MSB to LSB)	From −1000 feel to 126,752 feet, LSB 8 feet
5,2	1	Status	Set to 0 if any of the three parameters reported are invalid. (Identical to register 5,1)
	2-5	FOM/ Source coding	0 = FOM > 10 NM or unknown accuracy 1 = FOM 10 NM, pressure altitude 2 = FOM 4 NM, pressure altitude 3 = FOM 2 NM, pressure altitude 4 = FOM 1 NM, pressure altitude 5 = FOM 0.5 NM, pressure altitude 6 = FOM 0.3 NM, pressure altitude 7 = FOM 0.1 NM, pressure altitude 8 = FOM 0.05 NM, pressure altitude 9 = FOM 30 m, pressure altitude 10 = FOM 10 m, pressure altitude 11 = FOM 3 m, pressure altitude 12 = FOM 30 m, GNSS height 13 = FOM 10 m, GNSS height 14 = FOM 3 m, GNSS height 15 = Reserved
	6 to 23	Fine Latitude (MSB to LSB)	Range 0 to +180/128, MSB 90/ 128 degrees, LSB 90/16777216 degrees. 2's compliment.
	24 to 41	Fine Longitude (MSB to LSB)	Range 0 to +180/128, MSB 90/ 128 degrees, LSB 90/16777216 degrees. 2's compliment.
	42	Altitude sign	0 = positive, 1 = negative
	43 to 56	Altitude (MSB to LSB)	From −1000 feel to 126,752 feet, LSB 8 feet

FIG. **1** is a drawing of a registration system **100** for a directed mode registration of a radar system **110** using a target **120** of opportunity as described in various representative embodiments. In FIG. **1**, the registration system **100** comprises the radar system **110** and the target **120** of opportunity. The radar system **110** comprises a transmitter **130**, a receiver **140**, an antenna **145**, a computing apparatus **150**, an azimuth indicator **155** and a display **165**. The computing apparatus **150** comprises a processor **160** which could be a computer processor **160**, a timer **170** and a memory **175**. The target **120** of opportunity comprises a transponder **180**. In the representative embodiment of FIG. **1**, the antenna **145** is coupled to the transmitter **130**, the receiver **140** and to the azimuth indicator **155**. The transmitter **130** is further coupled to the processor **160**; the receiver **140** is further coupled to the processor **160**; and the processor **160** is further coupled to the azimuth indicator **155**, to the display **165**, to the timer **170** and to the memory **175**.

In operation, the transmitter **130** of the radar system **110** transmits non-directed radar signals **191** via the antenna **145** which are received by the transponder **180** located on the target **120**. The timer **170** records the time each non-directed radar signal **191** is transmitted. Following reception of each non-directed radar signal **191** by the transponder **180**, it transmits a transponder response signal **195** which is detected by the receiver **140** via the antenna **145**. Upon reception of each transponder response signal **195**, the timer **170** record the time of reception. A range to the target **120** is measured by the processor **160** based on the time a given non-directed radar signal **191** was transmitted by the transmitter **130** and the time its corresponding transponder response signal **195** was received by the receiver **140**. An azimuth to the target is measured by knowing the azimuth at which the antenna **145** is pointing at the time that each transponder response signal **195** is received by the receiver **140**.

Interleaved with the non-directed radar signals **191**, the transmitter **130** of the radar system **110** transmits a directed radar signal **190** via the antenna **145** which is received by the transponder **180** located on the target **120**. The transponder **180** then transmits a transponder response signal **195** which is detected by the receiver **140** via the antenna **145**. Target reported values for the range and azimuth of the target **120** relative to the radar system are obtained from computations based on information received in the transponder response signal **195** from the target **120**. Information (latitude, longitude, and altitude of the target **120**) received in the transponder response signal **195** can comprise Global Positioning System (GPS) location information, inertial navigation system (INS) location information, and/or other appropriate location information for the target **120**. By converting the target **120** reported latitude/longitude geographical data to radar polar coordinates, the error between the measured (range and azimuth) and target **120** reported (latitude/longitude) positions can be calculated and registration correction values for range and azimuth for the radar system **110** extracted. Range and azimuth values compensated respectively by the range and azimuth error bias values and/or target **120** location relative to the radar system **110** can be displayed on the display **165**.

FIG. **2**A is a flowchart of a method **201** for obtaining measured target **120** range and azimuth data for the directed mode registration of the radar system **110** using the target **120** of opportunity of FIG. **1**. In block **205**, of FIG. **2**A, the radar system **110** transmits a non-directed radar signal **191** that includes instructions to the target(s) that receive the signal to respond with a transponder response signal **195**. Block **205** then transfers control to block **207**.

In block **207**, the time that the non-directed radar signal **191** is transmitted is recorded. Block **207** then transfers control to block **210**.

In block **210**, the target **120** receives the non-directed radar signal **191**. Block **210** then transfers control to block **215**.

In block **215**, the target **120** transponder **180** transmits a transponder response signal **195** in response to the non-directed radar signal **191** received by the transponder **180**. Block **215** then transfers control to block **220**.

In block **220**, the radar system **110** receives the transponder response signal **195** from the target **120**. Block **220** then transfers control to block **230**.

In block **230**, the time that the transponder response signal **195** is received by the radar system **110** receiver **140** is recorded. Block **230** then transfers control to block **240**.

In block **240**, the time that the non-directed radar signals **191** is transmitted and the time that the transponder response signal **195** is received by the radar system **110** receiver **140** are used to determine the target **120** measured range R_m. Block **240** then transfers control to block **243**.

In block **243**, a measured azimuth Az_m from the radar system **110** to the target **120** is obtained from the direction in which the antenna **145** of the radar system **110** is pointing at the time that the transponder response signal **195** is received by the radar system **110** receiver **140**. Block **243** then transfers control to block **244**.

In block **244**, the measured range R_m and azimuth Az_m from the radar system **110** to the target **120** is recorded in the memory **175**. Block **244** then transfers control to block **205** wherein subsequently either the same target **120** or a different target **120** could receive the non-directed radar signal **191** in block **210**.

FIG. **2**B is a flowchart of another method **202** for obtaining measured target range and azimuth data for the directed mode registration of the radar system **110** using the target **120** of opportunity of FIG. **1**. In block **246**, of FIG. **2**B, the radar system **110** transmits a directed radar signal **190** that includes instructions to the target **120** to which it is directed to respond with a transponder response signal **195**. Block **246** then transfers control to block **247**.

In block **247**, the time that the directed radar signal **190** is transmitted is recorded in the memory **175**. Block **247** then transfers control to block **248**.

In block **248**, the target **120** receives the directed radar signal **190**. Block **248** then transfers control to block **249**.

In block **249**, the target **120** transponder **180** transmits a transponder response signal **195** in response to the directed radar signal **190** received by the transponder **180**. Block **249** then transfers control to block **250**.

In block **250**, the radar system **110** receives the transponder response signal **195** from the target **120**. Block **250** then transfers control to block **251**.

In block **251**, the time that the transponder response signal **195** is received by the radar system **110** receiver **140** is recorded in the memory **175**. Block **251** then transfers control to block **252**.

In block **252**, the time that the directed radar signal **190** is transmitted and the time that the transponder response signal **195** is received by the radar system **110** receiver **140** is used to determine the target **120** measured range R_m. Block **252** then transfers control to block **253**.

In block **253**, a measured azimuth Az_m from the radar system **110** to the target **120** is obtained from the direction in which the antenna **145** of the radar system **110** is pointing at the time that the transponder response signal **195** is received by the radar system **110** receiver **140**. Block **253** then transfers control to block **254**.

In block **254**, the measured range R_m and azimuth Az_m from the radar system **110** to the target **120** are recorded in the memory **175**. Block **254** then transfers control to block **246** wherein subsequently either the same target **120** or a different target **120** could receive the directed radar signal **190** in block **248**.

FIG. **2**C is a flowchart of a method **203** for the directed mode registration of a radar system **110** using the target **120** of opportunity of FIG. **1**.

In block **261**, the latitude, longitude, and altitude of the target **120** are extracted from the transponder response signal **195** (in response to the directed radar signal **190**) by the radar system **110** processor **160**. Block **261** then transfers control to block **262**.

In block **262**, the latitude, longitude, and altitude of the target **120** are transformed to radar referenced azimuth and range to the target **120** by the radar system **110** processor **160**. The range and azimuth obtained in this process is referred to herein as the computed range R_c and the computed azimuth Az_c. A method for performing this transformation will be shown in more detail in the discussion of FIG. **4**. Block **262** then transfers control to block **263**.

In block **263**, a non-directed radar signal **191** and its associated transponder response signal **195** are selected or a directed radar signal **190** and its associated transponder response signal **195** are selected as the source for the radar measured range R_m and azimuth Az_m. Block **263** then transfers control to block **264**.

In block **264**, the target **120** is tested against user-defined filters to determine if it is suitable for use in the error calculation. Filters can include minimum and maximum range/azimuth/altitude, Figure of Merit (FOM), range and azimuth outlier, minimum and maximum velocity, and UTC time sync (for BDS 0,5 only). Targets that fail the filter criteria are discarded. Block **264** then transfers control to block **265**.

In block **265**, the difference between the computed azimuth Az_c and the measured azimuth Az_m from the radar system **110** to the target **120** are used by the radar system **110** processor **160** to compute an azimuth registration error Az_b which is also referred to herein as an azimuth registration bias error Az_b, and the difference between the computed range R_c and the measured range R_m from the radar system **110** to the target **120** are used by the radar system **110** processor **160** to compute a range registration error R_b which is also referred to herein as a range registration bias error R_b. Block **265** then transfers control to block **266**.

In block **266**, the azimuth registration error Az_b and the range registration error R_b obtained in block **265** are stored in the memory **175**. Block **266** then transfers control to block **270**.

In block **270**, average range and azimuth registration errors R_b,Az_b are calculated by averaging the difference between the target's **120** reported position and the radar system **110** measured position for any previous data for the present and other targets **120** used in the process. Block **270** then transfers control to block **275**.

In block **275**, standard and maximum deviations for average range and azimuth registration errors R_b,Az_b are computed. Block **275** then transfers control to block **280**.

In block **280**, the standard and maximum deviations for average range and azimuth registration errors R_b,Az_b in block **275** are stored in the memory **175**. Block **280** then transfers control to block **285**.

If the standard deviations for average range and azimuth registration errors R_b,Az_b obtained in block **275** are less than preselected values, block **285** terminates the process. Otherwise, block **285** transfers control to block **261**.

FIG. **3** is a drawing of various coordinate systems used in computing the target **120** range R and azimuth Az obtained from the transponder response signal **195** from the target **120** transponder **180** as described in various representative embodiments. For each reporting target **120**, the registration error is calculated as the difference between the target **120** position as reported by the target **120** (latitude/longitude) and the measured position by the radar system **110** (range/azimuth). Referring to FIG. **3**, to calculate this error in a representative embodiment, the target latitude/longitude position is converted to the local radar polar position as follows: (1) the latitude/longitude and altitude data reported by the target **120** are transformed to the geocentric Earth-Centered, Earth-Fixed (ECEF) Cartesian coordinates utilizing the World Geodetic System latest revision WGS-84 ellipsoid Earth model, (2) the ECEF coordinates are converted to local Cartesian radar referenced coordinates, and (3) the local Cartesian radar referenced coordinates are converted to local polar coordinates with the radar system **110** being at the center of the local polar coordinate system.

The ECEF Cartesian coordinate system represents a position as an X, Y, and Z coordinate. The point (0,0,0) denotes the mass center of the earth, and the z-axis is defined as being parallel to the earth rotational axes, pointing towards north. The x-axis intersects the sphere of the earth at 0° latitude and 0° longitude. Thus the ECEF coordinate system rotates with the earth around its z-axis and the ECEF coordinates of a point fixed on the surface of the earth do not change. The World Geodetic System is a standard used in navigation among other areas and comprises a standard coordinate frame for the Earth based on a standard spheroidal reference surface that defines the nominal sea level.

The ECEF coordinate vector $\vec{X}$ is described by the expression of equation (1),

$$\vec{X}_{ECEF} = \begin{bmatrix} X_{ECEF} \\ Y_{ECEF} \\ Z_{ECEF} \end{bmatrix} \quad (1)$$

where

$$X_{ECEF} = \left(\frac{a}{K} + h\right)\cos(Lat)\cos(Long) \quad (2)$$

$$Y_{ECEF} = \left(\frac{a}{K} + h\right)\cos(Lat)\sin(Long) \quad (3)$$

$$Z_{ECEF} = \left(\frac{a(1-e^2)}{K} + h\right)\sin(Lat) \quad (4)$$

where Lat and Long are the latitude and longitude of the target **120**.

In the above equations, a, h, K and e^2 are given as:

a=6378137.0 m (earth's semi-major axis, WGS-84)

h=height

$K=\sqrt{1-e^2\sin^2(\text{Lat})}$

$e^2=2f-f^2$ (1^{st} eccentricity squared)

where,

$$f = \frac{1}{298.257223563} \quad \text{(earth's flattening, WGS-84)}$$

Using the expressions (2) through (4) above, the target and radar latitude and longitude (Lat and Long) are both converted to ECEF coordinates.

The target data is then converted to Cartesian Radar Referenced Coordinates:

$$\vec{X}_{RRc} = A(\vec{X}_{tgt} - \vec{X}_{radar}) \quad (5)$$

$$\vec{X}_{RRC} - A\Delta\vec{X} \quad (6)$$

where $\vec{X}_{tgt}$ and $\vec{X}_{radar}$ are the ECEF target and radar coordinate calculated in (2) through (4) above. The A matrix is given as:

$$A = \begin{bmatrix} -\sin(Long_R) & \cos(Long_R) & 0 \\ -\sin(Lat_R)\cos(Long_R) & -\sin(Lat_R)\sin(Long_R) & \cos(Lat_R) \\ \cos(Lat_R)\cos(Long_R) & \cos(Lat_R)\sin(Long_R) & \sin(Lat_R) \end{bmatrix} \quad (7)$$

where Lat_R and Long_R are the radar system **110** latitude and longitude.

Simplifying (6) and (7), the RRC target values, X_{tgt}, Y_{tgt} and Z_{tgt} are:

$$X_{tgt} = -\Delta X \sin(\text{Long}_R) + \Delta Y \cos(\text{Long}_R) \quad (8)$$

$$Y_{tgt} = -\Delta X \sin(\text{Lat}_R)\cos(\text{Long}_R) - \Delta Y \sin(\text{Lat}_R)\sin(\text{Long}_R) + \Delta Z \cos(\text{Lat}_R) \quad (9)$$

$$Z_{tgt} = \Delta X \cos(\text{Lat}_R)\cos(\text{Long}_R) + \Delta Y \cos(\text{Lat}_R)\sin(\text{Long}_R) + \Delta Z \sin(\text{Lat}_R) \quad (10)$$

where: ΔX, ΔY and ΔZ are the components of the difference vector $\Delta\vec{X}$.

The target range and azimuth can now be calculated from the expression below:

$$R_{tgt} = \sqrt{X^2_{tgt} + Y_{tgt}{}^2 + Z_{tgt}{}^2} \quad (11)$$

$$Az_{tgt} = \tan^{-1}\left(\frac{X_{tgt}}{Y_{tgt}}\right) \quad (12)$$

The range and azimuth registration errors are calculated by averaging the difference between the targets reported position and the radar measured position for all N targets used in the process as in equations (13) and (14).

$$R_{reg} = \frac{1}{N}\sum_{N}(R_{tgt} - R_{measured}) \quad (13)$$

$$Az_{reg} = \frac{1}{N}\sum_{N}(Az_{tgt} - Az_{measured}) \quad (14)$$

As more data is collected, the registration error, due to the averaging process, becomes more accurate. A count of the number of plots used for the registration process as well as a standard deviation value can be used for registration quality and for determining when to terminate an automatic registration process.

For proper registration, the aircraft position at the time the radar data is collected should be known to the best possible accuracy. Unfortunately, this may not be the case (i.e. INS drift, reporting time delay, poor GPS FOM). However, unlike the case of a PARROT where data is provided by a single source, the targets of opportunity provide multiple data sources having their errors randomly spread over time and space. Thus, the data reported by the different targets can be averaged and the bias error can be extracted to the required accuracy.

FIG. **4** is a flowchart of a method **400** for transforming the target range and azimuth as described in various representative embodiments. In a representative embodiment, the steps of FIG. **4** replace block **262** of FIG. **2**C. In the case of FIG. **2**C, once block **261** of FIG. **2**C has completed obtaining target **120** latitude, longitude and altitude, block **261** transfers control to block **410** of FIG. **4**. In block **410** of FIG. **4**, the target **120** latitude, longitude and altitude information contained in the transponder response signal **195** are transformed in a representative embodiment to target **120** location ECEF Cartesian coordinates wherein ECEF Cartesian coordinates are the geocentric Earth-Centered, Earth-Fixed (ECEF) Cartesian coordinates utilizing the World Geodetic System latest revision WGS-84 ellipsoid Earth model. Block **410** then transfers control to block **420**.

In block **420**, the ECEF coordinates are converted to local Cartesian radar referenced coordinates. Block **420** then transfers control to block **430**.

In block **430**, the local Cartesian radar referenced coordinates are converted to local polar coordinates with the radar system **110** being at the center of the local polar coordinate system. In the representative embodiment wherein the steps of FIG. **4** replace block **262** of FIG. **2**C, block **430** then transfers control to block **263** of FIG. **2**C.

FIG. **5** is a drawing of a registration system **500** for an asynchronous mode registration of a radar system **510** using a target **520** of opportunity as described in various representative embodiments. In FIG. **5**, the registration system **500** comprises the radar system **510** and the target **520** of opportunity. The radar system **510** comprises a transmitter **530**, a first receiver **542**, a second receiver **544**, a first antenna **546**, a second antenna **547**, a computing apparatus **550**, an azimuth indicator **555** and a display **565**. The computing apparatus **550** comprises a processor **560**, a timer **570** and a memory **575**. The target **520** of opportunity comprises a transponder **580**. In the representative embodiment of FIG. **5**, the first antenna **546** is coupled to the transmitter **530**, the first receiver **542** and to the azimuth indicator **555**, and the second antenna **547** which is preferably an Omni antenna **547** is coupled to the second receiver **544**. The transmitter **130** is further coupled to the processor **560**; the first receiver **542** is further coupled to the processor **560**; the second receiver **544** is further coupled to the processor **560**; and the processor **560** is further coupled to the azimuth indicator **555**, to the timer **570**, to the memory **575** and to the display **565**.

In operation, the transmitter **530** of the radar system **510** transmits non-directed radar signals **590** via the first antenna **546** which is received by the transponder **580** located on the target **520**. The transponder **580** then transmits transponder response signals **595** which are detected by the first receiver **542** via the first antenna **546**. The timer **570** records the times the non-directed radar signals **590** are transmitted and the times the transponder response signals **595** are received by the first receiver **542** of the radar system **510**. Ranges to the target **520** are measured by the processor **560** based on the times the non-directed radar signals **590** were transmitted by the transmitter **530** and the times the transponder response signals **595** were received by the first receiver **542**. Azimuths to the target are measured by knowing the azimuths at which the first antenna **546** is pointing at the times that the transponder response signals **595** are received by the first receiver **542**. The transponder **580** transmits a transponder asynchronous signal **597** which is detected by the second receiver **544** via the second antenna **547**. The transponder asynchronous signal **597** is correlated to the transponder response signal **595** using the Mode S address of the target **520**. Target **520** reported values for the range and azimuth to the target **520** relative to the radar system **510** are obtained from computations based on information received in the transponder asynchronous signal **597** from the target **520**. Information (latitude, longitude, and altitude of the target **520**) received in the transponder asynchronous signal **597** can comprise Global Positioning System (GPS) location information, inertial navigation system (INS) location information, and/or other appropriate location information for the target **520**. The target **520** reported latitude/longitude and altitude geographical data is converted to radar referenced Cartesian coordinates. The Cartesian coordinates are then propagated to the latest transponder response signal **595** time and converted to radar polar coordinates. The error between the measured (range and azimuth) and target **520** reported (latitude/longitude) positions can then be calculated and registration correction values for range and azimuth for the radar system **510** extracted. Range and azimuth values compensated respectively by the range and azimuth error bias values and/or target **520** location relative to the radar system **510** can be displayed on the display **565**.

In the Automatic Dependent Surveillance Broadcast (ADS-B) Extended Squitter mode, target position data is transferred to the transponder **580** from its on-board GPS/INS system. The transponder **580** asynchronously broadcasts its position and Mode S identification code twice per second. An ADS-B ground station receiver, utilizing an OMNI directional antenna, receives the ADS-B data and passes it to the MSSR where it is used to identify targets **520** in the surveillance volume. ADS-B is a cooperative surveillance technique for air traffic control. An ADS-B-equipped target (aircraft) **520** determines its own position using GPS obtained information and periodically broadcasts this position and other relevant information to potential ground stations and other aircraft with ADS-B equipment without knowing what other aircraft or entities may receive it. ADS-B can be used over several different data link technologies, including Mode-S Extended Squitter (1090 ES) operating at 1090 MHz, Universal Access Transceiver (978 MHz UAT), and VHF data link (VDL Mode 4).

By adding an ADS-B receiver to the MSSR, target responses to SIF/Mode S surveillance interrogations will be augmented by the asynchronous Mode S ADS-B reports. The target **520** latitude, longitude and altitude along with the Mode S target **520** address as received by the ADS-B receiver are merged with the SSR data, to generate an integrated target **520** track report. The integrated message contains two independent position reports, the range and azimuth measured from the SSR reply and the ADS-B latitude, longitude and altitude data. However, both data sources may be erroneous. The SSR data may contain registration bias errors and random measurement errors. The ADS-B data, due to lack of GPS data, INS drift, and/or latency in reporting, may point to an incorrect target position. However, by proper data propagation to a common time and integration of multiple target **520** samples, the random errors may be averaged and the bias error can be extracted to the accuracy required.

Once a target **520** plot report is detected by the SSR interrogation, it is associated with its corresponding track. The ADS-B data is converted from Latitude and Longitude to Cartesian coordinates and is propagated to the latest SSR plot time. The data is then converted to radar polar coordinates where it is compared to the radar system **510** measured position. This comparison yields separate range and azimuth error estimates. These estimates are averaged over time providing increasingly accurate range and azimuth.

The ADS-B Extended Squitter message is 112 bits long and contains 56 bits of ADS position information along with the 24-bit aircraft address. The content of the ADS field can be one of six types: (1) Airborne position (transmitted when airborne)—BDS 0,5; (2) Surface position (transmitted when on airport surface)—BDS 0,6; (3) Extended Squitter Status, BDS 0,7; (4) Extended Squitter Aircraft Identification and Type, BDS 0,8; (5) Airborne Velocity, BDS 0,9 (there are 4 sub-types of this report—2 subsonic and 2 supersonic); and (6) Event driven Information, BDS 0,A. which is not presently used. In a representative embodiment, the Airborne position format BDS 0.5 is shown in Table 2.

The availability of ADS-B data depends upon the ADS-B receiver system used and the target load. In a representative embodiment, an OMNI antenna provides approximately 9 dB of gain and uses a simple receiver having a minimum trigger level (MTL) of approximately −80 dBm. This ADS-B

receiver system can provide a conservative maximum detection range of approximately 50 to 100 NM. In another representative embodiment, a Sector antenna containing 6 to 12 antennas each having approximately 14 dB gain and an improved receiver having an MTL of approximately −87 dBm can provide a maximum detection range of approximately 200 NM. A typical link budget showing the gains and losses for a specified transmission/reception path and a final margin is shown in Table 4.

TABLE 4

Link Budget for OMNI and Sector antenna

Item	OMNI (50 NM)	Sector (200 NM)
Aircraft transmitted power(dBm)	57	57
Transmitter cable losses(dB)	−3	−3
Transmitter Antenna gain(dBi)	0	0
Path loss at 1090 MHz(dB)	−132.5	−144.5
Receiver antenna gain(dBi)	9	14
Receiver losses(dB)	−2	−2
Received power(dBm)	−71.5	−78.5
MTL(dBm)	−80	−87
Link margin(dB)	8.5	8.5

Although the ADS-B broadcast report rate is 2 per second, the number of reports detected by the Omni antenna/receiver may be significantly less due to the level of Selective Identification Feature (SIF) and Mode S False Replies Unsynchronized In Time (FRUIT). In a typical application, the number of ADS-B decoded reports can range from approximately 1 report every 10 seconds under high target load conditions to 2 reports every 1 second under low target load conditions.

FIG. **6** is a flowchart of a method **600** for obtaining measured range R_m and azimuth Az_m data for the asynchronous mode registration of a radar system **510** using the target **520** of opportunity of FIG. **5**. In block **605**, of FIG. **6**, the radar system **510** transmits a non-directed radar signal **590**. Block **605** then transfers control to block **607**.

In block **607**, the time that the non-directed radar signal **590** is transmitted is recorded in the memory **575**. Block **607** then transfers control to block **610**.

In block **610**, assuming that the target is within range of the non-directed radar signal **590**, the target **520** receives the non-directed radar signal **590**. Block **610** then transfers control to block **620**.

In block **620**, the transponder **580** in the target **520** transmits a transponder response signal **595**. Block **620** then transfers control to block **625**.

In block **625**, the second receiver **544** of the radar system **510** receives the transponder response signal **595**. Block **625** then transfers control to block **630**.

In block **630**, the time that the first receiver **542** of the radar system **510** receives the transponder response signal **595** is recorded in the memory **575**. Block **630** then transfers control to block **640**.

In block **640**, the time that the non-directed radar signal **590** is transmitted and the time that the transponder response signal **595** is received by the radar system **510** first receiver **542** are used to determine a target **520** measured range R_m. Block **640** then transfers control to block **645**.

In block **645**, a measured azimuth Az_m from the radar system **510** to the target **520** is obtained from the direction in which the first antenna **546** of the radar system **510** is pointing at the time that the transponder response signal **595** is received by the radar system **510** first receiver **542**. Block **645** then transfers control to block **650**.

In block **650**, the target **520** measured range R_m and azimuth Az_m are recorded in the memory **575**. Block **650** then transfers control to block **605** wherein subsequently either the same target **520** or a different target **520** could receive the non-directed radar signal **590** in block **610**.

FIG. **7** is a flowchart of a method **700** for the asynchronous mode registration of a radar system **510** using the target **520** of opportunity of FIG. **5**. In block **755** of FIG. **7**, the radar system **510** receives a transponder asynchronous signal **597** transmitted by a transponder **580** in the target **520**. Block **755** then transfers control to block **757**.

In block **757**, the transponder asynchronous signal **597** is correlated to the closest in time transponder response signal **595** using the Mode S address of the target **520**. Block **757** then transfers control to block **760**.

In block **760**, the latitude, longitude, and altitude of the target **520** is extracted from the transponder asynchronous signal **597** by the radar system **510** processor **560**. Block **760** then transfers control to block **763**.

In block **763**, the latitude, longitude, and altitude of the target **520** extracted from the transponder asynchronous signal **597** is transformed to radar system **510** referenced target Cartesian coordinates. In a representative embodiment, the target **520** latitude, longitude and altitude information could be transformed to the target **520** location ECEF Cartesian coordinates wherein ECEF Cartesian coordinates are the geocentric Earth-Centered, Earth-Fixed (ECEF) Cartesian coordinates utilizing the World Geodetic System latest revision WGS-84 ellipsoid Earth model. The ECEF coordinates can then be converted to local Cartesian radar system **510** referenced coordinates. Block **763** then transfers control to block **765**.

In block **765**, the radar system **510** referenced target Cartesian coordinates are propagated to their projected coordinates at the closest time of a transponder response signal **595**. Block **765** then transfers control to block **767**.

In block **767**, the radar system **510** referenced projected target Cartesian coordinates are converted to radar system **510** referenced target **520** computed range and azimuth. Block **767** then transfers control to block **770**.

In block **770**, the target **520** information is tested against user-defined filters to determine if it is suitable for use in the error calculation. Filters can include minimum and maximum range/azimuth/altitude, Figure of Merit (FOM), range and azimuth outlier, minimum and maximum velocity, and UTC time sync. Targets **520** that fail the filter criteria are discarded. Block **770** then transfers control to block **775**.

In block **775**, the difference between the radar system **510** referenced target **520** computed range R_c and the measured range R_m from the radar system **510** to the target **520** are used by the radar system **510** processor **560** to compute a range registration error R_b, and the difference between the radar system **510** referenced target **520** computed azimuth Az_m and the measured azimuth Az_m from the radar system **510** to the target **520** are used by the radar system **510** processor **560** to compute an azimuth registration error Az_b. Block **775** then transfers control to block **780**.

In block **780**, the range registration error R_b and the azimuth registration error Az_b obtained in block **775** are stored in the memory **575**. Block **780** then transfers control to block **785**.

In block **785**, average range and azimuth registration errors R_b,Az_b are calculated using any previous data for the present and other targets **520** used in the process. Block **785** then transfers control to block **790**.

In block **790**, standard and maximum deviations for average range and azimuth registration errors R_b,Az_b are computed. Block **790** then transfers control to block **793**.

In block **793**, the standard and maximum deviations for average range and azimuth registration errors R_b,Az_b are stored in the memory **575**. Block **793** then transfers control to block **795**.

If the standard deviations for average range and azimuth registration errors R_b, Az_b obtained in block **790** are less than preselected values, block **795** terminates the process. Otherwise, block **795** transfers control to block **755**.

FIG. **8** is a flowchart of a method **800** for registering a radar system **110**,**510** as described in various representative embodiments. In block **810** of FIG. **8**, first values for a range and an azimuth from the radar system **110**,**510** to a target **120**,**520** are obtained using radar system **110**,**510** initiated signals **190**,**195**,**590**,**595**. Block **810** then transfers control to block **820**.

In block **820**, geo-referenced position data is obtained from the target **120**,**520**. Block **820** then transfers control to block **830**.

In block **830**, second values for the range and the azimuth from the radar system **110**,**510** to the target **120**,**520** are obtained using the geo-referenced position data. Block **830** then transfers control to block **840**.

In block **840**, a range registration bias error for the radar system **110**,**510** is computed using the difference between the first and second values for the range. Block **840** then transfers control to block **850**.

In block **850**, an azimuth registration bias error for the radar system **110**,**510** is computed using the difference between the first and second values for the azimuth. Block **850** then transfers control to block **860**.

In block **860**, range and azimuth readings are adjusted in accordance with the range and azimuth registration bias errors.

In the above disclosed techniques the target **120**,**520** could be an aircraft and the radar registration system **100**,**500** could be used in an air traffic control system. While the above representative embodiment has been described in terms of using Mode S targets of opportunity for the registration of monopulse secondary surveillance radars (MSSR) either through a directed interrogation or via an Automatic Dependent Surveillance Broadcast (ADS-B), it will be understood by one of ordinary skill in the art that other representative embodiments can be implemented using these techniques with different technologies.

In a representative embodiment, a method **800** for registering a radar system **110**,**510** is disclosed. The method **800** comprises obtaining first values for a location of a target **120**,**520** relative to the radar system **110**,**510** using radar system **110**,**510** initiated signals **190**,**191**,**195**,**590**,**595**, obtaining geo-referenced location data for and from the target **120**,**520**, obtaining second values for the location of the target **120**,**520** relative to the radar system **110**,**510** using the geo-referenced location data, computing location registration bias errors for the radar system **110**,**510** using the first and second values, and registering the radar system **110**,**510** using the computed location registration bias errors.

In another representative embodiment, a registration system **100**,**500** for registering a radar system **110**,**510** is disclosed. The registration system **100**,**500** comprises the radar system **110**,**510**, The radar system **110**,**510** is capable of measuring first values for a location of a target **120**,**520** relative to the radar system **110**,**510** using radar system **110**,**510** initiated signals **190**,**191**,**195**,**590**,**595**, receiving geo-referenced location data for and from the target **120**,**520**, computing second values for the location of the target **120**,**520** relative to the radar system **110**,**510** using the geo-referenced location data, computing location registration bias errors for the radar system **110**,**510** using the first and second values, and registering the radar system **110**,**510** using the computed location registration bias errors.

In still another representative embodiment, a radar registration system is disclosed. The radar registration system comprises a radar operable to output radar data including a plurality of radar-based position reports associated with one or more targets moving within a range of the radar, a geo-referenced position source operable to output a plurality of geo-referenced position reports associated with the one or more targets, and a processor operable to compute position bias parameters associated with the radar by analyzing the radar-based position reports using the geo-referenced position reports as a reference.

In yet another representative embodiment, a method of registering a radar is disclosed. The method comprises collecting a plurality of radar data samples from the radar, the radar data samples comprising radar-based position reports associated with one or more targets moving within range of the radar, collecting a plurality of geo-referenced data samples from a geo-referenced position source, the geo-referenced data samples comprising geo-referenced position reports associated with the one or more targets, and computing position bias parameters associated with the radar by analyzing the radar-based position reports using the geo-referenced position reports as a reference.

The representative embodiments, which have been described in detail herein, have been presented by way of example and not by way of limitation. It will be understood by those skilled in the art that various changes may be made in the form and details of the described embodiments resulting in equivalent embodiments that remain within the scope of the appended claims.

What is claimed is:

1. A method for registering a radar system, comprising:

obtaining first values for a location of a target relative to the radar system using radar system initiated signals;

obtaining geo-referenced location data for and from the target;

obtaining second values for the location of the target relative to the radar system using the geo-referenced location data;

computing location registration bias errors for the radar system using the first and second values; and

registering the radar system using the computed location registration bias errors.

2. The method as recited in claim **1**, wherein the geo-referenced location data for the target comprises latitude, longitude and altitude of the target.

3. The method as recited in claim **1**,

wherein the first values comprise values for a measured range and a measured azimuth from the radar system to the target located on a set of orthogonal coordinates,

wherein the second values comprise values for a computed range and a computed azimuth from the radar system to the target located on the orthogonal coordinates, and

wherein the location registration bias errors for the radar system comprise a range registration bias error and an azimuth registration bias error.

4. The method as recited in claim **3**,

wherein the radar system initiated signals comprise a directed radar signal transmitted from the radar system and a transponder response signal transmitted by the target,

wherein the directed radar signal comprises instructions to the target to which it is directed to respond with the transponder response signal when the target receives the directed radar signal, and

wherein the transponder response signal comprises the geo-referenced location data for the target.

5. The method as recited in claim **4**,

wherein the radar system initiated signals further comprise a non-directed radar signal,

wherein the non-directed radar signal includes instructions to the target(s) that receive the signal to respond with the transponder response signal, and

wherein the non-directed radar signal is not addressed specifically to the target.

6. The method as recited in claim **5**, further comprising:

selecting the directed radar signal and its associated transponder response signal as the source for the radar measured range and azimuth or

selecting the non-directed radar signal and its associated transponder response signal as the source for the radar measured range and azimuth.

7. The method as recited in claim **6**, further comprising:

extracting the geo-referenced location data for the target from the transponder response signal transmitted by a transponder in response to the directed radar signal,

transforming the geo-referenced location data for the target to radar referenced coordinates;

computing a computed range and a computed azimuth using the transformed geo-referenced location data for the target;

computing a range registration bias error using the computed range and the measured range; and

computing an azimuth registration bias error using the computed azimuth and the measured azimuth.

8. The method as recited in claim **7**, further comprising:

computing an average range registration bias error using the computed range registration bias error and other previously computed range registration bias errors; and

computing an average azimuth registration bias error using the computed azimuth registration bias error and other previously computed azimuth registration bias errors.

9. The method as recited in claim **8**, further comprising:

registering the radar system using the average range registration bias error and the average azimuth registration bias error.

10. The method as recited in claim **8**, further comprising:

computing a figure of merit for the range registration bias error and the azimuth registration bias error; and

if the computed figure of merit does not meet preselected criteria, repeating the above method steps.

11. The method as recited in claim **3**,

wherein the radar system initiated signals comprise a non-directed radar signal transmitted from the radar system and a transponder response signal transmitted by the target,

wherein the non-directed radar signal comprises instructions to the target to respond with the transponder response signal when the target receives the non-directed radar signal,

wherein a transponder asynchronous signal comprises the geo-referenced location data for the target, and

wherein the non-directed radar signal is not addressed specifically to the target.

12. The method as recited in claim **11**, further comprising:

selecting the non-directed radar signal and its associated transponder response signal are selected as the source for the radar measured range and azimuth;

extracting the geo-referenced location data for the target from the transponder asynchronous signal transmitted by a transponder asynchronously;

correlating the asynchronous transponder signal with the closest in time transponder response signal;

transforming the geo-referenced location data for the target to radar referenced coordinates;

computing a computed range and a computed azimuth using the transformed geo-referenced location data for the target;

computing a range registration bias error using the computed range and the measured range; and

computing an azimuth registration bias error using the computed azimuth and the measured azimuth.

13. The method as recited in claim **12**, further comprising:

computing an average range registration bias error using the computed range registration bias error and other previously computed range registration bias errors; and

computing an average azimuth registration bias error using the computed azimuth registration bias error and other previously computed azimuth registration bias errors.

14. The method as recited in claim **13**, further comprising:

registering the radar system using the average range registration bias error and the average azimuth registration bias error.

15. The method as recited in claim **13**, further comprising:

computing a figure of merit for the range registration bias error and the azimuth registration bias error; and

if the computed figure of merit does not meet preselected criteria, repeating the above method steps.

16. A registration system for registering a radar system, comprising:

the radar system,

wherein the radar system is capable of measuring first values for a location of a target relative to the radar system using radar system initiated signals,

wherein the radar system is capable of receiving geo-referenced location data for and from the target,

wherein the radar system is capable of computing second values for the location of the target relative to the radar system using the geo-referenced location data,

wherein the radar system is capable of computing location registration bias errors for the radar system using the first and second values, and

wherein the registration system is capable of registering the radar system using the computed location registration bias errors.

17. The registration system as recited in claim **16**, wherein the geo-referenced location data for the target comprises latitude, longitude and altitude of the target.

18. The registration system as recited in claim **16**,

wherein the first values comprise values for a measured range and a measured azimuth from the radar system to the target located on a set of orthogonal coordinates,

wherein the second values comprise values for a computed range and a computed azimuth from the radar system to the target located on the orthogonal coordinates, and

wherein the location registration bias errors for the radar system comprise a range registration bias error and an azimuth registration bias error.

19. The registration system as recited in claim **18**,

wherein the radar system initiated signals comprise a directed radar signal transmitted from the radar system and a transponder response signal transmitted by the target,

wherein the directed radar signal comprises instructions to the target to which it is directed to respond with the transponder response signal when the target receives the directed radar signal, and

wherein the transponder response signal comprises the geo-referenced location data for the target.

20. The registration system as recited in claim **19**,

wherein the radar system initiated signals further comprise a non-directed radar signal,

wherein the non-directed radar signal includes instructions to the target(s) that receive the signal to respond with the transponder response signal and

wherein the non-directed radar signal is not addressed specifically to the target.

21. The registration system as recited in claim **20**,

wherein the directed radar signal and its associated transponder response signal are selected as the source for the radar measured range and azimuth or the non-directed radar signal and its associated transponder response signal are selected as the source for the radar measured range and azimuth,

wherein the radar system is capable of extracting the geo-referenced location data for the target from the transponder response signal transmitted by a transponder in response to the directed radar signal,

wherein the radar system is capable of transforming the geo-referenced location data for the target to radar referenced coordinates,

wherein the radar system is capable of computing a computed range and a computed azimuth using the transformed geo-referenced location data for the target,

wherein the radar system is capable of computing a range registration bias error using the computed range and the measured range and

wherein the radar system is capable of computing an azimuth registration bias error using the computed azimuth and the measured azimuth.

22. The registration system as recited in claim **18**,

wherein the radar system initiated signals comprise a non-directed radar signal transmitted from the radar system and a transponder response signal transmitted by the target,

wherein the non-directed radar signal comprises instructions to the target to respond with the transponder response signal when the target receives the non-directed radar signal,

wherein a transponder asynchronous signal comprises the geo-referenced location data for the target, and

wherein the non-directed radar signal is not addressed specifically to the target.

23. The registration system as recited in claim **22**,

wherein the non-directed radar signal and its associated transponder response signal are selected as the source for the radar measured range and azimuth,

wherein the radar system is capable of correlating the asynchronous transponder signal with the closest in time transponder response signal,

wherein the radar system is capable of extracting the geo-referenced location data for the target from the transponder asynchronous signal transmitted by a transponder asynchronously,

wherein the radar system is capable of transforming the geo-referenced location data for the target to radar referenced coordinates,

wherein the radar system is capable of computing a computed range and a computed azimuth using the transformed geo-referenced location data for the target,

wherein the radar system is capable of computing a range registration bias error using the computed range and the measured range, and

wherein the radar system is capable of computing an azimuth registration bias error using the computed azimuth and the measured azimuth.

24. A radar registration system comprising:

a radar operable to output radar data including a plurality of radar-based position reports associated with one or more targets moving within a range of the radar;

a geo-referenced position source operable to output a plurality of geo-referenced position reports associated with the one or more targets; and

a processor operable to compute position bias parameters associated with the radar by analyzing the radar-based position reports using the geo-referenced position reports as a reference.

25. The system of claim **24** wherein the position bias parameters comprise a range bias and an azimuth bias that are orthogonal to one another.

26. The system of claim **24** wherein the processor is included within an air traffic control system.

27. The system of claim **24** wherein said processor is further operable to perform quality monitoring during computation of the position and time bias parameters to provide an estimate of the quality of the position bias parameters.

28. A method of registering a radar, said method comprising:

collecting a plurality of radar data samples from the radar, the radar data samples comprising radar-based position reports associated with one or more targets moving within range of the radar;

collecting a plurality of geo-referenced data samples from a geo-referenced position source, the geo-referenced data samples comprising geo-referenced position reports associated with the one or more targets; and

computing position bias parameters associated with the radar by analyzing the radar-based position reports using the geo-referenced position reports as a reference.

29. The method of claim **28** wherein in said step of computing position bias parameters, the position bias parameters comprise a range bias and an azimuth bias that are orthogonal to one another.

30. The method of claim **28** wherein said step of computing position bias parameters, computation of the position and time bias parameters occurs on a processor within an air traffic control system.

31. The method of claim **28** further comprising the step of:

performing a quality monitoring during computation of the position bias parameters to provide an estimate of the quality of the position bias parameters.

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