

[54] PROXIMITY INDICATION WITH RANGE AND BEARING MEASUREMENTS
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Related U.S. Patent Documents

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Appl. No.: 371,839
Filed: June 20, 1973

U.S. Applications:
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[52] U.S. Cl. 343/16 R; 343/6.5 LC; 343/106 R
[51] Int. Cl.² G01S 9/56
[58] Field of Search 343/106 R, 6.5 R, 6.5 LC, 343/112 CA, 16 R

[56] References Cited
UNITED STATES PATENTS
1,135,604 4/1915 Meissner 343/106 R
2,112,283 3/1938 Fritz 343/106 R
2,531,918 11/1950 O'Brien 343/106 R
2,586,810 2/1952 Frum 343/106 R
2,826,378 3/1958 Childs, Jr. 343/106 R
2,829,364 4/1958 Latimer, Jr. 343/106 R

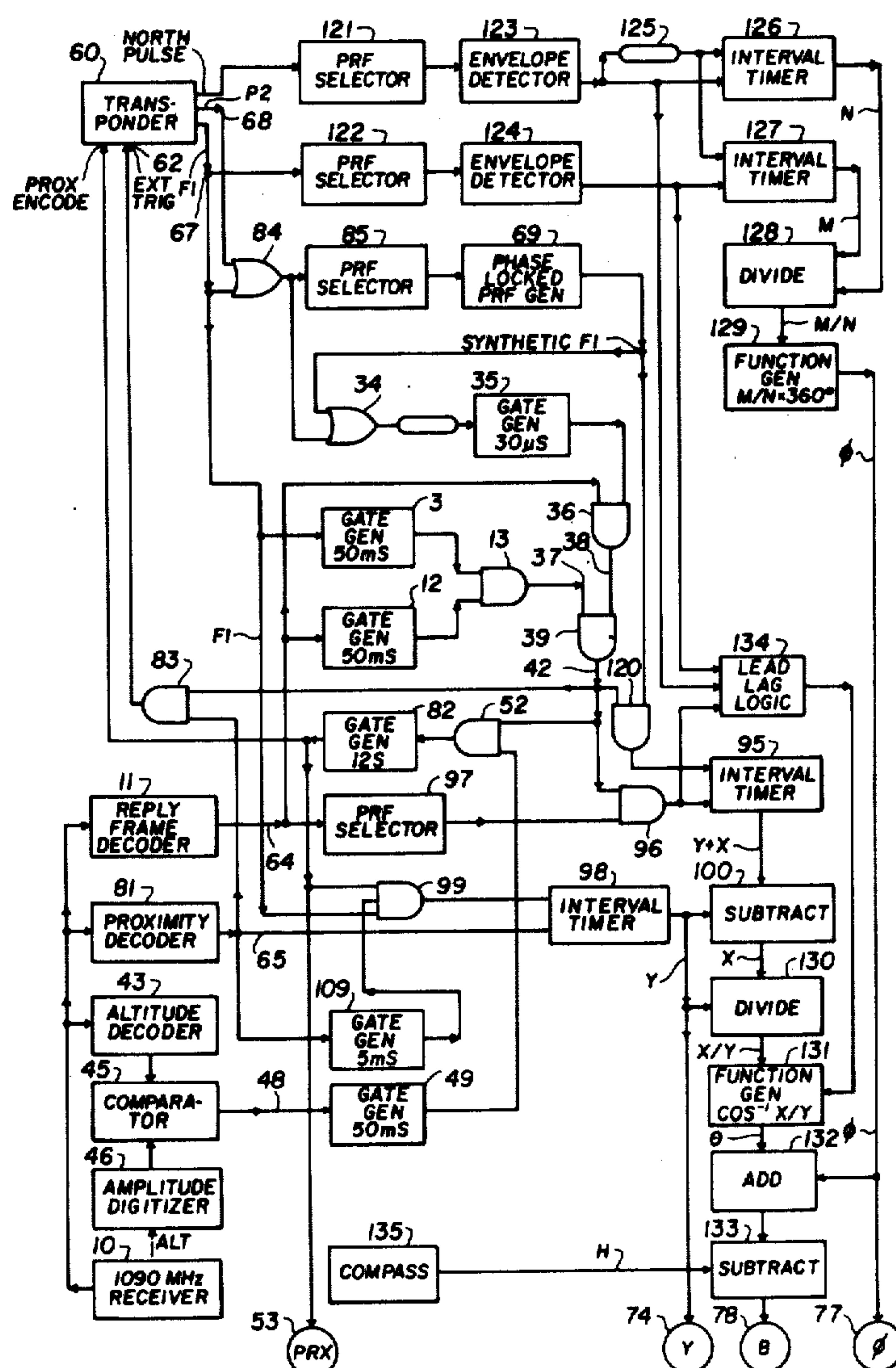
FOREIGN PATENTS OR APPLICATIONS

1,146,559 3/1969 United Kingdom 343/6.5

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Attorney, Agent, or Firm—Brumbaugh, Graves, Donohue & Raymond

[57] ABSTRACT
Proximity indication and evaluation for aircraft, using only the signals emitted by secondary surveillance radar and cooperating transponders, to detect intrusion in a monitored proximity volume and determine slant range and relative bearing to the intruder.

8 Claims, 7 Drawing Figures



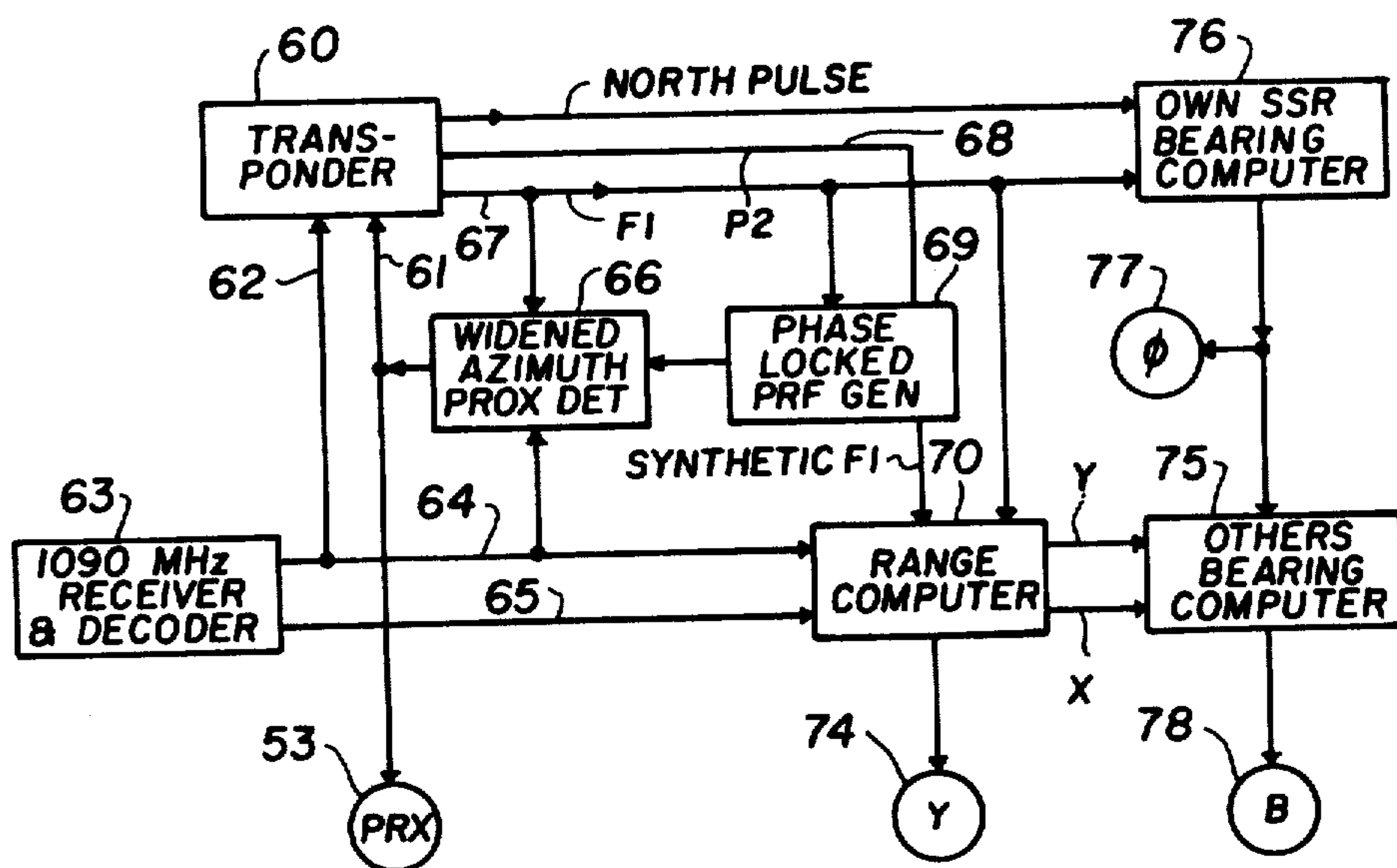


FIG. 1

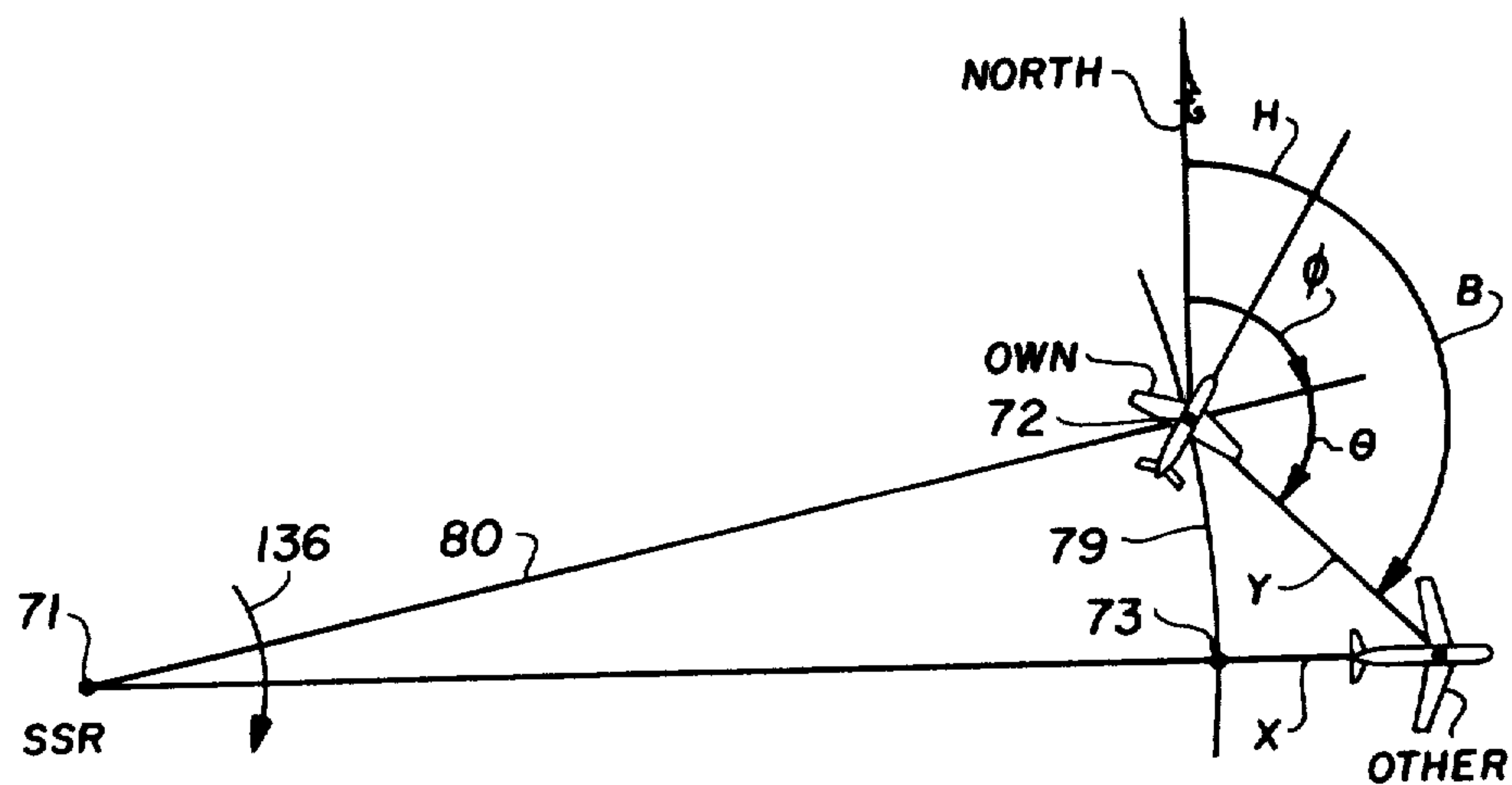


FIG. 2

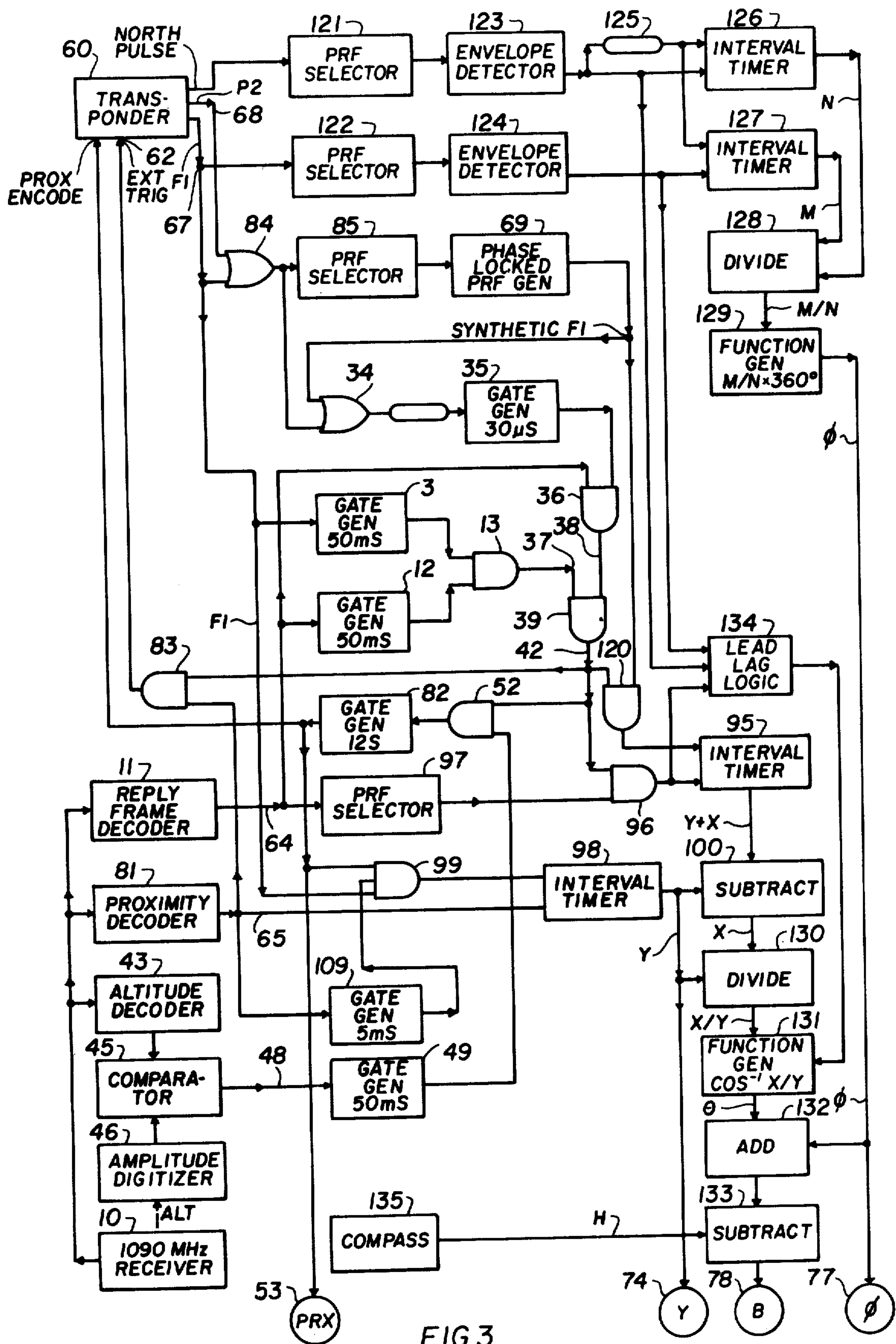


FIG. 3

FIG. 4

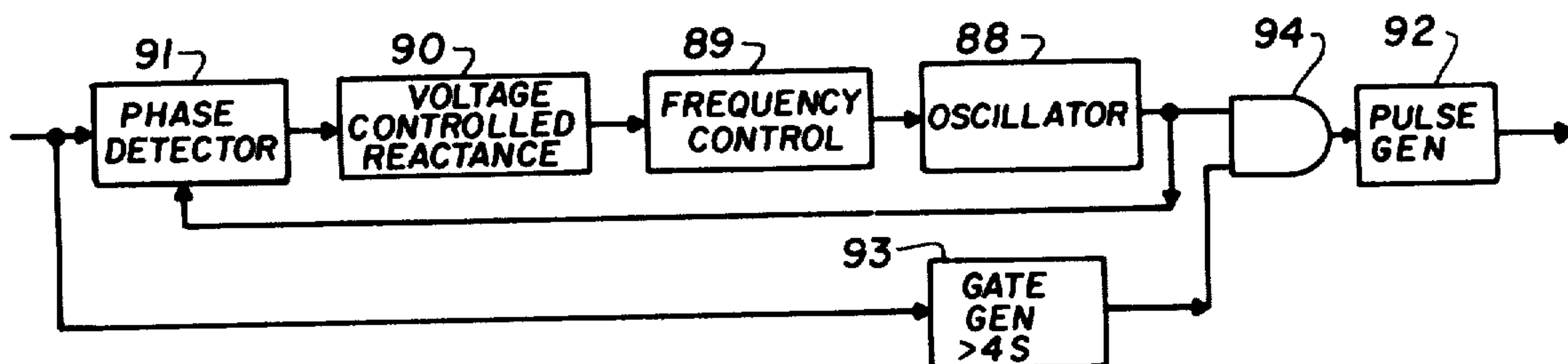
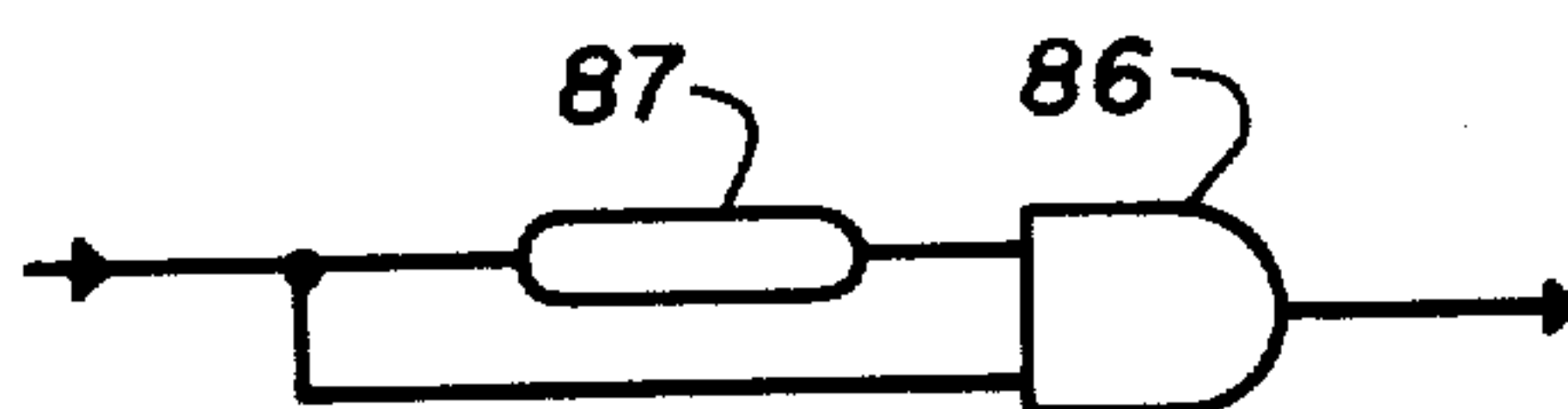


FIG. 5

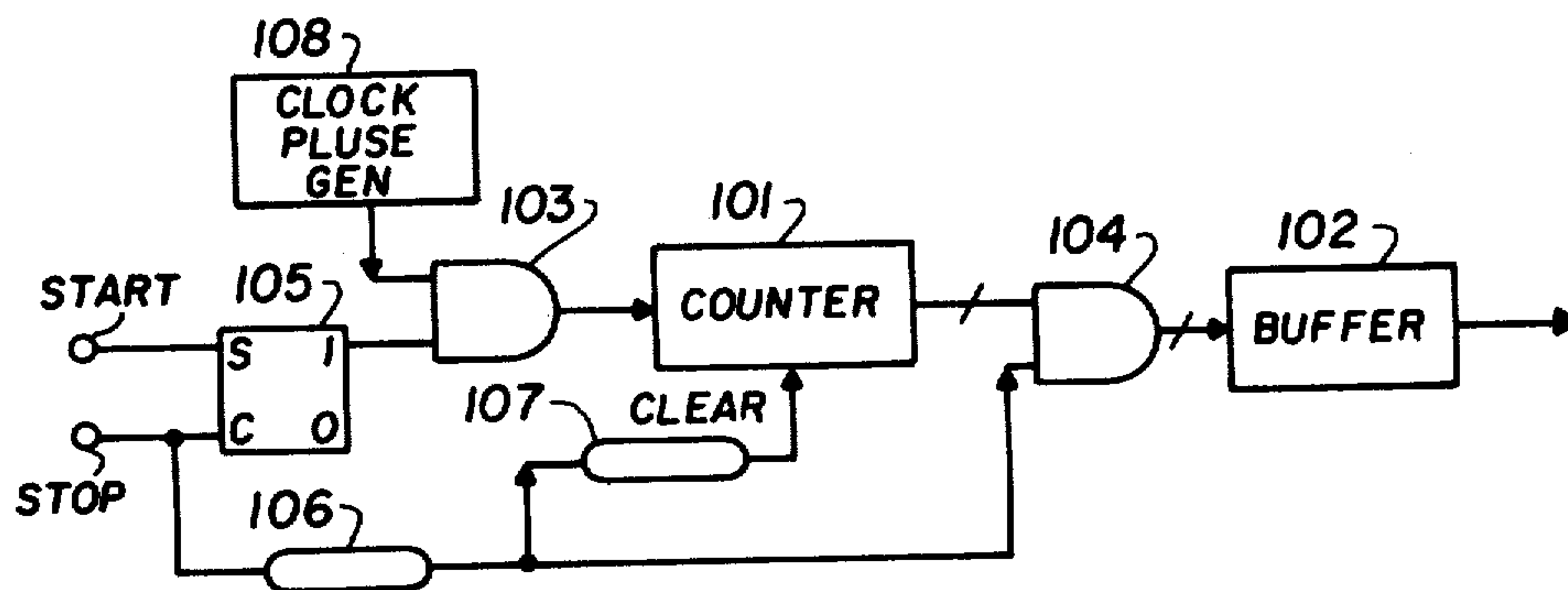


FIG. 6

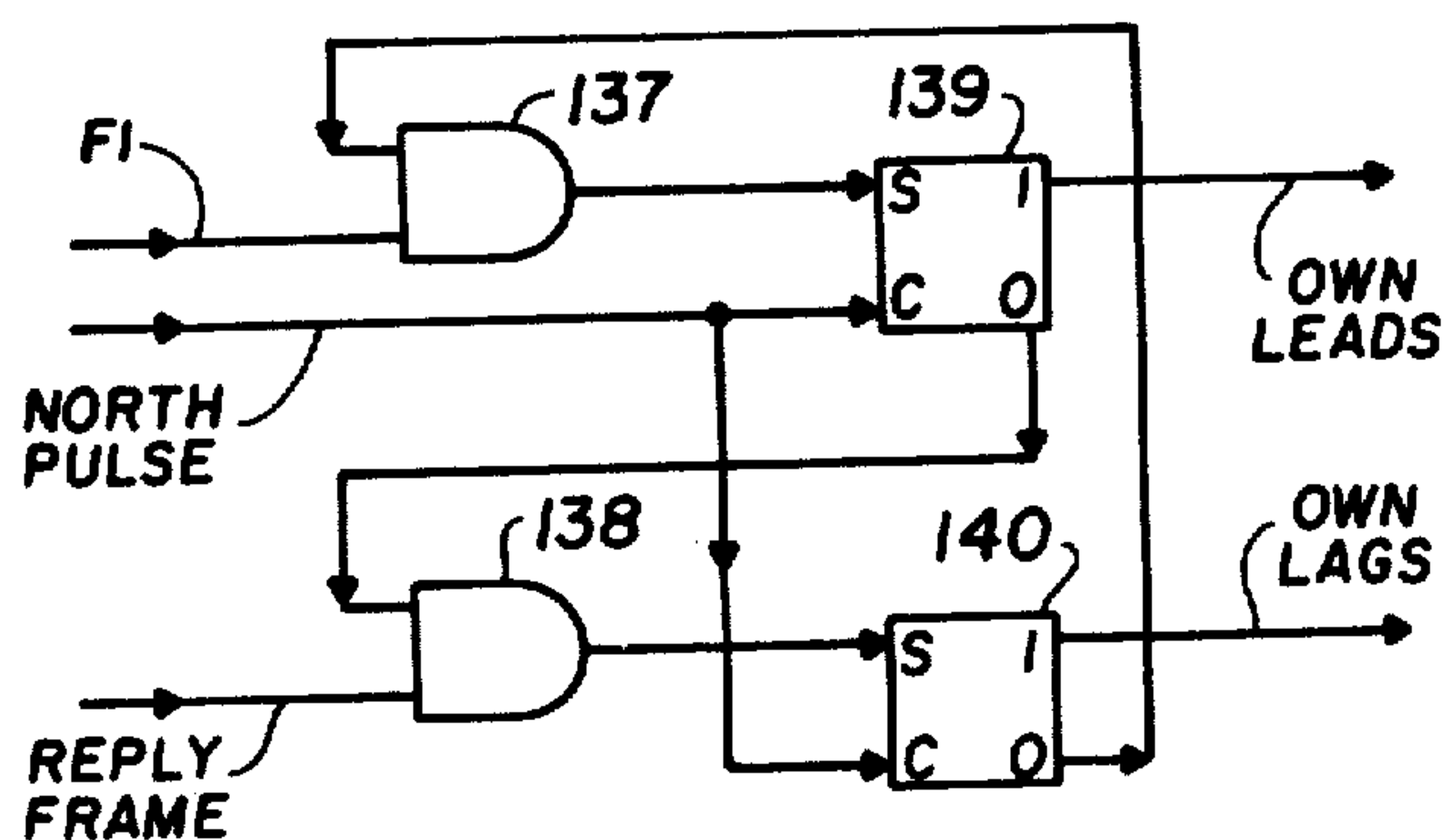


FIG. 7

PROXIMITY INDICATION WITH RANGE AND BEARING MEASUREMENTS

Matter enclosed in heavy brackets **[]** appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This application is a division of application Ser. No. 180,578, filed Sept. 15, 1971 now U.S. Pat. No. 3,757,324.

BACKGROUND

1. Field of the Invention

This invention pertains to radiolocation of mobile vehicles, such as aircraft, with respect to each other within the coverage of a scanning radar at a reference location.

2. Description of the Prior Art

Major airports and way points are presently equipped with secondary surveillance radar (SSR) adapted to cooperate with transponder beacons carried on aircraft to discriminate against interference and ground clutter and to provide for transmission of identification and other data such as altitude from the craft to the ground-based radar. A traffic controller observing the radar display directs the pilots of the involved aircraft by radio, usually with voice communication, so as to maintain or restore safe separations between craft. Such systems are limited in capability because each craft must be dealt with individually and requires its share of the controller's time and attention and its share of the available radio spectrum. When traffic is heavy, take-offs and landings are delayed, and the possibility of collisions increases.

The number of mid-air collisions and near misses has become so large in busy areas that numerous interaircraft cooperative proximity warning systems have been proposed. Those more prominently under study or development at this time involve frequent or quasicontinuous exchange of signals between all cooperative aircraft within the region of interest and make no provision for non-cooperating aircraft. The required airborne equipment would be bulky and expensive, use more of the already crowded radio spectrum and would be generally independent of other needed and existing equipment, such as transponders. Another drawback of some of the proposed systems is that they provide only relative positional information, without ground reference but in effect with respect to a randomly floating reference.

My copending U.S. patent application Ser. No. 130,952, filed Apr. 5, 1971, now U.S. Pat. No. 3,735,408 and entitled Common Azimuth Sector Indicating System describes the use of a standard airborne transponder with additional equipment including a receiver for receiving other's transponder replies and means for indicating the presence of another transponder-equipped aircraft within a monitored airspace sector or volume.

SUMMARY

According to the present invention, detection of a proximity situation as in the above-identified U.S. Pat. No. 3,735,408 is used to add a special proximity code signal to the normal transponder reply. Such a signal,

when received from another similarly equipped aircraft, initiates an exchange of interrogations and replies between the respective transponders of a proximity pair, enabling measurement of the direct slant range between the two craft. This operation may be accomplished without modification of the standard SSR-transponder traffic control system, and without interference with its normal operation.

The slant range information, useful in itself as a quantitative measure of the degree of proximity, may also be used in the determination of relative bearings of the two aircraft from each other. To this end, the SSR must be arranged to transmit omnidirectionally a reference signal, called a "North pulse" when the sweeping main radar beam points toward the local magnetic North. North pulse reference signals are available at existing SSR installations, and can be transmitted as required with slight modification of the equipment.

The North pulse, received and decoded by the transponder when the beam points North, and the normal interrogation, received when the beam points at the aircraft, define a time interval which is a measure of the craft's own magnetic bearing from the radar. The own radar bearing, slant range, and the differential range from the radar, which can be determined from the interval between a radar interrogation and the reception of the other's reply to the same interrogation, provide sufficient data for a simple computation of other's relative bearing.

DRAWINGS

FIG. 1 is a block diagram illustrating generally a preferred embodiment of the invention.

FIG. 2 is a geometrical diagram used in explaining the operation of the apparatus of FIG. 1.

FIG. 3 is a more detailed block diagram showing a specific implementation of the embodiment of FIG. 1.

FIG. 4 is a block diagram of a PRF selector suitable for use in the system of FIG. 3.

FIG. 5 is a block diagram of a phase locked PRF generator used in the system of FIG. 3.

FIG. 6 is a block diagram of an interval timer used in the system of FIG. 3.

FIG. 7 is a block diagram of a lead-lag logic device used in the system of FIG. 3.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, a transponder 60 is arranged to receive the usual 1,030 MHz interrogations from secondary surveillance radars, and to transmit 1,090 MHz replies in response thereto. Many transponders are provided with terminals where the P2 of SLS pulse of the interrogation and the first frame pulse F1 of the reply are available; others may be readily modified for external access to these pulses. A specially coded North reference signal, for example a PO pulse preceding the standard P1 interrogation pulse while the SSR main beam points North, is made available by slight modification of the transponder decoder, or by addition of a simple special decoder.

All transponders include reply encoders which may be set either manually or by electrical inputs to add any of 4096 coded messages to the reply signal. Some of the available code groups are used to transmit identification, barometric altitude, and various emergency or situation messages; many are not used presently. The transponder 60 is provided with an input line 61 con-

connected to encode a special range command message on the replies when it is energized, for example, in response to the detection of the proximity of another aircraft's transponder. Another input line 62 is connected to a point in the transponder where the reply trigger pulse usually appears. When a pulse is applied to line 62, the transponder is triggered to send a reply in the same manner as if it were interrogated by an SSR, although such interrogation is not received.

A 1,090 MHz receiver and decoder 63 is adapted to receive and decode transponder replies of other aircraft in the general vicinity. The decoder portion of this device provides an output pulse on line 64 in response to the reception of both reply frame pulses F1 and F2 from another aircraft's transponder, and an output pulse on line 65 in response to the reception of a range command message.

A widened common azimuth sector proximity detector system 66, which may be the same as that described in the abovementioned copending U.S. Pat. application Ser. No. 130,952, now U.S. Pat. No. 3,735,408, receives the reply frame decode pulse on line 64 and the own transponder F1 pulse and P2 decode pulse on lines 67 and 68. Output from the proximity detector 66 energizes the transponder input line 61 to encode proximity and energizes a proximity indicator 53.

An alternative F1 input to the proximity detector 66 is provided under certain conditions by a phase locked PRF pulse generator 69, which can be synchronized to the pulse repetition frequency of a selected radar either by the repetitive burst of F1 pulses resulting from interrogations received from that radar, or by the continuous train of decoded P2 pulses received from that radar within the SLS area. The output of the PRF generator 69 is a "synthetic F1" pulse, coincident with the actual F1 pulse when it is present, and substituting for the actual F1 pulse as a time reference when it is absent.

The actual and synthetic F1 pulses are applied to a range computer 70, which also receives as inputs the reply frame decode pulse on line 64 and the proximity decode pulse on line 65. The range computer 70, as will be described in detail with reference to FIG. 3 later, utilizes measurement of the time interval between the F1 and proximity decode pulses, when said pulses are present, to determine the direct slant range Y between the aircraft of a proximity pair. The range computer also utilizes measurement of the interval between synthetic F1 pulses and next following reply frame decode pulses to determine the difference X between the ranges of the two craft from a selected SSR.

Referring to FIG. 2, the selected SSR is at point 71, the "own" aircraft is at point 72, and the other aircraft is at point 73. The slant range Y is proportional to the time required for a radio signal to travel from one aircraft to the other and back again, less system delays. The differential radar range X is proportional to the time interval between reception of an interrogation from the SSR by the own craft at 72, and reception of the same interrogation by the other craft at 73.

Returning to FIG. 1, the computed slant range Y is displayed by a meter or other quantitative indicator 74. Representations of X and Y are applied to an other's bearing computer 75, which utilizes there and the output of an own SSR bearing computer 76 to determine the bearing of the other craft from one's own craft.

The own SSR bearing computer 76, as will be described further below, utilizes measurements of the time intervals between successive decoded North refer-

ence signals, and between North reference signals and next subsequent F1 bursts, to determine own magnetic bearing ϕ from the selected SSR. The other's bearing computer 75, also to be described later, determines the angle θ between one's own line of position from the radar as $\theta = \cos^{-1}X/Y$, adds own SSR bearing ϕ , and subtracts own magnetic heading H, to determine other's bearing B relative to own's heading. The angular quantities ϕ and B are displayed by indicators 77 and 78, respectively.

Referring to FIG. 2, it is seen that the arc 79 closely approximates a straight line perpendicular to the differential radar range line X, and also approximately perpendicular to the own line of position 80. Accordingly, the angle θ is approximately $\cos^{-1}X/Y$, within one or two degrees in a typical situation. As shown in the diagram, $B = \phi + \theta - H$.

The system of FIG. 1 operates at all times in the usual manner of an ordinary SSR beacon transponder, replying to interrogations received during the dwell time as the main beam of an SSR sweeps by it. Similar replies from transponders on other aircraft, received and decoded by the 1,090 MHz receiver-decoder 63, are ignored unless the other aircraft enters the widened common azimuth sector that is swept by the main beam immediately before or immediately after the "own" aircraft carrying the equipment of FIG. 1. If these replies, as processed in the detector system 66, define a proximity situation, the transponder 60 adds the proximity message to each of its [transmission] transmissions, thereby alerting the air traffic control system by way of the ground based SSR display.

If the other, or "intruder," aircraft is equipped with a receiver-decoder 63 and a detector system 66, it will also add the proximity message to each of its replies. In the usual case, the two aircraft will not approach the proximity condition along a common radial from the SSR. Accordingly, the rotating radar beam will first illuminate only one of the aircraft, then possibly both, if they are near enough to a common radial, then only the other. In the unusual case, when the aircraft approach proximity along a common radial from one SSR, they will nearly always be within operating range of another differently located SSR, and on different radials from that SSR.

When one aircraft is being illuminated by a particular radar beam and the other is not, the one in the beam will be replying with the added proximity message. This message received by the 1,090 MHz receiver-decoder on the aircraft which is not then in the radar beam, will trigger the transponder on that aircraft, causing it to transmit a reply, not solicited by a direct SSR interrogation, but by the other aircraft's proximity message. The other aircraft, that is the one presently in the radar beam, will receive the special transmission at a time following its own SSR-solicited transmission by an interval corresponding to the direct slant range Y between the two aircraft. Thus either aircraft, if equipped with a range computer 70, is provided with slant range information updated with each rotation of the radar beam.

The range computer also provides differential SSR range X. Note that both Y and X are available on the equipped aircraft even if the other aircraft does not carry a range computer. Similarly, an aircraft with an own SSR bearing computer 76 and an other's bearing computer 75 will obtain ϕ and B angle information

from another that carries only the transponder 60, receiver-decoder 63 and detector system 66.

Referring to FIG. 3, the 1090 MHz receiver-decoder 63 of FIG. 1 includes a 1090 MHz receiver 10, a reply frame decoder 11 and an altitude decoder 43, all of which may be the same as the respective correspondingly designated elements of the system described in said copending U.S. Pat. application Ser. No. 130,952, now U.S. Pat. No. 3,735,408. In addition, a proximity decoder 81 is provided for producing an output pulse whenever a proximity coded reply signal is received by receiver 10.

The widened common azimuth sector proximity detector includes resettable gate signal generators 3, 12, 35 and 49, AND 45, all the same as the respective corresponding designated elements of the system described in U.S. Pat. No. 3,735,408, and interconnected in the same way. The output of AND gate 52 is applied to the start input terminal of a resettable gate signal generator 82 designed for a gate time interval of several SSR beam rotation periods, say 12 seconds. The output of a gate generator 82 supplies the proximity encode input 61 to the transponder 60, and energizes the proximity indicator 53.

The common azimuth sector and range warning signal on line 42 at the output of AND gate 39 goes to an AND gate 83, which receives the output of proximity decoder 81 on line 65 as another input. Simultaneous presence of both inputs to AND gate 83 produces an output pulse for the external trigger input 62 of the transponder 60.

An OR gate 84 is connected to supply the F1 pulse on line 67 or the decoded P2 pulse on line 68 if either is present, or both if both are present, to the gate generator 35 by way of OR gate 34, and to the phase locked PRF generator 69 by way of a PRF selector 85. The PRF selector consists of an AND gate 86 and a delay device 87 connected as shown in FIG. 4. The delay 87 is made equal to the pulse period frequency, that is, to the interval between successive interrogations of a selected SSR.

Each SSR is assigned a characteristic PRF to distinguish its transmissions from those of others. The delay 87 may be adjusted by the aircraft operator to select the transmissions of a favorably located SSR. Each delay pulse reaches the AND circuit coincidentally with the next undelayed pulse, producing an output pulse.

Referring to FIG. 5, the phase locked PRF generator 69 of FIG. 1 includes an oscillator 88 with frequency control means 89 that can be adjusted, for example by selection of an appropriate crystal, to the desired PRF. A voltage controlled reactance device 90, for example a varactor diode, is coupled to the frequency control 89 to control the phase of the oscillator 88 in known manner. The oscillator output is coupled to a phase detector 91, which also receives the selected F1 or decoded P2 pulses from the PRF selector.

When the aircraft is within the SLS coverage area of the selected radar, decoded P2 pulses are present continuously. Any phase difference between these and the output of oscillator 88 is detected by the phase detector 91, which automatically adjusts the voltage controlled reactance device to null the difference. The oscillator 88 drives a pulse generator 92 to produce a continuous train of pulses, hereinafter referred to as "synthetic F1" pulses, that are phase locked to the selected radar PRF.

When the aircraft is outside the SLS coverage, a burst of about twenty actual F1 pulses occurs during the dwell time of the main beam. These adjust the phase of the oscillator 88 once during each beam rotation. The reactance device 90 is designed in known manner to hold its adjustment between bursts. An AND gate 94, controlled by a resettable gate signal generator 93, couples the oscillator 88 to the pulse generator 92. The gate generator 93 is designed for a gate time interval somewhat longer than one SSR beam rotation, say four seconds. When no F1 or decoded P2 pulses occur within about four seconds after the most recent burst, the AND gate 94 is disabled, disconnecting the oscillator 88 from the pulse generator 92 and stopping it.

Returning to FIG. 3, the synthetic F1 output of the phase locked PRF generator 69, when present, supplies an alternative input by way of OR gate 34 to the range warning gate generator 35. The synthetic F1 also goes through AND gate 120 to the start input terminal of an interval timer 95, which is one of the elements of the range computer 70 of FIG. 1. A second input to gate 120 is taken from the common azimuth sector range warning line 42. The stop input terminal of interval [time] timer 95 receives the output of an AND gate 96, which has one input from the common azimuth and range warning line 42 and another input from the reply frame decoder 11, through a PRF selector 97. This selector, like the selector 85, is adjusted to pass only the repetition frequency of a desired radar.

The range computer also includes another interval timer 98, which receives its start input from an AND gate 99 connected to the F1 line 67 and the proximity signal gate 82, and its stop input from the proximity decode 81. Gate 99 receives a third input from a 5-millisecond resettable gate generator 109, connected to be started by a proximity decode pulse on line 65. Outputs of the interval timers 95 and 98 are applied to a subtractor 100, and the output of interval [time] timer 98 is displayed on indicator 74.

Referring now to FIG. 6, the interval timers 95 and 98 may be digital devices each including a counter 101, a buffer 102, AND gates 103 and 104, a control flip-flop 105, and delay [device] devices 106 and 107. A common or system clock pulse generator 108 provides one input to AND gate 103.

A pulse applied to the start input terminal sets the flip-flop 105, energizing its 1 output terminal and enabling gate 103 to conduct clock pulses to the counter 101. The counter continues to count until a pulse is applied to the stop input terminal, clearing the flip-flop and deenergizing its 1 output to disable the AND gate 103 and stop the counter. The accumulated count at this time represents the length of the time interval between the start and stop input pulses.

After a brief delay in device 106, the stop pulse enables gate 104 to transfer the accumulated count into buffer 102. Gate 104 may be a multiple gate arranged in known manner to effect parallel transfer, or may be a known arrangement for slower, but adequately rapid serial transfer. In either case, the buffer 102 is simply forced into a state representing the count most recently transferred to it, holding that state until forced into another that represents a new, updated count.

Following a further delay in device 107, long enough to complete the transfer, the stop input pulse clears the counter 101. The output of the buffer, which may be either in digital or analog form, represents the most

recently measured interval continuously until again updated.

Returning to FIG. 3, the interval timer 98 operates only when a proximity condition has been detected, producing an output from gate generator 82, and proximity messages are being received from another aircraft, producing an output from gate generator 109. These two gate signals enable the AND gate 99 to pass F1 pulses to start the timer 98. Each next following pulse from the proximity decoder 81 stops the timer, which thus measures the interval between the two pulses. This interval, taking system delays into account, is the round trip radio transit time between the two aircraft, and is therefore, a measure of the direct slant range Y.

It should be noted that the described range measuring operation can occur between two suitably equipped aircraft in response to any SSR that illuminates them sequentially. Two or more such radars can cause such ranging without interference, except at the extremely unusual times when both beams point simultaneously into the proximity space. That situation, when it does occur, can persist only temporarily because each radar has a different assigned beam rotation period and pulse repetition period.

The interval timer 95 operates only when a common azimuth sector range warning signal exists on line 42, enabling AND gates 96 and 120, the PRF generator 69 is locked to a selected radar, producing synthetic F1 pulses, and reply frames are being received from another aircraft interrogated by the same selected radar. Under these conditions, the interval timer is started by each synthetic F1 pulse and stopped by each decoded reply frame pulse that passes the PRF selector 97.

The measured interval is that between one's own decoded interrogation or the synthetic F1 and the reception of the other's reply to the corresponding interrogation. This interval, taking system delays into account, is a measure of $Y + X$, the algebraic sum of the slant range and the differential SSR range. The output of interval timer 95 goes to the subtractor 100, where the difference between it and that of interval timer 90 produces a representation of the differential SSR range X, to be utilized by the other's bearing computer.

Turning to the upper portion of FIG. 3, the own bearing computer 76 of FIG. 1 comprises PRF selectors 121 and 122, envelope detectors 123 and 124, delay device 125, interval timers 126 and 127, divider 128 and function generator 129. The interval times may be like those described above, but designed for operation on a large time scale, measuring intervals of up to a radar beam rotation period, say four seconds. Alternatively, they may be simple electromechanical clock devices of known type. The envelope detectors are diode rectifiers with low pass filters, or any other convenient means for converting pulse bursts into single, preferably longer pulses.

In operation, each North pulse from the selected SSR first stops interval timer 126 if it has been running, then after a brief delay in device 125, starts both timers 126 and 127. The next subsequent burst of F1 pulses, occurring as the radar beam sweeps by the aircraft, stops timer 127, which remains stopped until the next North pulse occurs.

The output of timer 126, designated N, represents the length of time required for the radar beam to make a complete revolution. The output of timer 127, designated M, represents the length of time required for the

beam to rotate from magnetic North to the line of position of the aircraft from the radar. These outputs are applied to the divider 128, which in turn produces an output representing the quotient M/N .

The quantity M/N has a value between zero and unity representing the magnetic bearing ϕ of the aircraft from the SSR as a fraction of a complete circle, i.e., 360° . The representation may be digital or analog, electrical or mechanical, depending upon the specific design of the timers 126 and 127 and the divider 128. The function generator 129 converts this representation to a form suitable for display by indicator 77 and for utilization in the other's bearing computer. It is noted that the computed value of ϕ is independent of the individual beam rotation rate of the selected SSR.

The other's bearing computer 75 of FIG. 1, appearing generally in the lower right hand portion of FIG. 3, includes a divider 130, a function generator 131, an algebraic adding device 132, an algebraic subtracting device 133, and a lead-lag logic device 134. The usual magnetic compass 135 provides own heading, H, information for the computation.

Referring to FIG. 2, it is seen that the angle θ between own SSR line of position 80 and the line from own craft to other craft, measured clockwise from the extension of line 80 past own location 72, is less than 90° . When the other aircraft is closer to the SSR, θ as thus measured is between 90° and 270° . The differential SSR range X is considered positive when the other craft is farther from the SSR, and negative when the other is nearer.

This sign convention is automatically taken into account by the normal operation of the interval timer 95 and subtractor 100 of FIG. 3, because of the differential transit time measured by the timer 95 is proportional to $Y + |X|$ when the other craft is farther, and to $Y - |X|$ when the other is nearer. Thus, when Y is subtracted from $Y \pm |X|$ is the subtractor 100, the difference X is of the appropriate sign.

Again referring to FIG. 2, all SSR beams rotate clockwise as viewed from above, as indicated by the arrow 136. When the aircraft is illuminated before the other as would occur with the own positions shown, the angle θ is between zero and 180° . When the other craft is illuminated first, θ lies between 180° and 360° . The first mentioned condition, shown, is called "lead." The other, not shown, is called "lag." Adopting the convention that Y is positive under the lead condition and negative under the lag condition, the sign of Y is determined by the lead-lag logic device 134.

Referring to FIG. 7, the lead-lag logic comprises AND gates 137 and 138, and flip-flops 139 and 140. A North pulse signal taken from the output of the envelope detector 123 clears both flip-flops, energizing their 0 outputs and enabling both AND gates. Gate 137 is connected to receive detected F1 burst signals from envelope detector 124, and gate 138 is connected to receive decoded reply frame pulses in the output of AND gate 96 of FIG. 3.

After a North pulse signal occurs while the beam of the selected radar is pointing North, an F1 signal will appear while the beam points at the own aircraft and a reply frame signal will appear when the beam points at the other aircraft. When the F1 signal occurs first, flip-flop 139 is set, energizing its 1 output terminal to indicate a lead condition, and deenergizing its 0 output terminal. This disables AND gate 138 to prevent a

subsequent reply frame signal from setting flip-flop 140.

When a reply frame signal occurs before the F1 signal, flip-flop 140 sets, energizing its 1 output to indicate a lag condition, and deenergizing its 0 output to prevent setting of flip-flop 139 by a subsequent F1 signal. Accordingly, the sign of Y is determined by which of the flip-flop 1 outputs is energized.

Returning to FIG. 3, the Y sign information from lead-lag logic device 134 and the output of divider 130, representing the quotient X/Y with the X sign, are applied to the function generator 131, which may be a digital or analog device of known type that produces an output representing the angle $\cos^{-1} X/Y$, including its quadrantal position. This angle is a close approximation, within two or three degrees in a typical situation, of the angle θ .

The adding device combines the representations of θ and ϕ to produce an output representing $\theta + \phi$, which, as shown in FIG. 2, is the magnetic bearing from the own aircraft to the other aircraft. A similar representation of own magnetic heading H, provided by the compass 135, is as subtracted in the subtractor 133 to provide an output representing $\theta + \phi - H$, which is seen in FIG. 2, is the other craft's bearing from own craft's heading, B. This representation, exhibited by display device 78, indicates directly the line of sight to an intruder aircraft with respect to the own craft's longitudinal axis.

I claim:

1. A method of determining at an own transponder station the bearing angle ϕ of said own station from a selected one of a plurality of secondary surveillance [radar] radars (SSR) that transmit directional interrogation signals of the same frequency and that omniazimuthally [transmits a] transmit reference [signal] signals as the main radar [beam sweeps] beams thereof sweep through a standardized reference direction, such as magnetic North, said method comprising the steps of:

- (a) receiving said reference signals [.] from said radars,
- (b) receiving interrogation signals from said [radar] radars as the main [beam sweeps] beams thereof sweep by the own location,
- (c) [measuring the time interval between successive reception of one of said reference and said interrogation signals and producing a quantitative first representation of the main beam rotation interval,] selecting the reference and interrogation signals received from one of said secondary surveillance radars,
- (d) [measuring and producing a quantitative second representation of the time interval between reception of a reference signal and reception of the next subsequently received interrogation signal,] measuring the time interval between successive reception of one of said selected reference and said selected interrogation signals and producing a quantitative first representation of the main beam rotation interval,
- (e) [dividing the value of said second representation by that of said first representation to produce the quotient of said values, and] measuring and producing a quantitative second representation of the time interval between reception of one of said selected reference and said selected interrogation sig-

nals and the next subsequently received other one of said signals,

- (f) [producing a quantitative representation ϕ of said quotient.] dividing the value of said second representation by that of said first representation to produce the quotient of said values, and
- (g) producing a quantitative representation ϕ of said quotient.

2. Apparatus for determining at an own transponder station the bearing angle ϕ of said own station from a selected [azimuthally scanning radar that omnidirectionally transmits a] one of a plurality of secondary surveillance radars (SSR) that transmit directional interrogation signals of the same frequency and that omniazimuthally transmit reference [signal when its directional beam points in a standard] signals as the main radar beams thereof sweep through a standardized reference direction, such as magnetic North, said apparatus comprising:

- (a) means for receiving said reference [signal] signals and for receiving the [normal] interrogation transmission signals of said radars as the radar [beam sweeps] beams sweep by the own location,
- (b) [a first interval timer for measuring the interval between successive reception of one of said reference and said normal transmission signals and producing a quantitative representation N of said interval,] means for selecting the reference and interrogation signals received from one of said secondary surveillance radars,
- (c) [a second interval timer for measuring and producing quantitative representation M of the interval between reception of a reference signal and a normal transmission signal,] a first interval timer for measuring the interval between successive reception of one of said selected reference and said selected interrogation signals and producing a quantitative representation N of said interval,
- (d) [divider means for computing the quotient M/N , and] a second interval timer for measuring and producing a quantitative second representation M of the time interval between reception of one of said selected reference and said selected interrogation signals and the next subsequently received other one of said signals,
- (e) [means for producing a quantitative representation ϕ of said quotient.] divider means for computing the quotient M/N , and
- (f) means for producing a quantitative representation ϕ of said quotient.

3. A method as in claim 1 for additionally producing at said own transponder station a representation of the angular relationship between the bearing of said own transponder station from said selected SSR and the bearing from said selected SSR of another transponder station within a common azimuthal sector with said own transponder station, including the further steps of:

- [(g)] (h) receiving at said own transponder station reply signals transmitted by said other transponder station in response to said interrogation signals as said main beam sweeps by said other transponder station,
- [(h)] (i) determining the time relationship between said interrogation signals and said reply signals, and
- [(i)] (j) producing, in accordance with said time relationship, a representation of said angular rela-

tionship between said bearing angles from said selected SSR.

4. The method according to claim 3 wherein step

[(i)] (j) comprises the steps of:

[(j)] (k) producing a lead signal in response to the prior occurrence of said interrogation signals immediately subsequent to said reference signals, and

[(k)] (l) producing a lag signal in response to the prior occurrence of said reply signals immediately subsequent to said reference signals.

5. Apparatus according to claim 2 for additionally producing at said own transponder station a representation of the angular relationship between the bearing of said own transponder station from said selected SSR and the bearing from said selected SSR of another transponder station within a common azimuthal sector with said own transponder station, further comprising:

[(f)] (g) means for receiving at said own transponder station reply signals transmitted by said other transponder station in response to said interrogation signals as said main beam sweeps by said other transponder station,

[(g)] (h) means for determining the time relationship between said interrogation signals and said reply signals, and

[(h)] (i) means for producing, in accordance with said time relationship, a representation of said angular relationship between said bearing angles from said selected SSR.

6. Apparatus according to claim 5 wherein the means

[(h)] (i) comprises:

[(i)] (j) means for producing a lead signal in response to the prior occurrence of said interrogation signals immediately subsequent to said reference signals, and

[(j)] (k) means for producing a lag signal in response to the prior occurrence of said reply signals immediately subsequent to said reference signals.

7. The method according the claim 1 wherein the reference and interrogation signals are selected in accordance with the pulse repetition characteristic associated with said one of said secondary surveillance radars.

8. The apparatus according to claim 2, wherein means (b) selects the reference and interrogation signals in accordance with the pulse repetition characteristic associated with said one of said secondary surveillance radars.

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