

[54] COLLISION PREVENTION

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[52] U.S. Cl. 343/112 CA, 73/179, 343/6.5 R,
343/7.3, 343/101, 343/112 A

[51] Int. Cl. G08g 5/04

[58] Field of Search 343/7.3, 7.4, 100, 108,
343/101, 102, 112, 106, 6, 12, 112.4, 65,
112.2; 73/178, 179; 340/27

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Primary Examiner—Malcolm F. Hubler

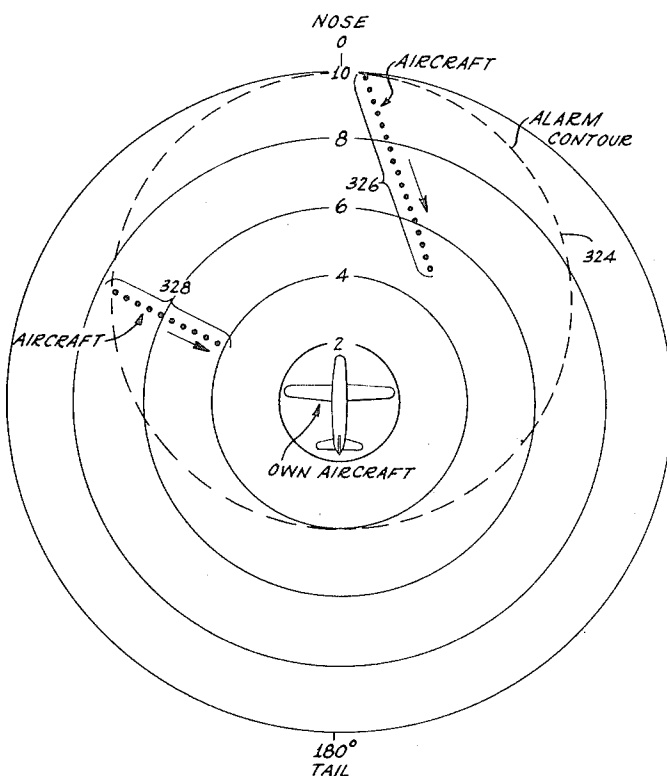
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Edward J. Norton

EXEMPLARY CLAIM

17. In combination: means for giving an indication representative of the direction of an intruding craft from an observing craft; and means preventing the operation of said first named means as long as said direction is changing.

21 Claims, 19 Drawing Figures



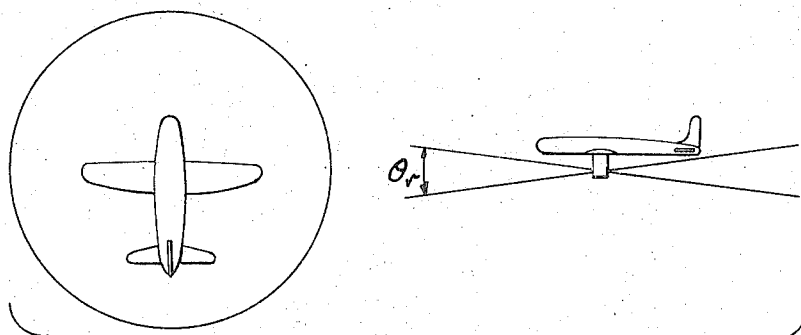
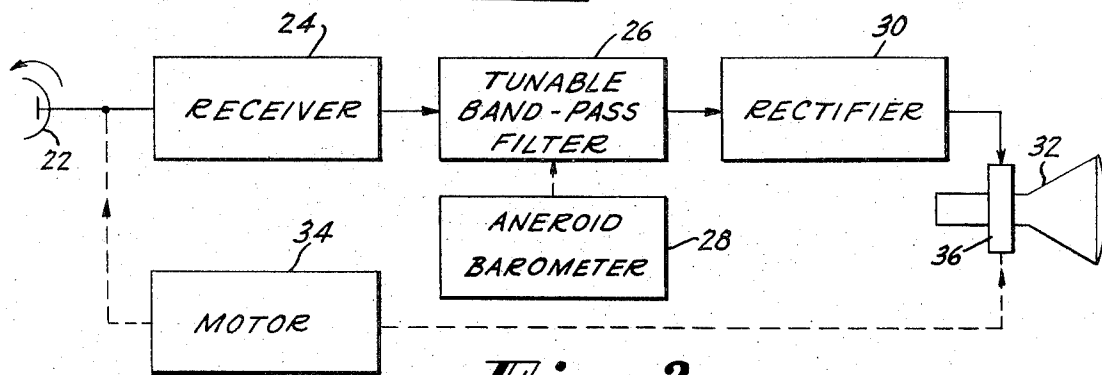
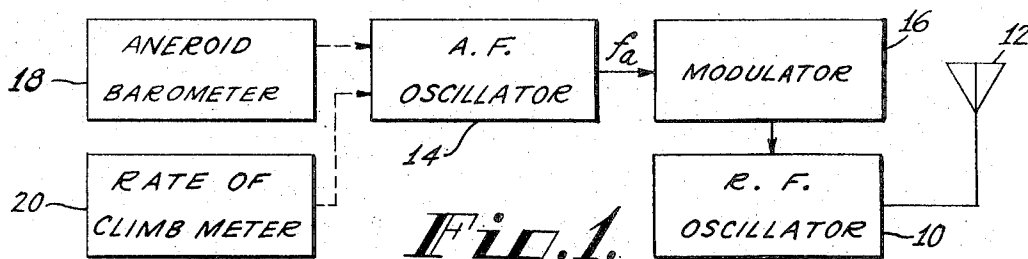


Fig. 3.

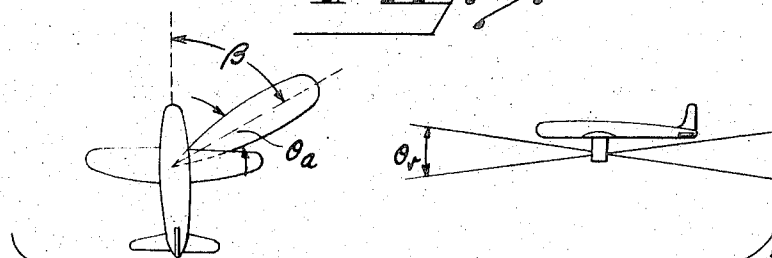


Fig. 4.

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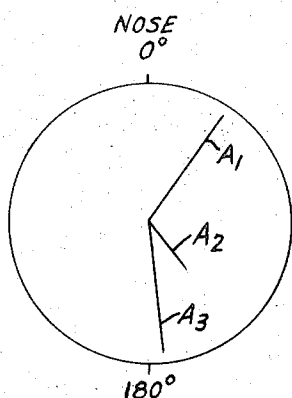


Fig. 5.

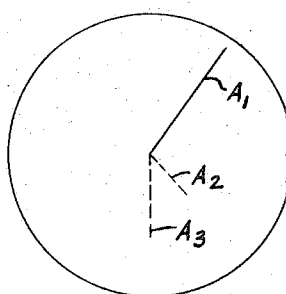


Fig. 7.

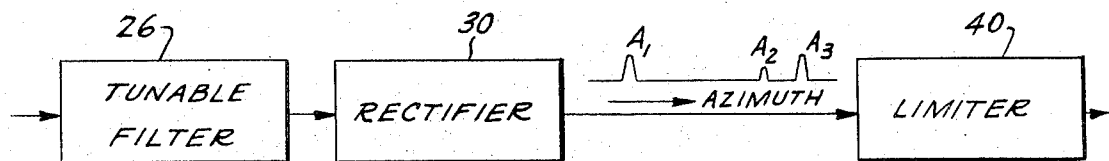
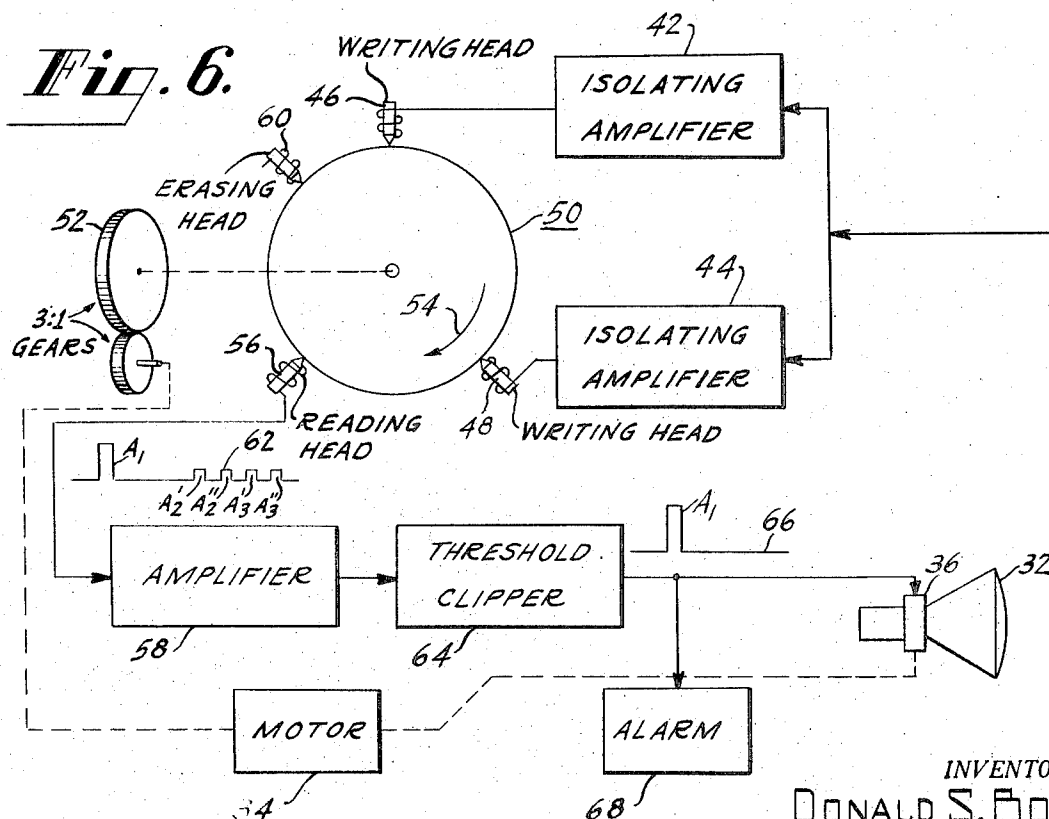


Fig. 6.



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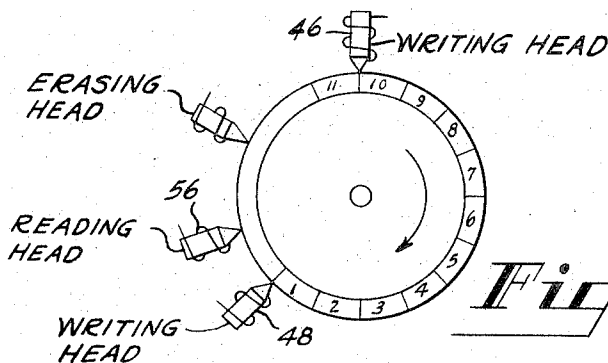


Fig. 8.

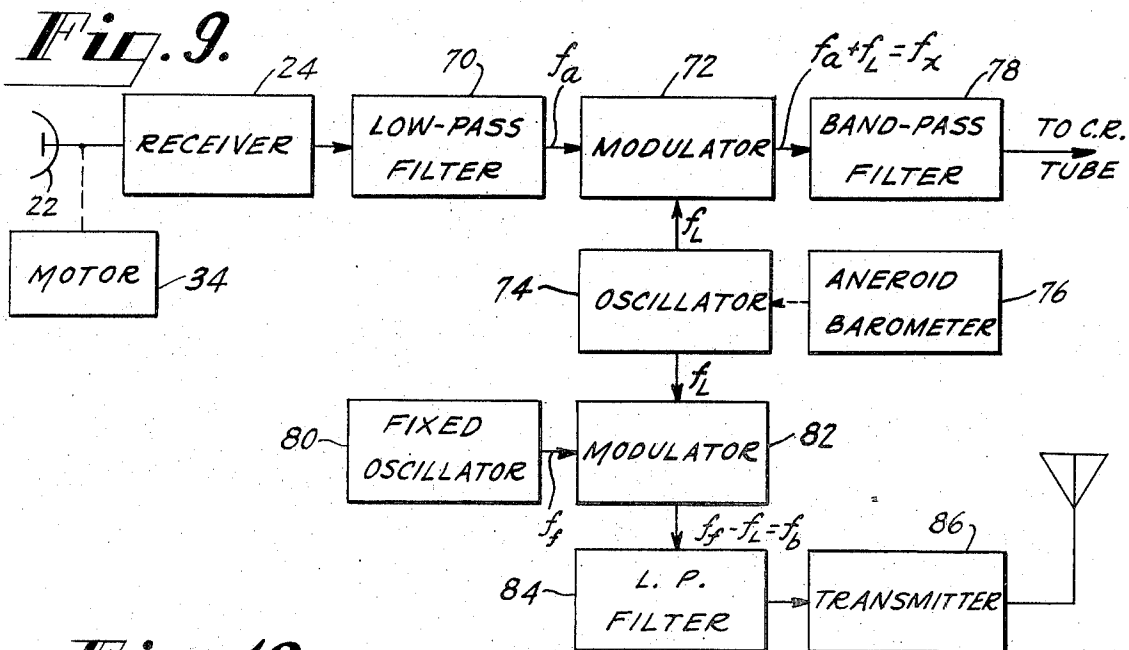
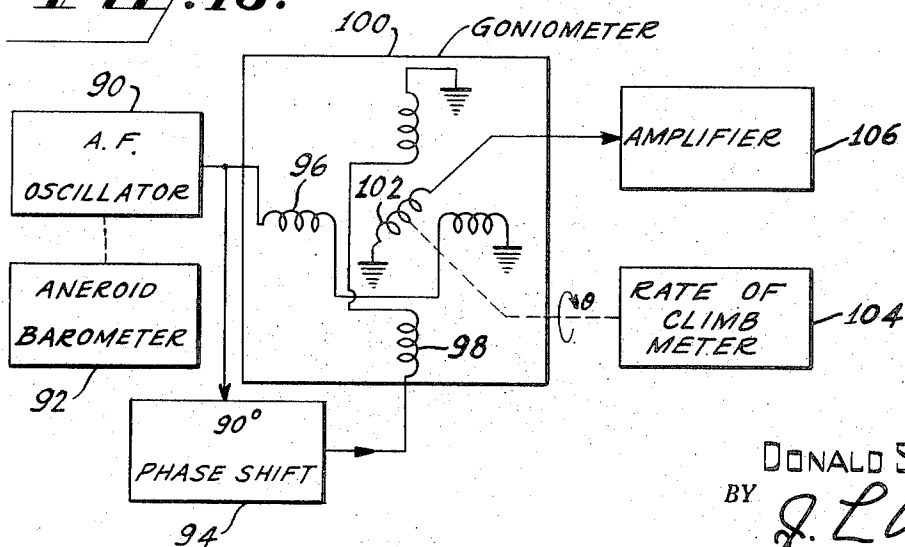


Fig. 10.



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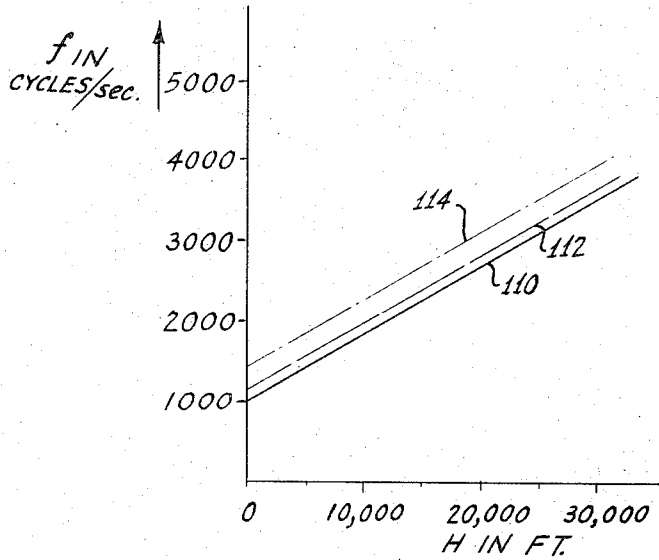


Fig. 11.

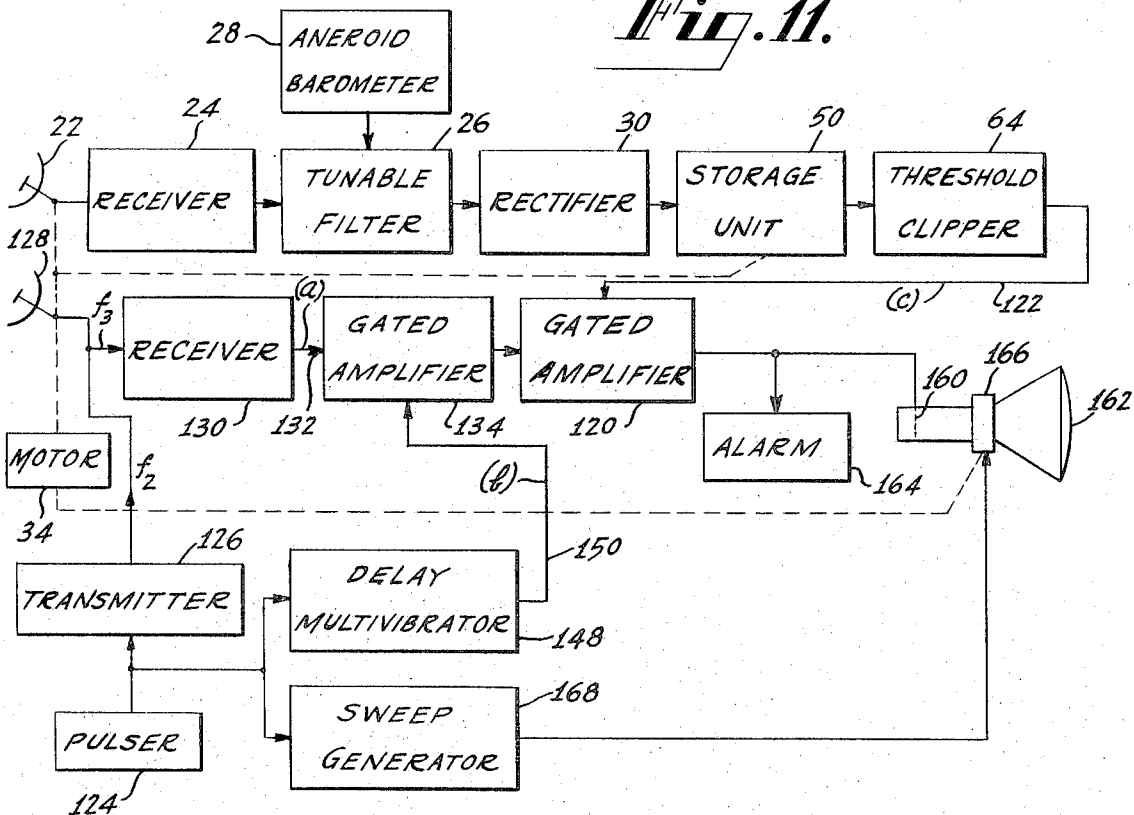
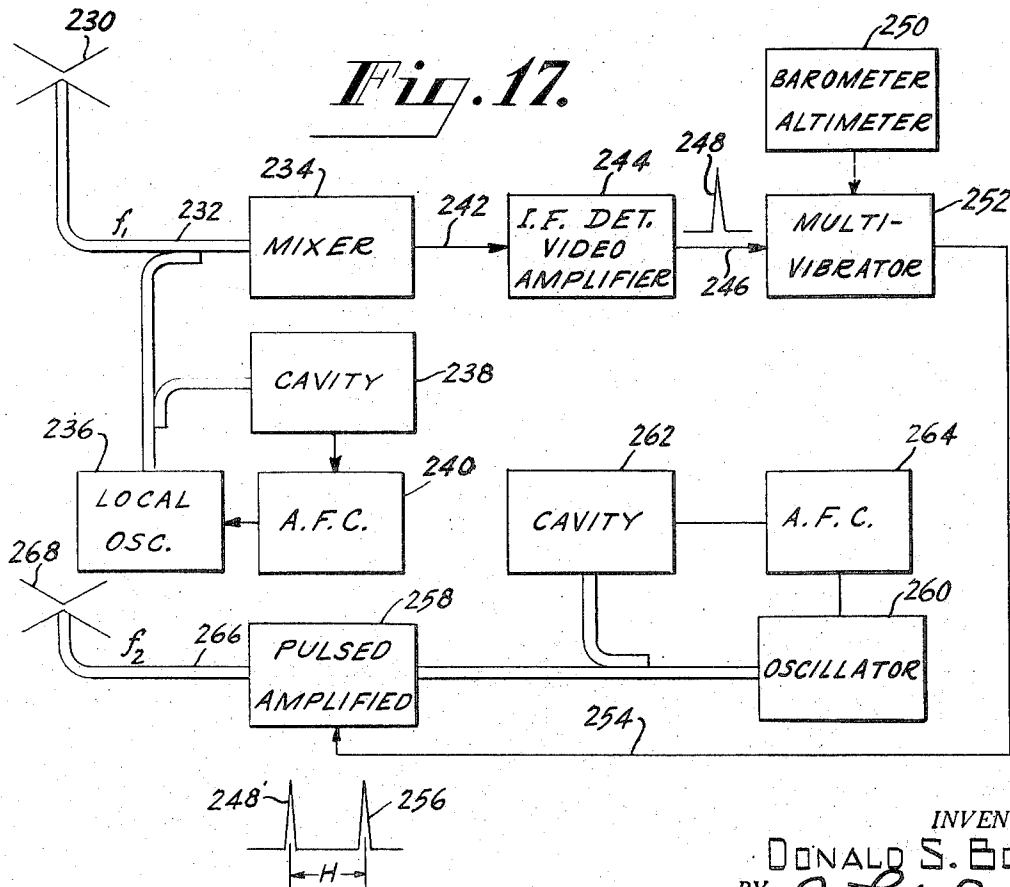
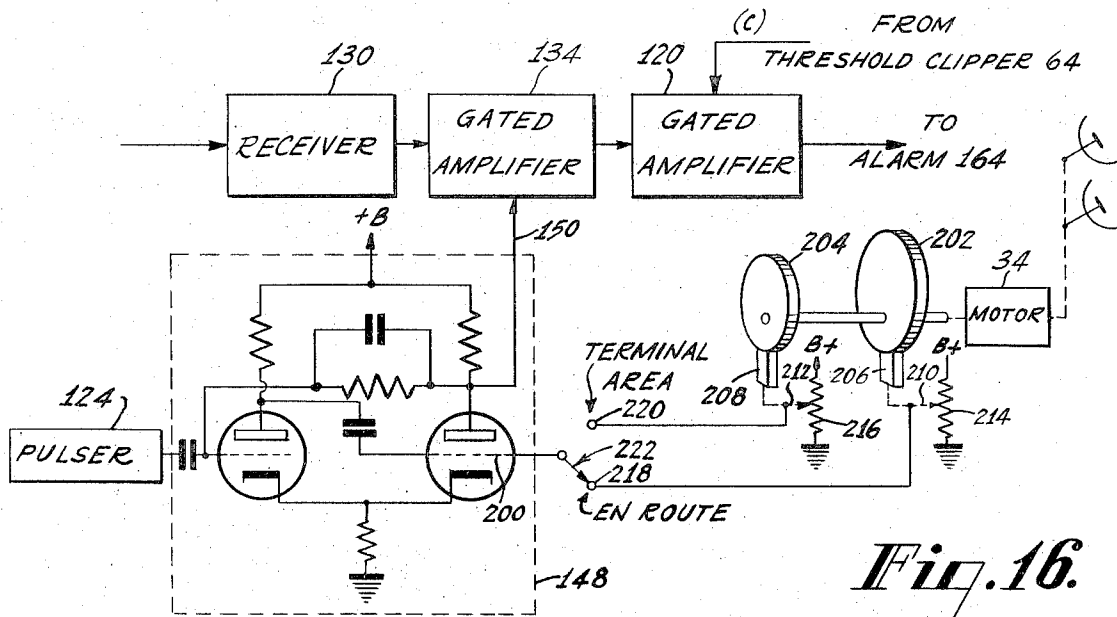
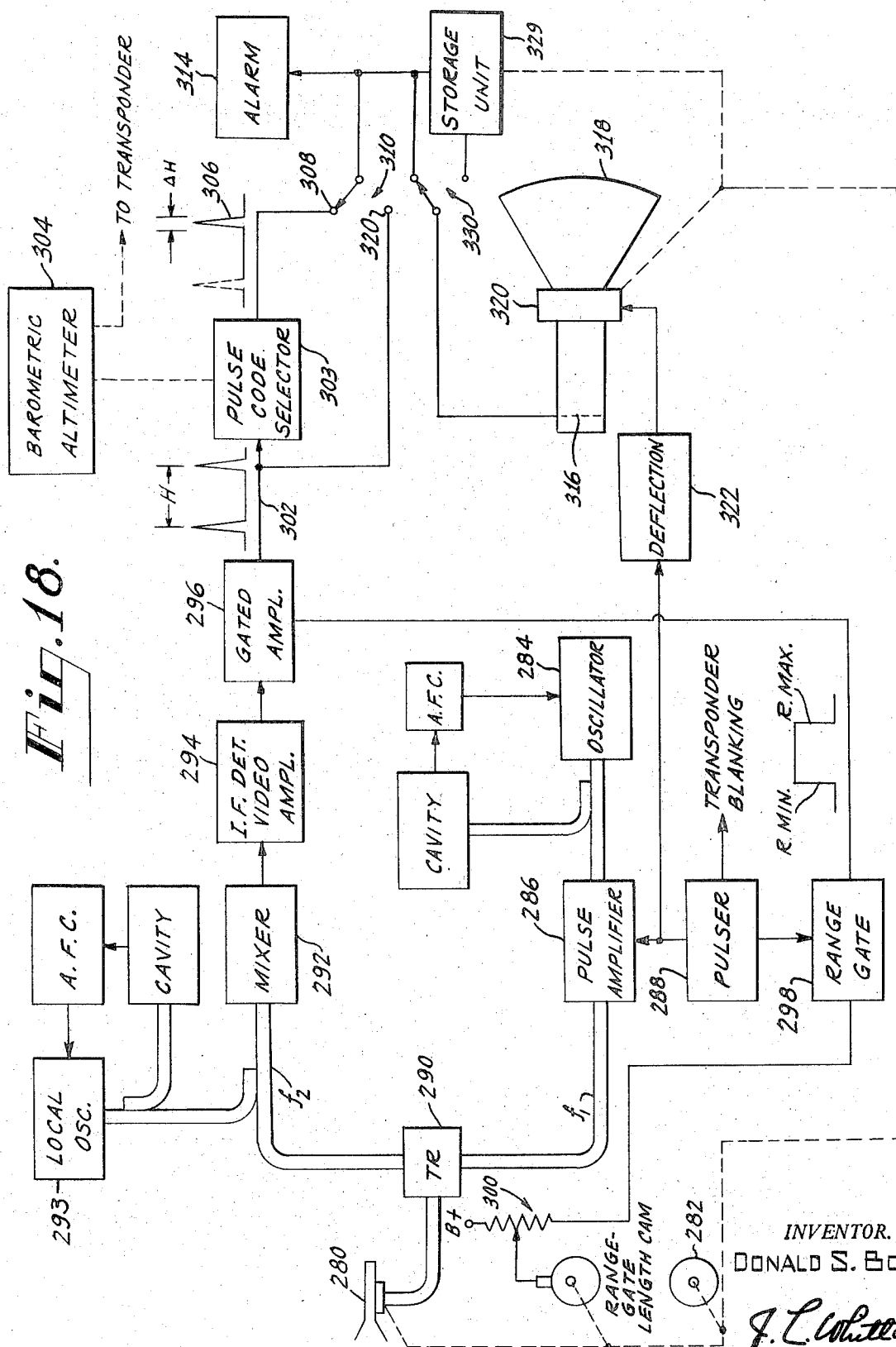


Fig. 12.

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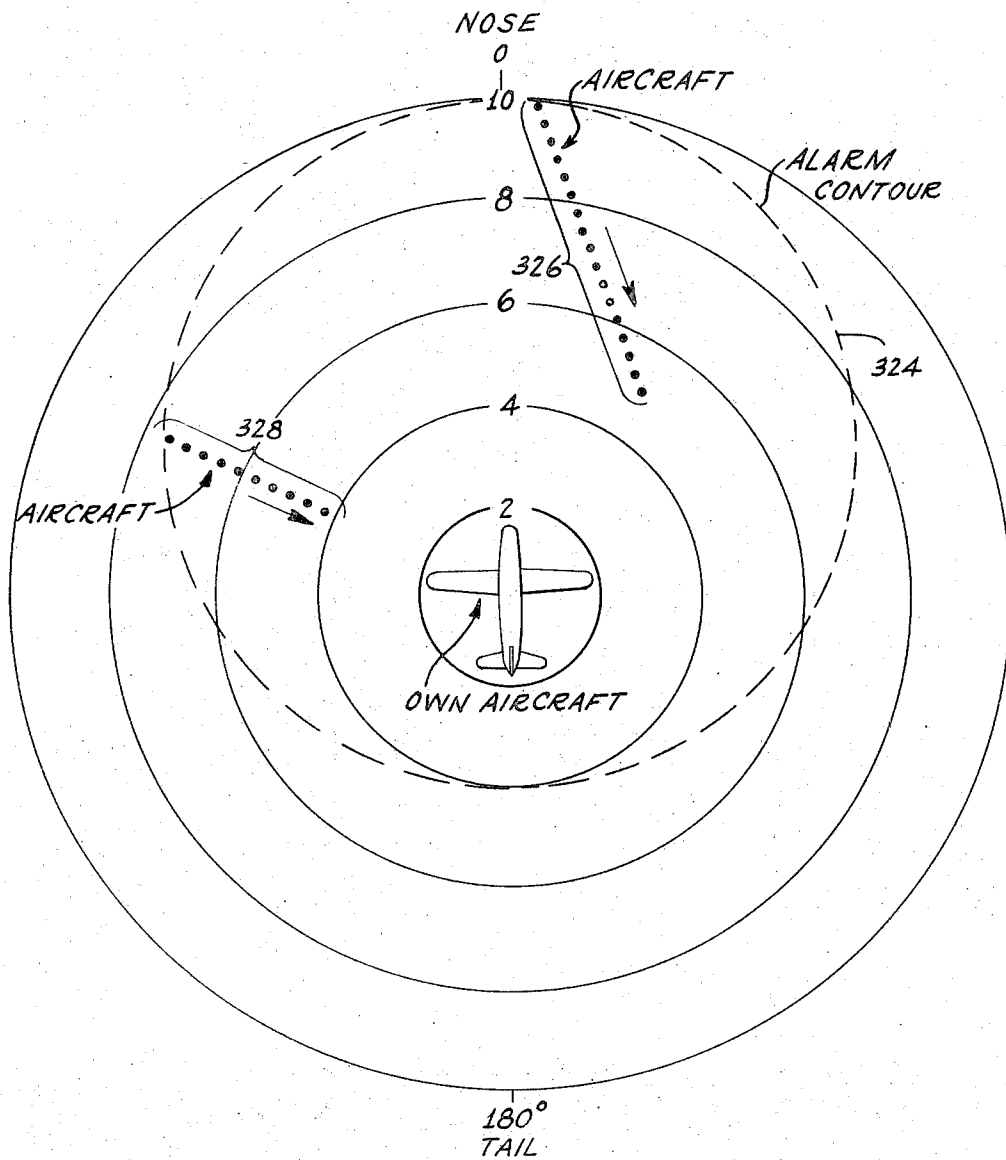
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Fig. 19.



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COLLISION PREVENTION

The present invention relates to improved systems for preventing collisions between two vehicles, particularly two aircraft.

Two general types of collision prevention systems are presently under consideration by the aircraft industry. One requires cooperation between aircraft (cooperative systems) and the other does not. Cooperative systems include at least a beacon of some type on all aircraft, regardless of their size. "Fully equipped aircraft," such as larger commercial and military aircraft, may carry, in addition, means for receiving the beacon transmissions and determining from them the positions of other aircraft in the vicinity. Examples of "non-cooperative" systems include radar systems, infra-red detector systems, and the like.

A general object of this invention is to provide improved and simplified types of cooperative collision prevention systems.

Another object of this invention is to provide an improved collision warning system which includes means for indicating in one aircraft when other aircraft in the vicinity are at or near the same altitude, and/or are on a collision heading, and/or are moving from one altitude layer to another at which there may be a collision hazard.

Yet another object of the present invention is to provide an improved interrogator-transponder system especially suitable for collision warning.

A more specific object of the present invention is to provide, in a collision prevention system, an improved circuit for generating a wave which is indicative of aircraft altitude and/or rate of climb.

The present invention relates to improved cooperative type collision warning systems. In its simplest form, the system includes a beacon on each aircraft which continuously transmits signals in an omnidirectional pattern. In a preferred form of the invention, the transmitted signals have a characteristic indicative of the altitude of the aircraft transmitting the signals. Fully equipped aircraft, such as those of the air lines and the like, include, in addition to the beacon mentioned above, a direction-finder, preferably of the type having a scannable, highly directive, receiving pattern. The direction-finder includes circuits which discriminate against signals transmitted from other aircraft not at or near the same altitude as the fully equipped aircraft and, in some forms of the invention, circuits which discriminate against signals transmitted from other aircraft not on a collision heading.

A feature of an improved form of the invention is a circuit in each beacon for altering a characteristic of the transmitted signal in a sense to indicate rate of aircraft climb or descent. This characteristic enables the fully equipped aircraft to detect other aircraft climbing or descending to an altitude presenting a collision hazard.

A modified form of the invention includes a transponder on all aircraft and an interrogator on fully equipped aircraft. If a transmitting aircraft A is within a given range of a fully equipped aircraft B, the former's transponder signal passes through a first gated amplifier on aircraft B. If, at the same time, aircraft A is on a collision course with aircraft B, the first amplifier output signal passes through a second gated amplifier on aircraft B. The output of the second gated am-

plifier actuates a load circuit such as an alarm or indicator.

The forms of the invention described in the preceding paragraphs may include, in addition, means for varying the range within which other aircraft A, A₁, etc., on collision courses are indicated as a function of bearing θ of the other aircraft with respect to aircraft B. The circuit may take the form of a cam driven by the motor which drives the directive antenna, and which controls the bias on a range gate multivibrator.

The invention will be described in greater detail by reference to the following description taken in connection with the accompanying drawing in which:

FIG. 1 is a block circuit diagram of a beacon according to this invention;

FIG. 2 is a block circuit diagram of a direction-finder according to this invention;

FIGS. 3 and 4 show antenna patterns for the beacon and direction-finder of FIGS. 1 and 2, respectively;

FIG. 5 is a display such as may be obtained with the system shown in FIG. 2;

FIG. 6 is a block circuit diagram of a portion of a direction finder system according to this invention which includes means for indicating aircraft on collision courses;

FIG. 7 is a display such as may be obtained with the system of FIG. 6;

FIG. 8 is a drawing of a portion of the system shown in FIG. 6, in modified form;

FIG. 9 is a block circuit diagram of an improved direction finder according to the invention;

FIG. 10 is a block and circuit diagram of a circuit for introducing a rate of climb characteristic to an electrical signal;

FIG. 11 is a graph to illustrate how the system of FIG. 10 operates;

FIG. 12 is a block circuit diagram of a modified beacon and beacon interrogator according to this invention;

FIG. 13 is a drawing of waveforms to explain how the system of FIG. 12 operates;

FIG. 14 is a display such as may be obtained with the system of FIG. 12;

FIG. 15 is a block circuit diagram of two beacons which cooperate with the system of FIG. 12;

FIG. 16 is a block and circuit diagram of a portion of the system shown in FIG. 12, in modified form;

FIG. 17 is a block circuit diagram of another type of beacon transponder according to the present invention;

FIG. 18 is a block circuit diagram of a direction-finder which cooperates with the system of FIG. 17; and

FIG. 19 is a display such as may be obtained with the system of FIG. 18.

Throughout the drawing, like reference numerals are applied to like elements.

One form of cooperative system, according to this invention, is shown in FIGS. 1 and 2. In this system, all aircraft are equipped with at least the equipment shown in FIG. 1. The equipment includes a radio frequency oscillator 10 supplying signals to an omnidirectional antenna 12. The antenna preferably has a relatively narrow pattern in the vertical direction as indicated in FIG. 3, the angle encompassed by the pattern being indicated by θ . Preferably, the transmitted carrier wave is modulated by an audio frequency signal generated in

oscillator 14 and applied to the radio frequency oscillator 10 through modulator 16. The frequency of the audio frequency oscillator is controlled by aneroid barometer 18 and rate of climb meter 20. The manner in which this may be accomplished is described in greater detail below. In their simplest form, control elements 18 and 20 may be mechanically connected to an impedance element such as a condenser in the tuned circuit of the oscillator. Other means of frequency control are possible.

In the beacon described above, the modulating frequency f_m is equal to $f_o + K H + \Delta R$, where f_o is the center frequency of oscillator 14, K is a constant, H is the aircraft altitude, and ΔR , which may be positive or negative, is proportional to the rate of climb of the aircraft. In level flight, ΔR , of course, reduces to zero. Amplitude, frequency, phase or other type of modulation may be employed. Also, the transmitted carrier wave may be a modulated continuous wave or a pulsed wave.

All fully equipped aircraft, hereinafter termed aircraft B, include at least the equipment shown in FIGS. 1 and 2. Referring to FIG. 2, antenna 22 has a highly directive receiving beam pattern (see FIG. 4). The antenna is continuously rotated in azimuth and the signals it receives are applied to receiver 24. The detected signals pass to tunable, band-pass filter 26, the center frequency of which is controlled by an aneroid barometer 28. The control is such that when the frequency of the detected signal is indicative of an altitude equal or close to that of aircraft B, the signal passes through the band pass filter 26 and rectifier 30 to cathode ray tube indicator 32, and when the frequency is not, the filter rejects the detected signal.

The indicator of FIG. 2 includes a rotatable yoke 36 driven in synchronism with antenna 22 by motor 34. The display consists of radial lines such as shown in FIG. 5. The display indicates that three aircraft A_1 , A_2 and A_3 are at or near the same altitude as aircraft B. The directions of the radial lines are the directions toward the aircraft. The lengths of the radial lines are rough indications of aircraft range. Preferably, the frequencies employed are in the super-high-frequency range. This enables the weight of the equipment to be substantially reduced.

The system as described so far accomplished the first objective of a collision warning system — it aids the pilot in scanning a solid altitude sector about him and gives him indications of those aircraft that, by virtue of their altitude, may be in a position to collide. This, in itself, is of value, for it tells the pilot to look in a few specified directions for aircraft in the vicinity. However, it fails to rule out those aircraft not on collision courses and those too far away to be an immediate threat.

It is desirable in a system of the type described to be able to narrow the number of targets A to those on or near collision courses. A modification shown in FIG. 6 enables this to be done. This modification depends for its operation on the principle that when the relative bearing of aircraft A measured at aircraft B is constant, the two airplanes are on collision courses. (There are two exceptions, that is, the cases of parallel flight and the cases in which one of the aircraft has changed its direction to one in which the two are receding at a constant bearing.)

Referring to FIG. 6, tunable band pass filter 26 is identical in structure and function to the one shown in FIG. 2. It is controlled by an aneroid barometer (not shown) and it receives a signal from receiver 24 (not shown). The output of the filter is rectified in stage 30 and applied to a limiter 40. The function of the limiter is to produce output signals of fixed amplitude from input signals of different amplitudes. The limited signals are applied through separate isolating amplifiers 42 and 44 to separate writing heads 46 and 48 of a magnetic recording drum. The motor 34, which drives the antenna and the yoke 36 of indicator 32 also drives the magnetic drum 50. In the embodiment illustrated, three-to-one step down gears 52 are employed for reducing the drum speed to one-third that of the antenna scanning speed and heads 46 and 48 are spaced 120° intervals apart. If the direction of drum movement is as indicated by arrow 54, signals written by writing head 46 will, if the azimuth of the radiating source remains the same scan-to-scan, appear under writing head 48 when the latter records the signal from the same source one scan interval later. Such signals therefore are recorded at an amplitude approximately double that of signals which change their bearing from scan-to-scan.

The recorded signals are picked up by a reading head 56 which applies them to an amplifier 58. After the signals have been read off the drum, they are erased by an erasing head 60. As mentioned above, with the timing of the system as indicated, writing heads 46 and 48 must be spaced 120° apart. The reading head 56 may be spaced almost anywhere beyond head 48, however, for the sake of convenience, it too is spaced 120° from head 48.

By way of example, assume that three aircraft A_1 , A_2 and A_3 are at or near the same altitude as the fully equipped aircraft B which carries the equipment of FIG. 6. At the lead between rectifier 30 and limiter 40, three signals appear. They are at a different range and therefore appear to be of different amplitude, and they are at different bearings or azimuth positions. In this example, aircraft A_1 is on a collision course and the remaining two are not. Therefore, the bearing of aircraft A_1 remains the same scan-to-scan and it is written on the recording drum at double amplitude. The remaining signals A_2 and A_3 change their bearing scan-to-scan and therefore are not written one on top of the other. The signal picked up by the reading head therefore is as indicated by wave 62. The first signal A_1 is of double amplitude and the remaining signals A_2 and A_3 appear as four rather than two signals since they are written at different places on the recording drum by heads 46 and 48.

Signals 62 are amplified in stage 58 and applied to threshold clipper 64. The latter is biased to a value such that double amplitude signals (A_1) pass through the clipper stage, whereas single amplitude signals (A_2 and A_3) do not. The resultant signal is as shown by wave 66. It is applied to the indicator 32 and also to alarm circuit 68. The latter may be a visual alarm such as a red light or the like or an audible one such as an alarm, buzzer or the like. In practice, the alarm may be applied as an audible tone to the intercommunications system in the aircraft. The display is as shown in FIG. 7. Signal A_1 appears as a radial trace pointing in the direction of the aircraft with which there is danger of collision. Signals

A₂ and A₃ do not appear on the indicator, however, they are shown in FIG. 7 as dashed lines.

Alternative types of displays may be employed with the system of FIG. 6. For example, the display may be the conventional PPI type display. In this case, signal 66 is applied to intensity modulate the beam rather than being applied to the rotatable yoke 66. Moreover, although a magnetic drum is shown for storing signals, other types of storage devices may be used instead. For example, a magnetic tape may be used or a storage tube or other types of memory device.

In another form of the invention, both the raw direction finder signal (available at the output of rectifier 30) and the collision signal may be applied simultaneously to indicator 32. In this form of the invention, time sharing techniques are employed. The output signal may be taken from threshold clipper 64 during one of the time intervals and from limiter 40, for example, during the other time interval. In this case, the gains of the various stages can be adjusted to a value such that the signals from aircraft on collision courses appear to be substantially stronger than those from aircraft not on collision courses.

In the event the change in bearing on two successive scans is not sufficient to distinguish a target on a collision heading from one not on such a heading, the magnetic memory device may be arranged to record a larger number of successive scans, and head 48 may be spaced from head 46 by an integral number of scans. Such an arrangement is shown in FIG. 8. While writing head 48 is beginning to record the first scan, writing head 46 is beginning to record the eleventh scan. Reading head 56 may be placed one or more scans behind writing head 48.

The embodiment of FIG. 9 illustrates an improved and simplified circuit for altitude-layer information transmission and reception. Receiver 24 and antenna 22 are identical to the like-numbered components of the system of FIG. 2. The detected receiver output signal is applied through a low pass filter 70 to modulator 72. This signal is at a frequency f_a and is indicative of the altitude of aircraft A from which it was received. A tunable local oscillator 74 controlled by the altimeter 76 in aircraft B produces an output signal f_L which is applied to modulator 72. The arrangement is such that frequency f_L decreases linearly as the altitude of aircraft B increases.

Modulator 72 adds signals f_a and f_L to obtain a sum signal f_s which is indicative of the difference in altitudes between aircraft A and B. Band pass filter 78 is tuned to a fixed frequency which indicates that aircraft A is at or near the same altitude as aircraft B.

Modulator 82 subtracts signal f_L from the signal f_f from fixed oscillator 80. The resultant, difference signal $f_f - f_L = f_b$ is directly proportional to the altitude of aircraft B. It may be applied through filter 84 to transmitter 86.

The manner in which the circuit described above operates may be best described by specific examples. The Table below shows various incoming modulating frequencies f_a and the other frequencies mentioned above. All frequencies are in cycles per second. Aircraft A and B are assumed to be at the same altitude.

TABLE

Altitude	f_a	f_L	f_f	f_b	Frequency to Which Filter 78 is Tuned
1000 ft.	1000	8000	9000	1000	9000
2000 ft.	2000	7000	9000	2000	9000
4000 ft.	4000	5000	9000	4000	9000

The above are given merely by way of example and are not meant to be limiting.

In order to provide an offset in frequency of oscillator 74 of FIG. 9 to anticipate a climb or descent to a new layer, the circuit of FIG. 10 may be employed. This same circuit may be employed with the embodiment of FIG. 1 and other forms of the invention described herein. Here, audio frequency oscillator 90 is controlled by aneroid barometer 92 in the manner already indicated. The output frequency of the oscillator therefore is indicative of aircraft altitude. This frequency is applied directly and through 90° phase shifter 94 to the stator windings 96, 98 of a goniometer 100. The output frequency of the goniometer with its rotor coil 102 in fixed position is the same as its input frequency. The rotor, however, is connected to a rate of climb meter 104 and is driven thereby in a rotational speed proportional to the rate of climb or descent dH/dt . In a practical circuit, the rate of climb meter may be connected to a potentiometer, and the potentiometer output used to control the speed of a D.C. motor which drives rotor 102. It can readily be shown that when the rotor winding revolves, the output frequency of the goniometer is changed, and changed by an amount proportional to the rotational speed. Thus, the frequency applied to amplifier 106 is proportional not only to the aircraft altitude but also to its rate of climb or descent. The mathematical explanation is as follows:

$$\omega_s = a (dH/dt) \quad (1)$$

$$\omega_s = d\psi/dt = 2\pi \Omega_s \quad (2)$$

where

ω_s = the angular speed of rotor 102;

$d\psi/dt$ = the rate of change of the angle θ with time;

Ω_s is in revolutions per second; and

a is a constant

Since the phase ϕ of the electrical output of the phase shifter 100 may be chosen to be

$$\phi = \phi_a + \psi \quad (3)$$

$$d\phi/dt = a dH/dt$$

$$\Delta f_{af} = [(1/(2\pi))] (d\phi/dt) = (a/2\pi) (dH/dt) \quad (4)$$

where Δf_{af} = change in frequency due to the rotor rotation. Thus, the output frequency of the phase shifter is shifted in frequency by $(a/2\pi) (dH/dt)$. The output frequency F of the phase shifter is:

$$F = f_{af} + \Delta f_{af} \quad (5)$$

where f_{af} is the frequency output of oscillator 90.

$$F = f_{af} + KH + (a/2\pi) (dH/dt) \quad (6)$$

where

H = aircraft altitude and

K = a constant

Let $b = a/2\pi$ (7)

The constant b is in cycles per foot (not cps per foot). If the offset in frequency due to climb, Δf_{af} is set equal to $K\Delta H$

$$b (\Delta H/\Delta t) = K\Delta H \quad (8)$$

$$\text{or } \Delta t = b/K \quad (9)$$

where

Δt = the warning time within which an aircraft will reach a new altitude layer.

The graph of FIG. 11 illustrates two cases in which the frequency is offset from the level flight frequency. The solid line 110 indicates the case in which the aircraft is in level flight. The plot is of altitude vs. frequency. If $\Delta t = 30$ seconds, that is, if the rate of climb is such that it will require 30 seconds for the aircraft to move from one layer H to a new layer $H + \Delta H$, and $K = 0.1$ cps/ft., $\Delta t = b/K$; $b = 3$ cycles per foot. If the rate of climb $dH/dt = 10$ feet per second, $\Omega_s = b \times dH/dt = 30$ rps, and the frequency is raised by 30 cycles per second. This case is illustrated by dashed line 112.

For 60 seconds warning of an aircraft climbing at 40 feet per second, $b = 6$ cycles per foot and $\Omega_s = 240$ cycles. This case is illustrated by dot-dash line 114.

The systems as described so far provide only rough indications of aircraft range. In the system described in FIG. 1, for example, the length of a track indicates range. However, in this system and in all the others which have been described, when an aircraft is on a collision course, an alarm is actuated, regardless of the range to the aircraft. Thus, many false indications may be expected as many aircraft will be well beyond the range within which collisions can occur.

The improved system shown in FIG. 12 overcomes the disadvantage described above. The direction finder portion of the system, that is, the portion of the system carried by fully equipped aircraft B is shown in FIG. 12. Elements 22, 24, 26, 28, 30, 50 and 64 are similar to the like-numbered elements described in the previous systems. In brief, antenna 22 has a highly directional receiving beam. It receives modulated signals from other aircraft (aircraft A_1 , A_2 , A_3 , etc.) which are modulated by a signal indicative of the altitude of the other aircraft. If the other aircraft is at or near the altitude of the aircraft B carrying the system of FIG. 12, the signal from that other aircraft will pass through tunable filter 26 and rectifier 30 and be stored in storage unit 50. If the aircraft A radiating the signal remains at the same bearing from antenna scan to antenna scan, storage unit 50 will add the signals received on successive scans and the added signals will pass through threshold clipper 64 and be applied to gated amplifier 120. The signal c at lead 122 is shown in FIG. 13c and will have a duration which depends upon the width of the receiving beam pattern, the constancy of bearing of the other

aircraft from scan-to-scan, etc. In a typical case, the width of pulse c may be on the order of 10 milliseconds or so.

The system of FIG. 12 also includes an interrogator. Pulser 124 applies short duration pulses to transmitter 126. The latter produces short bursts of radio frequency energy at frequency f_2 and applies them to directive antenna 128. The antenna is driven by the same motor 34 that drives antenna 22 so that the beams produced by the two antennas always point in the same direction. The return pulses transmitted from the transponders on other aircraft are received by antenna 128 and applied to receiver 130. Preferably, the return pulses are at a frequency f_3 which is slightly different than f_2 . The pulses are detected in the receiver and applied over lead 132 to gated amplifier 134. The pulses are shown in FIG. 13a, pulse 136 corresponding to a transmitted pulse and pulse 138 corresponding to a return pulse. Although frequencies f_2 and f_3 are slightly different, the relative power level of pulse 136 is such that the same is detected by the receiver.

The pulses from pulser 124 are also applied to a delay multivibrator 148. The latter produces a gate pulse at lead 150 which applies the pulse to the gated amplifier 134. The gate pulse is shown in FIG. 13b.

In operation, as already mentioned, if an aircraft is at a bearing and altitude such that it presents a collision hazard, a gate pulse is applied over lead 122 to gated amplifier 120. The amplifier is normally cut off, however, when gate pulse c is applied, it is placed in condition to amplify.

Delay multivibrator 148 produces a range gate having a duration which is equal to a range interval within which aircraft present a possible collision hazard. The gate duration, for example, may be equivalent to 10 miles. The gate pulse is applied to amplifier 134 which is placed in condition to conduct during the gate interval. If a return pulse from the transponder on the aircraft is received during the gate interval, it passes from receiver 130 to amplifier 134. If this aircraft is at a bearing and altitude such that it presents a collision hazard, gated amplifier 120 is open, and a pulse from amplifier 134 passes through amplifier 120 and is applied to the control grid 160 of indicator 162 and to an alarm device 164. Indicator 162 is a PPI type indicator. The sawtooth deflection voltages are applied to the rotatable deflection coil 166 from sweep generator 168, and the deflection coil is rotated in synchronism with antennas 22 and 128 by motor 34.

The display produced by indicator 162 is shown in FIG. 14. Dotted line 170 is the range within which targets are possible collision hazards. There are two targets shown which are on collision courses. One is at a range R_2 and the other is at a range R_1 . Preferably, the display is oriented so that the top of screen represents the heading of the aircraft.

The cooperating portion of the system of FIG. 12 is shown in FIG. 15. It includes a beacon transmitter 180 and a beacon transponder 182. The beacon transmitter is similar to the one already described, stages 14 and 18 corresponding to the like-numbered stages of the system of FIG. 1 and stage 184 corresponding to stages 10 and 16 of FIG. 1. Transponder 182 is conventional and includes an omnidirectional antenna 186, a transponder receiver 188 and a transponder transmitter 190.

In the system of FIG. 12, no aircraft outside of a pre-selected range is indicated. However, it is evident that

the available warning time is much less if two aircraft are approaching each other head on than if one is overtaking the other. Thus, it is desirable to be able to vary R_{max} (the range within which other aircraft (A_1 , A_2 , etc.) on collision courses are indicated) as a function of the bearing θ of other of the aircraft (A_1 , A_2) with respect to aircraft B. Furthermore, it would be desirable to be able to select one of a number of space patterns at will. In a typical case, for en route flying, R_{max} is 10 miles ahead 5 miles at bearings of 90° and 270° and 5 miles astern. For flight in terminal areas, the distance forward is 3 miles and at the other bearings referred to above $1\frac{1}{2}$ miles.

An improvement in the circuit of FIG. 12 for accomplishing the above is shown in FIG. 16. Stages 130, 134, 148, 124, 34 and others (not shown) are identical with the like-numbered components of FIG. 12. Multivibrator 148 is shown in schematic form. The width of the gate output of the multivibrator depends upon the bias applied to control grid 200. In the improved circuit shown, the bias is cyclically varied by a cam 202 or 204 which is driven by motor 34. Cam followers 206 and 208 drive the arms 210 and 212 of potentiometers 214 and 216. The outputs of potentiometers 214 and 216 are applied to terminals 218 and 220 of switch 222. Terminal 218 is the "en route" terminal, and terminal 220 is the "terminal area" terminal. When grid 200 is connected to 218, the multivibrator produces a variable width square wave whose duration varies from 5 to 10 miles, and when the grid is connected to terminal 220, the duration of the square wave varies from $1\frac{1}{2}$ to 3 miles. If desired, the display of FIG. 14 may be off centered by techniques well known in this art to take advantage of the generally oval type of display configuration which is produced.

A system which is in some respects simpler than the one shown in FIGS. 12 and 15 is illustrated in FIGS. 17 and 18. This system, in brief, comprises a transponder beacon on all aircraft A and B and an interrogator on all aircraft B. This system displays information as to the range and heading of all aircraft within collision range and at approximately the same altitude. Automatic means may also be provided for eliminating from consideration those aircraft not on collision courses.

The transponder portion of the system is shown in FIG. 17. It includes antenna 230 which is omnidirectional in the horizontal plane and directive in the vertical plane. The antenna shown is a biconical type of antenna. Its vertical beam width is determined by the expected roll and pitch of aircraft A in normal flight. In a preferred form of the invention, the antenna and transponder operate in the super-high frequency range as, for example, 35,000 megacycles.

The received interrogator signals at a frequency f_1 are applied via waveguide 232 to mixer 234. A local oscillator 236 which has associated with it a cavity 238 and automatic frequency control circuit 240 applies local oscillations to mixer 234. The resultant intermediate frequency signal at lead 242 is applied to intermediate frequency detector and video amplifier 244. At lead 246, the signal consists of detected pulses 248 shown here as a single pulse. Each such pulse signal is given a characteristic modulation determined by barometric altimeter 250 and multivibrator 252 to telemeter the quantity H_a , the altitude of aircraft A. For purposes of illustration, there is shown at lead 254 a second pulse 256 following the original pulse 248' by a spacing H

proportional to altitude H_a . It will be recognized that the art of time division multiplex communication includes various alternative modulation arrangements for accomplishing the same purpose.

Signal at lead 254 is applied to pulsed amplifier 258 which is driven by oscillator 260. Associated with the oscillator are cavity 262 and automatic frequency control circuit 264 for stabilizing the output frequency of the oscillator. The radio-frequency pulse signal which is at a frequency f_2 close to frequency f_1 , is applied over waveguide 266 to antenna 268. The latter may have directional characteristics similar to that of antenna 230.

The direction finder interrogator is shown in FIG. 18. It includes a rotatable directive antenna 280 shown here for purposes of illustration as a pill box with horn aperture. The antenna is driven by a motor 282. It receives pulse type signals from pulse amplifier 286 which is driven by oscillator 284. The pulser which controls the pulse amplifier 286 is shown as block 288. As already indicated, oscillator 284 operates at a frequency f_1 .

Return pulses from the transponders on aircraft A are applied through transmit-receive device 290 to mixer 292. Stabilized local oscillator 293 supplies local oscillations to mixer 292. The resultant intermediate frequency signals are applied to intermediate frequency detector and video amplifier 294 and thence to gated amplifier 296.

The gated amplifier is controlled by a range gate circuit such as shown in detail in FIG. 16. It is illustrated schematically in this figure by a single block 298 and the cam arrangement is shown schematically at 300.

If the return signals are from an aircraft A within the range interval of interest, two pulses appear at lead 302. These are applied to a pulse code selector circuit 303 which is controlled by barometric altimeter 304. The circuit is so arranged that when the aircraft A from which the pulses are received are within a given altitude increment $\pm\Delta H/2$ of aircraft B, pulse code selector 303 produces an output pulse 306 which appears at terminal 308. When switch 310 has its arm connected to terminal 308 and a signal appears there, alarm 314 is actuated and the signal is also applied to the control grid 316 of indicator 318. Alternatively, if it is desired to indicate all aircraft within the range gate interval, arm 310 may be connected to terminal 320, thereby by-passing the pulse code selector.

The indicator tube is preferably a direct view type storage tube. It includes a rotatable yoke 320 which is driven in synchronism with antenna 280 by motor 282. Sweep voltages for the indicator are derived from deflection circuit 322 which is triggered from pulses from pulser 288. Other, conventional circuits for the storage tube, all well known to those skilled in the art, are not shown.

The display obtained with the system of FIG. 18 is shown in FIG. 19. Range circles are indicated by solid concentric lines, each marked with the range interval it represents. The alarm contour is indicated by dashed line 324. Signals from other aircraft appear either as spaced dots or as solid lines, depending upon the aircraft speed and the antenna scanning speed. In the figure, the aircraft are shown as spaced dots. Two aircraft are shown, one at 326 and the other at 328. It is apparent that the aircraft at 326 is not a collision threat as it will pass to starboard. However, the aircraft indicated

by dots 328 is on a collision course and evasive maneuvers should be taken.

The display is left on as long as the operator desires. The observer may erase the display periodically at will by conventional means (not shown).

The display of FIG. 19 indicates all aircraft within a given altitude increment $\Delta H/2$ of aircraft B, regardless of whether or not they are on collision courses. However, if desired, means may be provided for discriminating against those aircraft such as 326 not on collision courses. Such a unit is shown in FIG. 18 by the dashed block 329. It may be a storage device of the type illustrated in FIG. 6 or FIG. 7. Preferably, the storage unit is arranged to be connected in circuit only when switch 310 is connected to terminal 308. A switch 330 is shown for this purpose. It may be ganged to switch 310 (the ganged connection is not shown on the drawing).

It is to be understood that various features of different embodiments of the invention may readily be incorporated in all embodiments, even though not specifically illustrated. For example, the circuit shown in FIG. 10 for applying a characteristic to the transmitted signal indicative of rate of climb or descent may readily be incorporated in all embodiments of the invention. In like manner the type of modulation employed to indicate altitude may be amplitude, frequency or other types discussed in the foregoing pages. All embodiments in which range is determined may employ the system shown in FIG. 16.

What is claimed is:

1. A system for preventing collisions between two vehicles comprising, in combination, means on one of the vehicles for transmitting signals; means on the other vehicle, including a directive receiving antenna for continuously scanning an angle in space, for receiving said signals and determining the direction from which said signals are received; means on said other vehicle for storing the signals it receives for n antenna scans through said angle, where n is an integer; means on said other vehicle for comparing the direction from which new signals are received with the direction from which the stored signal was received and, when they are within a given angle, producing an indication; and means for displaying the indication.

2. A system for preventing collisions between two vehicles comprising, in combination, means on one of the vehicles for transmitting signals; means on the other vehicle, including a directive receiving antenna for continuously scanning an angle in space, for receiving said signals and determining the direction from which said signals are received; means on said other vehicle for storing the signals it receives for n antenna scans through said angle, where n is an integer; and means on said other vehicle for comparing the direction from which new signals are received with the direction from which the stored signal was received and, when they are within a given angle, produce an output signal.

3. A system as set forth in claim 2, wherein n is equal to 1.

4. A system as set forth in claim 2, wherein n is equal to more than 1.

5. A system for preventing collisions between two vehicles comprising, in combination, means on one of the vehicles for transmitting signals; means on the other vehicle, including a directive receiving antenna for continuously scanning an angle in space, for receiving said

signals and determining the direction from which said signals are received; a magnetic storage means on said other vehicle driven at a speed which is $1/n$ times that of said antenna for storing the signals received by said antenna, where n is an integer; means on said other vehicle for sensing those signals recorded on said magnetic means which are recorded at the same place on said magnetic means or which at least overlap one another, and for producing an indication in response to such superimposed or overlapped signals; and means for displaying said indication.

6. A collision prevention system for aircraft comprising, in combination, means on one aircraft for transmitting a radio-frequency carrier wave modulated by a signal indicative of the height of that aircraft; means on another aircraft for receiving said carrier wave; means on said other aircraft responsive to the height of said other aircraft for sensing solely those of the received signals transmitted from an aircraft within a predetermined altitude of said other aircraft; and means on said other aircraft for sensing those of the signals passed by the last-named means which are received from an aircraft which remains at substantially the same bearing for a predetermined interval of time.

7. In a collision prevention system for aircraft in which at least some aircraft transmit carrier wave signals modulated by a frequency indicative of the height of the aircraft; receiver means on at least some of said aircraft for receiving said carrier wave signal; means on each aircraft carrying said receiving means for determining when the aircraft from which it receives signals is within a predetermined number of feet of its altitude; means on each aircraft carrying said receiving means for determining when the aircraft from which it receives signals is within a predetermined range; means on each aircraft carrying said receiving means for determining when the aircraft from which it receives signals is on a collision course; and means on each aircraft carrying said receiving means for producing an indication solely when the aircraft from which it receives signals is within a given altitude of its altitude, within a given range and is on a collision course.

8. In a collision prevention system in which aircraft A transmits a carrier wave modulated by a signal of frequency f_a indicative of the height of aircraft A, and aircraft B includes means for receiving said signal and detecting the modulation thereon, in combination, an oscillator on aircraft B responsive to the height of aircraft B for generating a signal having a frequency f_L which linearly varies in a sense opposite to that of the height of aircraft B; means for mixing the received signal with the generated signal for obtaining a sum signal $f_a + f_L$ which, when the two aircraft are at the same altitude, is some predetermined frequency f_c ; means for passing solely those of the detected signals the frequencies of which are within the band $f_c = \Delta f$ and $f_c - \Delta f$, where Δf is a relatively small frequency increment; means on aircraft B for generating a signal at a frequency f_f and for beating f_f with f_L to obtain a signal at a frequency $f_f - f_L$ which is directly proportional to the altitude of aircraft B; and means for radiating the signal of frequency $f_f - f_L$.

9. In a system as set forth in claim 8, further including means on aircraft B for adding to the radiated signal a frequency component indicative of the rate of climb or descent of aircraft B.

10. A circuit for producing a wave indicative of the height and rate of climb of an aircraft comprising, in combination, a transformer having at least a stator winding and a rotor winding; means for applying to said stator winding a signal at a frequency indicative of aircraft altitude; means for mechanically rotating said rotor winding at a rate indicative of the rate of climb of said aircraft; and a load circuit connected to said rotor winding.

11. The circuit as set forth in claim 10 wherein said transformer comprises a goniometer having a pair of perpendicularly disposed rotor windings, said signal being applied to said windings in quadrature relation.

12. A circuit for producing a wave indicative of the height and rate of climb or descent of an aircraft comprising, in combination, a transformer having at least a stator winding and a rotor winding; a tunable oscillator having a tunable element controlled by an altimeter and supplying its output frequency to said stator winding; and a means adapted to be connected to rate of climb meter and mechanically coupled to said rotor winding for rotating said rotor winding at a rate proportional to the rate of climb or descent of said aircraft.

13. In a collision prevention system in which aircraft A transmits a carrier wave modulated by a signal of frequency f_a indicative of the height of aircraft A, and aircraft B includes means for receiving said signal and indicating the modulation thereon, in combination, a local oscillator on aircraft B controlled by the height of aircraft B for generating a signal having a frequency f_L ; means for beating the received signal f_a against f_L for obtaining a resultant signal indicative of the difference in height between aircraft A and B; a fixed oscillator supplying signal having a frequency f_r , and means for beating the frequency f_L against f_r to obtain a second resultant signal at a frequency indicative of the height of aircraft B.

14. In a system as set forth in claim 13, further including means for receiving the second resultant signal and radiating the same.

15. A collision avoidance system for aircraft comprising, in combination, means on one aircraft for transmitting a radio-frequency carrier wave modulated by signals indicative of the height of that aircraft and its rate of climb or descent; means on another aircraft for receiving said carrier wave; means on said other aircraft responsive to the height of said other aircraft for sensing solely those of the received signals transmitted from an aircraft within a predetermined altitude of said other aircraft; and means on said other aircraft for sensing those of the signals passed by the last-named means which are received from an aircraft which remains at substantially the same bearing for a predetermined interval of time.

16. A collision avoidance system as set forth in claim 15, wherein said means for transmitting a radio-frequency carrier wave modulated by signals indicative of the height of the aircraft and its rate of climb or descent comprises, a transformer having at least a stator

winding and a rotor winding; means for applying to said stator winding a signal at a frequency indicative of aircraft altitude; means for mechanically rotating said rotor winding at a rate indicative of the rate of climb of said aircraft; and a load circuit connected to said rotor winding.

17. In combination: means for giving an indication representative of the direction of an intruding craft from an observing craft; and means preventing the operation of said first named means as long as said direction is changing.

18. In combination: means for giving an indication representative of the direction of an intruding craft from an observing craft; means normally preventing the operation of the first named means; and means disabling the last named means when said direction is invariant.

19. In combination: an oscilloscope including a viewing screen, an electron gun for emitting a beam of electrons directed to impinge on said screen at a predetermined point, and means energizable to prevent said beam from reaching said screen; rotatable means energizable to displace said beam radially of said point at an angle determined by the rotation thereof; means normally energizing said energizable means; means connected to said rotatable means for causing operation thereof representative of the direction of an intruding craft with respect to an observing craft; and means connected to the first named means for disabling it whenever said direction is invariant.

20. A computer comprising:

means for determining whether the distance of a first craft from a second craft is within a preselected range by comparing the elapsed time between a signal transmitted by the second craft and a signal received from said first craft in response to said second craft signal, and

means for indicating that said first craft is a navigational hazard to said second craft connected to said distance determining means for actuation when the distance of said first craft from said second craft is within the preselected range, said means requiring no other input than an input signal from said distance determining means.

21. A computer comprising:

Means for determining whether an altitude of a first craft is within a preselected range of the altitude of a second craft,

means for determining whether the distance of said first craft from said second craft is within a preselected range,

means for indicating that said first craft is a navigational hazard to said second craft connected to said altitude determining means and to said distance determining means for actuation when the altitude of said first craft is within the preselected range of the second craft altitude and the distance of said first craft from the second craft is within the preselected range.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,849,782 Dated 11/19/74

Inventor(s) Donald S. Bond

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 42, change "e" to --be--

Column 3, line 48, change "accomplished" to --accomplishes--

Column 3, line 58, after "narrow" add --down--

Column 4, line 60, after "A₃" insert --)--.

Column 11, line 20, after "readily" insert --be--

Column 12, line 57, change "=" to --+--

Column 14, line 38, change "navaga-" to --naviga- --

Signed and sealed this 18th day of February 1975.

(SEAL)

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks

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