

June 26, 1945.

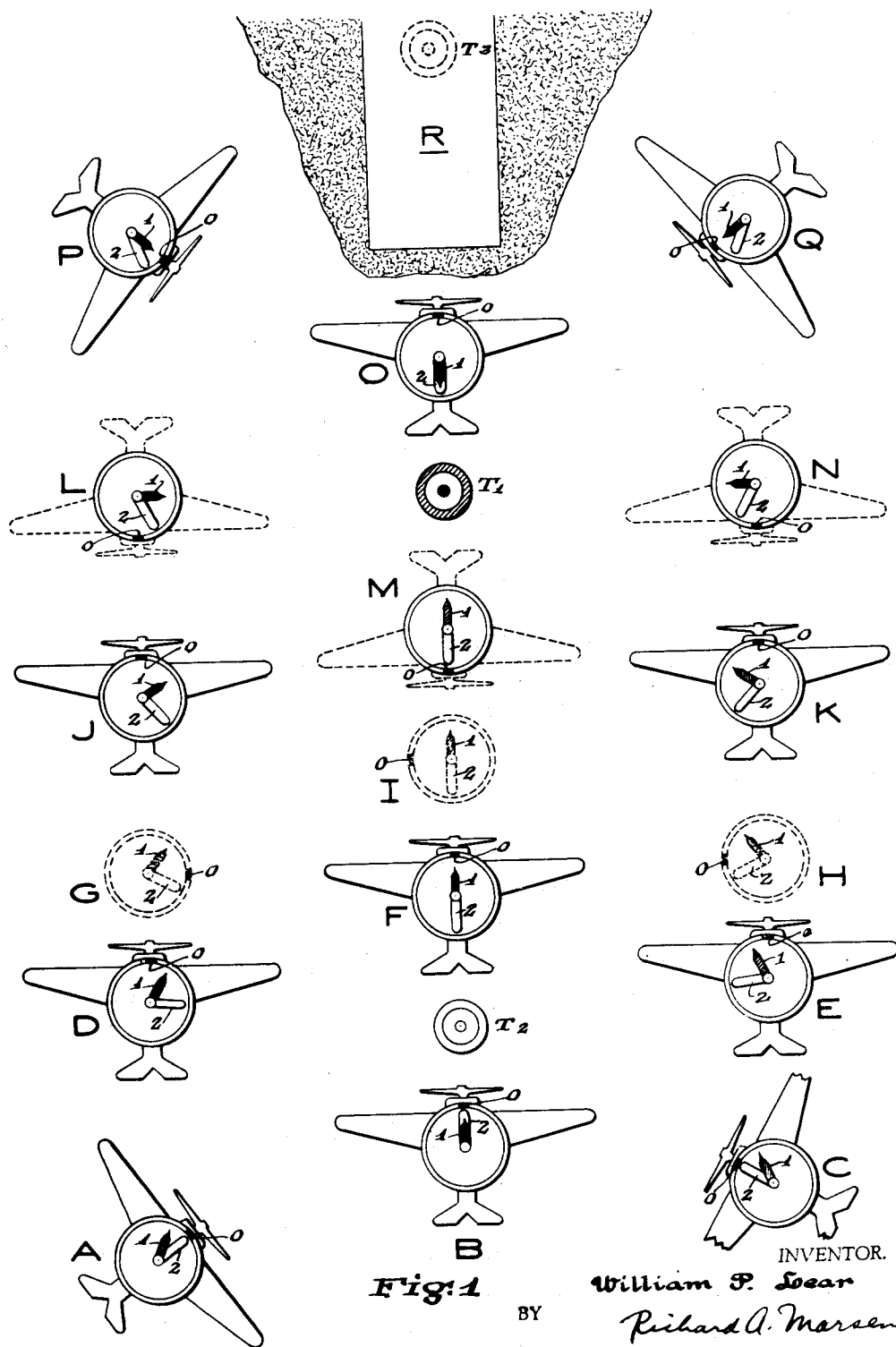
W. P. LEAR

2,379,362

RADIO GUIDANCE SYSTEM

Filed Aug. 25, 1939

9 Sheets-Sheet 1



BY

INVENTOR.  
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June 26, 1945.

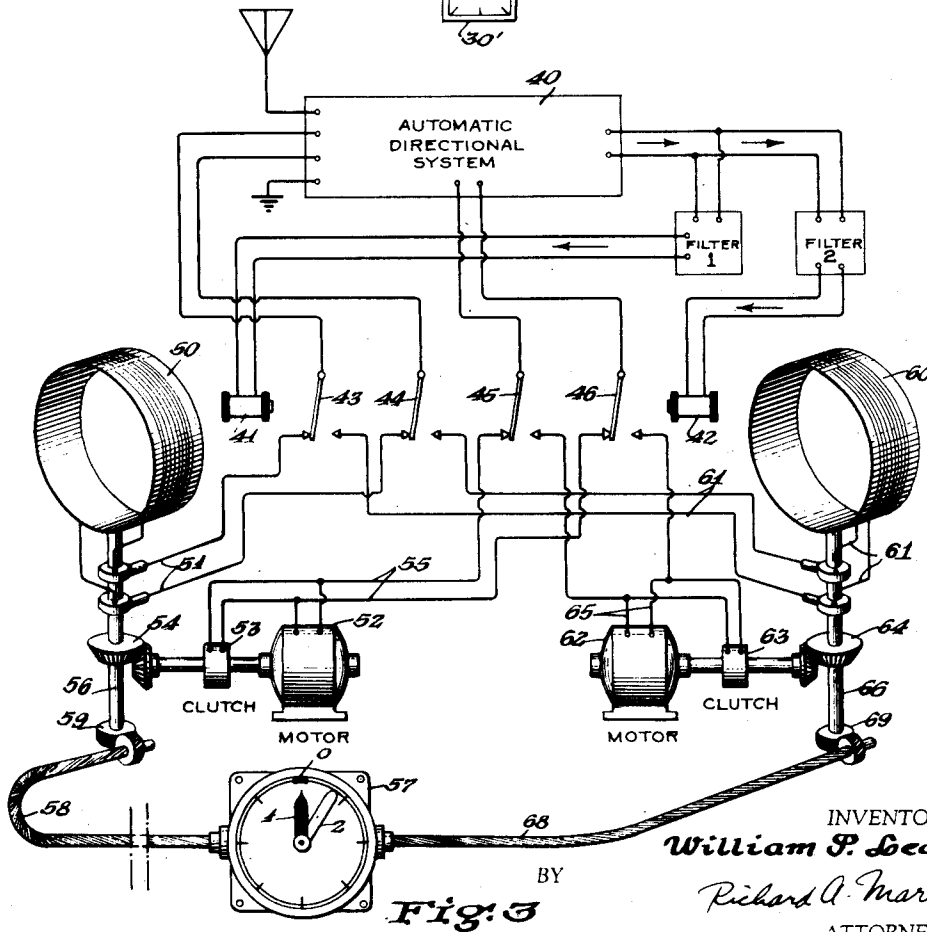
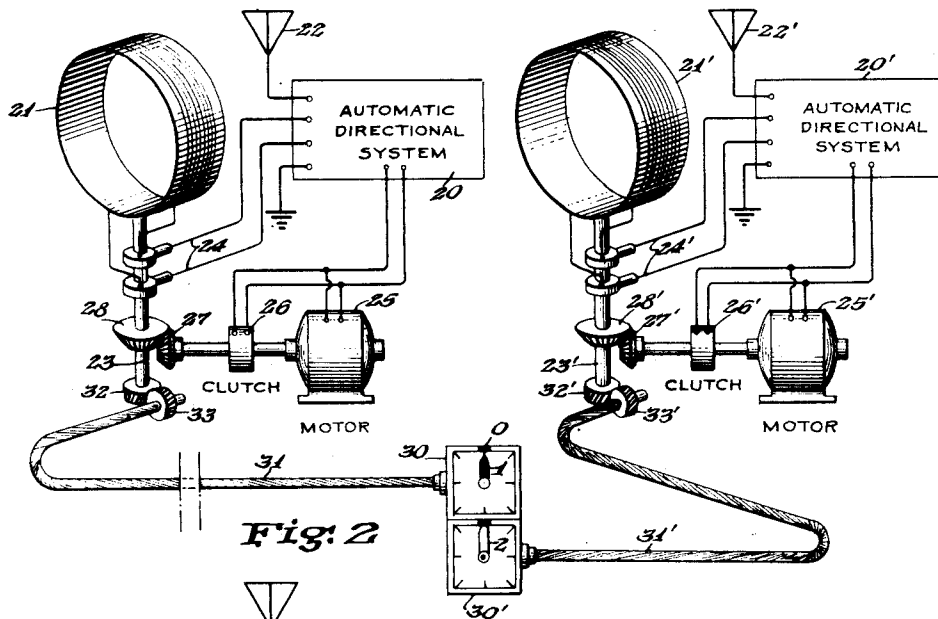
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RADIO GUIDANCE SYSTEM

Filed Aug. 25, 1939

9 Sheets-Sheet 2



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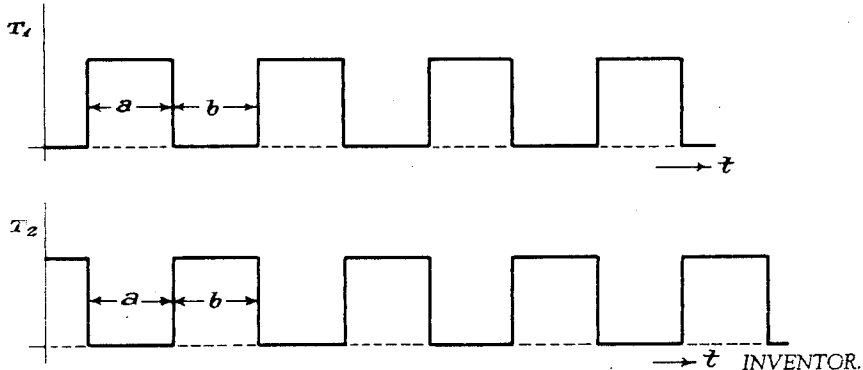
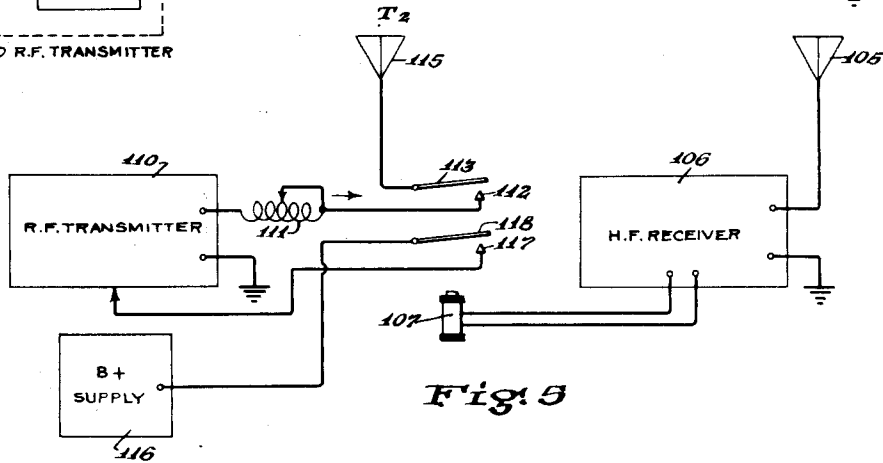
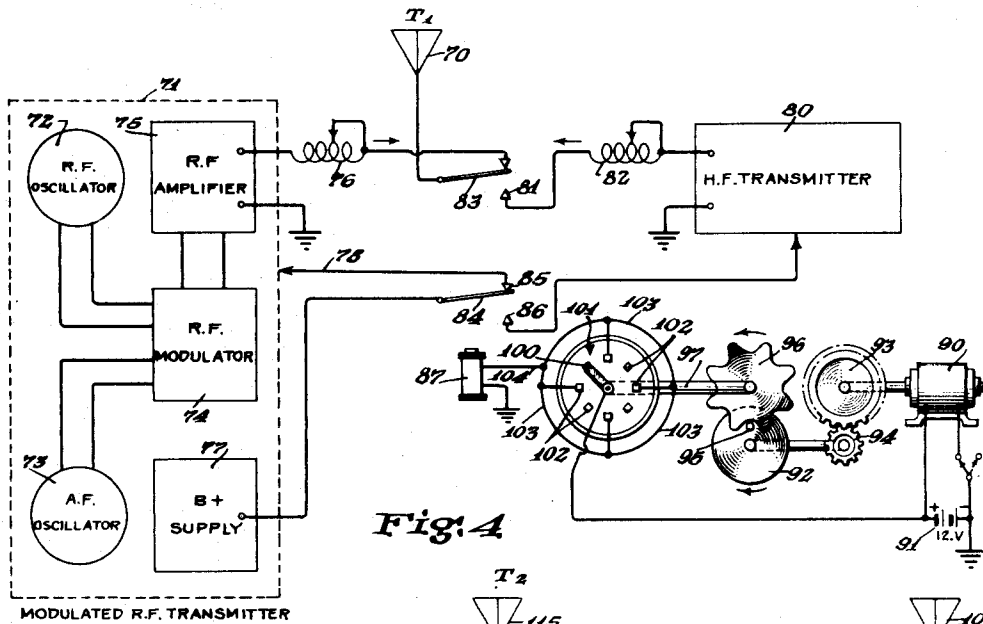
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RADIO GUIDANCE SYSTEM

Filed Aug. 25, 1939

9 Sheets-Sheet 3



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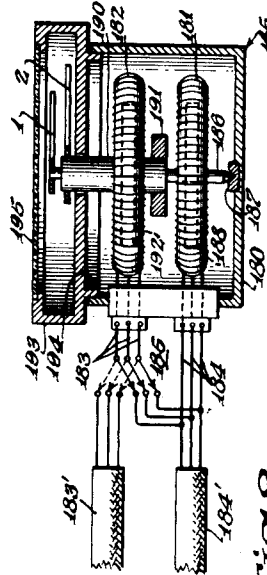
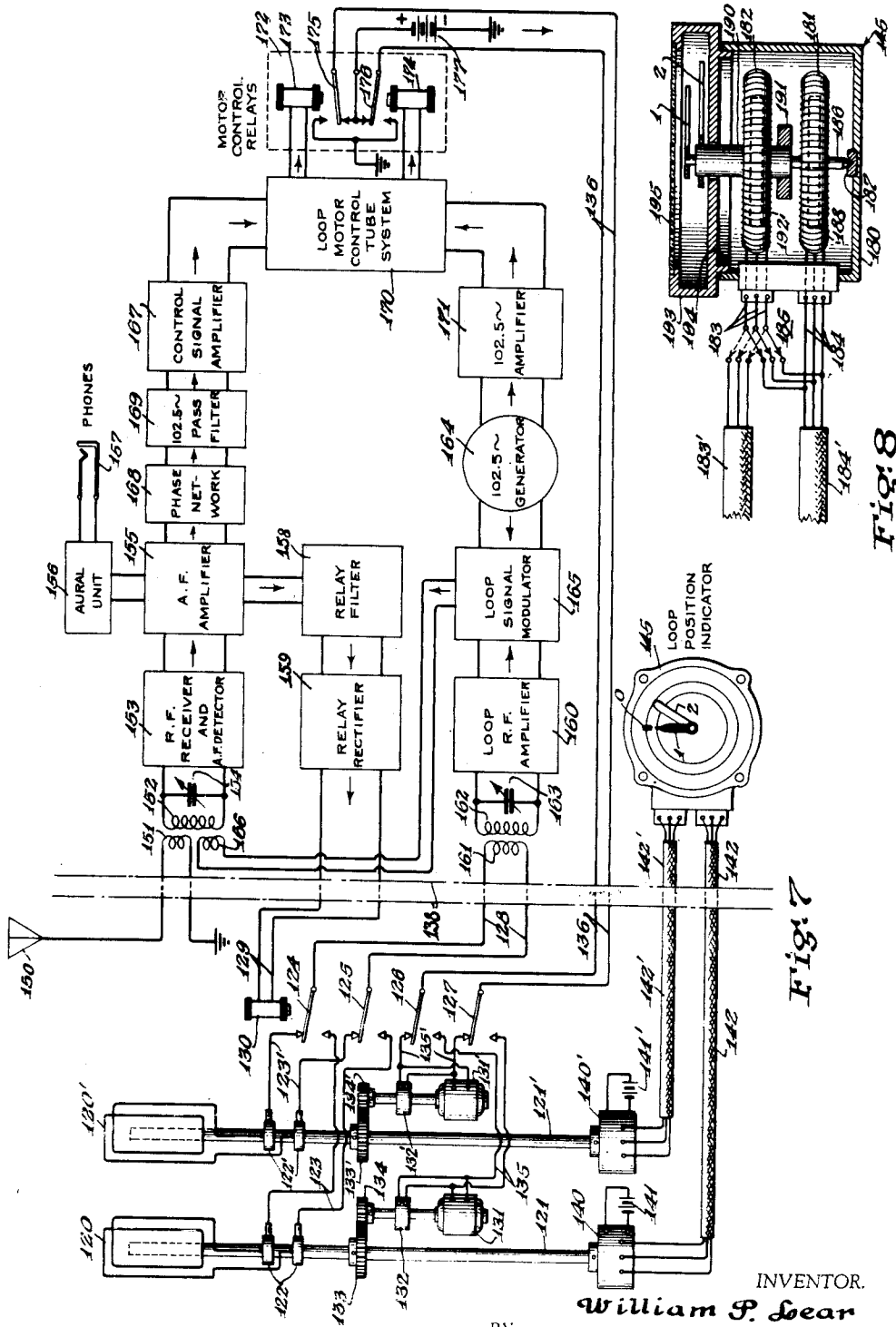
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## RADIO GUIDANCE SYSTEM

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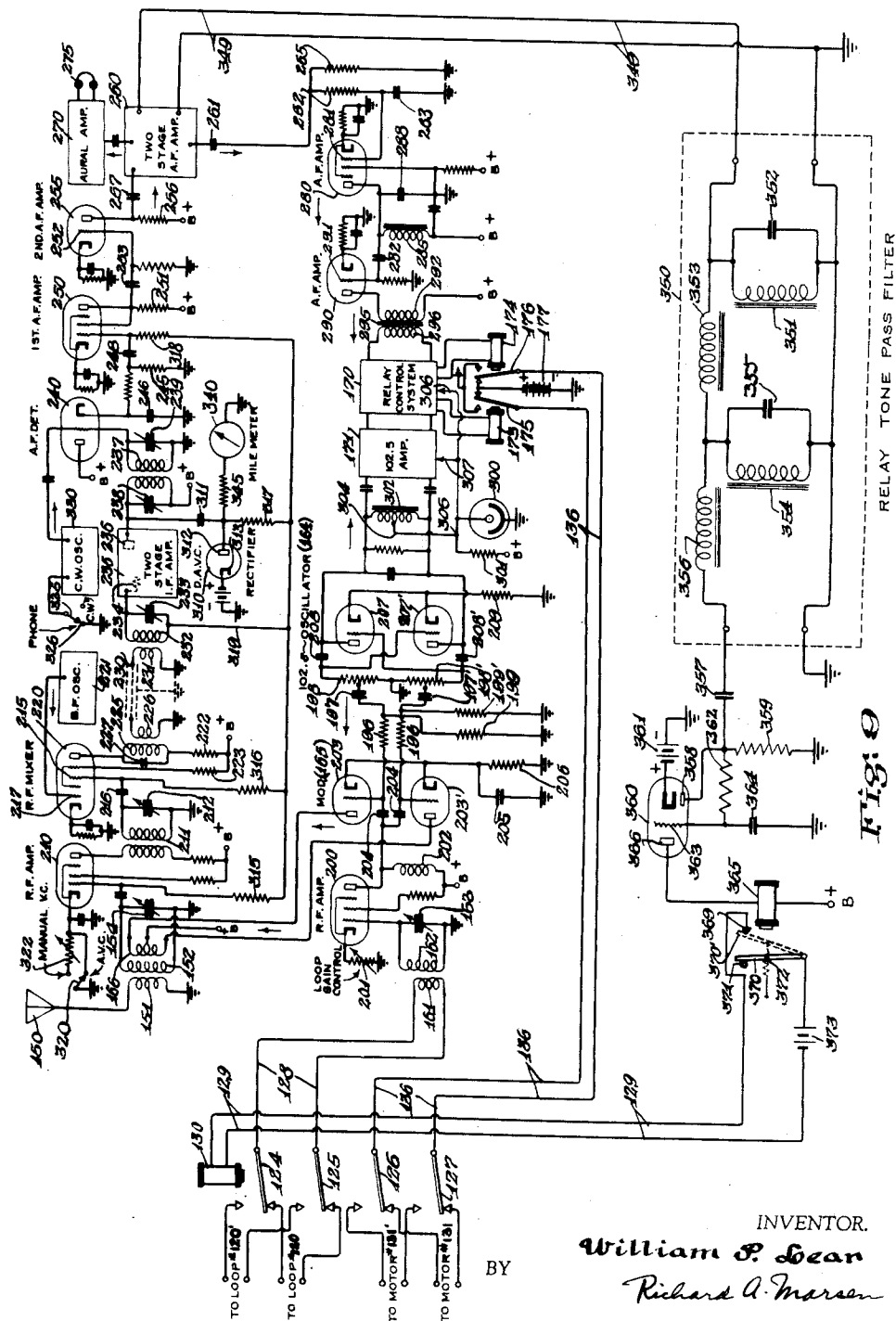
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RADIO GUIDANCE SYSTEM

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9 Sheets-Sheet 5



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2,379,362

RADIO GUIDANCE SYSTEM

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9 Sheets-Sheet 6

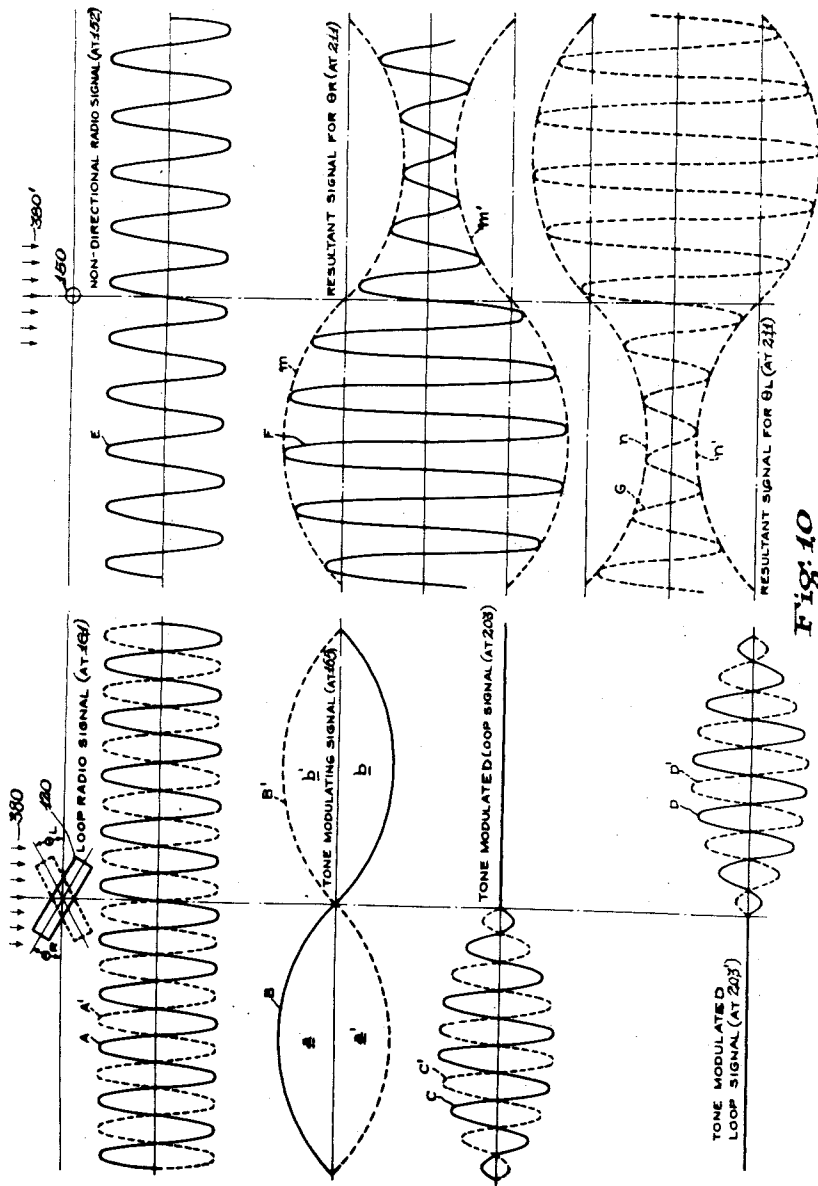


Fig. 10

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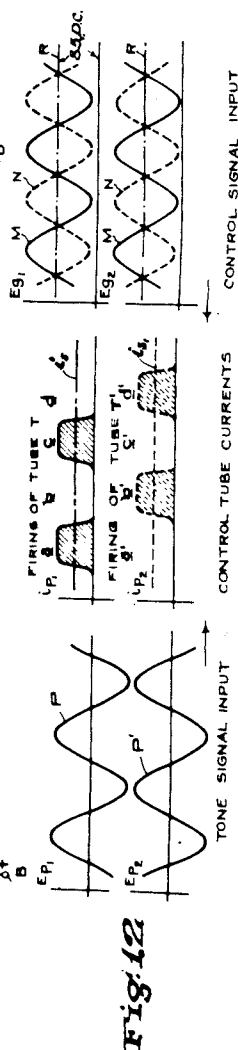
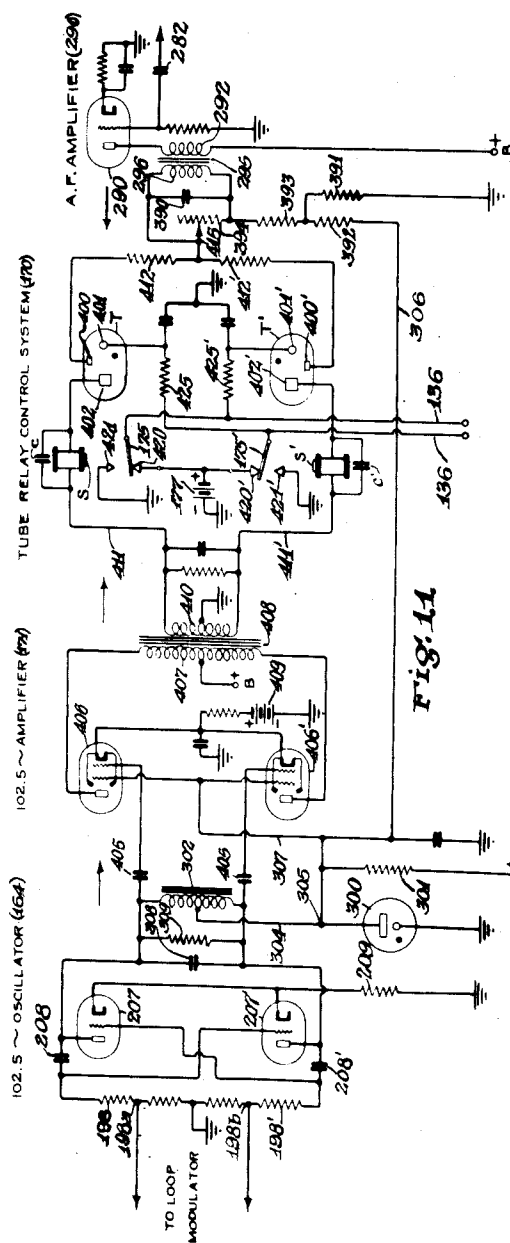
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**2,379,362**

# RADIO GUIDANCE SYSTEM

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June 26, 1945.

W. P. LEAR

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RADIO GUIDANCE SYSTEM

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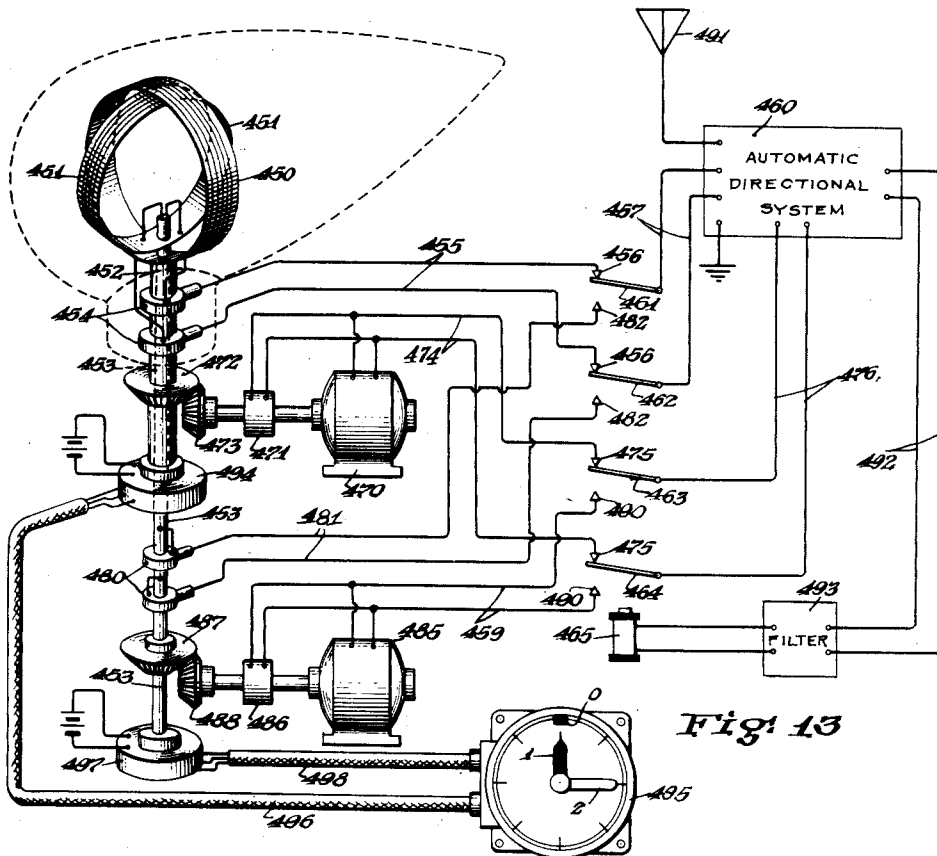


Fig. 13

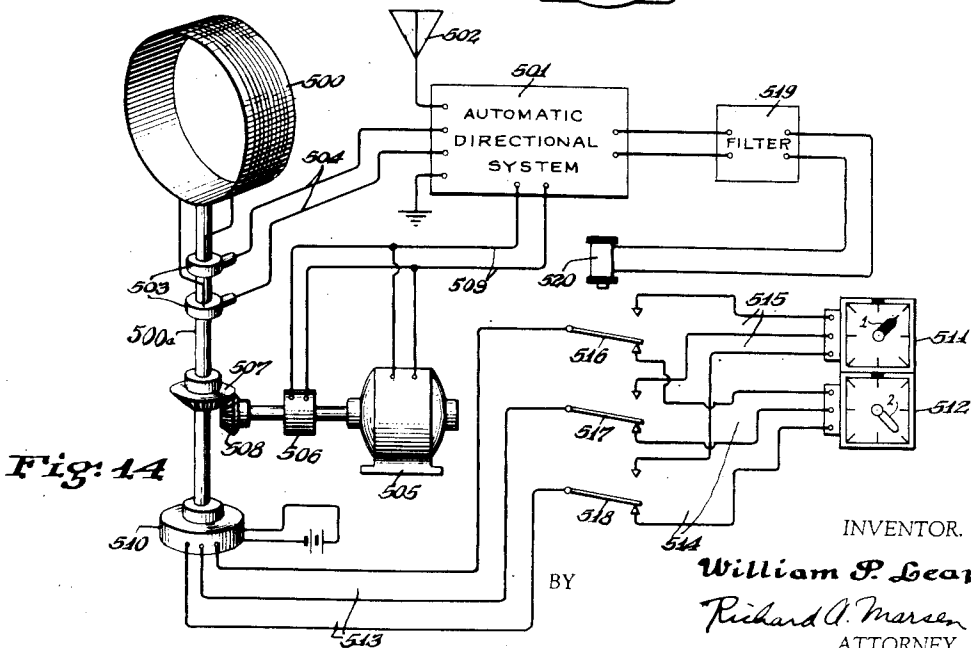


Fig. 14

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2,379,362

RADIO GUIDANCE SYSTEM

Filed Aug. 25, 1939

9 Sheets-Sheet 9

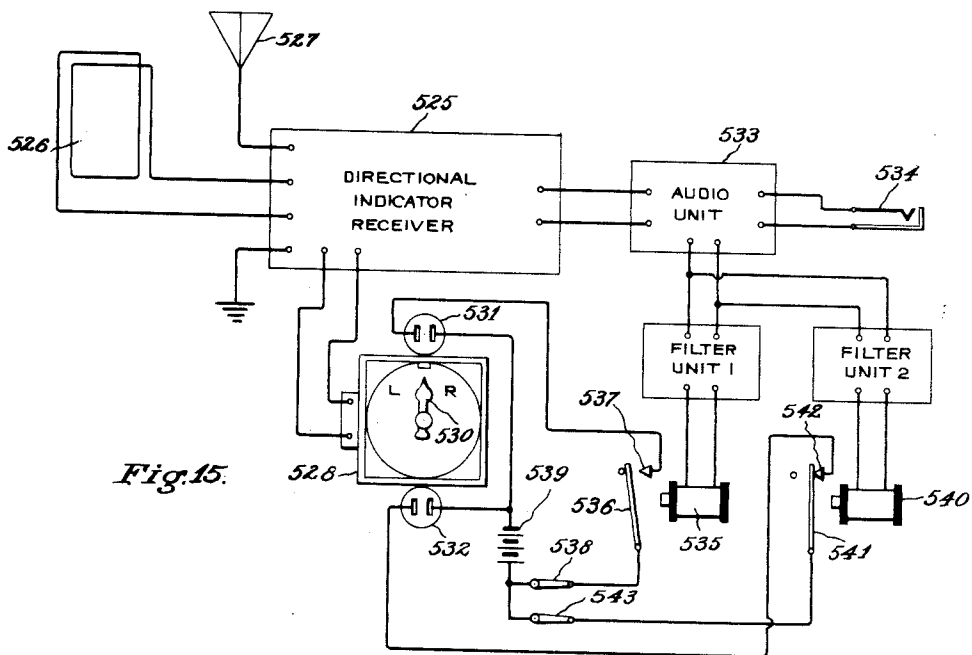


Fig. 15.

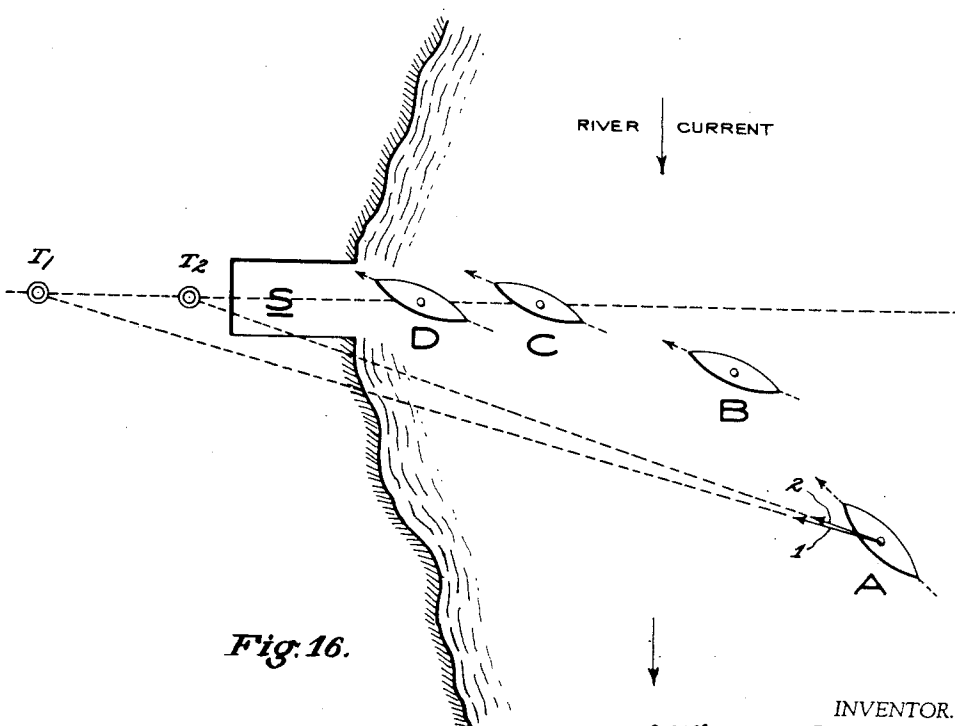


Fig. 16.

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## UNITED STATES PATENT OFFICE

2,379,362

## RADIO GUIDANCE SYSTEM

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Application August 25, 1939, Serial No. 291,807

12 Claims. (Cl. 250—11)

This invention relates to radio guidance systems for mobile craft and more particularly relates to novel radio blind approach systems and methods for guiding an aircraft to a landing runway, a marine vessel into a slip, and the like.

Radio direction finders have made it possible to guide an aircraft or ship directly to the vicinity of a radio transmitting station at its destination. During adverse weather conditions such as rain, fog or snow, it is impractical to land the aircraft or vessel without further aid. The so-called equi-signal runway localizing beacon was developed about 1930 for guiding an aircraft to a landing runway. In this system directional transmission of radio energy is concentrated along the approach to the runway. Upon locating the equi-signal path, the pilot must keep on the approach to the runway.

Various forms of the runway equi-signal localizer system have since been carried out in practice. The pilot arrives in the vicinity of the airport using a radio compass or flying on a leg of a radio range beacon. On reaching the transmitter station, as denoted by a cessation of the radio signal, he maneuvers in a predetermined manner in order to locate the equi-signal localizing beacon. It is then necessary for him to fly in the narrow path of the beacon. This often results in weaving and loss of the beacon. Marker beacons are employed at one or more points along the equi-signal path to apprise the pilot of his distance from the runway.

It is generally relatively difficult to locate the equi-signal beacon, and it is also difficult to stay on it for any reasonable distance due to wind currents and drift. The system is inflexible as to direction of arrival, and no determinations are afforded the pilot of his position with respect to the airport in general. Descent to the runway is performed with a radio glide path for vertical guidance, or by reliance on a sensitive altimeter.

A different radio approach system was developed in 1934 by Hegenberger and adopted by the U. S. Army Air Corps. The Hegenberger system employs two spaced radio transmitter stations, each radiating an independent non-directional radio wave as well as an ultra short wave vertical marker beacon signal. The two stations are mobile and placed in line with the desired direction of approach. The pilot uses an ordinary radio loop compass, such as a right-left indicator, and also a marker beacon indicator.

For approaching the vicinity of the airport the pilot tunes the right-left compass to one of the transmitter stations and flies directly towards

it. He is informed of his arrival over that station by the marker beacon indicator. He then quickly tunes his right-left indicator to the second transmitter station and flies directly towards that, knowing of his arrival thereover by a marker beacon indication. The pilot in this manner makes several trial flights along the line of approach between the two transmitter stations, and adjusts a directional gyroscope to compensate for drift.

In his maneuvers, the pilot using the Hegenberger system is required to quickly change the tuning of his radio compass between one and the other of the two radio stations as he passes over them several times. In order to ascertain his position with respect to the runway, the busy pilot must use his judgment and interpret his several maneuvers as well as the readings of several trial approaches before he is reasonably sure of his position and direction prior to gliding down to the runway. For descent, this system makes use of a sensitive altimeter. Drifting off the course is not directly apparent from the radio system, hence the reliance on the directional gyroscope.

In accordance with my present invention I provide a radio blind approach system which avoids the shortcomings of the prior systems. The system of my invention continuously indicates to the pilot his exact relative lateral position with respect to the airport in general, and his exact position with respect to the approach path to the runway. Two spaced non-directional transmitters are placed in line with the desired runway. The receiver system is simultaneously tuned to both transmitters and has two needle indicators arranged to continuously and independently point out the direction to each of the transmitters. The pilot is thus continually made aware of his position. No study or interpretation of the indications is necessary. No training period is required since the meaning of the indications is apparent almost by intuition.

With the system of my invention, the pilot may approach the runway directly on the shortest route and without any trial flight since he clearly knows his orientation with respect to the airport and runway course. The two indicator needles of the receiver are in line with the center-zero index when the pilot is on-course with the runway. As he passes over the outer transmitter, the "out" indicator needle reverses by 180°. This serves as a marker indication to apprise him of his exact distance from the edge of the runway. As the pilot continues on-course to the runway,

the second or "in" needle will reverse by 180° when he passes over the inner transmitter station. No separate marker beacons are thus necessary. The pilot is then ready to glide down to a landing using any suitable vertical guidance means.

Drifting from the predetermined approach course is accurately detected through the dual indicator readings, and is readily compensated for by the pilot. No reliance or directional gyroscopes or other flight instruments is necessary. The results are foolproof and independent of adverse weather conditions. There are no successive receiver tuning changes or other distracting duties required of the pilot with the system of my invention. After the initial tuning operation, the dual indicator arrangement is continually effective in guiding the pilot in the manner set forth.

In a preferred form of my invention I employ two transmitter stations having the same carrier frequency. The radiation by the stations is successively switched on and off at predetermined intervals. The two stations are differentiated with either separate audio frequency tone modulations, or with one station being tone modulated and the other unmodulated. A dual automatic directional indicator system is used aboard the mobile craft. In one form the receiver system has two separate rotatable directional antennae, one corresponding to each of the two field transmitters. An automatic radio control unit is used to individually orient the two directional antennae to their null signal positions with respect to the radio transmitters.

The directional antennae are operative over a 360° range. A separate automatic control radio unit may be used for each of the rotatable loop antennae. In a preferred embodiment, I use a single automatic radio control unit connected successively to each of the two rotatable directional antennae in correspondence with the intervals of radiation of the transmitters as controlled by the audio tone modulations thereof. A composite indicator is used, having two needles, one coupled to each of the rotatable antennae. The two needles point out the actual direction towards each of the field transmitters, and apprise the pilot of his exact lateral position with respect to the airport and the approach path to the runway as will be described in more detail hereinafter.

In practice, the receiver installation for the radio guidance system of the present invention is essentially an automatic 360° radio directional indicator or compass having one or two directional antenna systems and two indicators arranged for intermittent connection to the radio unit during the blind approach operations in response to the predetermined field transmitter tone signals. The pilot employs the general radio directional indicator in the usual manner for approaching the vicinity of the airport from a distance. When he reaches to say within 10 or 15 miles of the airport, he tunes the directional radio unit to the frequency common to the two field radio transmitters. The dual indicator and second directional antenna if present are thereupon immediately made effective to operate the directional receiver as a blind approach or guidance system in accordance with the present invention by the field station signals.

The present invention is applicable for guiding a marine vessel into its slip, such as during fog conditions. In this case, the two radio trans-

mitters are placed on land in line with the direction which the vessel is to enter the slip. The pilot employs the same approach equipment described in connection with the aircraft guidance and is accurately guided into the slip despite river current or zero visibility conditions. Anti-collision devices can be used for safety reasons when there is sole reliance on the radio guidance in docking the vessel.

It is accordingly an object of my present invention to provide novel methods of and means for radio approach guidance of mobile craft to a predetermined line of destination.

Another object of my present invention is to provide a novel lateral position radio indication method and system comprising two separate directional indicators.

Still another object of the invention is to provide a novel radio lateral position indicator system continuously effective in apprising the pilot of his exact relative position with respect to two spaced transmitter stations.

A further object of the present invention is to provide novel radio blind approach systems employing a plurality of rotatable directional antennae automatically controlled from a unitary directional control receiver.

Still a further object of the present invention is to provide novel systems for indicating the lateral position of a mobile craft with respect to two spaced radio transmitters comprising a single directional antenna and radio receiver.

These and further objects of my present invention will become apparent in the following description of exemplifications thereof shown in the following drawings in which:

Fig. 1 is a diagram illustrating the operation of the radio guidance system of the present invention in guiding an aircraft to a landing runway.

Fig. 2 is a schematic diagram illustrating one form which the receiver system of the invention may assume in practice comprising two separate receiver units.

Fig. 3 is another form which the receiver system may assume in practice comprising a single automatic receiver unit.

Fig. 4 is a schematic electrical diagram of the arrangement at one of the transmitter stations of the present invention.

Fig. 5 is a schematic electrical diagram of the arrangement at the second transmitter station.

Fig. 6 is a group of curves illustrating the electric switching operation for the two transmitter stations.

Fig. 7 is a diagrammatic arrangement of a complete receiver system incorporating the principles of the present invention.

Fig. 8 illustrates one form of the dual indicator mechanism, being partly in section.

Fig. 9 is a schematic electrical diagram of a preferred circuit arrangement for the automatic directional receiver equipment corresponding to the diagrammatic showing in Fig. 7.

Fig. 10 is a group of curves used in describing the theory of operation of the directional receiver system.

Fig. 11 is a schematic electrical diagram of the electronic motor control system for the directional receiver.

Fig. 12 is a group of curves used in describing the theory of operation of the electronic control system of Fig. 11.

Fig. 13 is a diagrammatic illustration of another form which the receiver system of the

present invention may assume in practice, comprising concentrically mounted loop antennae.

Fig. 14 is a further form for the directional receiver, employing a single loop antenna arrangement.

Fig. 15 is still a further modification of the receiver system of the present invention.

Fig. 16 illustrates an application of the principles of the present invention for guiding a marine vessel into a slip.

#### Aircraft guidance method

Fig. 1 is a diagrammatic showing of the application of the present invention in guiding an aircraft to a landing runway R. T<sub>1</sub> and T<sub>2</sub> are transmitter stations aligned with the runway R chosen for the landing of the aircraft. Station T<sub>1</sub> may be positioned about a half mile from the edge of the runway and station T<sub>2</sub> spaced about four miles from station T<sub>1</sub>. The spacing of transmitters T<sub>1</sub> and T<sub>2</sub> from runway R is optional, but is preferably prearranged in practical application. A receiver for the signals from stations T<sub>1</sub> and T<sub>2</sub> is aboard the aircraft, and indicator needles 1 and 2 are automatically controlled by the receiver to point towards the respective transmitter stations.

Needle 1, corresponding to the "in" position is arranged to point towards transmitter T<sub>1</sub>. Needle 2, the "out" needle, is arranged to point towards transmitter T<sub>2</sub>. The operation of the transmitter and receiver systems, to be described in detail hereinafter, is such that needles 1 and 2 individually point to their respective stations T<sub>1</sub> and T<sub>2</sub>, and give an accurate indication, without directional ambiguity, to these stations. A zero index 0 on the indicator dial corresponds to the longitudinal or axial position of the aircraft, being the direction of flight of the aircraft with no cross-winds.

Referring to position A of the aircraft, which is behind the outer station T<sub>2</sub> and towards the left of it, we note that "out" needle 2 pointing towards T<sub>2</sub> and "in" needle 1 pointing towards T<sub>1</sub> give a rapidly comprehended indication of the plane's lateral position. A pilot at position A notes that both stations T<sub>1</sub> and T<sub>2</sub> are ahead and that he is heading directly towards T<sub>2</sub> and towards station T<sub>1</sub>, from the left of the approach path T<sub>1</sub>—T<sub>2</sub>. As he moves towards the right, for example to position B, needle 1 moves into the index 0 position.

At position B, which is in line with the runway and transmitters T<sub>1</sub> and T<sub>2</sub>, both needles 1 and 2 are on-course and point to index 0. If the aircraft were approaching the field from position C which is behind the transmitters and to the right thereof, the pilot quickly notes his relative lateral position by the orientation of needles 1 and 2 with respect to the zero-center index. In position C, needle 1 is deflected towards the right of needle 2 indicating the relative position of the plane towards T<sub>1</sub> and runway R.

At position D, the aircraft is at the left side of transmitter T<sub>2</sub> as ascertained by the near 90° position of needle 2, and the position of needle 1 to the right of index 0. When the aircraft is at the right side of station T<sub>2</sub>, such as at position E, the indication of needles 1 and 2 thereat readily signifies this fact. If the pilot is in alignment with the runway or is otherwise on-course, "out" needle 2 reverses by 180° as he passes over station T<sub>2</sub>. Position F shows the "out" needle 2 in the 180° position, and needle 1 at the 0° position. The pilot then knows that he is properly heading

on-course and is between transmitters T<sub>1</sub> and T<sub>2</sub>, having just passed station T<sub>2</sub>.

At position G shown in dotted, the aircraft is heading transverse to the on-course direction as denoted by the position of index 0 corresponding to the flight direction of the aircraft. Needles 1 and 2 point towards transmitters T<sub>1</sub> and T<sub>2</sub> practically in the orientation of adjacent position D. The general orientation of needles 1 and 2 at D and G appraises the pilot that he is somewhere between stations T<sub>1</sub> and T<sub>2</sub> and to the left of the approach path between them. The index 0 at position G, lying between needles 1 and 2 appraises him that he is heading directly towards the approach path T<sub>1</sub>—T<sub>2</sub> rather than along the path as at position D. Similarly dotted position H indicates that the aircraft is heading towards the approach path from the right.

Index 0 as well as indicator needles 1 and 2 coact to apprise the pilot of his relative lateral position and as well as direction with respect to the required radio course. The pilot, with negligible consideration or interpretation immediately realizes how to maneuver his plane to arrive at the proper path and correct altitude. At position I, the plane lies on the approach path, needles 1 and 2 being 180° apart as they are at position F. However, the direction of flight of the plane at I is transverse to the on-course path as denoted by index 0. At position I, the reading of needle 1 on the scale is 90°, and needle 2 is 270°. At position F however, needle 1 reads 0° and needle 2 reads 180°, corresponding to the on-course position between stations T<sub>1</sub> and T<sub>2</sub>.

At position J, the aircraft is intermediate between stations T<sub>1</sub> and T<sub>2</sub> and clearly to the left of the on-course path between them. The position of index 0 at J informs the pilot that he is heading in a general direction from station T<sub>2</sub> towards station T<sub>1</sub>, and that he is to the left of the approach path T<sub>1</sub>—T<sub>2</sub>. Symmetrical position K to the right of the path has a similar indication to J, with needles 1 and 2 both showing that stations T<sub>1</sub> and T<sub>2</sub> are to the left of the direction of flight indicated by index 0.

The dotted position of the aircraft at L indicates a reverse flight direction. By observing that "in" needle 1 points to his left and that "out" needle 2 points nearer to index 0, the pilot knows that he is flying generally towards outer station T<sub>2</sub> and accordingly will have to reverse his direction of flight to approach runway R. At dotted position M, the pilot is on the approach path T<sub>1</sub>—T<sub>2</sub> and between stations T<sub>1</sub> and T<sub>2</sub> as denoted by a 180° displacement of needles 1 and 2. However, since "out" needle 2 points towards index 0, and "in" needle 1 to the 180° scale position, the pilot realizes that he is flying in a direction away from the runway even though he is on-course. At dotted position N which is symmetrical with position L, the pilot similarly ascertains that he is flying generally away from the runway and is to the right side of it.

The interpretation of the indications by index 0 and needles 1 and 2 are natural and readily comprehended to any pilot without a study or training period. The meaning of any reading is apparent to him practically by intuition. No unnecessary maneuvering with respect to stations T<sub>1</sub> and T<sub>2</sub> is required with the system of my invention. As the pilot approaches the vicinity of the airport from any direction he can, by the lateral position indications, ascertain exactly how to maneuver his plane to reach head position B

which is on-course with the runway and behind outer transmitter T<sub>2</sub>.

Should the pilot approach the airfield from position A or C he will know that he is properly behind transmitter T<sub>2</sub> and need merely direct his plane nearer to the right or left as the case may be to reach the approach path position indicated to him by an indicator reading as at B. Similarly, should the pilot approach the airfield from the rear as from position P or Q, the relative indications of needles 1 and 2 with respect to the index 0 will inform him that he is nearer transmitter T<sub>1</sub> than transmitter T<sub>2</sub>; that he is flying generally in a direction away from the runway; and that he should continue flying until he is beyond station T<sub>2</sub> and reverse his flight direction in order to reach position B at the head of the approach path.

Should the pilot arrive at the airport in a direction transverse to approach path T<sub>1</sub>—T<sub>2</sub>, it will be readily apparent to him. Positions G and H, for example, indicate such direction of arrival. The orientation of needles 1 and 2, on opposite sides of index 0, appraises the pilot that he is somewhere between stations T<sub>1</sub> and T<sub>2</sub> and approaching towards the path between them from the left or right side as the case may be. Should he approach the path from position H, a 180° displacement of the needles 1 and 2 when he reaches position I informs him that he is crossing the approach path T<sub>1</sub>—T<sub>2</sub>. From the indications, the pilot can readily tell the most direct manner in which to maneuver his aircraft towards head-on position B for approaching runway R.

In accordance with the present invention, the two synchronized transmitters T<sub>1</sub> and T<sub>2</sub> are arranged in line with the approach path to the chosen runway R upon which the aircraft is to descend. The inner station T<sub>1</sub> is spaced a predetermined distance from the edge of runway R, for example, 500 feet or a half mile. The outer transmitter T<sub>2</sub> is spaced a predetermined distance from station T<sub>1</sub>, say 4 or 5 miles. In view of the fact that in my system marker indications are given the pilot when the aircraft passes over either station T<sub>1</sub> or T<sub>2</sub>, predetermined spacing from the edge of the runway R is a marked advantage in practice. The pilot thus is given a clear indication of his position prior to landing and it assists his proper maneuvering for descent to the runway. As hereinabove explained, the relative indications between needles 1 and 2 and index 0 give the pilot a clear aspect of his lateral position with respect to the airport, stations T<sub>1</sub> and T<sub>2</sub> and runway R, enabling him to directly maneuver his aircraft to head-on position B behind outer transmitter T<sub>2</sub> in preparation for an approach to the runway.

With the system of the present invention, the pilot thus quickly determines his lateral position and attitude from any direction of approach, and moves to head-on position B where needles 1 and 2 both point to index 0 if there is no cross-wind or drift and the attitude of the aircraft is on-course. The pilot then continues flying along path T<sub>1</sub>—T<sub>2</sub>. As he passes over station T<sub>2</sub> "out" needle 2 reverses by 180°, the needles assuming the 180° displacement such as shown at F. The pilot knows that he then is at the predetermined distance of station T<sub>2</sub> from the runway, and is properly on-course. The flight is continued towards T. As soon as the pilot passes over station T<sub>1</sub>, the "in" needle 1 reverses its indication by 180° and reads as shown at position 0. The pilot then knows that he is the predetermined distance

of T<sub>1</sub> from the edge of runway R, and is in line with the runway.

An important feature of my present system resides in the accurate appraisal of drift of the mobile craft in its movement along the predetermined on-course path. Whenever needles 1 and 2 are 180° apart such as shown at positions F, I and M, or aligned and 0° apart such as at positions B and 0, the craft is directly on-course. As long as the pilot is flying along path T<sub>1</sub>—T<sub>2</sub> needles 1 and 2 are either zero or 180° apart. Cross-wind or wrong attitude of the aircraft tending to move it off path T<sub>1</sub>—T<sub>2</sub> is readily made apparent by a corresponding change in the 0° or 180° displacement of needles T<sub>1</sub> and T<sub>2</sub>. The concentric mounting of needles T<sub>1</sub> and T<sub>2</sub> and accurate bearing indications affords a sensitive drift indication, since needle displacements of even 1° are easily read. It is to be noted that the on-course indications by the 0° or 180° needle displacements are independent of the position of index 0 with respect to needles 1 and 2. The relative position of index 0 with respect to needles 1 and 2 gives the relative position of the axis of the aircraft in its movement along the path T<sub>1</sub>—T<sub>2</sub>.

In utilizing this significant characteristic of the system, the pilot can readily and accurately adjust his controls to keep the plane on-course despite variable or unknown drift due to cross-winds and the like. It is merely necessary for him to jockey or otherwise crab the aircraft on path T<sub>1</sub>—T<sub>2</sub> and maintain needles 1 and 2 zero or 180° apart to insure his arrival to runway R in the exact predetermined direction as determined by stations T<sub>1</sub> and T<sub>2</sub>. As he passes over station T<sub>2</sub>, "out" needle 2 reverses 180° from its showing at position B to that at position F, without affecting the drift indications noted, yet serving as an accurate marker indication of the distance of the aircraft from the edge of runway R. Similarly, as the aircraft passes over station T<sub>1</sub> to position such as at 0, "in" needle 1 reverses to the 180° position and in alignment with reversed needle 2, still sensitive to any drift indications and serving as a marker indication of the aircraft with respect to the edge of runway R.

Descent to the runway may then be effected by any suitable method. A general method employs a sensitive altimeter. The pilot brings the aircraft to a predetermined altitude when he, for example, reaches over station T<sub>1</sub> prior to his descent. A preferred method of descent to the runway R is one employing a third transmitter station, such as T<sub>3</sub>, of horizontally polarized waves in conjunction with a receiver having a loop antenna rotatable about its horizontal axis and the orientation of which is automatically controlled by the directional receiver unit resulting in a straight line glide path indication direct to the landing field. The angle of the descent path to the landing field is optional and is determined by the altitude of the aircraft prior to the descent.

Transmitters T<sub>1</sub> and T<sub>2</sub> may be independent of each other and have separate radio frequencies. The receiver system shown and described in connection with Fig. 2 is indicated for such arrangement. However, in commercial operation, where weight and bulk of equipment placed upon an aircraft is significant, I prefer the form of receiver equipment hereinafter disclosed using a single automatic receiver unit tuned to one frequency. Such equipment contemplates transmitter stations T<sub>1</sub> and T<sub>2</sub> using the same carrier frequency arranged for synchronous and successive transmission. When using the same radio fre-

quency carrier, transmitters  $T_1$  and  $T_2$  are distinguished by an audio frequency signal modulation. When both stations  $T_1$  and  $T_2$  are modulated by a distinguishing audio frequency signal, a single unit, double filter receiver system described in connection with Fig. 3 is indicated. In a more simplified arrangement, only one transmitter is modulated with an audio frequency note and the other transmitter is made to radiate an unmodulated carrier wave. Receiver systems operative with the latter form of transmission are shown and described in connection with Figs. 7 to 15, and use a single automatic receiver unit.

#### General receiving system

Two separate automatic directional receivers having individual indicators, or a combined system employing a single automatic receiver unit may be employed in carrying out my invention. Fig. 2 shows an arrangement using two separate automatic directional receivers, each corresponding to an automatic 360° radio directional indicator such as for example disclosed in my co-pending application, Serial Number 286,733 filed on July 27, 1939, entitled "Automatic radio direction indicator," now Patent No. 2,308,521, issued January 19, 1943. The directional control receiver units 20, 20' of the system each have an associated rotatable loop antenna 21 and 21', as well as non-directional antennae 22 and 22' respectively.

Loop antennae 21, 21' are rotatably mounted upon their respective shafts 23 and 23', and are connected to receivers 20 and 20' through slip rings and connections 24 and 24'. Both directional systems 20 and 20' are individually and simultaneously tuned to the field transmitters  $T_1$  and  $T_2$ . System 20, for example, may be made responsive to the radio signals emanating only from transmitter  $T_1$  while system 20' is made responsive to signals from transmitter  $T_2$ . The loop motor 25, connected to output of control system 20 drives loop shaft 23 through an electromagnetic clutch 26 and gearing 27, 28.

As described in my said Patent No. 2,308,521, the orientation of loop antenna 21 is automatically brought to the null signal position with respect to the oncoming radio signals from the transmitter it is responsive to, namely station  $T_1$  in the present case. Motor 25 is a reversible motor which brings loop antenna 21 in the predetermined null signal position without directional ambiguity. A remote indicator 30 is coupled to loop shaft 23 so that its needle 1 continually indicates the actual angular position of loop antenna 21. A flexible mechanical cable 31 interconnects remotely placed meter 30 with loop shaft 23 through coacting gearing 32, 33, shown as spiral gears. An electrical telemetering system may instead be used.

In a similar manner the radio signals emanating from transmitter  $T_2$  controls directional unit 20' to operate motor 25' to rotate loop shaft 23' through clutch 26' and gearing 27', 28' to bring loop antenna 21' in the predetermined null signal position with respect to the signals from the transmitter  $T_2$ . A separate indicator 30' is mechanically coupled to loop shaft 23' through flexible cable 31' and coacting spiral gears 32', 33'. The position of needle 2 depends upon the angular position of loop antenna 21' and a continuous indication of the position of loop 21' is accordingly effected at the remote position such as in the cockpit of the aircraft.

The directional accuracy of the bearings by needles 1 and 2 on the respective transmitter stations  $T_1$  and  $T_2$  is preferably designed to be accurate to within 1° of arc. An automatic 360° directional indicator unit such as described in my Patent No. 2,308,521 already referred to, provides such accuracy. Such accurate dual directional bearings combine to provide a reliable drift indication for the approach course, which is extremely useful in aircraft landing during adverse weather conditions. Both indicators may be combined in a common housing and their shafts made concentric as shown in Figs. 1 and 8. Alternatively two separate meters such as 30 and 30' may be used, one above the other as shown in Fig. 2 to give equally effective lateral position indications. It is to be understood that quadrantal compensators may be employed between the loop antennae and the respective indicator needles to compensate for metallic masses and unequal radio field distribution about the structure of the vehicle.

In Fig. 3 I illustrate a form of the invention employing a single automatic directional receiver unit 40 in place of the two separate receivers 20 and 20' of Fig. 2. Receiver 40 is tuned to the one frequency corresponding to the carrier frequency chosen for both transmitters  $T_1$  and  $T_2$ . In this case, transmitter  $T_1$  may for example be modulated with one audio frequency tone and transmitter  $T_2$  with a different tone frequency. The tone frequency for transmitter  $T_1$  may for example be 75 cycles; and that of  $T_2$ , 150 or 300 cycles. Two filters, 1 and 2 are connected to the audio output of receiver 40 for segregating the predetermined tone signals and selectively energizing solenoids 41 and 42 of four pole relay 43, 44, 45, 46.

With the receiver system of Fig. 3, field transmitters  $T_1$  and  $T_2$  are made to radiate alternately instead of continuously as is feasible in the modification of Fig. 2. Transmitter  $T_1$ , for example, may be made to radiate for a period of the order of one-third to one-half of a second, and shut off while transmitter  $T_2$  is energized to radiate for an equal period. Receiver solenoids 41 and 42 will be selectively energized in accordance to which of transmitters  $T_1$  or  $T_2$  is radiating.

Rotatable loop antenna 50 is connected to the left contacts of armatures 43 and 44 through leads 51. Motor 52, which drives loop antenna 50 through clutch 53 and gearing 54, is correspondingly connected to the left contacts of armatures 45, 46 through leads 55. When relay 41 is energized, relay poles 43 to 46 are in the illustrated (left) position connecting the winding of directional antenna 50 and its associated control motor 52 in a predetermined manner to automatic directional receiver 40. During the interval of energization of relay 41 through the radiation of transmitter  $T_1$ , motor 52 is controlled to move loop 50 into the null signal position with respect to the direction to transmitter  $T_1$ . Loop shaft 56 is connected to indicator 57 through flexible cable 58 and spiral gearing arrangement 59. The angular position of needle 1 of indicator 57 is controlled by the movement of loop 50, continuously pointing out the position of loop 50 and corresponding to the direction towards transmitter  $T_1$  with respect to the axis of the moving craft.

A second directional antenna system is used to derive the direction towards transmitter  $T_2$ . A loop antenna 60 is connected to the right contacts of relay armatures 43, 44 through leads 61. A separate motor 62 controls the orientation of loop 60 through electromagnetic clutch 63 and reduc-

tion gearing 64. Motor 62 and clutch 63 are connected to the right contacts of relay armatures 45, 46 through leads 65.

During the energization of solenoid 42 through radio signals emanating from transmitter T<sub>2</sub>, relay armatures 43 to 46 are moved to connect with the right contacts of the relay connecting loop 60 and its motor 62 to transmitter 40. During the transmission interval of T<sub>2</sub>, loop 60 is moved to the null signal position with respect to the direction towards station T<sub>2</sub>. The orientation of loop 60 is transmitted to needle 2 of meter 57 through flexible cable 68 connected to loop shaft 66 through gearing arrangement 69.

In the system of Fig. 3, loop antennae 50 and 60 are successively moved by their associated control motors 52 and 62 to the corresponding null signal positions towards transmitters T<sub>1</sub> and T<sub>2</sub>, pointing out the direction thereto within 1° of arc. Lateral position indication of the vehicle or aircraft is thus effected with respect to stations T<sub>1</sub> and T<sub>2</sub> and the field. Indicator needles 1 and 2 point out the absolute direction towards stations T<sub>1</sub> and T<sub>2</sub> over a 360° scale. The position of needles 1 and 2 with respect to the zero index apprises the pilot of his lateral position with respect to the landing field in a manner already described in connection with Fig. 1.

#### General transmitter system

The relation between transmitters T<sub>1</sub> and T<sub>2</sub> may assume various forms in practice. Two independent continuously energized transmitters may be employed having separate carrier frequencies and containing tone modulations or not. A double receiver system such as described in connection with Fig. 2 is indicated where two such separate frequencies are used. However, for aircraft use and in general it is commercially and practically more expedient to employ the novel selectively operated single receiver unit arrangement such as described in connection with Fig. 3 or one of the equivalent forms to be described. For such single receiver unit arrangement, a single carrier frequency is preferably employed for both transmitter stations T<sub>1</sub> and T<sub>2</sub> so that the single receiver unit (corresponding for example to 40 of Fig. 3) may be tuned to that carrier frequency.

An alternative form for the transmitters is to use two carrier frequencies separated by, for example, only 1000 cycles. The single receiver unit is tuned to or near one of the two closely spaced frequencies and selectively operated through the resultant audio beat note or notes. The selective operation in this form is derived by filtering out the predetermined beat note or notes and operating relays thereby. The operation of the transmitters may be by successive switching on and off, or by continuous operation. Crystal controlled reception is preferably indicated in this form since for a predetermined selective beat frequency operation the radio tuning should be accurate for proper selective filtering action.

A preferred form for the transmitter system is illustrated in Figs. 4 and 5, and forms the subject matter of my copending application Serial No. 495,978, filed July 24, 1943, for "Direction radio transmitting system," which is a division of the present application and assigned to the same assignee. Fig. 4 is a schematic arrangement corresponding to one of the transmitters, say T<sub>1</sub>; and Fig. 5 to the other, T<sub>2</sub>. Antenna 70 is a transmitting antenna designed to efficiently radiate the radio frequency signal of T<sub>1</sub>. Any suit-

able carrier frequency may be used. A commercial airport frequency may be used, a broadcast frequency if permissible, or a high frequency or even ultra-high frequency. An efficient receiver and directional antenna for operation at the selected frequency is provided. A carrier frequency of for example 209 kilocycles may be used for T<sub>1</sub> and T<sub>2</sub>. Similarly, a frequency of, say 1614 kilocycles, may be used, or 4790 cycles, etc.

The radio generator for T<sub>1</sub> is schematically indicated within dotted rectangle 71. Radio frequency oscillator 72 generates the carrier at the preferred radio frequency. An audio oscillator 73 generates the tone signal for modulating the radio frequency carrier. The tone or audio frequency used is for operating the relay system of the receiver for selectively controlling the operation of the receiver unit with respect to the two directional antennae such as described in connection with Fig. 3, and as will be described in connection with Figs. 7 to 15. The audio frequency of generator 73 may be 75 cycles, 150 cycles or higher as desired. The radio frequency carrier is modulated by the audio frequency tone at radio frequency modulator 74, the output of which is connected to radio frequency amplifier 75. The output of amplifier 75 is connected to loading coil 76 and in turn to antenna 70. Loading coil 76 is adjusted for most efficient radiation of the radio frequency wave through antenna 70.

An arrangement is provided for maintaining the transmission of the modulated radio frequency wave through antenna 70 for a predetermined period, in the range say of one-third to one-half of a second; extinguishing the transmission of the radio signal corresponding to T<sub>1</sub> at T<sub>1</sub>; and successively provide for the transmission of the radio frequency signal from the other station T<sub>2</sub>. A high frequency relaying transmitter 80 is arranged to radiate from antenna 70 to control remote transmitter T<sub>2</sub>. Transmitter 80 radiates while transmitter 71 is extinguished, and vice versa.

In the arrangement of Fig. 4, I employ the same antenna 70 for the transmission of both the modulated radio frequency wave from 71 as well as the high frequency relaying signal from unit 80. Separate antennae may be used. The output of transmitter 80 is connected to back contact 81 of relay armature 83 through a loading coil 82. When relay armature 83 connects with back contact 81, high frequency transmitter 80 is connected to antenna 70. Loading coil 82 is adjusted for most efficient radiation of the high frequency wave from antenna 70. To insure the proper extinguishing of the radiation of the radio frequency waves, I prefer to disconnect the positive B potential supply from the transmitters. For this I use relay armature 84 connected to B supply 77 which is connected to radio frequency generator 71 through relay contact 85 and lead 78 as shown schematically. Common B supply 77 is also connectable to high frequency transmitter 80 through relay contact 86 when armature 84 contacts therewith upon energization of solenoid 87.

In the described switching arrangements for stations T<sub>1</sub> and T<sub>2</sub>, any time lag due to the action of relays or other components should be properly designed and arranged to give the indicated mode of operation. To simplify the exposition, no lag will be assumed. However, suitable construction in practice to accomplish the desired results will be apparent to those skilled in the art. The design of the commutators or cams or other

switch-over means would naturally account for the lag in the connection and disconnection of the circuits by the relays and associated armatures.

Relay solenoid 87 is suitably energized at the proper time intervals to attract relay armatures 83, 84 from their normal upper position shown, to the lower contact position for correspondingly extinguishing the generation and transmission of the radio frequency signal of unit 71 and initiate the generation and transmission of the high frequency relay signal of unit 80 through the antenna 70 successively and without overlapping. A preferred transmission and cessation interval is one-third of a second for aircraft guidance. However, it is to be understood that different intervals, such as one-half second or greater are equally suitable, as are intervals of less than one-third second also feasible. For marine guidance longer intervals are useful since the approach speed is smaller.

An arrangement for alternately energizing relay solenoid 87 to effect the successive switching at predetermined intervals is diagrammatically illustrated in Fig. 4. The timing intervals are equal and cyclic, not necessarily absolute in value, but generally within the predetermined timing interval desired. A constant speed motor 90 is energized through a local potential source 91, such as the 12 volt battery. An alternating current motor and supply may also be used. Motor 90 drives disk 92 through suitable reduction gearing 93, 94. A pin 95 projects from the face of disk 92. A star wheel 96 is arranged to coact with pin 95 on each revolution of disk 92. Star wheel 96 is advanced through an arc equal to the width of one of its teeth per revolution of disk 92. The speed of motor 90 as well as the ratio of the respective gearings 93, 94 and 95, 96 is designed so as to advance the commutator by one segment corresponding to one switching interval, one-third of a second in the present case.

Commutator 101 comprises switch arm or blade 100 rotatable over a plurality of equi-spaced contact segments 102. Alternate segments 102 are connected together by connection leads 103 and in turn connected to relay solenoid 87 through lead 104. Switch arm 100 is electrically insulated from contacts 102 and is connected to one side of the potential source, namely battery 91. Switch arm 100 is shown on one of the isolated contacts. The motivation of switch arm 100 is by star wheel 96 interconnected through shaft 97. The battery circuit through relay 87 and ground is open during such position. When switch arm 100 connects one of the four interconnected contact elements 102 of commutator 101, relay 87 is energized by battery 91 to attract armatures 83, 84 to the downward or front contact position.

Armatures 83, 84 are normally biased upwards towards the back contacts maintaining transmitter 71 energized and connected for radiation through antenna 70. When relay 87 is energized, armatures 83, 84 are attracted to front contacts 81 and 86 respectively, energizing high frequency relaying transmitter 80 and connecting it to antenna 70 for radiation. During this interval, radio signal transmitter 71 is incapacitated and not transmitting. Constant speed motor 90 causes star wheel 96 to advance one segment for every predetermined interval. Commutator arm 100 accordingly is moved to successively cause energization and deenergization of relay 87 resulting

in corresponding alternate transmission of the modulated radio signal from unit 71 and high frequency relaying signal from unit 80.

During transmission of the modulated radio frequency signal of transmitter 71, the corresponding loop antenna of the receiver is automatically moved so that its associated indicator will point towards transmitter T<sub>1</sub> in the manner already described. The speed of action of the automatic directional receiver is proportioned to effect the directional indication well within the station transmission interval. In using my system for aircraft approach guidance I have found a one-third to one-half second switching interval preferable. The automatic directional receiver should give a rapid, accurate and stable directional bearing on the transmitter stations, and hold the indications stationary between switching intervals. The loop antennae should be shielded from wind currents to prevent upsetting their inter-period bearings. Streamlined enclosures for the directional antennae are preferred if they are mounted outside the aircraft.

While transmitter unit 71 is quiescent and high frequency relay transmitter 80 is radiating from station T<sub>1</sub>, high frequency receiver 106 of Fig. 5 is energized. Antenna 105 of tuned receiver 106 picks-up the radiated high frequency signals. The output of high frequency receiver 106 is connected to relay solenoid 107 for effecting transmission of radio frequency transmitter 110 at station T<sub>2</sub>. Radio frequency transmitter 110 is connectable to transmitter antenna 115 through adjustable loading coil 111, front relay contact 112, and relay armature 113. Positive B supply 116 is connectable to radio frequency transmitter 110 through contact 117 and armature 118 of the relay. Energization of solenoid 107 by receiver 106 during the high frequency relaying period causes the attraction of armatures 113 and 118 against relay contacts 112 and 117, energizing radio frequency transmitter 110 with B supply 116 and connecting the output of transmitter 110 to antenna 115 for radiation.

Radio frequency transmitter 110 preferably has the same carrier frequency as transmitter unit 71, corresponding to the frequency of oscillator 72. Although audio frequency modulation of radio frequency transmitter 110 may be used to actuate a relay of the blind approach receiver, I prefer to employ no modulation for transmitter 110 but transmit a continuous wave signal instead. Fig. 6 shows curves illustrating the relative periods of transmission of stations T<sub>1</sub> and T<sub>2</sub> to give the radio guidance signals. The equally spaced rectangular curves represent the uniform duration of transmission of the radio frequency signals. Signal transmission period *a* of station T<sub>1</sub> is equivalent to the cessation of transmission period *a* of station T<sub>2</sub>. Similarly, cessation of transmission period *b* of station T<sub>1</sub> corresponds to the duration of transmission period *b* of station T<sub>2</sub>. Signal transmission from both stations T<sub>1</sub> and T<sub>2</sub> is at the maximum amplitude during radiation. In the transmission system of Figs. 4 and 5, stations T<sub>1</sub> and T<sub>2</sub> have the same radio frequency carrier, station T<sub>1</sub> being modulated with an audio frequency signal such as 75 cycles and station T<sub>2</sub> being continuous wave. It is not necessary to have stations T<sub>1</sub> and T<sub>2</sub> radiate for the full indicated intervals. However simultaneous transmission of T<sub>1</sub> and T<sub>2</sub> should not occur when a common carrier frequency and only one distinguishing modulation signal is used.

### Receiver circuit arrangement

Fig. 7 is an electrical diagrammatic representation of a complete receiving system for the radio guidance system employing transmitter stations  $T_1$  and  $T_2$  such as described in connection with Figs. 4 to 6. Two separate rotatable loop antennae 120 and 120' are mounted upon individual shafts 121 and 121'. Slip rings 122 connect the winding of loop antenna 120 to leads 123 for connection to the back contacts of relay armatures 124 and 125. Similarly slip rings 122' connect the winding of loop antenna 120' to leads 123' for connection to the front contacts of relay armatures 124 and 125.

Relay armatures 126 and 127 are employed for selectively connecting the control motor drive arrangement for the loop antennae to the receiver. Relay solenoid 130 is arranged to actuate relay armatures 124 to 127 when energized by currents from the automatic directional receiver system connected thereto through leads 129. The position of loop antenna system 120 is controlled by reversible motor 131 connected to loop shaft 121 through electromagnetic clutch 132 and gearing 133, 134. Motor 131 is connected in parallel with magnetic clutch 132 and in turn to the back contacts of relay armatures 126, 127 by leads 135.

The motor control system of rotatable loop antenna 120' comprises motor 131' connected to shaft 121' through electromagnetic clutch 132' and gears 133', 134'. Motor 131' and clutch 132' are connected across front contacts of relay armatures 126, 127 through leads 135'. Relay armatures 126, 127 are connected to the motor relay system of the automatic directional unit through connection leads 136. The preferred construction of the rotatable loop antennae 120, 120' and their associated electromotive drives is preferably in accordance with the disclosure of my Patent No. 2,308,521, hereinabove referred to.

The automatic radio directional receiver schematically illustrated in Fig. 7 is preferably similar to that disclosed in my patent modified to perform the radio guidance operation in connection with the two loop systems. Relay armatures 124 through 127 are normally attracted to the upper or front contact position shown, through normal continuous energization of relay solenoid 130. With the relay armatures in the upper position, loop antenna 120' is in circuit connection with the automatic radio directional circuit through leads 128, and its associated motor and clutch 131', 132' is also connected thereto through leads 136.

The receiver system normally operates in this position as an automatic directional receiver indicating the bearing on any radio station tuned in by the receiver unit. A loop position transmitter unit 140' is employed to transmit the angular position of loop antenna 120' to remotely located meter 145. A direct current Selsyn telemetering arrangement incorporating a battery 141' and three-wire cable 142' is used in the embodiment of Fig. 7. Needle 2 of meter 145 is associated with rotatable antenna 120' and indicates its angular position on the scale of meter 145.

When the automatic receiver is to be used for blind approach in conjunction with field transmitter stations  $T_1$  and  $T_2$  such as indicated in Figs. 1, 4 and 5, the directional receiver circuit is tuned to the predetermined frequency of the transmitters. In this case, directional antenna 120' will be moved to point so that its null signal

position corresponds to the direction towards station  $T_2$ , the unmodulated transmitter station, and "out" indicator needle 2 of meter 145 will point towards station  $T_2$ . The automatic angular orientation of loop 120' through control motor 131' is effected during the transmission interval of station  $T_2$ , within one-third of a second in the preferred case.

During the transmission interval of "in" station  $T_1$ , the predetermined audio frequency modulation of the radio frequency carrier wave at station  $T_1$  will cause relay 130 to be deenergized in a manner to be described, and relay armatures 124 to 127 will drop to the back contact position. Thus, while station  $T_1$  is being received, antenna system 120' is automatically disconnected and antenna 120 is connected to the directional receiver. A separate telemetering system is connected to shaft 121 of loop antenna 120 so that needle 1 of indicator 145 will accurately point out the position which loop antenna 120 is made to assume, being a bearing on station  $T_1$ . D. C. Selsyn transmitter 140 is used, energized by battery 141 and connected to meter 145 through cable 142. Loop antenna 120 is automatically moved so that its null signal position accurately corresponds to the direction towards "in" station  $T_1$ .

Indicator 145 corresponds to the indicator described in connection with Fig. 1 having "in" needle 1, and "out" needle 2. The zero index 0 corresponds to the axis of the aircraft. After adjustment of the tuning of the directional receiver to the carrier frequency of stations  $T_1$  and  $T_2$ , blind approach guidance as described in connection with Fig. 1 is effected. Alternately radiating stations  $T_1$  and  $T_2$  cause relay solenoid 130 to correspondingly switch rotatable antenna system 120' and alternately system 120 out of and into circuit relation with the automatic directional receiver. The arrangement is such as to successively move the respective antennae and their associated needles on indicator 145 to point out, preferably to within 1° of arc, the direction towards the respective stations  $T_1$  and  $T_2$ .

The preferred automatic directional receiver, common to both rotatable loop antenna systems, is shown in block diagram in Fig. 7 and corresponds to Fig. 1 of my Patent No. 2,308,521 already referred to. The system of Fig. 7, details of which are shown in Figs. 8 and 9, forms the subject matter of my copending application Serial No. 499,754, filed August 24, 1943, for "Directional radio receiver," which application is a division of the present application and assigned to the same assignee. The directional receiver is remotely positioned with respect to the rotatable loop antennae and the non-directional antenna, as indicated by the broken lines 138. Non-directional antenna 150 is connected to primary winding 151 which is coupled to secondary winding 152 of the radio frequency transformer coupled to radio frequency receiver and audio frequency detector 153. Variable condenser 154 is shunted across secondary winding 152 and is adjusted to tune-in the proper radio frequency to be received for radio guidance or automatic direction finding as required.

The radio frequency signals impressed upon radio frequency receiver 153 are demodulated and impressed upon audio frequency amplifier 155. During the transmission interval of unmodulated transmitter  $T_2$ , no separate tone or audio frequency relay signal is derived and relay sole-

noid 130 remains normally energized attracting relay armatures 124 through 127 as indicated in Fig. 7. However, during the transmission interval of radio transmitter T<sub>1</sub> modulated by a relay tone, say of 75 cycles, a corresponding 75 cycle note will appear at the output of audio frequency amplifier 155. The 75 cycle tone is impressed upon relay filter 158 which prevents the passage of other frequency signals and passes the predetermined relay frequency of 75 cycles in the present example.

The output of filter 158 is connected to relay rectifier 159, the output of which is connected to solenoid 130. A preferred arrangement for the actuation of solenoid 130 is such that the solenoid is normally energized connecting loop antenna system 120' to the directional receiver. Upon reception of a radio signal bearing a substantial 75 cycle (or other predetermined frequency) signal, relay 130 is arranged to be deenergized and switch the directional receiver from directional antenna system 120' to directional antenna system 120. It is to be understood that relaying action wherein the predetermined (75 cycle) note causes energization of relay 130 instead of deenergization thereof may equally well be employed. Detailed circuit diagram Fig. 9 illustrates the arrangement for effecting the herein described operation of relay solenoid 130 by the 75 cycle signal.

The loop winding relay armatures 124, 125 are coupled to the loop radio frequency amplifier 160 through radio frequency transformer 161, 162 by transmission cable 128 which is preferably of low impedance. A variable condenser 163 in shunt with the secondary winding 162 is used to tune-in the desired radio station. All the tuning controls such as condensers 154 and 163 are preferably mechanically ganged together to provide a unitary tuning control. It is to be understood that a plurality of receiving bands may be employed to permit operation of the receiver system over a wide range of radio transmission frequencies. If a particular frequency is used for effecting the blind approach to an airport, a rapid switch over means to bring the receiver to that frequency may be provided, as will be understood by those skilled in the art.

In describing the operation of the automatic directional receiver section, which lies to the right of broken lines 138, reception by one of the loop antennae is first assumed. With the position of relay armatures 124 through 127 as shown in Fig. 7, loop antenna 120' and its associated control motor circuit are connected to the automatic receiver. The automatic receiver of Fig. 7 corresponds to schematically shown unit 40 of Fig. 3, or to units 20 and 20' of Fig. 2. In accordance with the automatic receiver used in the system of the present invention and described in detail in my Patent No. 2,308,521 referred to, a loop control signal is provided dependent upon the received loop antenna signal, to operate the motor drive for the loop antenna and rotate it to its null position with respect to the oncoming radio signals. The normal or stable position of the loop antenna is at the null or electrical neutral position with respect to the oncoming radio signals from the associated transmitter station, giving an exact angular indication of the direction to the transmitter of the radio signals. In the present case, transmitter T<sub>2</sub> is assumed to be radiating for controlling the orientation of loop antenna 120' and needle 2. When station T<sub>1</sub> is transmitting, loop antenna 120 instead is connected to the system, resulting in a similar electrical action.

When the angular position of the loop antenna 120' is changed from null during approach maneuvers, the radio signal is picked-up by the loop and impressed upon amplifier 160. The magnitude and phase of this signal depends upon the amount of the off-null angular position of the loop and the direction of the transmitter to the right or left thereof, respectively. A local generator 164 of an audio frequency current, preferably of the order of one hundred cycles, is used to modulate the radio signals derived from the loop antenna and produce a resultant tone modulated radio signal. I prefer to use a tone signal of 102.5 cycles as indicated in the drawings, but a different frequency may instead be used so long as it is different than the signal for relay 130. Loop signal modulator 165 schematically designates the modulation stage, preferably a balanced modulator, for combining the loop signal of 160 with the tone signal of 164.

The resultant tone modulated radio signal at 166 has a magnitude and phase dependent upon the off-null position of the receiving loop antenna. The tone modulated signal is then suitably combined with the non-directionally received signal from antenna 150 by a coupling means, such as coupling coil 166 linked with secondary winding 152 of the input transformer to radio frequency receiver 153. The nature of the radio signal impressed upon the input of amplifier 153 will be described in more detail, hereinafter, particularly in connection with Fig. 10. At this point it is sufficient to say that the superposition of the non-directional radio signals with the locally modulated loop signals provides a resultant radio signal with the 102.5 cycle tone component having a magnitude and relative phase dependent upon the off-null position of the loop antenna with respect to the oncoming wave. Radio frequency receiver 153 may be a tuned radio frequency circuit or a superheterodyne circuit. The receiver unit 153 contains a demodulator or detector for the audio frequency components of the amplified radio signals. The audio frequency signals at the output of unit 153 comprise modulations of the original radio wave plus the 102.5 cycle tone or control signal obtained when the loop antenna is off null.

An audio frequency amplifier 155 is connected to the output of receiver-detector unit 153. Amplifier 155 supplies audio unit 156 with sufficient energy for operating headphones connectible to jack 157 at the output thereof. The output of audio frequency amplifier 155 is also connected to a separate control signal amplifier 167 through a suitable phase shifting network 168 and 102.5 cycle pass filter 169. The 102.5 cycle tone signal is thus filtered out from the output of audio frequency amplifier 155 and amplified a substantial degree for use as a control signal to operate the relay control tube system indicated at 170. The relay control tube system is energized by both the control signal from amplifier 167 as well as the correspondingly amplified tone signal obtained directly from generator 164 and intermediate tone amplifier 171. Details of the operation and interrelation of the respective control signals and the relay control tube system 170 will be described in further detail in connection with Figures 11 and 12.

Control relays indicated at 172 comprise solenoids 173 and 174 connected to the relay control tube system 170. Solenoids 173 and 174 are selectively energized from control system 170 in accordance with the angular position to the right

or left of the loop connected, with respect to the direction of the oncoming radio waves. When relay 173 is energized, it attracts its armature 175 to close the electrical circuit through ground including its front contact, battery 177, and the loop motor. For the antenna 120' motor 131' is energized. Motors 131 and 131' are connected in a predetermined manner to operate in the direction to rotate loop antennae 120 and 120' respectively towards their null signal position through their shafts 121 and 121' and associated gearing. Energization of either relay 173 or 174 is determined upon the direction of the angular deviation of the connected loop antenna (120') from its null position with respect to the radiating station (T<sub>2</sub>) so that the proper counter-rotation of the associated motor (131') will occur to bring the loop antenna to the null signal position.

Relay 173 remains energized until the loop antenna is rotated to reach its null position, whereupon the control signal derived from the loop signal impressed upon amplifier 160 is so reduced in value or obliterated as to cause relay armature 175 to drop back to its neutral or back contact position, deenergizing and stopping the associated motor. Electromagnetic clutches 132 and 132' are electrically shunted across their motor energization circuits to immediately disconnect the associated motor from the loop antenna, insuring a rapid stop of the loop rotation at the time of motor deenergization, and eliminating the possibility of overshooting or overdriving by the motor due to its mechanical inertia. The frictional forces of the gearing and the bearings of the loops are generally sufficient to quickly stop the loop rotation.

In practice I have constructed systems in accordance with the present invention which automatically operate the loops and therefore the associated bearing indicators at a rate of 180° and more per second. The accuracy of the resultant bearing may readily be made within 1° of arc, i. e. the actual directional indication on each radio transmitter being correct to within 1° or less. The bearing indications are on a 360° dial and move to the stationary bearing position through the shorter angular path. I prefer a rate of indication of about 125° per second for the one-third of a second transmitter T<sub>1</sub> and T<sub>2</sub> radiation periods.

When the loop antenna reaches, or is substantially at, its null signal position a zero or substantially zero magnitude radio frequency signal is impressed upon radio frequency amplifier 160 for modulation at 165 by the generated tone signal from amplifier 164. The magnitude of the control signal from amplifier 160 accordingly is also zero, or substantially zero at that time, and control relays 173, 174 are in the deenergized position shown. The loop accordingly remains stationary when it is at its electrical signal null position with respect to the direction of the oncoming waves. This position corresponds to the geometric position of the loop where the plane of the open face thereof is perpendicular to the direction of the oncoming radio waves.

Should the aircraft carrying the loop antenna deviate from this direction the loop will be energized by the oncoming radio signal from the transmitter, and impress it upon amplifier 160 with a magnitude and phase relation corresponding to the altered direction thereof. Should the deflection of the aircraft cause the loop to receive a signal of phase corresponding to that

which energizes solenoid 173, the above described operation of the loop motor is repeated to bring the loop to the new null signal position. Should, however, the aircraft turn so that the loop is deviated in the opposite angular direction, the phase of the control signal impressed upon relay control tube system 170 will be different by 180° and energize solenoid 174 instead.

When solenoid 174 is energized, its armature 176 is attracted to the front contact to electrically complete the connected loop motor circuit including its associated clutch, ground, and battery 177. Electromagnetic clutch 132' is thereupon immediately engaged and motor 131' is rotated in the direction opposite to that corresponding to its energization by solenoid 173 when loop system 120' is in connection with the receiver as shown. Motors 130 and 130' are reversible in the present case, and are not necessarily a direct current type. Relay armatures 175 and 176 are arranged so that the direction of current flow through the connected motor is selectively reversed to cause the motor to rotate its associated loop towards its null signal position in the shorter path of rotation. Thus, when solenoid 174 is energized, the motor will rotate in a direction opposite to that due to energization of relay 173.

An important feature of the preferred automatic directional receiver resides in the fact that for any bearing, the loop antennae are at their electrically neutral and geometric null positions, and remain stationary for the duration of the bearing. Furthermore, as will be shown in more detail hereinafter, no sense or directional ambiguity occurs, and the null position which the loop assumes is accurate for any bearing on the transmitters. Pointer 2 of indicator 145 moves in exact correspondence with loop antenna 120' and is arranged to point to the center zero position 0 shown on the dial, when the open plane of loop 120' is perpendicular to the longitudinal axis of the aircraft. Similarly, pointer or needle 1 moves in exact correspondence with loop antenna 120, pointing to center zero when the plane of loop 120 is perpendicular to the flight direction.

The accuracy of indication is independent of the position of indicator needles 1 and 2 since any reading thereof corresponds to an electrical null position of loop antennae 120 and 120', and no balancing of electrical parameters or signal components are required to maintain the readings. The interpretation of the readings is readily apparent to the pilot, and he effects a blind approach as described in connection with Fig. 1.

In Fig. 8 I have diagrammatically illustrated components of one form of dual indicator 145. A common housing 180 encloses the direct current Selsyn movements for both needles 1 and 2 having corresponding toroidal or annular actuating coils 181 and 182. Coil 181 is connected by leads 184 to three-wire cable 184' which in turn is connected to a direct current loop position transmitter of one loop system. Annular winding 182 is similarly connectable by leads 183 to three-wire cable 183', for connection to the direct current loop position transmitter of the second loop system. Three-pole double-throw switch 185 is used to connect cable 183 with cable 183' as shown in dotted during the double indicator blind approach operation of the system as described hereinabove so that both needles 1 and 2 of meter 145 are independently controlled.

Indicator needle 1 is connected to central spindle 186 pivoted in end bearing 187. Mag-

netic core 188, shown in dotted, is secured to spindle 186 and arranged to magnetically coact with the interior of annular winding 181 in the usual telemetering manner. Indicator needle 2 is coupled to the end of tube 190 concentric about spindle 186. Tube 190 is rotatable on diagrammatically indicated bearing 191 for independent rotation with respect to spindle 186 of needle 1. Magnetic core 192, shown dotted, is mechanically secured with rotatable tube 190, and is magnetically coactable with annular winding 182. Indicator needles 1 and 2 are coaxial and independently controlled to assume the angular positions of the two loop antenna systems during the blind approach maneuvers described. A casing 193, having a flange 194, fitted within the open end of housing 180, encloses indicator needles 1 and 2 and contains the scale for the indications. A transparent window 195, such as glass, is fitted into the top end of enclosure 193.

When the dual receiver system is to be used for taking normal directional bearings on only one transmitter station and not for the described two-station blind approach maneuvering, three-pole switch 185 is thrown to the position drawn in solid lines in Fig. 8 connecting annular windings 181 and 182 in parallel. Both indicator needles 1 and 2 then act in unison, one above the other, and each assumes the same angular position on the scale of meter 145. For ordinary automatic directional operation, both sections of the meter are connected in parallel with one of the loop position transmitters and give the same reading.

Accordingly, when the dual indicator of Fig. 8 is in circuit with a dual receiver system in accordance with the present invention, three-wire cable 184' connects to the position transmitter of the loop antenna normally in circuit with the receiver, and not to the loop antenna switched-in by the reception due to the field stations corresponding to T<sub>1</sub> and T<sub>2</sub>. For example, if used in the receiver system of Fig. 7, cable 184' would correspond to cable 142', connecting to position transmitter 140' of loop antenna system 120' normally connected to the receiver through relay armatures 124 to 127. Three-pole switch 185 is operated to the solid position for both needles of indicator 145 to give a single reading when the automatic directional system is used for radio guidance in general, and is connected to the dotted position when the pilot is ready for blind approach to a runway having stations corresponding to T<sub>1</sub> and T<sub>2</sub> when both needles become independently operative in the manner described.

#### Receiver circuit details

Fig. 9 is a detailed schematic electrical diagram, partially in block form, of a commercial form of the automatic receiver system constructed in accordance with the principles of my present invention. Relay system 124 through 127 selectively connects the two loop antennae systems 120 and 120' to the receiver as shown in Fig. 7. Fig. 9 is a specific electrical showing of the system shown generally in Fig. 7, and represents a preferred embodiment thereof though not limited thereto.

Signals from the rotatable loop antenna in circuit with loop transmission cable 128 are impressed upon primary winding 161 of the loop radio frequency input transformer, secondary winding 162 of which is shunted by tuning condenser 163 and connected to the control grid of radio frequency amplifier pentode 200 for amplification and introduction to the control grids of

balanced modulator stage 165. The gain of loop amplifier 200 is manually controllable by rheostat 201 connecting the cathode thereof to ground. The anode of amplifier 200 is energized through a shunt radio frequency choke coil 202 connected to the B supply.

The output of loop amplifier 200 is coupled to the control grids of tubes 203, 203' of modulator 165 through coupling condensers 204. The cathodes of tubes 203, 203' are tied together and connected to ground through by-pass condenser 205 and biasing resistance 206. An audio frequency oscillator 164 comprising two triodes 207, 207' is arranged to generate an audio or tone frequency current of a relatively low frequency. The control grids of triodes 207, 207' are coupled to the anodes thereof by condensers 208, 208'. Cathodes of the oscillator triodes are tied together and connected to ground through biasing resistor 209.

Resistors 198 and 198' are coupled between the grid electrodes of triodes 207, 207' and ground. Intermediate taps on the resistors 198 and 198' couple a portion of the available alternating current tone energy from oscillator 164 to the grids of modulator triodes 203, 203' through coupling resistances 196 of about one megohm each and through coupling condensers 197, 197'. Further resistances 199, 199' normally connect grid coupling resistors 197, 197' to ground to stabilize the grid circuits of tubes 203, 203'.

The actual frequency of the tone current generated by oscillator 164 as used in the system is optional, and may for example lie anywhere in the audio frequency spectrum, or even higher. Practically, however, the tone frequency should be chosen so as to efficiently pass through the respective radio frequency circuits as sidebands, and the audio frequency circuits as well, be audible to the pilot when present and differ from the relaying tone from the field transmitters as T<sub>1</sub> or T<sub>2</sub>. It is also desirable to prevent interference with the intelligibility of the aural messages of the radio signals. An important consideration is to minimize any effect due to the sound modulations of the radio wave upon the control circuit. I have found that a control signal in excess of 200 to 300 cycles contains sound modulation components after filtering out for control purposes.

Modulation "kicks" occur when the sound frequencies of the radio signals coincide with the control frequency, and interfere with the stability of the directional indications. A tone frequency of the order of 100 cycles is sufficiently high to efficiently pass through the radio and audio frequency channels of the system, sufficiently low to not interfere with the intelligibility of the audio frequency modulations of the radio signal, and is not affected by modulation kicks. A practical tone frequency in this range I found to be a tone of 102.5 cycles, as indicated in the figures. This frequency is satisfactory when the loop relaying frequency of station T<sub>1</sub> is 75 cycles. The field transmitter tone should differ sufficiently from the receiver control frequency, 102.5 cycles in the present case, to be properly filtered out of the audio output circuit. Thus 75 or less cycles, or 150 or more cycles per second are satisfactory for T<sub>1</sub> when 102.5 cycles is used in the receiver.

Control grid electrodes of modulator triodes 203, 203' accordingly simultaneously receive the audio frequency tone signal from oscillator 164 and the radio frequency signal picked up by the connected directional antenna. The electrical interaction of these respective signals is described

in connection with Fig. 10. The output of modulator stage 165, obtained through the anodes of tubes 203, 203', is connected to opposite sides of radio frequency winding 166 coupled to secondary winding 152 of the non-directional antenna circuit. The anode supply for modulator tubes 203, 203' is obtained through a center tap on winding 166 connected to the common B supply as indicated.

The wave form of the resultant radio frequency signal imparted by winding 166 to secondary 152 corresponds to that indicated by curves C, C' and D, D' of Fig. 10, or zero when loop antenna 10 is on null. The frequency of the loop modulated signals is the sum and difference of the received radio signals and the low frequency oscillator tone signal. The simultaneous induction of the non-directional radio frequency signals with the tone modulated loop signals upon winding 152 produces a resultant signal upon the control grid of radio frequency amplifier 210 of wave shape corresponding to curves F or G. The non-directional signal from antenna 150 serves as a reference signal or sense determinator, so that the right or left sense of the loop antenna signals is established for further control action on the orientation of the loop antennae. Thus proper functioning of the automatic directional receiver is assured, quickly bringing the connected loop antenna back to its null signal position to give accurate bearing indications on the field station transmitting.

The signals impressed upon the control grid of radio frequency pentode 210 are amplified and transmitted through output radio frequency transformer 211 having its secondary winding tuned to resonance by variable condenser 212 shunted there-across. The output of transformer 211 is coupled to intermediate grid electrode 215 of the radio frequency mixer stage 220 through coupling condenser 216. Radio frequency mixer 220 is shown as a hexode wherein grid electrode 217 adjacent to the cathode is energized by a signal emanating from a local beat frequency oscillator 221 operated in the usual manner for superheterodyne reception. The anode and screen grid operating potential for stage 220 is supplied through respective resistors 222, 223.

The output of radio frequency mixer stage 220 comprises primary winding 225 of a step-down intermediate frequency transformer shunted by adjustable condenser 227 for resonating the coil at the intermediate frequency, such as 455 kilocycles. Transformer 225, 226 is a step-down transformer so that a long low impedance transmission line 230 may be used to permit placing the intermediate frequency and audio frequency amplifier equipment remote from the radio frequency section including the directional and non-directional radio signal amplifiers, and loop modulator stage. Transmission cable 230 is an electrically shielded low impedance cable terminating in a correspondingly low impedance primary winding 231 of step-up intermediate frequency transformer 231, 232. Secondary winding 232 of the terminating transformer is shunted by a resonating adjustable condenser 233 to tune the transformer to the intermediate frequency used.

The output of step-up intermediate frequency transformer 231, 232 is connected to the grid electrode indicated at 234 of the input stage of two-stage intermediate frequency amplifier 235 shown in block diagram form. The anode indicated at 236 of output stage of intermediate frequency amplifier 235 is connected to trans-

former 237, the primary and secondary windings of which are respectively shunted by adjustable condensers 238 and 239 and tuned to the intermediate frequency. An audio frequency detector stage 240 has its control grid connected to the output of intermediate frequency transformer 237 for demodulating the signals and producing corresponding audio frequency currents across cathode resistor 245 connected to ground.

Both the radio signal tone modulations as well as the local control signal if present, produce a corresponding audio frequency signal across resistor 245 by the detector action. The anode of detector 240 is connected to the common B supply as indicated. Condenser 246, between the cathode of detector 240 and ground, by-passes the higher order frequency currents from the audio frequency path. The derived audio frequency signals are coupled to audio frequency pentode amplifier stage 250 by coupling condenser 248. The anode circuit of amplifier 250 comprises resistance 251 connected to the common B supply and is coupled to the control grid 252 of a second audio frequency amplifier stage 255 through coupling condenser 253. Second audio frequency amplifier stage 255 is resistance-capacity coupled by anode resistor 256 and coupling condenser 257 to a further two-stage audio frequency amplifier 260.

It is to be understood that both the original audio frequency signal modulations on the radio carrier wave and the control or tone signal amplified together therewith, are impressed upon two-stage amplifier 260 for further amplification to an appreciable signal level. The output of amplifier 260 is coupled to the aural amplifier indicated at 270, to the output of which earphones 275 are connected. The pilot adjusts the aural level of the signals by a separate manual control in aural unit 270. The output of audio frequency amplifier 260 is also coupled to amplifier stages 280 and 290 for selecting and further amplifying the 102.5 cycle loop motor control signal and impressing it upon relay control system 170, and also to pass filter 350 for controlling the selective connection of loop systems 120 and 120' to the receiver, through transmitted relaying signals.

The output of audio frequency amplifier 260 is coupled to the control grid 281 of amplifier stage 280 by coupling condenser 261 and phase shifting network 262, 263. Resistor 265 is shunted across phase shifting network 262, 263 connecting the control grid of stage 280 to ground. The relative impedance of resistor 262 and condenser 263 is chosen to suitably shift the phase of the 102.5 cycle control signal to be impressed upon control grid 281 to compensate for any misphasing thereof caused in the circuits prior to that point. Such phasing is made to cause the phase relation of the signal arriving at the input of tube relay control system 170 to be substantially in-phase or 180° out-of-phase with the correspondingly impressed tone signal from amplifier 171.

The control signal impressed upon control grid electrode 281 of pentode amplifier stage 280 is amplified in a conventional manner. The output of amplifier 280 is impressed upon control grid 291 of a further amplifier stage 290 through coupling condenser 282. A tuned filter 285, 288 is used to filter out other signals or modulations than the 102.5 cycles, and most efficiently pass this signal frequency. Other filter arrangements than the shunt choke coil 285 and condenser

288 may be used. Amplifier stage 290 comprises a triode tube, the anode circuit of which includes primary winding 292 of audio frequency coupling transformer 295. Secondary winding 296 of transformer 295 is shown schematically coupled to the input of the relay control system 170. The output of 102.5 cycle amplifier 171 is impressed upon relay control system 170. Fig. 11 is a preferred circuit arrangement for the relay control tube system 170.

Variations in the level of the received radio signals are compensated for by an automatic level control. A further arrangement of the system maintains constant the anode or B voltage supply for critical parts of the circuit despite variations in the supply voltage thereto, to insure uniform sensitivity and operation of the loop motor controls and associated electronic relay system. A voltage regulator tube 300 is connected between a particular point 305 and ground, to maintain a predetermined and uniform operating voltage supply for the critical part of the electronic control arrangement which includes the anodes of oscillator 164 through lead 304, the amplifier 171 through lead 307 and electronic relay system 170 through lead 306 as will be explained in more detail in connection with Fig. 11.

An automatic level or volume control arrangement is provided through rectifier 310 fed by an intermediate frequency signal tapped from intermediate frequency output anode 236 through coupling condenser 311 to anode 312 thereof. Delayed automatic volume control (D. A. V. C.) action is obtained by providing a positive biasing voltage raising the potential of cathode 313 to delay the biasing control action till the received radio signals reach a predetermined level. Anode 312 of rectifier 310 is connected to the control grids of the respective radio frequency, intermediate frequency and audio frequency stages of the circuit to establish a substantially flat and uniform amplification response of the signals through the system.

Coupling resistances 315, 316, 317, 318 are used in this level control circuit, and control grid 234 of the intermediate frequency amplifier is connected thereto by direct connection 319 through secondary winding 232. The second stage of the intermediate frequency amplifier 235 is preferably also controlled by the level control circuit described. The inclusion of at least the first audio frequency amplifier stage 250 in the signal control circuit from rectifier 310 results in a very flat overall response despite wide signal level changes in the received radio waves.

A manual switch 320 is provided at the cathode of the first radio frequency amplification stage 210 to disconnect the automatic volume control effected thereto through resistor 315, for manually controlling the bias through variable resistor 322 in the cathode circuit. This manual volume control is useful for communication or reception of radio range signals. A further switch 325 is provided for continuous wave beat frequency oscillator 330 to connect it to audio frequency detector stage 240 for heterodyning continuous waves. Continuous wave oscillator 330 is used for audibly perceiving continuous wave transmission and serves as a signal "station finder" for such stations, e. g. T<sub>2</sub>. The normal connection of switch 325 to ground contact 326 is schematically indicated for rendering oscillator 330 ineffective as a heterodyning means, which connection is used for phone reception. By ungrounding switch

325, oscillator 330 becomes effective for heterodyne reception of continuous waves.

A direct current millimeter 340 is connected between the output of automatic volume control stage 310 and ground, through series resistance 345. Meter 340 serves as a measure of the automatic level biasing current and indicates the relative signal strengths of received radio signals. Meter 340 serves as a relative distance or millimeter. Flight toward a station increases the signal strength and therefore the indication on meter 340. Flight away from a station correspondingly decreases its indications.

The audio frequency output of amplifier 260 is connected to a highly selective filter 350 by leads 349 to segregate the radio relay tone, 75 cycles in the present embodiment, from other audio frequency signals which may be present. Pass filter 350 is selected to efficiently pass the chosen relaying frequency. The actual construction of pass filter 350 is optional, and I have illustrated one form which it may assume in practice. A resonant shunt path comprising inductance 351 and capacitance 352 tuned to the frequency to be passed, comprises the initial section thereof. A series inductance 353 connects shunt path 351, 352 to a further shunt path 354, 355. The output of filter 350 contains series inductance 356.

Filter 350 is specifically designed to reject the 102.5 motor control frequency which orients the loop antennae. The invention is not limited to any particular frequency for either the loop motor control or the relay switching control. The output of filter 350 is coupled to a rectifier amplifier stage 360 through coupling condenser 357. The 75 cycles signal is impressed upon detector anode 358 having shunt resistor 359 to ground across which the rectified component is built up. The cathode of stage 360 is positively biased with respect to ground by battery 361. Control grid 363 of the triode section of tube 360 is coupled to diode anode 358 through resistor 362. A by-pass condenser 364 connects grid 363 to ground.

Relay solenoid 365 is connected between anode 366 and the B supply for stage 360. Normal anode circuit current passes through solenoid 365, when no relaying tone signal is impressed upon stage 360 from filter 350. This current is sufficient to energize the solenoid 365 and attract armature 370 against contact 369 as shown in dotted. In this position, relay contact 369 is connected with armature 370, and energization of relay solenoid 130 is maintained through local source 373. Relay armatures 124 through 127 accordingly are normally against their front contact position as shown in Fig. 7, connecting loop antenna system 120 to the directional receiver circuit.

When transmitter station T<sub>1</sub> is operating and the audio frequency tone modulation thereof is present in the receiver, the relaying tone, namely the 75 cycles frequency signal, passes through filter 350, is rectified by stage 360 and causes a substantial negative bias upon control grid 363 thereof. The negative bias chokes off the normal anode current flowing through solenoid 365, and permits spring 372 to draw armature 370 from contact 369 against backstop 371 as shown in solid in Fig. 9, opening the circuit between battery 373 and solenoid 130. When the 75 cycle relaying signal is received, switch-over relay 130 is accordingly deenergized in the described embodiment. When relay solenoid 130 is deenergized, armatures 124 through 127 drop to their back contact position shown in Fig. 9, disconnecting

loop system 120' from the directional receiver and connecting loop system 120 thereto.

The switch-over or relaying action by solenoid 130 occurs when the tone modulated field station, corresponding to transmitter  $T_1$ , is radiating. The automatic loop orientation by the directional receiver is made effective on loop antenna system 120 for the duration of transmission of station  $T_1$ . Loop antenna 120 is quickly moved to its null signal position with respect to station  $T_1$  by stable action, bringing the local 102.5 cycle signal below the value to cause firing of gaseous triodes  $T$  and  $T'$  (Fig. 11) or operation of loop motor 131. Indicator needle 1 of indicator 145 (Fig. 7) corresponds to loop antenna 120 and to station  $T_1$  as previously described. Needle 1 remains at the position which antenna 120 assumes after antenna system 120 is unswitched from the directional receiver, upon cessation of  $T_1$  and transmission of  $T_2$ .

In accordance with the operation of the receiver system described, when station  $T_1$  ceases transmitting and station  $T_2$  starts transmitting, loop antenna system 120 is disconnected from the receiver circuit and remains stationary while the other antenna system 120', is placed under the control of the directional receiver. Signals from station  $T_2$  orient loop 120' to point thereto. Needles 1 and 2 remain stationary during the quiescent periods of  $T_1$  and  $T_2$ . Since approach maneuvers take place at a speed in the range of 80 to 120 miles per hour, a switching rate of about one-third of a second for transmitters  $T_1$  and  $T_2$  is preferred. I have found during extensive experimentation that a rate of switching less than one-half of a second gives indications by the needles 1 and 2 which effectively indicate the pilot's lateral position with respect to the landing field stations  $T_1$  and  $T_2$  in the manner described in connection with Fig. 1.

#### *General theory of the receiver circuit operation*

The broader principles of my present invention are not dependent upon the specific automatic receiver unit disclosed for operating the dual indicator system. However, the success of the invention depends upon the use of a rapidly operating and accurate automatic direction indicating receiver unit such as I have hereinabove disclosed in connection with Figs. 7 and 9 and also in my Patent No. 2,308,521 previously referred to. The speed of loop orientation by the receiver unit is preferably at a rate of the order of 125 to 150 degrees per second without sacrificing accuracy in directional positioning of the loop antenna and its corresponding indicator needle. Such rate of operation results in completion of bearings on  $T_1$  and  $T_2$  well within the preferred one-third of a second period of transmission of stations  $T_1$  and  $T_2$ .

The automatic directional receiver unit plays a vital role in the practical performance and reliability of the present invention. The operation of the disclosed automatic directional control unit of the receiver will be better understood by a consideration of the following theory in connection with the curves of Figs. 10 and 12. The oncoming radio wave from the transmitting field station,  $T_1$  or  $T_2$ , is indicated by arrows 380 directed toward the loop antennae. Since the operation of the automatic receiver unit is the same regardless of whether loop antenna system 120 or 120' is in circuit therewith, in the present discussion the case where loop antenna system 120 is in circuit connection with the receiver unit

corresponding to the interval of transmission by station  $T_1$  shall be considered.

The loop antenna indicated in solid at 120 is tilted towards the right of the direction of radio waves 380 from station  $T_1$ , forming angle  $\theta_R$  with the horizontal axis. When the open plane of loop 120 is in a horizontal position, namely perpendicular to wave direction 380, it receives no signal. The magnitude of the radio signal picked up by the loop antenna is dependent upon its off-perpendicular or off-course angular relation with respect to the direction to  $T_1$ , and is proportional to the sine of this angle. Curve A in Fig. 10 indicates a radio carrier wave corresponding to the received loop radio signal, and may be said to correspond to the  $\theta_R$  position of the loop.

When the loop antenna is in the position indicated in dotted, deflected towards the left of radio wave direction 380, it forms a corresponding angle  $\theta_L$  with the perpendicular direction thereto. The radio signal indicated by dotted curve A' corresponds to reception in this position. It is well known that when the loop antenna passes through its null or perpendicular position, the phase of the resultant signal reverses by 180°. This is illustrated by the phase difference of 180° between radio signal curves A and A'. The amplitude of radio signal curves A and A' are shown equal, and is so when  $\theta_R$  equals  $\theta_L$ . Modulations of the radio wave are not shown, but are to be understood. Curves A and A' correspond to the carrier wave. Signal A or A' corresponds to that received by the loop antenna and impressed upon the loop radio frequency amplifier, and modulated at 165 by the local signal generated at 164.

Curves B and B' represent the tone modulating signal impressed by balanced oscillator 164 upon the grid electrodes of the balanced modulator 165. Curves B and B' are 180° out of phase corresponding to the opposed polarity of the balanced output of oscillator 164. Curve B may be assumed to correspond to the phase of the signal impressed upon the grid of modulator tube 203, and curve B' that impressed upon the grid of the modulator tube 203'. For diagrammatic reasons, the tone cycle is represented as including only five cycles of the radio frequency signals indicated at A. However, the frequency of curves B and B' is the 102.5 cycles as already described, and radio signals A and A' of the order of kilocycles. The tone signal corresponding to curves B and B' is impressed upon the grid electrodes of balanced modulator stage 203, 203' through coupling resistors 196 and coupling condensers 197, simultaneous with the impression of a received loop radio signal corresponding to curve A or A' through coupling condensers 204.

Grid circuit modulation is effected in balanced modulator 165, cancelling out the carrier wave in its output connected across coupling coil 166. The side bands follow through, corresponding to the addition and subtraction of the tone frequency with the radio carrier frequency. Curve C corresponds to the tone modulated loop signal as passed for example by modulator tube 203 when the positive half cycle  $a$  of the B curve is effective thereon. Square-law modulation is effectively employed and the resultant signal indicated by curve C is proportional to the instantaneous value of tone signal B and the loop signal A.

Upon the second half or negative cycle  $b$  of tone curve B, upper modulator stage 203 will be choked or negatively biased and not pass any signal. During this half cycle, the current flow from tube 203 will be zero as indicated on curve

C. The frequency of curve C corresponds to the radio frequency side bands due to the modulation by the tone signal, and the envelope thereof corresponds to the shape and frequency of the modulating tone current. Dotted curve C' represents the modulated resultant at the first half of the modulation stage, but corresponds to the dotted reception position of the loop antenna and is identical with curve C except for a 180° phase displacement with respect thereto.

Curves D and D' represent the signal flow through the lower or second modulator stage 203'. Dashed tone curve B' represents the tone modulating signal impressed upon the grid of modulator tube 203', 180° out of phase with that impressed upon upper stage 203. The first half of the cycle, a', negatively biases stage 203' resulting in a zero signal output therefrom. During the second half, b', of the cycle, the biasing is positive and proportional to the instantaneous magnitude of curve B', resulting in solid curve D corresponding to curve C for loop position  $\theta_R$ , and the oppositely phased dotted curve D' when the loop is at dotted position  $\theta_L$ . The output of modulator 165 is balanced and connected to opposite sides of coupling coil 166. Secondary winding 152 of radio frequency amplifier 210 is accordingly continually impressed with tone modulated signals corresponding to curves C and D, or C' and D', since tubes 203 and 203' are alternately rendered conductive.

Radio signals from non-directional antenna 150 are also impressed upon secondary winding 152. Directional arrows 300' in Fig. 10 indicate the same radio waves impressed upon non-directional antenna 150 as are impressed upon the loop antenna. Curve E represents non-directionally received radio wave signals by antenna 150 connected to primary winding 151 and impressed upon secondary winding 152 for amplifier stage 210. The radio signal is the same as that received by the loop and has the same wave form. Non-directional signal E is used as a reference, and when combined with the modulated loop signals imparts a "sense" to the resultant motor control signal and eliminates directional ambiguity for the system. Choke coil 202 of stage 200 serves as a 90° phase shifter for the loop radio signals to compensate for the 90° difference between the resultant loop signal voltage and antenna 150 voltage. In practice, choke coil 202 serves as a capacitance due to distributed capacitance thereof.

The superposition of the modulated loop signals impressed by winding 166 and the non-directional radio signals by winding 151 upon secondary winding 152 causes simultaneous actuation of the grid electrode of radio frequency amplifier 210. When the loop antenna is in position  $\theta_R$ , inducing loop radio signal A at amplifier 200 and resultant signals C and D at modulator stage 165, a resultant signal occurs at output transformer 211 of stage 210 corresponding to the curve shown at F. The envelope  $m, m'$  of curve F conforms to the tone modulating signal. In the first half of the illustrated wave form, the radio frequency wave E is added to or increased due to the in-phase relation of curve C therewith. In the second half of curve F, the amplitude thereof is decreased due to the opposite phase relation of the signal due to curve D.

When the loop antenna is at the position forming angle  $\theta_L$  with respect to its null position, the resultant signal at output transformer 211 of radio frequency amplifier stage 210 is represented

by dotted curve G. Curve G is similar to curve F except that envelope  $n, n'$  is 180° out-of-phase with respect to envelope  $m, m'$  of curve F. This is due to the respective 180° phase displacement of loop modulated signals C' and D' with respect to signals C and D, as will now be evident to those skilled in the art.

The resultant radio frequency signals corresponding to curves F and G are further amplified through the superheterodyne circuit including intermediate frequency stages 235, and audio frequency detector stage 240. The audio frequency components of the amplified radio waves includes the 102.5 cycle tone frequency component of the wave corresponding to the envelope of curves F or G, together with the 75 cycle audio frequency switch-over relaying signal, when antenna 120 is receiving signals from station T<sub>1</sub>, as well as any voice modulations which may be present in the radio frequency waves transmitted. It is to be understood that regular verbal landing instructions or weather reports may be transmitted from synchronized stations T<sub>1</sub> and T<sub>2</sub>. As already described, the audio frequency signal components are further amplified by audio frequency amplifier stages 250, 255, 260.

The output of audio frequency amplifier 260 is introduced to phasing network 262, 263 and another audio frequency amplifier stage 280. A pass filter for the tone frequency, namely 102.5 cycles, substantially rejects other audio frequencies including the 75 cycle signal and efficiently passes the 102.5 cycle tone or control signal for further amplification by stage 290 whereupon it is introduced to audio frequency transformer 295 connecting to control system 170. The 75 cycle relay tone signal passes from amplifier 260 through its selective pass filter 350, and is arranged to actuate relay solenoid 365 to operate solenoid 130 in the already described manner to selectively switch loop antenna systems 120 and 120' in circuit relation with the automatic receiver unit for effecting the blind approach operation with respect to stations T<sub>1</sub> and T<sub>2</sub>.

#### Receiver electronic control tube circuit

Fig. 11 is a schematic electrical diagram of an arrangement for electronic control system 170, shown together with the associated tone oscillator 164 and control signal amplifier 171. Audio frequency amplifier stage 290 is at the right. The output signal of amplifier stage 290 is predominantly the tone frequency resulting from the demodulation of the tone modulated wave corresponding to curves F or G of Fig. 10, since any other frequency including the 75 cycle transmitter tone is substantially rejected by filter 285, 288 as already described. Curves M and N of Fig. 12 illustrate the wave form of the 102.5 cycle signal impressed upon secondary winding 296 of transformer 295. Curve M corresponds to envelope  $m, m'$  of curve F; and curve N, to envelope  $n, n'$  of curve G. Curves M and N are above the horizontal zero axis corresponding to a substantial initial biasing voltage indicated by broken line R. A condenser 390 is shunted across secondary winding 296 arranged for more efficiently passing the selected tone frequency of 102.5 cycles to the tube control system 170, and rejecting other frequencies.

The substantial positive initial biasing voltage on secondary winding 296 makes the operation of tube relay control system 170 more sensitive to the control signal. The biasing voltage is supplied from constant B voltage potential point 305

through lead 306 and resistor network 391, 392, and 393. The voltage at point 305 is held constant to keep the sensitivity and performance of the circuit uniform. The B voltage supply to point 305 is obtained from the common B voltage supply of the system, through series resistor 301. A voltage regulator device 300 is shunted across the uni-potential point 305 and ground to hold the operating potential at point 305 constant over wide variations in the B potential supply thereto.

A suitable voltage regulator for the receiver unit is a cold-cathode, glow-discharge tube. In the practical embodiment I employ a voltage regulator tube at 300 rated to maintain a voltage of 150 volts at point 305. Variation in the voltage supply causes a variable drop across series resistor 301, which is 2000 ohms in the chosen circuit. The current flow through regulator tube 300 varies in the well-known manner to maintain the rated voltage, of 150 volts, at point 305. It is to be understood that other voltage regulator devices than tube 300, and a different voltage value or circuit connections to maintain the constant voltage potential at point 305 may be used.

The selective operation of the relay system depends upon the 180° relative phase displacements of the control signal as hereinabove described. For best practical operation, the phase relations and relative voltage magnitudes should be near the predetermined values for proper automatic operation of the system. Should the voltage rise, the control tubes of system 170 would fire and defeat any selective or automatic operation thereof. Should the voltage fall too low, the sensitivity of action of the control tubes would be impaired. Constant voltage supply for oscillator 164 insures proper tone signal generation as to amplitude and frequency, and maintains the overall sensitivity of the automatic receiver unit.

The tube relay control system 170 illustrated in Fig. 11 comprises two associated electronic control tubes T and T'. Electronic tubes T and T' may be high-vacuum triodes, mercury vapor relay tubes or Thyratrons, or cold-cathode glow-discharge tubes with a starter-anode. I prefer to use the latter type as schematically indicated in the figure, containing starter-anodes 400, 400', cathodes 401, 401' and anodes 402, 402'. The tube, currently known as type OA4-G, has been found suitable in practice for this purpose. The OA4-G tubes are designed so that a starter anode voltage of 110 volts at electrodes 400, 400' will fire or break-down the tube affected and establish a current flow between the anode and cathode thereof. Anodes 402, 402' of relay tubes T and T' are energized by an alternating current signal at the control frequency of 102.5 cycles derived from the oscillator 164 and amplifier 171 connected in a push-pull relationship, i. e. 180° phase displacement relation.

The output of oscillator 164 is coupled to push-pull amplifier stage 171 by coupling condensers 405. Amplifier tubes 406, 406' of stage 171 are preferably of the high efficient type known as electron beam power tubes. A battery biasing arrangement, using 409, the ship's battery, aids in stabilizing the action of amplifier stage 171. Curves P and P' of Fig. 12 represent the relative phase and wave form of the tone frequency signal input to anodes 402, 402' of respective control tubes T and T'. The output of amplifier tubes 406 and 406' is coupled to center-tapped primary winding 407 of step-down transformer

408. Secondary winding 410 of transformer 408 is center-tapped to ground, the outer terminals thereof being connected to control tube anodes 402, 402' through relay solenoids S and S' respectively. Signal curve P may be said to represent the voltage input to anode 402 of upper tube T; curve P', displaced 180° with respect to curve P by the balanced connection, to anode 402' of tube T'.

The control signal impressed across starter anodes 400, 400' is in phase for both starter anodes, and is adjusted through variable tap 415 of potentiometer 394 connected across secondary 296 of transformer 295. As already described, the direct current biasing voltage supplied by bleeder or resistance network 391, 392, 393 is of the order of 85 volts with respect to ground as represented by lines R in Fig. 12 in the control signal input curves M and N. Series resistors 412, 412' are connected between tap 415 and starter anodes 400, 400'. The magnitude of the resultant signal impressed upon starter anodes 400, 400' is adjustable by the variable tap 415 of potentiometer 394, to establish a predetermined sensitivity for the system. When a control signal resulting from the position of loop antenna at  $\theta_R$  as shown in Fig. 10 is impressed upon secondary winding 296, both starter anodes 400 and 400' are similarly energized by the biased signal of curve M. When the loop antenna is in the opposite position, corresponding to angle  $\theta_L$ , the dotted curve N is effective in controlling the voltage on starter anodes 400 and 400'.

An alternating tone frequency voltage is continually impressed upon anodes 402, 402' by transformer 408 of the order of 140 to 150 peak volts for each anode with respect to ground. The voltage across the terminals of secondary winding 410 of transformer 408 is accordingly 280 to 300 volts peak volts. Transformer 408 is preferably a step-down transformer limiting the peak value of the voltage impressed upon the anodes of control tubes T and T', and giving good current regulation for the transformer 408 despite the drawing of current by the anode circuit of the tubes upon firing. The peak voltage of the tone signal applied to anodes 402, 402' is not above 150 volts per tube for the preferred arrangement, in order to avoid breakdown or firing of the tubes until a control signal of proper magnitude is applied to their starter-anodes 400, 400'. A step-down transformer 2:1 ratio is satisfactory, giving a peak instantaneous signal voltage across the outside terminals of primary winding 407 of the order of 600 volts. Curves P and P' of Fig. 12 show equal magnitude but 180° displacement of signals impressed upon anodes 402 and 402' respectively.

The initial positive bias upon starter anodes 400, 400' is of the order of 85 volts with respect to ground in the preferred arrangement employing OA4-G tubes. Cathodes 401, 401' are normally maintained at a positive 12 volt potential with respect to ground through respective cathode resistors 425, 425' connected to battery 177 through relay armatures 175 and 175' respectively. The relative potential of starter anodes 400, 400' with respect to anodes 402, 402' is 85 volts minus 12 volts, or 73 volts. When superimposed control-signal M or N, is of the order of 30 volts peak value, one of the control tubes T or T' will in this event break down or fire, since the peak positive value then imparted to starter anodes 400, 400' will be about 115 volts with respect to ground, or about 103 volts with respect to anodes 402, 402'. However, the phase relation

of signal M or N with respect to anode signals P or P' determines which of tubes T or T' will fire.

In a practical embodiment for the receiver unit, a loop antenna displacement of about 1° from null signal position produces an alternating control signal component for M or N of about 10 to 15 volt peak value. A displacement of the loop slightly more than 1° will bring it to a 30 or 40 volt peak value. A displacement of between 2 and 3 degrees will bring the control signal component to its highest value of 50 to 60 volt peak. Above 60 volts, saturation of the control signal amplifier tubes may occur in practice, passing the signal but flattening its wave shape to maintain the signal at the 60 volt peak. Accordingly, a sufficient control signal is effective for operating the motor relays S and S' when the loop is as much as 1° off-null. A novel connection of cathode resistors 425, 425' with respect to relay armatures 175 and 175' insures an even closer tolerance than the 1° accuracy as will be hereinafter described, as well as minimizes possible hunting by the motor.

When the loop antenna is displaced to the position corresponding to angle  $\theta_a$  in Fig. 10, resultant signal M shown in Fig. 12 is impressed upon starter-anodes 400, 400' of control tubes T and T'. Anodes 402, 402' of the control tubes are continuously energized by oppositely phased tone signals represented by curves P and P'. For loop position  $\theta_a$  tube T will fire at alternate half cycles, corresponding to the periods when anode 402 and starter-anode 400 are at their positive half cycle values. Tube T will accordingly break down or fire during half cycle periods a and c shown by firing current curve  $i_{p1}$  thereof. It is to be noted that voltage curve P' applied to anode 402' of tube T', is 180° out-of-phase, and negative when starter-anode voltage curve M is positive so that tube T' does not fire. Conversely, when the loop antenna is at position  $\theta_L$  as shown in Fig. 10, producing resultant control signal shown in dotted at N for starter anodes 400, 400', only tube T' will fire since the positive half cycles corresponding only to curves P' and N will coincide to initiate the firing action. Current curve  $i_{p2}$  shows the firing of tube T' at the b' and d' half cycle period, tube T being non-conductive during that time.

It will now accordingly be evident that selective firing of tubes T and T' takes place dependent upon the relative off-null position of the loop antenna connected in circuit with the receiver unit. One of the tubes, such as tube T, is arranged to fire when the loop antenna is deflected in the  $\theta_a$  direction; and the other tube T', when the loop is deflected in the opposite or  $\theta_L$  direction. Condensers C and C' are respectively shunted across relay solenoids S and S' for smoothing out pulsating current flow resulting from the interrupted firing action of tubes T and T'. A condenser of the order of one and one-half microfarads is satisfactory for flattening out the current of solenoids S and S', producing corresponding currents  $i_1$  and  $i_1'$  as shown in Fig. 12. The average value of the solenoid current is about 40 to 50% of the peak value of the control tube currents. Solenoids S and S' of Fig. 12 correspond respectively to solenoids 173 and 174 of Figs. 7 and 9.

It is to be understood that only one or the other of solenoids S or S' is energized at any given time dependent upon the direction of the displacement of the loop antenna from its null with re-

spect to its associated transmitter. Accordingly, when either tube is fired, an anode current will flow through the respective relay solenoids S or S' of sufficient magnitude, and energize it to attract its respective armatures 175 or 175'. Solenoids S and S' may each have a 2000 ohm impedance. An average current of 12 milliamperes flows through either solenoid when using the chosen parameters. The abrupt and large current changes of the gaseous control tubes permits the use of less sensitive relays for S and S' for satisfactory service. The use of the gaseous control tubes T and T' instead of vacuum tubes results in a rugged relay system giving foolproof service in practice for automatic remote motor operation of the loop antennae.

Relay armatures 175 and 175' are connected directly to connections 136, 136' to the loop motor relay armatures 126, 127. Armatures 175, 175' are normally against their respective back contacts 420 and 420' which are in turn connected to the positive terminal of direct current source 177, the negative terminal of which is grounded. Front contacts 421 and 421' of relays S and S' connect to respective armatures 175 and 175' when corresponding solenoid S or S' is energized. When solenoid S is energized due to the firing of tube T, armature 175 is attracted to its front contact 421 and current will flow to the motor in circuit with armatures 126, 127; motor 131, when the loop 120 is connected to the receiver. The small power needed to drive the loop antenna permits the use of an efficient permanent magnet type motor of relatively low current drain for motors 131, 131'. The usual 12 volt battery of an aircraft is sufficient to properly drive the reversible motors.

When relay armature 175 is attracted by solenoid S upon firing of tube T, the loop motor is arranged to rotate in a direction to turn the loop antenna in the direction to decrease angle  $\theta$  and bring it to the null signal position. In the example described above, relay S is energized when loop 120 forms an angle  $\theta_a$ , with respect to its null position to the field transmitter as shown in Fig. 10. Motor 131 will then be energized to turn the loop counter-clockwise to the null position. As the loop approaches the null signal position, the magnitude of control signal M correspondingly decreases. When the loop is practically at the null position, within 1°, the magnitude of control signal M will fall below the value necessary to cause tube T to fire, and relay S and motor 131 become deenergized. The loop is thus brought to null and stopped in that position to within 1° of the direction to the station T1.

Conversely, when the orientation of the loop antenna forms an angle to the left, or  $\theta_L$ , with respect to the direction of the radio waves 380 shown in Fig. 10, control signal N is produced which causes the firing of tube T' and not T. In this case solenoid S' is energized, attracting its armature 175' to front contact 421'. Armature 175 remains in the neutral back contact position and the motor is energized by the direct current source in a reverse direction to that previously described. Thus, the loop antenna will be rotated in the clockwise direction with the motor oppositely energized, decreasing the magnitude of angle  $\theta_L$  and bringing the loop to practically the null signal position, such as within 1° of arc, whereupon tube T' ceases firing, and solenoid S' and the motor are deenergized.

The rate of loop rotation to the null signal position for the bearing may be designed to be 180°

per second or greater and depends upon the motor speed and gearing ratio. I have found a rotation rate of the order of 125° to 150° per second most satisfactory for commercial operation of the present approach system. It is however to be understood that a substantially greater or smaller rate of automatic loop rotation for the approach bearing determinations may be used. The loop is rotated to the bearing position through the shorter path.

#### *Anti-hunting loop antenna control*

The automatic loop antenna control system is instantly effective at the full normal speed, torque and energization for motivating the loop antenna to the bearing position should it pass beyond the null bearing position, within 1° in the present case. My Patent No. 2,308,521 hereinabove referred to describes several arrangements for accomplishing such desired performance so useful in carrying out the blind approach system of the present invention. The preferred automatic receiver unit for controlling the loop antenna systems 120 and 120' should be designed to substantially prevent hunting, overshooting or overdriving of the loop motivation means, stabilizing the action of the automatic direction indicator with bearings which do not wobble or have extraneous movements. The illustrated receiver unit is designed to accomplish such ends.

The electromagnetic clutches shown at 132 and 132' in Fig. 7 are important elements for stabilizing the loop antenna drives. When motor 131 or 131' is energized by battery 177, clutch 132 or 132' respectively also is energized, immediately coupling the motor shaft to the reduction gearing of the associated loop antenna. The particular form of magnetic clutch is immaterial, and any suitable one known in the art may be employed. Fig. 10 of my Patent No. 2,308,521 illustrates in detail one form which such construction may take in practice. When a loop motor is energized for rotation in either direction, it is immediately engaged with the loop antenna by its clutch. As soon as the motor is deenergized, the clutch disconnects the motor shaft from the loop gearing. Thus, overdriving of the loop motor due to inertia of its rotor is not transmitted to the loop antenna. Ordinary frictional resistance in the loop bearings and gearings is sufficient to stop the loop upon deenergization of its motor and disconnection of its clutch.

A further feature of the illustrated receiver is the anti-hunting circuit provided for the electronic loop motor control tube system as shown at 170 in Fig. 11. Cathode resistors 425, 425' are connected to the positive terminal of battery 177 through relay armatures 175 and 175' respectively which are in turn connected to the proper loop motor through leads 136, 136'. When neither solenoid S or S' is energized, armatures 175 and 175' are against their back contacts 420, 420' normally biasing cathodes 401, 401' to the positive 12 volt (or other desired voltage) value. The 12 volt value is chosen since it is the usual aircraft battery supply voltage.

The action of the positive 12 volt potential on cathodes 401, 401' is to reduce the effect of the biasing of starter anodes 400, 400' by a corresponding amount. Thus the described starter anode biasing of the order of 85 volts, is reduced to an effective 73 volts. When either tube T or T' is fired due to a suitable control signal impressed upon starter anodes 400, 400', corresponding armature 175 or 175' is attracted to the

front contact position 421 or 421' respectively to energize the connected motor in the proper direction. The direction of rotation of the motor, as already explained, is arranged to bring the connected loop antenna to the null signal position by the shorter angular route.

When tube T is energized, relay armature 175 is attracted to front contact 421 and away from back contact 420. At this instant, the positive 12 volt bias on cathode 401' of tube T' is removed. The removal of the 12 volt positive bias from cathode 401' increases the sensitivity of starter anode 400' with respect to anode 402' by an equal amount. The effect of bias removal from cathode 401' is to enhance the sensitivity of control tube T'. The bias increase by such action should be below that directly causing firing of the tube. Unenergized tube T' is made more sensitive to a control signal of phase opposite to that firing tube T, and be more readily responsive to control the motor to the opposite direction of rotation should the loop antenna be moved beyond the null position by the firing of tube T.

The unfired tube is thus rendered more sensitive to a control signal from the opposite direction to that causing the firing. Any tendency of the connected loop antenna to overshoot the null signal position is more readily counteracted by a lower than normal control signal value, due to the increased sensitivity of the unfired side. Conversely, when tube T' is energized, attracting relay armature 175' to rotate the motor in the opposite direction, cathode 401 of tube T is connected to ground, increasing its firing sensitivity. A control of the motor drive is thus provided to prevent hunting or overshooting, within rather close limits, well within the 1° in the practical embodiment.

#### *Modified receiver arrangements*

Further forms which the receiver system of my present invention may assume in practice are illustrated in Figs. 13, 14 and 15. The previously described receiver systems have two separate rotatable loop antenna systems. The form of the invention shown in Fig. 13 employs two concentrically mounted loop antennae and a single automatic receiver unit for effecting the radio guidance in accordance with the invention. The form of Fig. 14 utilizes a single loop antenna system with two separately switched indicators. The system of Fig. 15 comprises a single loop right-left indicator with flasher indications.

Referring to the concentric loop system, Fig. 13, rotatable windings 450 and 451 comprise the loop antennae of the system. Loop winding 450 is mounted upon rotatable sleeve 452. Loop winding 451 is a little smaller than winding 450, fitting within winding 450. Loop 451 is mounted upon shaft 453 concentric within sleeve 452 and extending below it. Both loop antennae 450 and 451 are independently rotatable with respect to each other. The loop antennae are preferably mounted outside the structure of the aircraft for most efficient signal pick-up, and may advantageously be enclosed in a common streamline housing indicated in dotted lines to minimize the aerodynamic resistance thereof during flight. Both loops are designed with substantially the same signal pick-up sensitivity.

The terminal leads of loop coil 450 are connected to slip rings 454 insulatingly mounted on sleeve 452 and electrically connected by leads 455 to back contacts 456, 456' of relay armatures 461, 462 in turn connected to the loop input of

automatic receiver unit 460 by leads 457. Four-pole relay, 461 through 464, is arranged for actuation by relay solenoid 465 to successively switch the loop antennae into electrical coaction with automatic receiver unit 460 in the manner described in connection with the previous receiver modifications, for example Figs. 7 and 9.

Loop antenna 450 is operated to its null signal position when in circuit connection with receiver 460 by its associated reversible motor 470 mechanically coupled to loop sleeve 452 through electromagnetic clutch 471 and gearing 472, 473. Electromagnetic clutch 471 is electrically connected in parallel with motor 470, and both in turn are connected by leads 474 across back contacts 475, 476 of relay armatures 463, 464. The motor relay armatures 463, 464 are connected to corresponding loop motor control terminals of the automatic receiver 460 by leads 476 in the manner of the previously described embodiments.

The terminal leads of the inner loop winding 451 pass through shaft 453 and are individually connected to slip rings 480 insulatingly mounted on central shaft 453 as indicated in the drawings. Slip rings 480 are connected to receiver unit 460 through leads 481, front contacts 482, 482 of relay armatures 461, 462 and leads 457. Loop winding 451 is in this manner connected to the receiver unit by the relay arrangement after loop winding 450 is disconnected therefrom. A separate control motor 485 is used to automatically orient loop 451 to the null signal position during its connection to receiver 460 through electromagnetic clutch 486 electrically connected in parallel therewith and gearing 487, 488 coupled to loop shaft 453. Motor 485 and clutch 486 are connected by leads 489 to front contacts 490, 490 of relay armatures 463, 464, in turn connected to automatic receiver 460 by leads 476. One of the two loop motors 470, 485 may be dispensed with by providing a clutching switch-over arrangement between a single motor drive and the two loop systems, the mechanical switch-over arrangement being electrically controlled through the relay operation.

Automatic receiver unit 460 has a single non-directional antenna 491. The operation of relay armatures 461 through 464 is controlled by relay solenoid 465 connected to receiver 460 by leads 492 in a series with pass-filter 493. The operation of relay 465 by the receiver is similar to the operation of relay 130 already described in connection with Figs. 7 and 9. With relay armatures 461 through 464 in the back contact position shown in Fig. 13, loop antenna system 450 and its associated control motor 470 are connected to the receiver unit 460, and its orientation is controlled by the receiver during the reception of signals from its corresponding transmitter, say T<sub>1</sub>. When station T<sub>1</sub> ceases transmission and station T<sub>2</sub> begins to radiate, relay 465 is energized in a manner such as previously outlined, moving relay armatures 461 through 464 to the front contact position against contacts 482, 482 and 490, 490 to disconnect loop antenna system 450 from receiver 460 and connect loop antenna system 451 and its associated motor drive 485 thereto. During the interval of reception of signals from the second station, T<sub>2</sub> in this case, loop antenna 451 will be moved to its null signal position with respect to the direction of the oncoming waves from that station.

A two-needle indicator 495, corresponding to those previously disclosed, is used to apprise the pilot of the exact angular position of both loop

antenna systems, effecting the blind approach radio guidance of my invention. Loop position transmitter 494, in this case shown as an electrical telemetering arrangement employing direct current Selsyn type mechanism, is connected by three-wire cable 496 to one of the needles, say needle 1, corresponding to the "in" station T<sub>1</sub>. The other needle 2, corresponding to outer station T<sub>2</sub>, is by three-wire cable 498 connected to loop position transmitter 497 coupled to shaft 453 of loop antenna 451. It is to be understood that mechanical telemetering arrangements similar to those disclosed in connection with Figs. 2 and 3 may be employed instead of the disclosed electrical telemetering arrangement.

In Fig. 14 I illustrate a form of the present invention wherein a single loop antenna 500 is used in conjunction with a single automatic directional receiver unit 501 and non-directional antenna 502, further reducing the physical components of the receiving system. The terminal leads of loop winding 500 are connected to slip rings 503 which in turn are connected to the automatic receiver unit 501 by leads 504. Control motor 505 for loop antenna 500 is connected to loop shaft 500a through electromagnetic clutch 506 and gearing 507, 508. Clutch 506 and motor 505 are electrically connected in parallel to the proper motor control section of automatic receiver 501 by leads 509. An electrical telemetering arrangement employing loop position transmitter 510 coupled to shaft 500a thereof is provided in conjunction with remote dual indicator arrangement 511, 512. The preferred indicator is the direct current Selsyn type, although other types may equally well be used. A three-wire cable 513 connects loop position transmitter 510 to either of the remote indicators through a relay. Meter 512 has three-wire cable 514 connectable to cable 513 through the relay arrangement. Three-wire cable 515 of meter 511 is also connectable to transmitter cable 513 through the relay.

The relay arrangement comprises relay armatures 516, 517, 518 actuated by relay solenoid 520. In the indicated position, meter 512 is connected to cable 513 and transmitter 510 through the back contacts of the relay. When relay solenoid 520 is energized, meter 512 is disconnected and meter 511 is connected to the loop position indicator 510 through the front contacts of the relay. Relay solenoid 520 is connected to the automatic receiver unit 501 through pass-filter 519 and is energized by the transmitted modulated tone, say 75 cycles, in the manner previously described in connection with solenoid 130 in Figs. 7 and 9.

Relay solenoid 520 is selectively energized and deenergized in accordance with the reception of the tone signal from either of the two transmitter stations T<sub>1</sub> or T<sub>2</sub> at the landing field. Meter 511 contains needle 1, corresponding to one of the field stations, say transmitter T<sub>1</sub>; and needle 2 of meter 512, to the other station, T<sub>2</sub>. Although I have illustrated two separate meters 511 and 512, a common housing enclosing the two movements such as illustrated in Fig. 8 may be used, with two separate Selsyn receiver movements and coaxial needle arrangements.

The principle of the form of the invention illustrated in Fig. 14 is the selective connection of each of two position indicators to a position transmitter of a single loop antenna system controlled by a single automatic directional receiver, in accordance with the reception of a relay signal from the successively operated transmitters T<sub>1</sub> and T<sub>2</sub> at the landing field. The indicators correspond-

ing to 511 and 512 are designed with sufficient damping that upon disconnection of either one from the circuit of loop position transmitter 510, their corresponding needles, 1 and 2, remain in their last position until the meter is reconnected to the position transmitter.

In practice, loop antenna 500 will be rapidly moved, say at the rate of 150° per second, by motor 505 to the direction of the oncoming waves from station T<sub>1</sub> or T<sub>2</sub> as the case may be. Only one of the two stations, T<sub>1</sub> or T<sub>2</sub>, is transmitting at one time, and the automatic receiver 501 is tuned to their common radio carrier frequency. Motor 505 will be energized whenever loop antenna 500 is not at the null signal position with respect to the field station transmitting. The movement of loop antenna 500 to the direction to one or the other of the stations is sufficiently rapid so that it assumes the stable null signal position well within the period of transmission of the stations, say one-third or one-half of a second or otherwise as disclosed in connection with Fig. 6.

When meter 511, corresponding to "in" station T<sub>1</sub> is connected to loop position transmitter 510, its needle 1 is immediately moved to the position on the scale corresponding to the orientation of the mechanism within the loop position transmitter 510 caused by the transmission of station T<sub>1</sub>. In the drawing, meter 512, having needle 2, is shown connected to loop position transmitter 510. Needle 2 points out the direction to station say T<sub>2</sub>, upon its indicated connection since loop antenna 500 is moved to a stable on-course position with respect to station T<sub>2</sub> before station T<sub>2</sub> ceases its transmission interval and the connection of meter 512 to transmitter 510 is effected prior to that time. Needle 2 then remains stationary on the scale of meter 512.

When station T<sub>2</sub> ceases transmitting and "in" station T<sub>1</sub> starts transmitting, directional receiver 501 tuned to their common frequency, distinguishes between these two stations by the predetermined relay tone modulation of one of them, say of T<sub>1</sub>. The predetermined tone, say 75 cycles, is selectively passed by filter 519 to energize relay 520 and operate relay armatures 516, 517, 518 to their front contact positions, disconnecting meter 512 from position transmitter 510 and connecting meter 511 thereto instead. The action of the electrical telemetering arrangement herein described, is similar to the action of the direct current Selsyn transmitter described in detail in my Patent No. 2,308,521 particularly in connection with Fig. 10 thereof. Needle 1 assumes the angular position corresponding to the position of the rotatable mechanism within position transmitter 510, in turn corresponding accurately to the angular position of the loop antenna 500.

The action of relay armatures 516, 517, 518 is slowed or otherwise damped in any suitable manner so that connection of transmitter 510 to either indicator 511 or 512 is materially delayed. A suitable delay is about half the station transmission interval. In other words, the movement of relay armatures 516, 517, 518 from one set of contacts to the other, is made to consume about half the time of the whole switching interval. Thus, the relay armatures remain on one or the other set of the relay contacts for a time interval corresponding to about half or less of the period of transmission of stations T<sub>1</sub> and T<sub>2</sub>. In the case, where stations T<sub>1</sub> and T<sub>2</sub> transmit for one-third of a second, relay armatures are made to take one-sixth of a second or less to move from one set of relay contacts to the other. Systems

similar to that of Fig. 14 and incorporating damping means for the relay means are described and claimed in my copending application Serial No. 495,977, filed July 24, 1943, for "Direction finding system," which is a continuation of the present application and assigned to the same assignee.

It is to be understood that the damped action on the relay armatures may be designed to consume more or less than such amount. The advantage due to the delay in indicator connection is to reduce unnecessary movements of indicator needles 1 and 2. Thus, the positioning of loop antenna 500 between one and the other of the field stations is effected without unduly disturbing the positions of needles 1 and 2 from their "at rest" indications. The delayed action on the relay armatures connects the proper indicator in circuit when the loop antenna has practically been moved to its new stable bearing position with respect to the corresponding transmitter station. As soon as either indicator is connected to the loop position transmitter 510, it quickly assumes the angular position of loop 500.

When the station tuned-in ceases transmitting, the other station causes relay solenoid 520 to change the position of relay armatures 516, 517, and 518. Connection of the indicator 511 or 512 to unit 510 is thereupon immediately broken and its corresponding reading is "frozen." Due to the damping action, armatures 516, 517, and 518 are slowly moved into the opposite position. Automatic receiver 501 however, in the meantime quickly energizes loop motor 505 in the manner described in connection with Figs. 7 and 9, to reorient loop antenna 500 so that it assumes a null signal position with respect to the field station then transmitting. The action of the receiver 501 and motor 505 on loop 500 is such that the loop antenna is quickly moved to the directional position bearing on the field station transmitting, preferably within about half the time of the transmission interval. When the loop reorientation is about completed, the corresponding indicator is connected to position transmitter 510 through the delayed armature 516, 517, 518 action, and the needle thereof quickly changes its previously "frozen" position to the angular position which the loop antenna then has corresponding to the new bearing between the aircraft in its approach to the field stations. The described action is repeated for the next transmission interval.

In Fig. 15 a further form of receiver system is illustrated for use in conjunction with the synchronized field stations of the invention. A right-left indicating direction finder is employed having a single receiver unit 525, a loop antenna 526 and a non-directional antenna 527. The right-left indicator may be any preferred type having an indicator 528 with a pointer 530 arranged to deflect to the left L or right R when the direction of the station being received is correspondingly to the left or right of the plane of loop antenna 526.

Two flasher lamps 531 and 532 are arranged adjacent indicator 528. Lamps 531 and 532 are arranged to successively flash or light-up in correspondence with the reception of signals from the the field transmitter stations such as T<sub>1</sub> and T<sub>2</sub> described above. The illustrated arrangement for effecting such operation of lamps 531 and 532 utilizes filter units 1 and 2 connected to the output of audio unit 533 of the right-left indicator arrangement. Filter 1 is tuned to pass one of the audio frequency signals corresponding to one of the field transmitter stations, and filter unit 2 to a different audio frequency signal from the

second field station. One of the filter units may be dispensed with when only one of the field stations is arranged with control signal modulation.

The output of filter unit 1 is connected to solenoid 535 arranged to actuate armature 536 to complete the energization circuit for indicator lamp 531 through front contact 537. Single pole switch 538 is closed to permit lamp 531 energization by battery or potential source 539. When the predetermined audio frequency signal is received, corresponding to the transmission of one of the two field stations, it passes through selective filter unit 1 and energizes solenoid 535 to illuminate indicator lamp 531. A gaseous lamp type for 531 and 532 is preferred to minimize lag in lighting-up or extinguishing thereof and insure a close correspondence between the illumination of lamps 531 and 532 and the transmission intervals of their associated stations.

When the station causing actuation of armature 536 and illumination of lamp 531 such as T<sub>1</sub> of Fig. 1, shuts down, solenoid 535 is deenergized and the circuit to lamp 531 is opened as shown. The second station, say T<sub>2</sub>, is then received and its corresponding predetermined audio frequency control signal passes through filter unit 2 rather than unit 1 energizing relay solenoid 540 to attract armature 541 to front contact 542 as illustrated in the figure. The energization circuit for lamp 532 is thereupon completed through single pole switch 543. Indicator lamp 532 is illuminated for the duration of transmission for its associated station, T<sub>2</sub> in this case.

In employing the modification of Fig. 15 for approach purposes in accordance with the invention, the receiver 525 is tuned to the common frequency for the two field stations (T<sub>1</sub> and T<sub>2</sub>). Loop antenna 526 is adjusted on a predetermined angular position, such as on-course, homing or in direction with the axis of the aircraft. Indicator needle 530 points to the left or right of its zero position in the usual manner. In the present arrangement such indications on T<sub>1</sub> and T<sub>2</sub> signify a left or right position of the field station (T<sub>1</sub> or T<sub>2</sub>) transmitting during the deflection interval, with respect to the direction of movement of the aircraft. However, simultaneously with the reception of the transmitter stations, one or the other of indicator lamps 531 and 532 is correspondingly illuminated. Lamp 531 may be made to correspond to inner station T<sub>1</sub>, shown in Fig. 1; and lamp 532, to outer station T<sub>2</sub>. The lamps correspondingly are lit-up during the transmission intervals of their respective stations.

The pilot can readily maneuver his aircraft to the head position B (Fig. 1) and fly on-course to runway R by the system of Fig. 15 in the following manner: Both switches 538 and 543 are connected as shown. When station T<sub>1</sub> is transmitting, lamp 531 illuminates. During that interval the pilot is apprised whether he is heading to the right or left of the inner station T<sub>1</sub> by a corresponding deflection of needle 530. Lamp 532 remains extinguished during this interval. When transmitter T<sub>2</sub> is radiating, lamp 531 is extinguished and lamp 532 lights up in the manner previously described. The pilot knows then that a right or left deflection of needle 530 while lamp 532 is illuminated corresponds to a right or left course with respect to the outer station T<sub>2</sub>.

In arriving to the airport from a distance, one of the switches such as 543 is opened so that only one lamp is on, and pilot directs his flight to one of the field stations, say inner station T<sub>1</sub>. When

he is within 5 or 10 miles of the runway, both switches 538 and 543 are placed in the closed position and both indicator lamps 531 and 532 are alternately energized in the manner described.

When the pilot is out of line with the approach path T<sub>1</sub>—T<sub>2</sub>, indicator needle 530 deflects differently for either station. The needle 530 deflections correspond with the successive illuminations of lamps 531 and 532, and the pilot can readily maneuver his craft to head position B. When the pilot is in line with stations T<sub>1</sub> and T<sub>2</sub>, indicator needle 530 will deflect neither to the right or left, but read on center zero during reception of both stations. The pilot thus knows that he is flying in line with transmitters T<sub>1</sub> and T<sub>2</sub>.

#### Marine vessel guidance

Fig. 16 diagrammatically illustrates the application of my present invention for guiding marine vessels, such as ferry boats, into a slip. In this case, the two transmitters corresponding to the airport transmitters previously described, (T<sub>1</sub> and T<sub>2</sub>), are placed on land behind slip S and in line with the preferred approach path thereto, as shown in the diagram.

The vessel at position A is to be guided into slip S against a river current and possibly during fog conditions and inclement weather with low visibility. By employing a receiver system as described in connection with the previous figures, the pilot tunes to the frequency of stations T<sub>1</sub> and T<sub>2</sub> and obtains two indications of their direction corresponding to arrows 1 and 2 at position A of the diagram. The sense of indications corresponding to arrows 1 and 2 immediately apprises the pilot of the relative lateral position of his vessel with respect to the approach path to slip S.

At position A, the pilot realizes he must move in a direction against the river current and towards the shore in order to bring deflections 1 and 2 into the coincidence indicating on-course movement of the vessel to slip S. The river current corresponds to wind currents on an aircraft, causing drift of the vessel. The boat is crabbed or headed up-stream at a proper angle to compensate for the drift. At position B, the boat is closer to the approach path T<sub>1</sub>—T<sub>2</sub>, and has assumed an angle which will properly direct it toward path T<sub>1</sub>—T<sub>2</sub>, compensating for the drift caused by the river current.

In the present example the boat is headed up-stream at the chosen angle until it reaches position C on the T<sub>1</sub>—T<sub>2</sub> path to slip S. Coincident indications of needles 1 and 2 (not shown) on a dual indicator receiver system used by the pilot, tuned to the synchronized transmitters T<sub>1</sub> and T<sub>2</sub>, definitely indicate travel on path T<sub>1</sub>—T<sub>2</sub>. As long as indicator needles 1 and 2 remain coincident, i. e. have the same angle of incidence regardless of their angular reading, the boat is on the required approach path T<sub>1</sub>—T<sub>2</sub>. The angle of the boat with respect to path T<sub>1</sub>—T<sub>2</sub> is adjusted to keep it on the path against river or wind currents. The relatively slow travel of boats permits accurate and ready maneuvering in this fashion. Drifting off-course is readily apparent and ascertained by non-coincident readings of the receiver indicators. At position D, the boat is about to enter slip S.

By employing the 360° automatic directional receiver modifications, corresponding to Figs. 2, 3, 7, 9, 13 and 14, the pilot obtains accurate angular indications of his angle of crabbing against the river current to keep on approach path T<sub>1</sub>—T<sub>2</sub>. With the receiver shown in Fig. 15, the loop an-

tenna 528 thereof is adjusted to keep the boat headed to properly compensate for drift and obtain the zero or steady readings of needle 530. The angular position of the loop antenna for such condition indicates the drift angle.

Vessels, whether aircraft or marine, may be automatically controlled into and on their approach path by means responsive to the dual deflections corresponding to bearings on the synchronized stations T<sub>1</sub> and T<sub>2</sub>. Drift of the vessel off the approach path may be automatically compensated for or the vessel automatically brought directly to the approach path therewith.

Although I have described different forms and arrangements which my invention may assume in practice, it is to be understood that variations and modifications therein may be made without departing from the broader spirit and scope of the invention, and accordingly I do not intend to be limited except as set forth in the following claims:

What I claim is:

1. The method of laterally guiding a mobile craft in a predetermined path which comprises successively transmitting non-directional radio signals at predetermined intervals from a plurality of points linearly spaced in line with the path and deriving a uni-directional lateral bearing indication over 360° of arc on each of the radio signals with respect to the position of the craft during each of the transmission intervals thereof.

2. The method of laterally guiding a mobile craft with respect to a predetermined path which comprises successively transmitting non-directional radio signals of substantially the same frequency at predetermined intervals from two points spaced in line with the path by a predetermined amount, directionally receiving the radio signals aboard the craft and deriving an accurate uni-directional lateral bearing indication over 360° of arc on each of the radio signals during each of the transmission intervals thereof.

3. The method of laterally guiding a mobile craft with respect to a predetermined path which comprises successively transmitting non-directional radio signals of substantially the same frequency at predetermined intervals from two points spaced in line with the path by a predetermined amount, directionally receiving the radio signals aboard the craft and deriving an accurate uni-directional lateral bearing indication over 360° of arc on each of the radio signals during each of the transmission intervals and maintaining the derived bearings during the intervals of non-transmission of the corresponding radio signal.

4. The method of laterally guiding an aircraft with respect to a predetermined path of approach to a runway which comprises successively transmitting non-directional radio signals at predetermined intervals from two points spaced in line with the path and deriving individual lateral uni-directional bearing indication over 360° of arc on each of the radio signals with respect to the position of the aircraft during each of their respective transmission intervals and individually maintaining the derived indications during the non-transmission intervals thereof.

5. The method of laterally guiding an aircraft with respect to a predetermined path of approach to a runway which comprises successively transmitting non-directional radio signals of substantially the same frequency at predetermined substantially equal intervals from two points spaced

in line with the path, directionally receiving said radio signals aboard the aircraft, deriving an accurate lateral uni-directional bearing indication over 360° of arc on each of the radio signals during each of the transmission intervals and individually maintaining the derived indications during the intervals of non-transmission thereof.

6. The method of laterally guiding a vessel in a predetermined path of approach to a slip which comprises successively transmitting non-directional radio signals at predetermined intervals from two points on shore spaced in the linear direction of the path, directionally receiving said radio signals aboard the vessel and deriving independent lateral uni-directional bearing indications over 360° of arc on each of the radio signals with respect to the position of the vessel during each of their respective transmission intervals.

7. The method of laterally guiding a mobile craft with respect to a predetermined path which comprises successively transmitting radio signals of the same frequency at predetermined substantially equal intervals from two points spaced in line with the path by a predetermined amount, modulating one of the radio signals with a distinguishing audio frequency note, directionally receiving said radio signals aboard the craft and deriving a uni-directional lateral bearing over 360° of arc on each of the radio signals with respect to the position of the craft during each of their respective transmission intervals, and maintaining the derived bearings during the respective intervals of non-transmission.

8. The method of laterally guiding an aircraft with respect to a predetermined path of approach to a runway which comprises successively transmitting radio signals at predetermined intervals of the order of one-third of a second from two points spaced along the path by a predetermined amount, directionally receiving said radio signals aboard the aircraft, deriving a uni-directional lateral bearing over 360° of arc on each of the radio signals with respect to the position of the aircraft during each of their respective transmission intervals, maintaining the derived bearings during the respective intervals of non-transmission, and providing distinctive indications from the radio signals corresponding to movement of the aircraft over the points.

9. A radio directional receiving system comprising a plurality of rotatable directional antennae; a receiver unit having means for rotating a connected one of said directional antennae to a bearing position with respect to correspondingly received radio signals; an indicator connected with each of said directional antennae for individually pointing out their angular orientation; and means responsive to the received radio signals for successively connecting each of said directional antennae to said receiver unit for individual orientation to obtain corresponding directional bearings of the vehicle with respect to the transmitters of separately transmitted radio signals.

10. A radio directional receiving system for a vehicle comprising two rotatable directional antennae mounted on the vehicle; a receiver unit having means for automatically rotating a connected one of said directional antennae to a bearing position with respect to correspondingly received radio signals; an indicator connected with each of said directional antennae arranged to individually point out their respective angu-

lar orientations at a common position, said indicators having pointers arranged coaxially; and means responsive to radio impulses received by said receiver unit for automatically connecting said directional antennae to said receiver unit for individual orientation to obtain corresponding directional bearings of the vehicle with respect to the transmitters of separately transmitted radio signals.

11. A radio directional receiving system comprising two rotatable directional antennae coaxially arranged with respect to each other; a receiver unit for automatically orienting a connected one of said directional antennae to a stable bearing position with respect to correspondingly received radio signals; an indicator connected with each of said directional antennae for individually pointing out their angular orientation at a common position; and means

responsive to the received radio signals for successively connecting said directional antennae to said receiver unit for individual orientation to obtain corresponding directional bearings on separately transmitted radio signals.

12. A radio directional receiving system comprising a directional antenna; a receiver unit responsive to radio signals received by said directional antenna having an indicator giving directional indications with respect to the received radio signals; two lamps individually arranged for illumination adjacent said indicator; and means for successively illuminating said lamps in correspondence with the reception of two separately transmitted radio signals for associating the directional indications of said indicator with said separate radio signals.

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