Dec. 6, 1949 F. C. WILLIAMS 2,490,394

WIRELESS SIGNALING SYSTEM

Filed July 25, 1947 6 Sheets-Sheet 1

FIG. 1

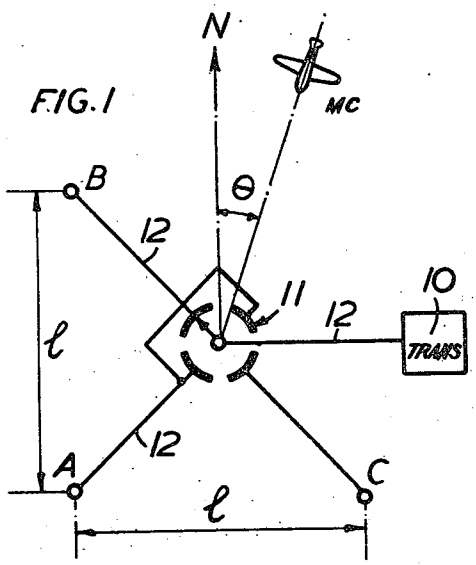


FIG. 12

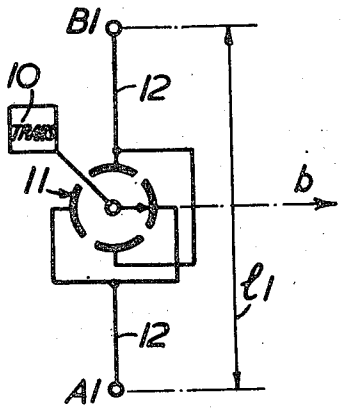


FIG. 2

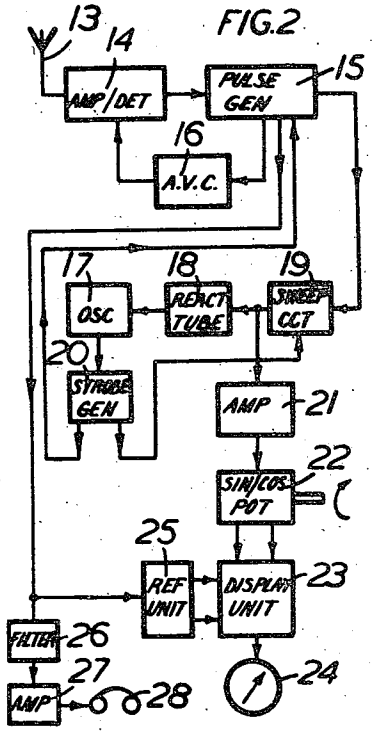
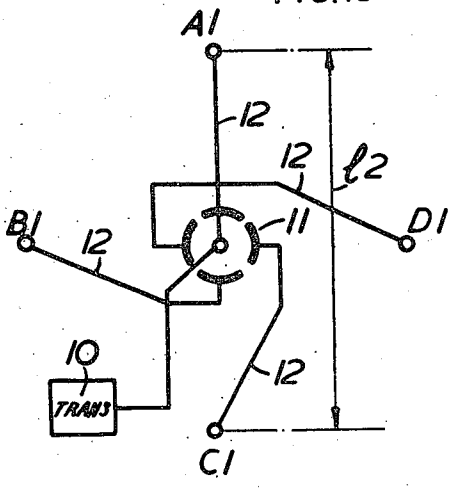


FIG. 13



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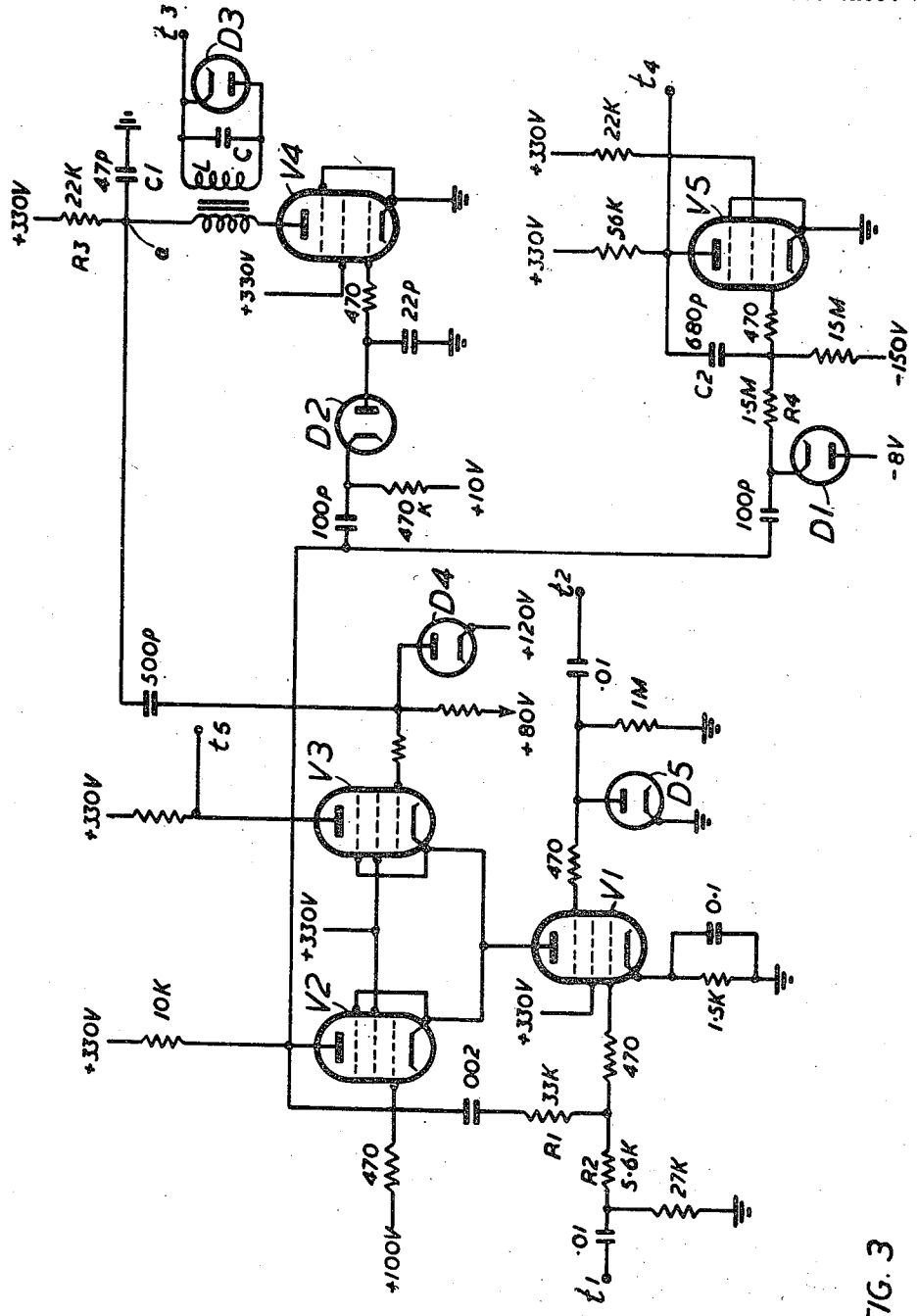


FIG. 3

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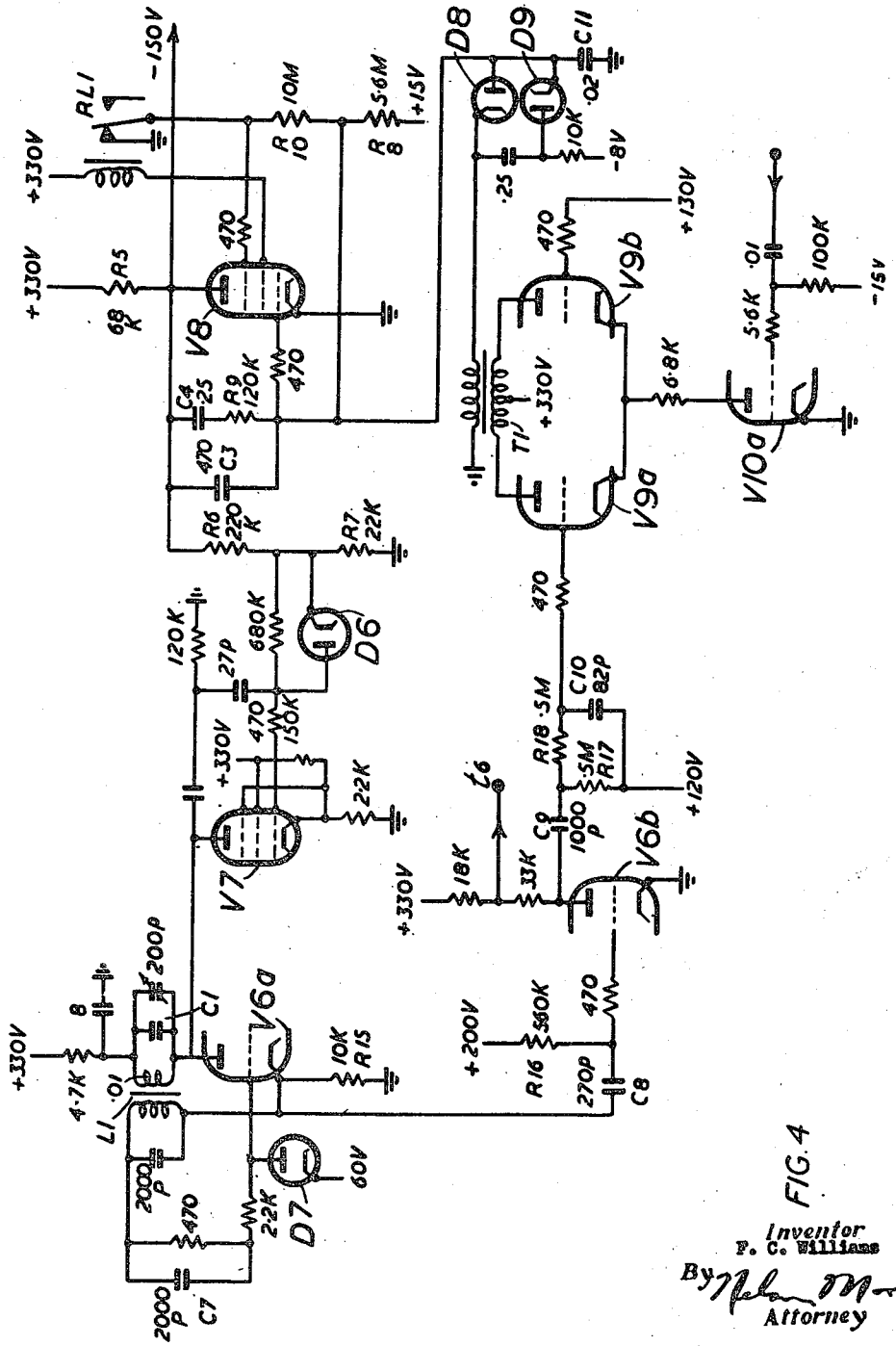


FIG. 4

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WIRELESS SIGNALING SYSTEM

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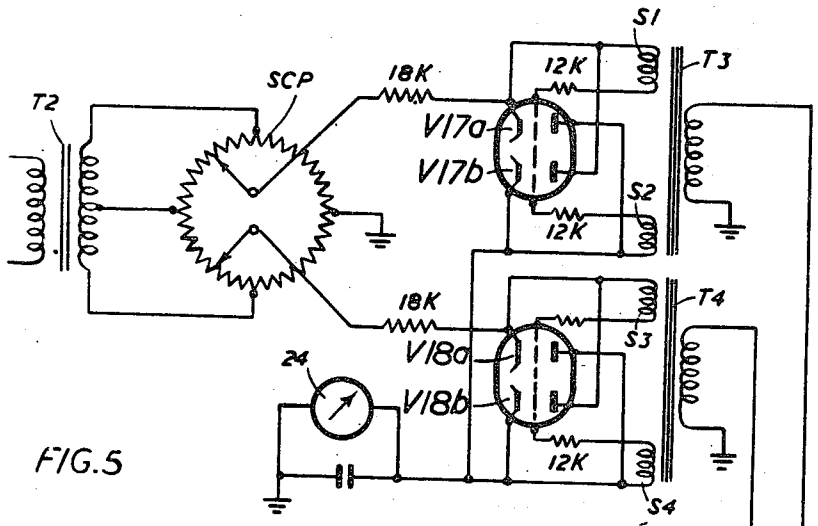
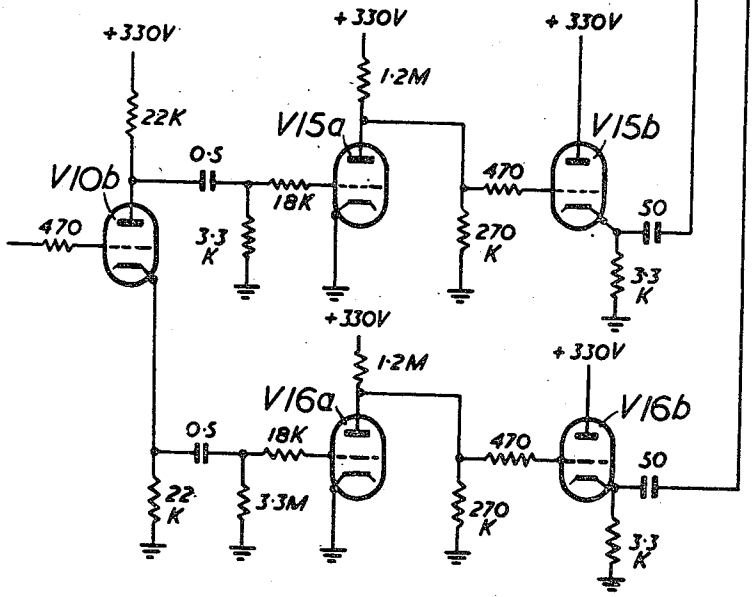


FIG.5



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WIRELESS SIGNALING SYSTEM

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FIG. 6

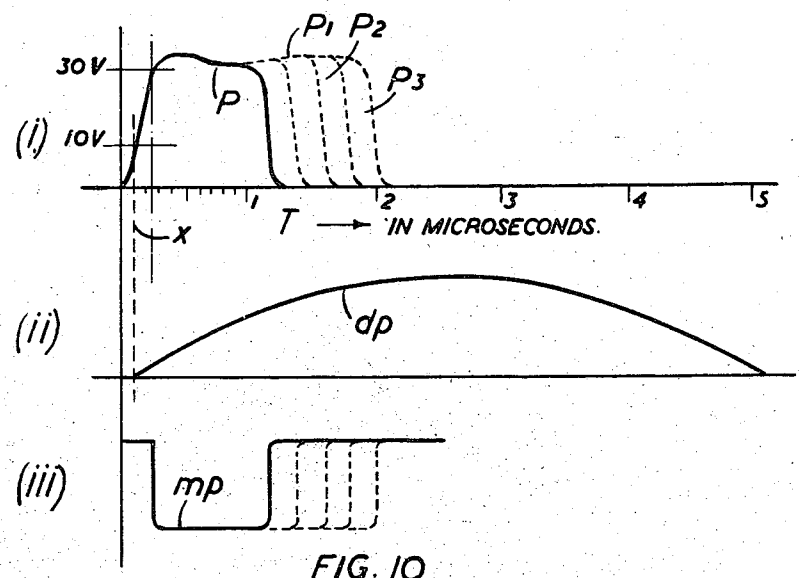


FIG. 10

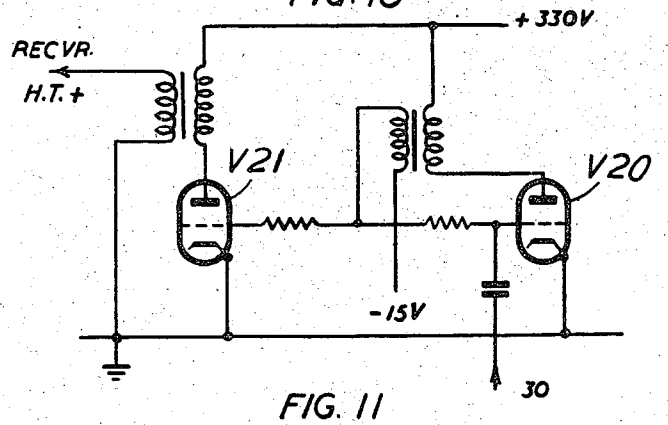
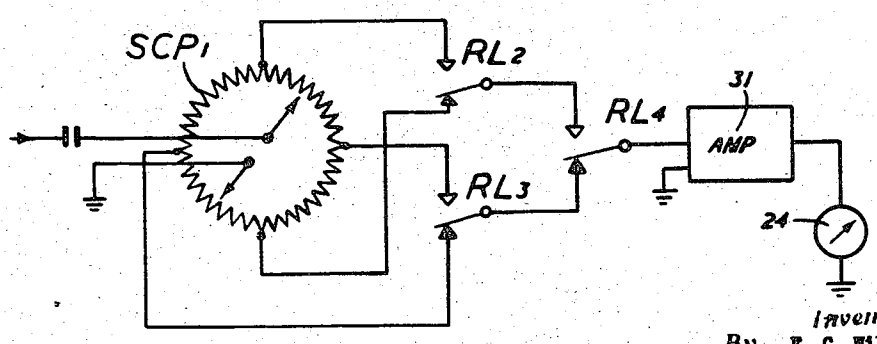


FIG. 11



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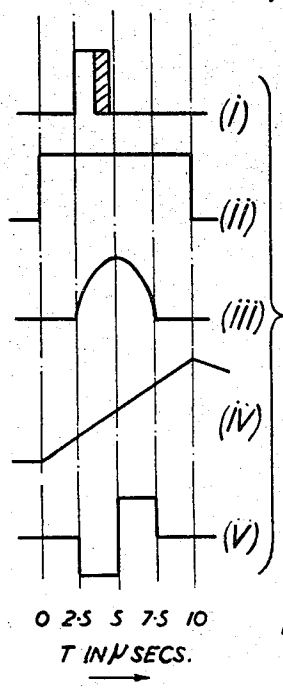


FIG.7

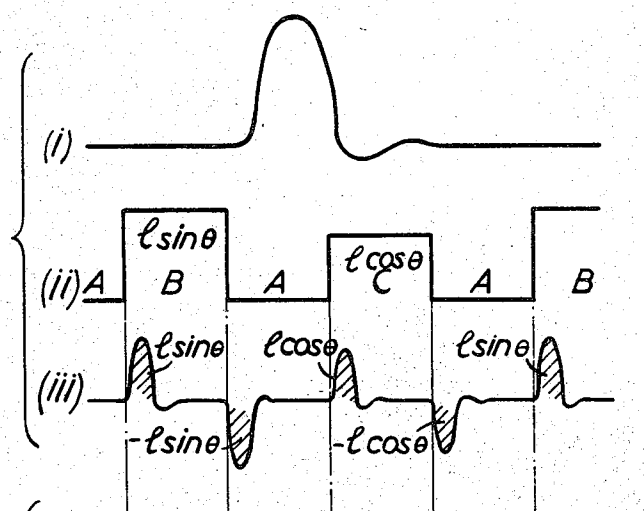


FIG.8

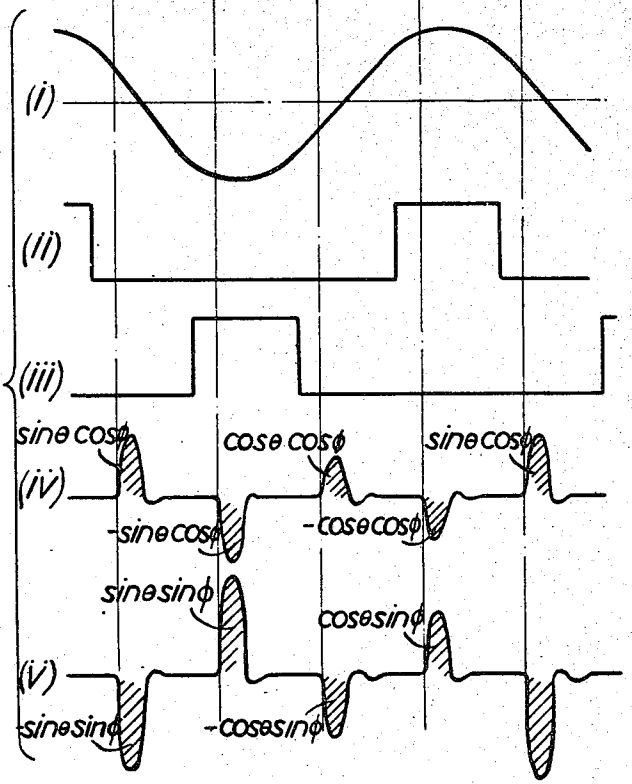


FIG.9

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Patented Dec. 6, 1949 2,490,394

UNITED STATES PATENT OFFICE

2,490,394

WIRELESS SIGNALING SYSTEM

Frederic Calland Williams, Timperley, England

Application July 25, 1947, Serial No. 763,713
In Great Britain June 14, 1945

Section 1, Public Law 690, August 8, 1946
Patent expires June 14, 1965

17 Claims. (Cl. 343—105)

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This invention relates to wireless signalling systems and is more particularly concerned with arrangements using a pulsed signal wave.

One particular aspect of the invention relates to arrangements for aiding the navigation of mobile craft, such as aircraft or shipping, employing pulsed transmission from a number of spaced fixed aerials and in which the different transit times taken by such pulse signals to travel from the various spaced aerials to a distant mobile craft serve to provide information in the latter of its bearing or position with respect to the known location of said fixed aerials. Examples of such systems are to be found in copending United States applications Serial Nos. 527,017 and 527,018.

According to one feature of this aspect of the invention information is provided in a mobile craft as to its bearing direction with respect to a ground beacon transmitter at a known geographical position by the radiation of pulse signals, at a constant pulse repetition frequency, in a series of groups in predetermined regular order from two or more suitably spaced ground transmitting aerials at said known location and by the comparison, at said mobile craft, of the phase relationship (at the pulse repetition frequency) of the pulses of the pulse groups received from one ground aerial with respect to those of pulse groups received from another fixed ground aerial.

The ground beacon transmitter may comprise two aerial pairs disposed in lines which are at right angles to one another. In one preferred arrangement three aerials are employed and are arranged respectively at the corners of a right-angled isosceles triangle. With this particular arrangement the pulse groups are radiated in cyclic order from the apex aerial, one base corner aerial, the apex aerial and then the opposite base corner aerial and so on. In an alternative embodiment four aerials are employed arranged respectively at the corners of a square, the pulse groups in such an arrangement being radiated in cyclic order from one corner, the diagonally opposite corner, a further corner and then its diagonally opposite corner and so on.

According to another feature of this aspect of the invention a wireless signalling system of the kind in which information is provided by the difference in transit time of pulse signals from a number of spaced fixed aerials to the mobile craft and in which such information is provided upon a pointer type electro-mechanical meter device by the application thereto in opposing sense of signal currents related to said different transit

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times, is characterised in that the various signals resulting in said opposed signal currents are arranged to traverse a common signal channel until they have been given the final form suitable for effecting direct operation of said meter device. In this way errors due to unbalance of parallel signal handling channels are avoided.

Another aspect of the invention concerns a phase discriminator arrangement particularly, although by no means exclusively adapted for use in a pulsed wireless signalling system for navigational aiding purposes as previously referred to.

According to this aspect of the invention a phase discriminator arrangement for use in a wireless signalling system employing pulsed signals conveying intelligence by phase variation of their pulse recurrence frequency includes an oscillator arranged for operation at the mean pulse recurrence frequency but capable of variation over a chosen frequency range centred about said mean frequency by the application of an appropriate controlling voltage thereto and phase-comparing means for determining the phase relationship between applied input pulse signals and an oscillation derived from said oscillator and providing a controlling voltage to said oscillator which tends to maintain the aforesaid phase relationship at a chosen value, said controlling voltage serving also to provide, by its variations, an output component related to the conveyed intelligence.

Yet a further aspect of the invention relates to a wireless signalling system wherein information or intelligence is derived at a receiving station from the arrival timing of pulses of a received pulsed signal wave. According to this aspect of the invention interference effects due to spurious and other signals, such as those arising from ground reflections are reduced or eliminated by the provision of means for initiating derived pulses of predetermined amplitude and time duration by the reception of a chosen leading-edge portion only of the received signal pulses and by the utilisation of such derived pulses instead of the actual received signal pulses for the derivation of the required information or intelligence.

In order that the various features of the invention may be more readily understood a number of embodiments thereof will now be particularly described with reference to the accompanying drawings in which

Figure 1 is a schematic lay-out diagram of one form of ground transmitting or beacon station,

Figure 2 is a block schematic diagram of one form of mobile craft apparatus.

Figures 3, 4 and 5 are circuit diagrams of certain portions of the apparatus shown in Figure 2.

Figures 6, 7, 8 and 9 are graphical waveform diagrams illustrating the operation of the mobile craft apparatus of Figures 2 to 5.

Figure 10 is a circuit diagram of a modified H. T. supply arrangement,

Figure 11 is a fragmentary circuit diagram of a modification,

Figure 12 is a schematic lay-out diagram, similar to Figure 1 of a modified ground transmitter arrangement, while

Figure 13 is a similar schematic lay-out diagram of a further modified ground transmitter arrangement.

Referring first to Figure 1, the ground transmitting or beacon station comprises three aerials A, B and C each having an omnidirectional radiation characteristic and located respectively at the corners of an isosceles triangle whose equal sides are of length l. These aerials are supplied through equal electrical length feeder lines **12** by a single transmitter **10**. The aerials are connected to the transmitter in turn by a rotary switch **11** in the cyclic order A, B, A, C, A, B, A, C and so on.

The transmitter **10** generates short pulses of RF power of the order of, say 1.5 microseconds duration at a constant repetition frequency of, say, 5 kcs./s. The switch **11** is arranged to operate regularly at, say 3000 R. P. M. with the result that, assuming perfect switching, groups of 25 pulses are radiated from each aerial in turn in the cyclic order stated above. Each group cycle A, B, A, C will be recurrent 50 times per second while each group will last for 0.005 second. The radiation frequency used is, say, 200 mc./s. or higher.

The transmitted pulses are width-modulated on their back edges by a sine wave whose frequency is accurately related to the rotation of the switch **11**, i. e., in the example quoted above, a 50 c./s. sine wave, hereinafter referred to as the "reference wave." In addition, the transmitted pulses may be subjected to further modulation, again on their back edges only, by speech or morse for the purpose of providing a communication channel.

Considering now the signals received from such a beacon transmitter arrangement by a mobile craft, e. g., an aircraft MC which is located at a bearing angle θ with reference to the direction through aerial A and B. The latter direction is conveniently, although not necessarily, one pointing due north. The aircraft will be assumed to be so remote from the beacon that the direct paths A—MC, B—MC and C—MC can be regarded without significant error as being parallel.

At the mobile craft there will be received the groups of pulses radiated in turn from the aerials A, B and C at the chosen 5 kc./s. recurrence frequency. As the pulses are switched from aerial A to aerial B there will be an apparent change in the phase of the new (B aerial) series of pulses relative to the old (A aerial) series because the first pulse of the series from aerial B will reach the mobile craft sooner, by a time proportional to $l \cos \theta$, than if it had been radiated from aerial A. Similarly, upon reversion to aerial A, 0.005 second later, there will be a further phase-change proportional to $-l \cos \theta$. Upon the following switching operation to aerial C there will be a phase change proportional to $l \sin \theta$ and upon the subsequent reversion to aerial A, a phase-change proportional to $-l \sin \theta$. This switching cycle is repeated continuously. These phase-changes

are summarised in Fig. 8 (ii) which is a plot of the time difference between the incoming 5 kc./s. pulses at the mobile craft MC and a steady series in phase with those from aerial A.

Referring now to Figure 2 which shows schematically the mobile craft equipment, pulse signals from the ground beacon are received by aerial **13**, are suitably amplified and demodulated in receiver **14** which provides a rectified pulse-form output for application to a pulse generating unit **15** by which a 5 microsecond pulse is generated for each received pulse signal.

These 5 microsecond pulses are arranged so as to be initiated in response only to the first 0.25 microsecond period following the leading edge of the related received pulse applied from receiver **14**.

Associated with this unit **15** is an automatic volume control circuit **16** which serves to provide a controlling voltage which stabilises the gain of receiver **14** at a chosen level. This AVC unit is arranged to be quick acting whereby it brings the amplitude of the pulse output of receiver **14** to the chosen level within a few, e. g., three, pulses of the beginning of any series of similar pulses.

U it **17** is an oscillator having a natural or free-running frequency substantially equal to the chosen pulse-recurrence frequency of the cooperating ground beacon e. g., 5 kc./s. This oscillator is arranged, however, to be varied continuously in the absence of any received signals, over a frequency range of $\pm 1\%$ e. g., from 5050 to 4950 c./s. by a reactance valve unit **18** which is, in turn, controlled by a saw tooth control waveform provided by a sweep valve unit **19**. The natural sweep period is of the order of a few seconds.

The oscillator unit **17** also controls a pulse generating unit **20** which provides a 10 microsecond pulse accurately time related with each oscillation of the oscillator **17** and therefore varying in phase with respect to the incoming signal pulses. Such a pulse is hereinafter referred to as a "strobe." These 10 microsecond "strobe" pulses are fed back to the 5 microsecond pulse generator unit **15**, where they serve to bring that unit, which is normally held inoperative, into operation during the actual pulse periods. By this arrangement interference by signals arriving at times other than those corresponding to the anticipated arrival times of signals at the chosen pulse repetition frequency of the ground beacon station is avoided.

These 10 microsecond strobe pulses are also applied to the sweep valve unit **19** where, upon the occurrence of a chosen time relationship thereof with the 5 microsecond pulses from unit **15** which are time-related to the received signals, the natural sweeping action of unit **19** is suspended and the oscillator **17** thereby kept at a chosen frequency. This effect clearly occurs only when the frequency and phase of the pulses derived from oscillator **17** coincide with the frequency and timing of the received signal pulses so that the arrangement is effectively one which will search for and then lock onto the signal pulses from the chosen ground station. Any phase discontinuity in the latter pulses is equivalent to a temporary change of frequency and in the process of re-establishing the locked condition above referred to the sweeping valve unit **19** provides a control waveform for the reactance valve **18** of a form that bears a linear relationship to the sine- and cos-phase-change values already referred to.

The circuit constants of the synchronising arrangement thus provided are such that any small discontinuity in phase of the incoming signal is followed by the oscillator 17 within 0.0025 second. In order to perform this "rephasing" the frequency of the oscillator 17 must be shifted from 5 kc./s. by the reactance valve 18 for a sufficient time to allow the integral of the change of frequency to equal the required phase shift. This follows from the fact that the phase-difference between two waves initially in phase is the integral of their frequency difference.

It follows from the above that when the phase of the received signals changes as shown in Figure 8 (ii) the frequency of the oscillator 17 will change as indicated in Figure 8 (iii) by virtue of the operation of the automatic synchronising means.

It further follows from the fact that phase is the integral of frequency that the areas under the pulses of change of frequency shown in Figure 8 (iii) are proportional to $l \sin \theta$ and to $l \cos \theta$ as indicated, and since the same channel is used for both, the constant of proportionality is the same for the $\sin \theta$ and $\cos \theta$ terms. There is thus in the circuit, a voltage proportional to frequency which controls the reactance value unit 18.

A version of the control waveform shown in Figure 8 (iii) is applied, after amplification in a linear amplifier 21 to a sin/cos potentiometer 22 by which two anti-phase versions of such control waveform at amplitude levels proportional respectively to the cosine and the sine values of the angular control setting ϕ of the potentiometer are made available. These two outputs, which are illustrated graphically in Figure 9 (iv) and (v), are applied to a display unit 23 which is effectively a switching device by which selected portions of each of said cos and $-\sin$ outputs may be applied in turn to a centre-zero indicating meter 24. The switching function of this display unit 23 is controlled so as to select the $-\sin \theta \cos \phi$ pulses of waveform, Figure 9 (iv) and the $\cos \theta \sin \phi$ pulses of waveform, Figure 9 (v), once during each cycle of the ground station aerial switching. Since this switching function must clearly be time controlled to synchronise with the ground beacon aerial switching cycle the necessary control for the display unit 23 is provided by applying the received signal pulses to a reference unit 25 where, by resolving the 50 c./s. width modulation imposed upon the rear edges of the received pulse signals, a 50 c./s. sine waveform is derived. From this waveform, shown in Figure 9 (i), there are developed two anti-phase square pulse switching waveforms, shown in Figue 9 (ii) and (iii), whose respective positive going pulses are appropriately timed to select the above stated portions of the two waveforms of diagrams (iv) and (v) Figure 9 applied to the display unit 23 from the sin/cos potentiometer 22.

The resultant meter indication is proportional to $\sin (\phi - \theta)$ and will become zero or balanced when θ equals ϕ or $\phi + 180°$. The control shaft of the sin/cos potentiometer is provided with suitably calibrated setting means relating the ground beacon bearing angle $(\theta + \pi)$ to the values provided thereby so that, by adjusting the potentiometer to the required bearing angle and then navigating the craft so as to maintain a zero meter indication, a straight course along such bearing direction may be travelled. Alternatively, by adjusting the potentiometer to obtain a zero meter reading, the bearing angle of the

ground beacon, may be read off directly from the calibrated scale. The possible 180° ambiguity can usually be resolved in a number of ways. The potentiometer calibration dial conveniently consists of a calibrated ring surrounding the centre zero meter 24.

The width modulated received signal pulses are also applied to a filter unit 26 which rejects the 5 kc./s. recurrence frequency and the 50 c./s. aerial switching frequency components and passes the remaining width modulation components (which may constitute a communication channel) to an amplifier 27 for ultimate operation of a sound reproducer such as head telephone 28.

The receiving aerial 13 may be of any suitable form and is conveniently of omnidirectional character. The receiver 14 is of conventional form, more particularly of the type used in connection with pulse modulated radar systems. In one practical embodiment it had a sensitivity of 80 microvolts and a bandwidth of 4 mc./s. at an operating frequency in the region of 200 mc./s.

A suitable form of the 5 microsecond pulse generating unit 15 and the A. V. C. unit 16 is shown in Figure 3 where valves V_1, V_2, V_3 and V_4 with their associated diodes D_2, D_3, D_4 and D_5 and other circuit components constitute the pulse generating unit and valve V_5, with its diode D_1 and associated components, the A. V. C. unit.

The output from receiver 14, in the form of positive-going pulses, is applied by way of terminal t_1 to the control-grid of valve V_1 whose anode circuit is completed by way of the parallel paths through valves V_2 V_3. The suppressor grid of valve V_1 is supplied by way of terminal t_2 with the strobe pulse waveform, derived in a manner described in detail later, comprising a series of positive-going pulses at the chosen pulse recurrence frequency and each of 10 microseconds duration. Except during the time of such positive going pulses, valve V_1 is cutoff at its suppressor grid and in consequence, any received signals will be quite ineffective to cause interference by spurious operation of the system.

When, as will be the case in proper operation, the received signal is applied to the control-grid of valve V_1 whilst the suppressor grid thereof is lifted to earth potential, then valves V_1 and V_2 take current, valve V_3 remaining cut-off by virtue of the greater bias potential upon its control grid. Amplified negative-going pulses therefore appear at the anode of valve V_2. By reason of the feedback path from anode to control-grid of valve V_1, the overall gain is stabilised at a valve determined by the ratio of resistances R_1 and R_2 and is, in the example given, equal to 5.

The negative pulses at anode of valve V_2 are applied through diode D_2 to control-grid of valve V_4 where they cause cut-off of anode current and consequent ringing of tuned circuit L. C. coupled to the valve anode circuit. The product of circuit components L. C. is such that, for each ringing operation, a 5 microsecond positive pulse is formed first, followed by a similar negative swing. The latter is absorbed by diode D_3 and the former applied by way of terminal t_3 to sweep valve unit 19.

The anode circuit of valve V_4 includes a resistance R_3 which, in conjunction with condenser C_1, causes the production of a positive-going sawtooth waveform at the point a. The time-constant of network R_3, C_1 is such that the potential rise of point a, which is applied to control-grid of valve V_3, is sufficient to open

or "turn-on" the latter at an instant 0.25 microsecond after the instant of original application of the related pulse to terminal t_1 from the receiver **14**. Valve V_3 thereupon takes the current through valve V_1 and valve V_2 is cut-off for the whole of the remaining period of the applied signal pulse. The rise in anode potential of valve V_2 does not reach valve V_4 owing to the blocking action of diode D_2.

The anode waveform of valve V_2 is also applied to diode D_1 and the rectified current produced operates valve V_5. If the amplitude of the received signal pulses increases an increase occurs in the mean rectified current flowing through resistance R_4 which causes a discharge of the feed back condenser C_2 and invokes a fall in potential at the anode of the valve. Since this anode potential is that which is applied by way of terminal t_4 to the screen-grids of some of all of the I. F. valves of the receiver **14** (Figure 2), there is a consequential reduction of the receiver gain to stabilise the receiver output at the chosen level. If the received signal amplitude decreases a reverse action takes place.

Valve V_3, as already stated is turned on 0.25 microsecond after the front edge of each received signal pulse and is turned off again at the end of each signal pulse by the cutting-off of valve V_1 in series therewith. Since the duration of the various signal pulses is determined by the width modulation of their rear or trailing edges, the anode waveform of valve V_3 will comprise a series of negative-going pulses still carrying the width-modulation of the original signal pulses. This anode waveform is applied by way of terminal t_5 to the reference unit **25** and filter unit **26** of Figure 2.

By the operation of the arrangement so far described both the A. V. C. level and the derived pulses, applied by way of terminal t_3 to sweep unit **19** and used ultimately to provide the required bearing information or intelligence, are dependent upon and influenced only by the first 0.25 microsecond period of each received signal pulse. By this means any interfering signals, particularly those due to reflections from ground objects, which arrive more than 0.25 microsecond after the front edge of each pulse are neglected. This increases the freedom of the arrangement from site errors. The manner of operation is illustrated by Figure 6 where, in diagram (i) P indicates a typical received signal pulse as applied from the receiver **14** to valve V_1. The A. V. C. system operates to maintain the signal at 30 v. amplitude at the instant 0.25 microsecond after the inception instant thereof. The potential level required to open the control-grid of valve V_1 is set at one-third of the A. V. C. level, i. e. 10 v., whereby the derived pulse available at terminal t_3 and shown at dp in diagram (ii) commences at that instant (x) and lasts for the chosen duration of 5 microseconds. The instant x is defined as the instant of arrival of the pulse. Fluctuations of the received pulse amplitude on its duration subsequent to the 0.25 microsecond point, as illustrated at p_1, p_2, p_3 in diagram (i) are entirely without effect upon the derived pulse. The output pulse from anode of valve V_3, on the other hand, shown at mp in diagram (iii) commences at the 0.25 microsecond point and is terminated in accordance with the received pulse duration as set by its fall in amplitude below the 10 v. level required to keep valve V_1 open.

One particular form of the oscillator unit **17**, reactance valve unit **18**, sweep valve unit **29** and strobe pulse generating unit **20** is shown in Figure 4, where valves V_8, V_{9a}, V_{9b} and V_{10a} with their associated diodes D8, D9 and other circuit components constitute the sweep valve unit **19** while valve V7 with diode D6 and other elements forms the reactance valve unit **18**. Valve V6*a* and diode D7 constitute the 5 kc./s. oscillator unit **17** and valve V6*b* the strobe unit **20**.

Valve V8 is arranged as a saw tooth waveform generator having a cycle period of the order of a few seconds. Its operation in the absence of a received signal input is briefly as follows. At the start of a cycle, the anode of V8 is at a voltage level, say +250 v., set by resistance network R5, R6 and R7. The control grid and the suppressor grid of the valve have previously been biased negatively due to connection of resistance R10 to a —150 v. supply by relay RL_1 but, on account of the de-energisation of such relay, resistance R10 has just been connected to earth.

Due to current flow through resistance R8, the control grid potential rises and the anode voltage runs down, being linearised by feed back network C3, C4, R9. Towards the end of the run down period the screen current increases, energising relay RL_1 and so bringing about reconnection of resistance R10 to the —150 v. supply. This causes cut-off of anode current and the charging of the feed back network through resistance R5. When the charging current begins to fall the control grid potential starts to move negatively whereby the screen current also falls and eventually de-energises relay RL_1 to recommence the sweep cycle afresh.

The reactance valve V7 is supplied on its control grid with a proportion of the anode waveform of valve V8 from the junction of resistors R6, R7 whereby it acts as a capacitance in shunt to the tuned circuit L_1, C_1 of the oscillator valve V6*a*, the value of such capacitance being lineraly related to the applied saw tooth control waveform from the sweep valve V8. In practice the application of this control voltage, in the absence of a received signal, causes the oscillator frequency to vary linearly between the limits of 5055 c./s. and 4950 c./s.

The oscillator valve V6*a* is of the Reinartz type but has a cathode load and a long time constant network C7, R14 in its grid circuit. The upper limit of the grid voltage swing is set at +60 v. by the diode D7 whereby an output in the form of positive pulses approximately 60 v. in amplitude and 20 microseconds in width are obtained at the cathode end of resistance R15. These pulses are applied to the grid of valve $V6_b$ by way of the network of condenser C8 and resistance R16. The negative-going trailing edge of each pulse serves to cut off the control grid of valve $V6_b$ and thereby to produce at its anode positive-going pulses which have a width of 10 microseconds set by suitable choice of the time constant of network C8, R16. These pulses are A. C. coupled by condenser C9 and resistance R17 about a potential level of +120 v. and are applied through integrating network C10 and R18 to the control grid of valve V_{9a} As a result, a rising saw tooth voltage is applied to the grid of valve V_{9a} for the 10 microseconds of each pulse provided by valve V_{6b}. The square positive-going 10 microsecond pulse from the anode of valve V_{6b} is also applied by way of terminal t_6 to the terminal t_2 of Figure 3 where it constitutes the strobe pulse previously referred to.

Valve V_{9a} and a second valve V_{9b} are effectively in series with a further valve V_{10a} which is nor-

mally held cut-off at its control grid, but which is, however, supplied at such control-grid with the 5 microsecond pulses generated by valve V_4, Figure 3, in response to each received signal pulse. When such 5 microsecond pulse is so applied to valve V_{10a}, current normally flows through this valve and through valve V_{9b}. If the oscillator valve V_{6a} is properly locked or synchronised with the received signals then the rising voltage applied from the anode of valve V_{6b} reaches a level at which valve V_{9a} is turned on at a time 2.5 microseconds after the initial edge of the 5 microsecond pulse applied to valve V_{10a} so that, for the remaining 2.5 microseconds of the 5 microsecond pulse period, current flow is through valve V_{9a} instead of through valve V_{9b}. These conditions are illustrated in Figure 7, where diagram (i) shows a received pulse signal with its rear edge width modulated as shown by the shaded region; diagram (ii) the 10 microsecond pulse generated at the anode of valve V_{6b}, i. e., the "strobe" pulse; diagram (iii) the 5 microsecond pulse generated in unit 15 from the received signal pulse of diagram (i) and diagram (iv) the rising sawtooth waveform derived from the pulse of diagram (ii) and applied to valve V_{9a}. Under these conditions the current flow through the primary winding of transformer of T1 is reversed at an instant substantially coincident with the centre of the 5 microsecond pulse period. This is illustrated in diagram (v) of Figure 7.

The secondary winding of transformer T1 is arranged to apply its output through reversed diodes D8, D9 to charge a condenser C11 which is also connected to the control grid of the sweep valve V8. Normally each of these diodes is biased off since the control grid of V8 is approximately at the potential of −4 v. whereas the anode of D9 is connected to a potential supply of −8 v. so that the anode of D8 is four volts below its cathode and the cathode of D9 is four volts above its anode. When the current flow through transformer T1 is reversed at the midpoint of the 5 microsecond pulse period as in diagram (v), Figure 7, the effective voltage across C11 is zero and no mean current reaches the control grid of valve V8. If, however, the change-over point is displaced to one side or the other of the midpoint, due to relative phase displacement between the received pulse signals and those due to oscillator valve V_{6a}, then the condenser C11 acquires a voltage of certain implitude and polarity and this is in turn applied to the control grid of sweep valve V_8 where it causes a related change of anode potential to cause reactor valve V_7 to alter the frequency of oscillator $V6_a$ so as to restore the previous condition of synchronism. In practice the change-over point is not precisely midway of the 5 microsecond pulse period but is displaced slightly to one side or the other in order to provide just sufficient current to the control grid of valve V8 to cancel the sweep current, previously referred to, passing through resistance R8. With the arrangement so far described, in the absence of any received signals or in the event of non-coincidence of such signals with the derived pulses from the oscillator valve V_{6a}, the frequency of the latter will be varied over the ±1% range by the action of the sweep valve V8 and reactance valve V7 until coincidence in the manner above referred to is obtained. When this occurs the particular frequency at which the oscillator is then functioning will be held by cancellation of the sweeping potentials of valve V_8 by the current derived from condenser C11. The oscillator valve V_{6a} is then held locked to the incoming received pulses.

In the event of phase change between the received pulses, i. e., upon switching from one ground aerial to another the aforesaid balance of current flow in the anode circuit of valves V_{9a} and V_{9b} will be disturbed and the sweep valve circuits V_8 appropriately effected to alter the oscillator frequency to re-establish locking. Since only the phase of the leading-pulse of each pulse group is altered relative to the last pulse of the previous group the aforesaid frequency change to re-establish locking will be followed by a further change of the oscillator frequency back to its original value. This is accomplished by a further control potential provided by the sweep valve V8 in similar manner to that already described. A representative waveform at the anode of valve V_8 for one aerial switching operation is shown to an enlarged scale in diagram (i) of Figure 8, while diagram (iii) of that figure shows an example of one complete cycle of aerial switching.

Since out of balance currents due to the relative phases of the signal and strobe voltages are integrated in the sweep valve circuit to produce the control voltage and since the control voltage changes the frequency of the oscillator, which in turn changes the phase, the circuit is of the feed back type with two integrations in the feed back loop i. e., the integration from current to voltage and the integration from frequency to phase. Hence the circuit has a natural period of oscillation and its resonance to impulses will be similar to that of an LC circuit. Intentional impulses, i. e., the phase changes of cos θ and sin θ previously mentioned are applied to the circuit and its response is controlled by the damping component R9 between the anode and control grid of valve V8. In practice, the circuit is so arranged that the base of each pulse of this control waveform, occupies approximately 45° of the total switching cycle period.

The linear amplifier 21 of Figure 2 may be of any suitable form adapted to increase the voltage amplitude of the control waveform while retaining its other characteristics unaltered.

Figure 5 shows in some detail one embodiment of the units 22, 23, 24 and 25 of Figure 2. In this figure, valves V_{10b}, V_{15a}, V_{15b}, V_{16a}, V_{16b} with their associated components constitute part of the reference unit 25, valves V_{17a}, V_{17b}, V_{18a} and V_{18b} form the display unit 23 and the potentiometer SCP with its associated transformer, the sin/cos potentiometer unit 22.

The amplified control waveform of Figure 8 (iii) is applied by way of transformer T2, having an earthed center tapped secondary winding to opposite points of a toroidal potentiometer SCP. The windings of this potentiometer are earthed at diametrically opposed points as shown while opposite points 90° displaced therefrom are connected respectively to the opposite ends of the secondary winding of transformer T2. The two moveable contacts on the potentiometer are displaced 90° with respect of one another whereby they provide voltage outputs which are proportional to cos ϕ and −sin ϕ of the input waveform to transformer T2 where ϕ is the angle of displacement of the controlling shaft for the sliders from a zero position. These output waveforms are shown in diagrams (iv) and (v) of Figure 9.

The cos ϕ output from the sine/cosine potentiometer SCP is applied to the anode and cathode

respectively of triode valves V_{17a}, V_{17b}. The grid cathode paths of each of these valves is shunted by a secondary winding S1 or S2 associated with a transformer T3 whose primary winding is supplied with a pulsed switching waveform from the reference unit 25 as described later. When the control-grids of valves V_{17a}, V_{17b} are driven positively by such switching waveform, one or the other will allow conduction of the current pulses thereof to the meter 24 whatever their polarity may be.

The $-\sin\phi$ output from the potentiometer SCP is similarly applied to valves V_{18a}, V_{18b} which are likewise controlled by a switching waveform supplied from reference unit 25 by way of secondary windings S_3, S_4 of transformer T_4.

The switching waveforms for these valves V_{17}, V_{18} must be in precise synchronism with the aerial switching cycle of the ground transmitting station and are obtained in the following manner. The width modulation of the rear edges of the received signal pulses are extracted by any suitable means forming part of the reference unit 25 (but not shown) and the resulting, e. g., 50 cycle, sine wave applied to valve V_{10b} which operates as a paraphase amplifier to drive valves V_{15a}, V_{16a} in push-pull. The latter valves are arranged to effect squaring of the applied sine wave oscillations whereby they each produce a square pulse waveform at their anodes comprising one negative-going pulse per cycle having a duration approximately equal to 90° of the cycle. The pulses of the two waveforms are 180° phase displaced with respect to one another and are applied by way of cathode follower valves V_{15b}, V_{16b} to the primary windings of transformers T3 and T4 respectively.

The secondaries of transformers T3, T4 are so connected that the similar but positive-going pulse waveforms, shown respectively in diagrams (ii) and (iii) of Figure 9, are applied to the related grids of the valves V17 and V18, so that the valves $V17_a$, $V17_b$ are opened for a chosen 90° cycle period during each aerial switching cycle and the valves V18*a* and V18*b* similarly opened for another 90° period 180° later in each aerial switching cycle. As already described and as illustrated by comparison of diagrams (ii) and (v) and of diagrams (iii) and (iv), Figure 9, the $-\sin\theta\cos\phi$ output pulses of waveform (iv) and the $\cos\theta\sin\phi$ output pulses of waveform (v) are passed to earth through the meter 24 which is shunted by a large condenser whereby integration takes place and an indication proportional to the mean current is obtained.

It will be noted that in the above described arrangement the final bearing is obtained by comparing the amplitudes of two pulses, and that these two pulses traverse the same network right through to the sine/cosine potentiometer. The only double-channel part of the system comprises the valves V_{17a}, V_{17b}, V_{18a} and V_{18b} and the resistors in series therewith. These resistors are chosen so as greatly to exceed the resistance of the anode-cathode paths of the valves when conducting, and to retain symmetry between the two channels it is necessary only to ensure that the two resistors are equal.

The phasing of the switching waveforms shown in diagrams (ii) and (iii) of Figure 9 is not critical; provided the selected pulse is entirely contained within the period of the operating pulse, small phase variations of these waveforms are irrelevant. It is for this reason that the switching waveforms pulses are desirably arranged so as to be maintained over a cycle period equal to 90° whereas the controlling waveform pulses themselves have a duration equal to about 45°.

Since the channel from the receiver to the indicating meter is opened up only during the 10 microsecond "strobe" pulse periods i. e., for a total of $5000\times10\times10^{-6}$ or 0.05 second in every second, an appreciable saving in H. T. supply to the associated receiver can be achieved by similarly limiting its application to short pulse periods coincident with said "strobe" pulses. Figure 10 shows a fragmentary circuit diagram of one arrangement for this purpose.

Referring to this figure, valve V_{20} is arranged as a blocking oscillator which is appropriately triggered by way of lead 30 from a suitable point of the oscillator circuit of unit 17, Figure 2, or more conveniently from the "strobe" pulse output of valve V_{6b}, Figure 4. When so triggered this valve provides a squegged pulse lasting, say, 30–60 microseconds and this is applied to the control grid of a valve V_{21} provided with a transformer T_5 in its anode circuit. A secondary winding of such transformer provides the H. T. supply, in the form of short pulses, to the associated receiver 14.

Instead of employing a thermionic valve switching circuit for the cos and $-\sin$ pulse selection as already described in connection with Figure 5, a mechanically operated relay device may be employed, particularly when a relatively slow rate of aerial switching is used at the ground beacon transmitter, e. g., 20 c./s.

Figure 11 shows, in fragmentary schematic form one such mechanical relay embodiment. In this arrangement, the amplified controlling waveform of Figure 8 (iii) is applied as an unbalanced input to the moveable tappings of the toroidal potentiometer SCP 1. The quadrantal pairs of opposed fixed tappings of the potentiometer winding are taken to opposite fixed contacts of relays RL_2 and RL_3. The moveable contacts of such relays are connected in turn to the fixed contacts of a third relay RL_4 whose moveable contact is connected to the input terminal of a meter amplifier 31 supplying the meter 24.

In operation, the relay RL_4 is arranged to be changed over from one fixed contact to the other every 180° of the ground aerial switching cycle while the relays RL_2 and RL_3 are arranged also to be changed over every 180° of the cycle but at times which are 90° displaced with respect to relay RL_4. The relay operation is conveniently effected by means of a thermionic valve circuit controlled by the sine wave derived from the width-modulated back edges of the received pulses.

A modification of the arrangements described above suitable for delineating a single track is shown in Figure 12. In this arrangement two aerials A1, B1 only are used on the ground and the power from the transmitter 10 is switched to each in turn. When a distant craft is located on the perpendicular bisector *b* of the line joining the aerials, there is no discontinuity in the phase of the pulses received at the craft. On either side of this bisecting line, however, there is a phase discontinuity on switching whose sense, relative to a reference wave, reverses as the line is crossed. The mobile craft equipment previously described can follow such a single track without modification. The sine/cosine potentiometer should be set to $-45°$. Two pulses of the same sign per revolution of the ground

aerial switch will be selected by the valve circuits of display unit 23 and passed to the meter 24. The meter will read zero only when the pulses disappear, i. e., when the craft is located on the wanted track constituted by the bisector line.

By this method the same equipment can be used in an aircraft for beam approach to a landing runway and for long range navigation. If working is required only with the modified arrangement just described, the sine/cosine potentiometer can, of course, be omitted with some simplification of the mobile craft apparatus.

Figure 13 shows a further alternative ground beacon lay-out using four aerials A', B', C' and D' at the corners of a square and each supplied, as before, from a single transmitter 10 through a switch 11 and equal length feeder lines 12. The switching sequence is A', C', B', D' . . . and so on and the related phase changes at a remote mobile craft $l \cos \theta$,

$$\frac{1}{\sqrt{2}}$$

$\cos (45°+\theta)$, $l \sin \theta$ and

$$\frac{1}{\sqrt{2}}$$

$\sin (45+\theta)$, where l is the diagonal length of the square. The control waveform pulses corresponding to $l \cos \theta$ and $l \sin \theta$ are selected as before. No modification to the mobile craft equipment is necessary.

The arrangements described above are capable of appreciable modification in order to adapt them to different specific purposes. For instance the oscillator unit 17 of the mobile craft equipment may be adapted so as to be adjustable to operate at any one of a number of pulse recurrence frequencies differing by more than 2%. A number of ground beacon stations may then operate on a common radio frequency but at different pulse recurrence frequencies. Selection of the required beacon is then effected by appropriate adjustment of the operating frequency of the oscillator unit 17.

I claim:

1. Radio navigation system in which the bearing of a mobile craft with respect to a fixed station is determined at said mobile craft, comprising at said fixed station a transmitter generating trains of pulses at constant pulse recurrence frequency, at least two spaced aerials associated with said transmitter and means for switching the trains of pulse signals between said aerials in predetermined regular order, and at said mobile craft, means for receiving said pulse signals, a phase comparing device for determining the phase relationship of the pulses received from one aerial with respect to those received from the other aerial, and an indicator operated by said phase comparing device providing a bearing indication in accordance with the particular phase relationship value.

2. Radio navigation system in which the bearing of a mobile craft with respect to a fixed station is determined at said mobile craft, comprising at said fixed station a transmitter generating trains of pulses at constant pulse recurrence frequency, at least two spaced aerials associated with said transmitter and means for switching the trains of pulse signals between said aerials in predetermined regular order, and at said mobile craft, means for receiving said pulse signals, means for generating a reference oscillation at the same pulse recurrence frequency as the transmitted pulses, a phase comparison circuit giving electrical outputs corresponding to the differences between the phase of the reference oscillation and that of the trains of transmitter pulses, and an indicator operated by the electrical outputs.

3. Radio navigation system in which the bearing of a mobile craft with respect to a fixed station is determined at said mobile craft, comprising at said station a transmitter generating trains of pulses at constant pulse recurrence frequency, at least two spaced aerials associated with said transmitter, and means for switching the trains of pulse signals between said aerials in predetermined regular order, and at said mobile craft, means for receiving and detecting said pulse signals, a local oscillator for generating a reference oscillation, means for changing and controlling the frequency of said local oscillator to bring said reference oscillation into a predetermined phase relationship with pulse signals received from each aerial in turn, means for deriving potentials proportional to the changes in frequency of said oscillator, and an indiactor operated by said potentials.

4. Radio system for signalling between a fixed station and a mobile craft, comprising at said fixed station a transmitter generating trains of pulses at constant pulse recurrence frequency, at least two spaced aerials associated with said transmitter, switching means for distributing trains of pulse signals between said aerials in cyclic order, and means for modulating the character of the pulses in accordance with the cyclic distribution of the trains of pulses, and at said mobile craft, means for receiving and detecting said pulse signals, a local oscillator for generating a reference oscillation, means for generating a potential for changing the frequency of the local oscillator, automatic means for locking the reference oscillation to the trains of pulses received from different aerials when said reference oscillations are in phase with said trains of pulses, means responsive to the modulation carried by the pulses for selecting the different frequency changing potentials, and an indicator operated by the cyclic application of said frequency modulated potentials.

5. Radio beacon comprising a radio transmitter generating pulses at constant pulse recurrence frequency, a plurality of spaced aerials associated with said transmitter, switching means for supplying the pulse output of said transmitter in trains of pulses to different aerials in predetermined cyclic order, and means for modulating the character of the pulses in accordance with the cyclic operation of said switching means.

6. Radio beacon as claimed in claim 5 wherein the aerials are spaced apart in the horizontal plane and disposed in lines at right angles to one another.

7. Radio beacon comprising a transmitter generating pulses at constant pulse recurrence frequency, three aerials associated with said transmitter and arranged respectively at the corners of a right-angled triangle lying in the horizontal plane, switching means for supplying the pulse output of said transmitter in trains of pulses to said aerials in the cyclic order, the apex aerial, one base corner aerial, the apex aerial, the opposite base corner aerial and so on, and means for modulating the character of the pulses in accordance with the position of the aerial to which they are switched.

8. Radio transmitting system comprising a pulse generator generating pulses at constant

pulse recurrence frequency, a plurality of spaced aerials associated with said transmitter, switching means for supplying the pulse output of said generator to different aerials in cyclic order, and means for modulating the width of the pulses in accordance with the cyclic operation of said switching means.

9. Radio transmitting system as claimed in claim 8 wherein means are provided for further width modulation of said pulses to provide a communication channel.

10. Radio receiver for a mobile craft comprising means for receiving and detecting pulse modulated radiation of constant pulse recurrence frequency and carrying an additional modulation characteristic, a phase discriminator providing an output dependent upon the phase difference between separate trains of pulses, means controlled by the additional modulation characteristic for selecting of the output of said discriminator in predetermined cyclic order, and an indicator giving an indication dependent on the relative values of the output portions selected.

11. Radio receiver for a mobile craft comprising means for receiving and detecting pulse modulated radiation of constant pulse recurrence frequency, means responsive to the leading edges of the detected pulses for initiating derived pulses of predetermined time duration, a phase discriminator providing an output dependent upon the phase difference of separate trains of said derived pulses, and an indicator operated by the output of said phase comparing means.

12. Radio receiver for a mobile craft comprising means for receiving and detecting pulse modulated radiation of constant pulse recurrence frequency, a local oscillator for generating a reference oscillation of the same pulse recurrence frequency, means for generating potentials for changing the phase of the reference oscillation into a predetermined phase relationship with different trains of received signals, said potentials being proportional to the change of phase, and means for measuring said potentials.

13. Radio receiver for a mobile craft comprising means for receiving and detecting pulse modulated radiation of constant pulse recurrence frequency, a local variable frequency oscillator for generating a reference oscillation, means for changing the frequency of said local oscillator to bring the reference oscillation into phase with different trains of received signal pulses, and means for comparing the different changes of frequency of the local oscillator effected.

14. Radio receiver for a mobile craft comprising means for receiving and detecting pulse modulated radiation of constant pulse recurrence frequency, a local variable frequency oscillator for generating a reference oscillation, means for changing the frequency of said local oscillator to bring the reference oscillation into phase with different trains of received signal pulses, means for locking the local oscillator in synchronism with different trains of signal pulses in turn, and means for comparing the different changes of frequency of the local oscillator effected.

15. Radio receiver as claimed in claim 14 including a gating circuit which suspends the operation of the apparatus except for short periods embracing the arrival times of pulses from the ground transmitter.

16. Radio receiver as claimed in claim 11 including an automatic volume control circuit for regulating the gain of the signal pulse receiving means, said circuit being responsive to the amplitude of the leading edge of said pulses.

17. A wireless signalling system for aiding navigation of a mobile craft, comprising a transmitter for generating pulse signals, a plurality of spaced aerials, means for switching trains of pulses between said aerials in a predetermined cyclic order, and means for modulating the character of the pulses in accordance with cyclic operation of said switching means, and at said mobile station, means for deriving an electrical output depending upon the difference in the transit times of pulses received from different aerials, indicating means, and a common signal path between said first mentioned means and said indicating means, and means responsive to the modulation of the pulses for the cyclic selection of portions of the output of said first mentioned means through said signal path.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,403,600	Holmes et al.	July 9, 1946
2,403,626	Wolff et al.	July 9, 1946
2,413,023	Young	Dec. 24, 1946
2,416,306	Grieg	Feb. 25, 1947