Jan. 5, 1932. A. BAILEY 1,839,290

DIRECTION FINDER FOR RADIOWAVES

Filed April 25, 1928 2 Sheets-Sheet 1

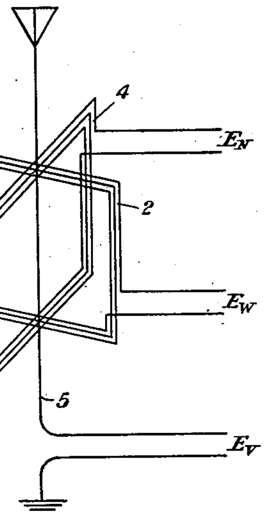

Fig. 1

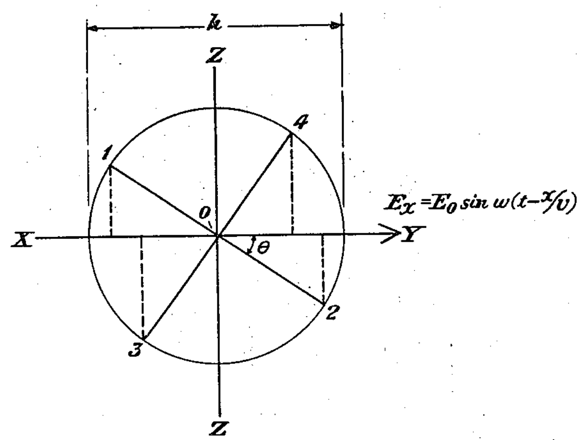

Fig. 2

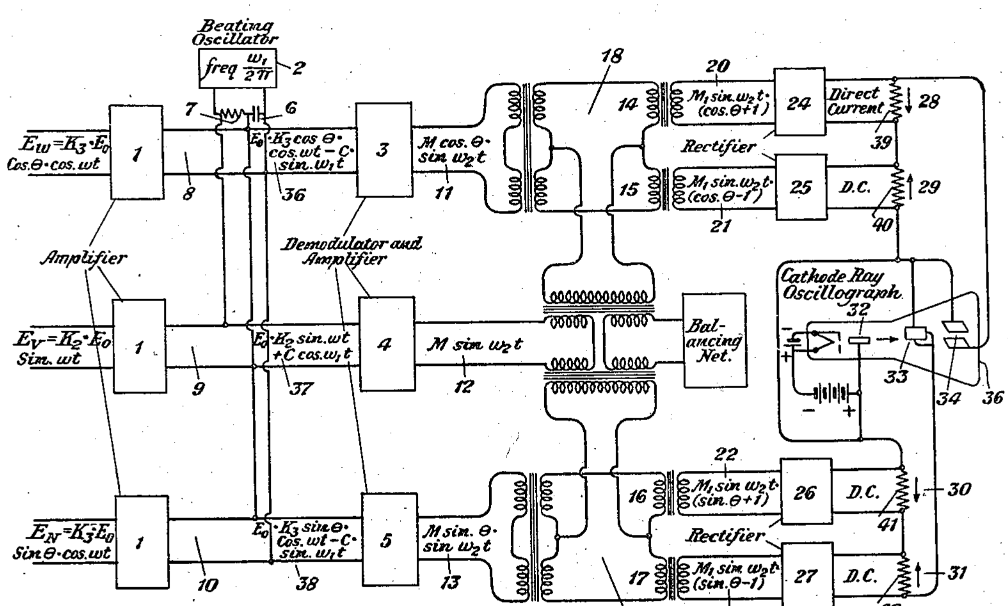

Fig. 3

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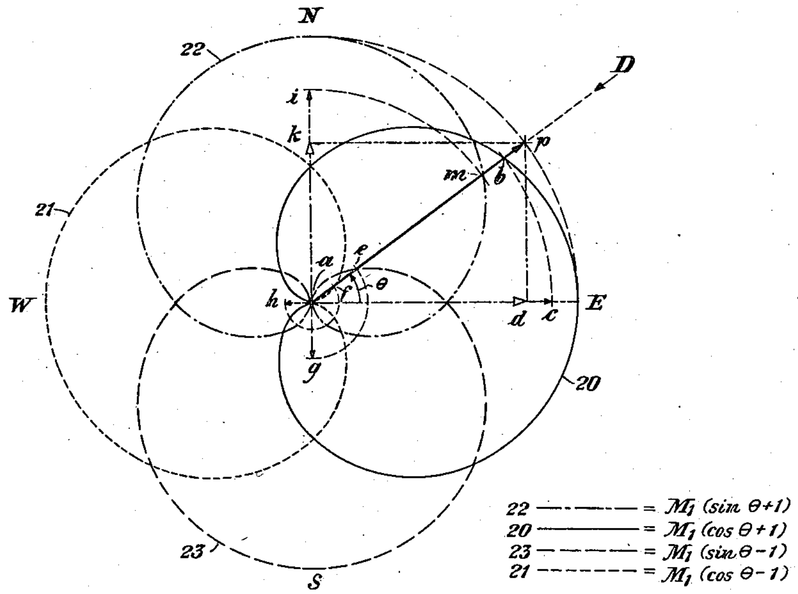

Fig. 4

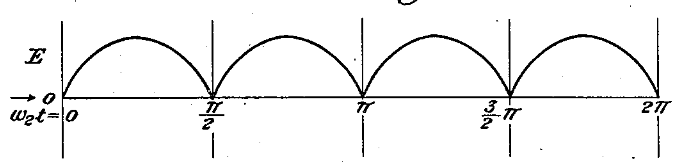

Fig. 5

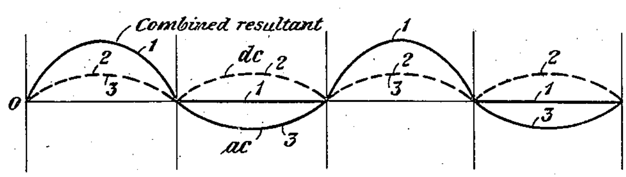

Fig. 6

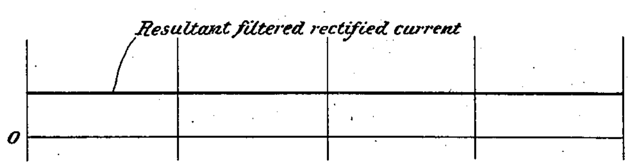

Fig. 7

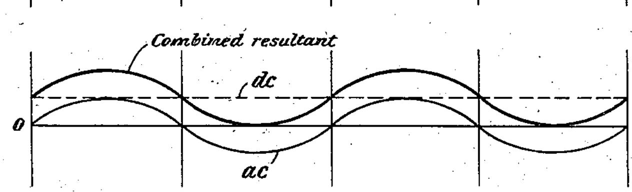

Fig. 8

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Patented Jan. 5, 1932

1,839,290

UNITED STATES PATENT OFFICE

AUSTIN BAILEY, OF MAPLEWOOD, NEW JERSEY, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK

DIRECTION FINDER FOR RADIOWAVES

Application filed April 25, 1928. Serial No. 272,702.

This invention relates to the art of radio communication, and more specifically to radio receiving apparatus for determining both the magnitude and absolute direction of propagation of radio waves.

The invention utilizes three separate coaxial antennæ comprising a vertical antenna and two identical loop antennæ the planes of which are set at right angles. Currents from the three antennæ are combined in such manner that when impressed upon two pairs of deflecting plates of a cathode ray oscillograph, which pairs of plates are set at right angles, a deflection of the electron stream on the screen is obtained which indicates both the magnitude and the absolute direction of propagation of the radio wave train impinging upon the antenna system.

The receiving system for accomplishing the above results is best explained by reference to the drawings of which Figure 1 shows in perspective and in schematic form the arrangement of the antenna system; Fig. 2 shows a plan view of the antenna system when viewed from above, together with certain mathematical relations necessary for explaining the theory of operation of the system; Fig. 3 shows schematically the electrical circuits to which the antennæ are connected, together with certain mathematical relations to be explained concerning the theory of circuit operation; Fig. 4 shows graphically the manner in which the currents in the different output circuits of Fig. 3 vary with the direction of propagation of the impinging radio wave train; and Figs. 5 to 8 show the variation with time of the currents in the output circuits of Fig. 3 for different assumed conditions of current rectification.

Referring more specifically to Fig. 1, loop antennæ 1—2 and 3—4 are arranged coaxially with their planes at right angles to each other and perpendicular to the ground, as shown. Coaxially with the loop antennæ is the vertical antenna 5. The three antennæ are electrically separate, as shown.

Referring now to the plan view of the antenna system shown in Fig. 2, assume a radio wave train to be traveling in the direction XY. Taking the axis O of the antenna system as an origin of coordinates, and the direction X to Y as positive, a single frequency wave train impinging upon the antenna system is given by the equation

$$E_x = E_0 \sin \omega \left(t - \frac{x}{v}\right) \quad (1)$$

where E_0 = the maximum generated voltage per unit length measured perpendicular to the earth;

E_x = the corresponding instantaneous voltage at a distance X from the line ZZ in the direction XY;

v = the velocity of propagation of the wave train;

$\frac{\omega}{2\pi}$ = frequency and t = time.

From Equation (1), the voltage induced in the vertical wires 1 (Fig. 1) of loop 1—2 is given by

$$E_1 = K_1 E_0 \sin \omega \left(t + \frac{h \cdot \cos\theta}{2v}\right) \quad (2)$$

where K_1 is a constant depending upon the number and length of the vertical wires 1;

θ is the angle between the plane of the loop and the direction of wave propagation;

h is the distance between the vertical leads of the loop 1—2.

In a similar manner, the voltage induced in the vertical wires 2 of loop 1—2 is given by

$$E_2 = K_1 E_0 \sin \omega \left(t - \frac{h \cdot \cos\theta}{2v}\right) \quad (3)$$

The resultant voltage E_W induced in the loop 1—2 is given by the difference of equations (2) and (3), namely

$$E_W = E_1 - E_2 = K_1 E_0 \left[\sin \omega \left(t + \frac{h \cdot \cos\theta}{2v}\right) - \sin \omega \left(t - \frac{h \cdot \cos\theta}{2v}\right)\right] \quad (4)$$

The right side of Equation (4) may be expressed more simply as

$$E_W = 2\, K_1 \cdot E_0 \cdot \sin\left[\frac{\omega h \cdot \cos\theta}{2v}\right] \cdot \cos \omega t \quad (5)$$

and since $\omega h \cos\theta$ is small in comparison with

$2v$, the sine of the bracketed member may be replaced by the angle, giving

$$E_W = K_1 \cdot E_0 \frac{\omega h \cdot \cos\theta}{v} \cdot \cos\omega t \quad (6)$$

For a given frequency, this becomes

$$E_W = K_3 \cdot E_0 \cos\theta \cdot \cos\omega t \quad (7)$$

where K_3 is a constant. By similar processes, the voltage E_N in loop 3—4 is

$$E_N = K_3 \cdot E_0 \sin\theta \cdot \cos\omega t \quad (8)$$

The voltage in the vertical antenna E_V is

$$E_V = K_2 \cdot E_0 \cdot \sin\omega t \quad (9)$$

where K_2 is a constant depending on the proportions of the antenna circuit. Comparing Equations (7), (8) and (9), it will be seen that the voltages induced in the vertical antenna lag in phase 90° behind the corresponding voltages induced in the loop antennæ. To obtain the best results in regard to directional effects by combining the voltage induced in a loop antenna with that of the vertical antenna, the voltages should be combined in like time phase relation. These phase relationships are cared for by the circuit of Fig. 3 in a manner now to be explained.

Assume the three antennæ voltages of Fig. 1 to be applied to the circuit of Fig. 3, as indicated. The currents are amplified in amplifiers 1, are combined with a heterodyne frequency supplied from oscillator 2 and are demodulated and amplified in circuits 3, 4 and 5. The output current from the beating oscillator 2 is fed through the resistance 7 and capacity 6 connected in series. The voltage drop across the condenser 6 is applied to the loop antennæ circuits 8 and 10, while that across the resistance 7 is applied to the vertical antenna circuit 9. Since the voltage drop across the condenser is 90° out of phase with that across the resistance, the heterodyne current applied to circuits 8 to 10, inclusive, owing to the manner of connecting the beating oscillator to such circuits, is expressed mathematically, as indicated on Fig. 3. The total current input to each modulator device 3 to 5, inclusive, is mathematically expressed by the expressions 36 to 38, inclusive, of Fig. 3. The output from demodulator 3 will contain, among other things, the product term

$$E_W = -K_3 \cdot E_0 \cdot C \cdot \cos\theta\,[2\cos\omega t \cdot \sin\omega_1 t] \quad (10)$$

in which the bracketed member is equal to the sum and difference of the two frequencies. Re-writing Equation (10) in this form, keeping only the difference term, gives

$$E_W = K_3 \cdot E_0 \cdot C \cdot \cos\theta \cdot \sin(\omega - \omega_1)t \quad (11)$$

By similar treatment, the output from demodulator 5 is

$$E_N = K_3 \cdot E_0 \cdot C \cdot \sin\theta \cdot \sin\omega_2 t \quad (12)$$

The output from demodulator 4 contains the product term

$$E_V = K_2 \cdot E_0 \cdot C \cdot 2\sin\omega t \cdot \cos\omega_1 t \quad (13)$$

which re-written, retaining only the difference term, gives

$$E_V = K_2 \cdot E_0 \cdot C \cdot \sin\omega_2 t \quad (14)$$

If the amplifier unit associated with demodulator 4 is properly adjusted with respect to units 3 and 5, the following relation can be obtained

$$E_0 \cdot K_3 \cdot C = E_0 \cdot K_2 \cdot C = M \quad (15)$$

thus giving the output currents shown at 11 to 13, inclusive, of Fig. 3 in which

$$\omega_2 = \omega - \omega_1 .$$

It will be noted here that the currents from the vertical and loop antennæ are now all in like time phase relation. The main object of demodulation at this point, therefore, is to furnish a convenient method of getting the currents from the various antennæ in like time phase relation. A secondary object is to step down the radio frequency to a value which can be efficiently amplified. The phase shifting arrangement shown by resistance 7 in series with condenser 6, Fig. 3, is merely by way of illustration. Numerous other well known means could be used to change the phase relationship of the current induced in the vertical antenna with respect to that induced in the loop antennæ. The outputs from the demodulator circuits 3 to 5, inclusive, are fed into the transformer circuits 18 and 19 in the manner shown on Fig. 3. Owing to the manner in which current from the vertical antenna is fed into the transformer circuit 18, demodulated current 11 from loop antenna 1—2 is combined in transformer 14 in like time phase relationship with demodulated current 12 in the vertical antenna. In transformer 15 current 11 is combined in phase opposition with current 12. In transformer 16 current 12 is combined in like phase relation with current 13, and in transformer 17 current 12 is combined in phase opposition to current 13. The resulting currents flowing into rectifier circuits 24 to 27, inclusive, are given by currents 20 to 23, respectively.

At this point it is well to consider the manner in which currents 20 to 23, inclusive, vary with the direction of propagation of the wave train impinging upon the antenna system. Fig. 4 shows a plot of currents 20 to 23, inclusive, at the instant when $\omega_2 t = \pi/2$, plotted against the directional angle θ as a variable. The current designations 20 to 23, inclusive, are the same in Fig. 4 as in Fig. 3.

The graph of Fig. 4 shows four cardiods arranged successively at right angles. As $\omega_2 t$ varies from zero to 2π, each cardiod increases from a point to a maximum value of $2M_1$ along the symmetrical axis, and decreases again to zero, reverses in direction and increases to $-2M_1$, returning again to zero. Owing to this reversal of current at $\omega_2 t=\pi$, the four currents cannot be combined directly to indicate the absolute direction of propagation of the radio wave. The currents could be combined to indicate the line along which the impinging radio wave train is propagated but there would be an ambiguity of 180°. For example, it would not be known whether the wave were traveling from east to west or from west to east, say. If, however, the currents 20 to 23 (Fig. 3) are passed through rectifying devices 24 to 27, inclusive, such that the rectified direct current in the output of each such circuit is proportional at each instant to the input alternating current, these rectified currents may be combined to indicate the absolute direction of propagation as well as the magnitude of the radio wave train. This is due to the fact, referring for a moment to Fig. 4, that after rectification the cardiods will not reverse in direction but will merely increase from zero to a maximum value, returning again to zero.

Referring to Fig. 3, the rectified currents 28 to 31 flow through equal resistances 39 to 42, inclusive, the output circuits of the rectifiers 24 to 27, inclusive, being arranged so that current 28 is poled opposite to current 29 and current 30 opposite to 31. The potential drop due to currents 28 and 29 flowing through resistances 39 and 40, respectively, is impressed upon a pair of deflector plates 34 of a cathode ray oscillograph 32, in the manner shown. With this connection, the voltage impressed across the deflector plates is proportional to the difference of the currents 28 and 29. In a similar manner, the potential drop due to currents 30 and 31 flowing through resistances 41 and 42, respectively, is impressed upon a pair of deflector plates 33 associated with the oscillograph 32, which deflector plates 33 are placed at right angles to deflector plates 34, as shown.

Assuming full wave rectification in rectifiers 24 to 27, inclusive, the rectified current in each output circuit will vary with time in manner shown in Fig. 5. Referring now to Fig. 4, a voltage will be impressed upon the deflector plates 34 of the oscillograph 32 which is proportional to rectified current 21 subtracted from current 20. If D (Fig. 4) indicates the direction of propagation of the wave train, the voltage impressed upon deflector plates 34 will be proportional to

$$ab-af \propto ac+ah=ad.$$

Correspondingly, the voltage impressed upon deflector plates 33 will be proportional to current 23 subtracted from current 22, or referring to Fig. 4, the voltage is proportional to

$$am-ae \propto ai+ag=ak.$$

Since the voltage impressed upon plates 34 acts upon the electron stream of the oscillograph at right angles to the voltage impressed upon plates 33, the electron stream will be deflected along a line determined by the resultant of these two voltages added vectorially. Referring to Fig. 4, the resultant voltage impressed upon the electron stream is proportional to ap, which is obtained by adding $ak=pd$ at right angles to ad. Since the rectified currents 28 to 31, inclusive, as explained above, fluctuate between zero and a maximum value proportional to the input alternating currents 20 to 23, inclusive, the electron stream will periodically trace out a path on the screen 36 of the oscillograph 32 from the center of the tube to a maximum value and back again along a line making an angle θ with the horizontal, the length of the path thus traced out being proportional to the magnitude of the voltage impressed upon the antenna system by the impinging radio wave train.

It will thus be seen from the explanation given above that the invention covers a circuit arrangement furnishing a method of determining both the magnitude and direction of propagation of a radio wave train impinging upon the antenna system.

It was shown above that for full wave rectification the currents 28 to 31, inclusive, fluctuated with time in the manner shown in Fig. 5. For half wave rectification the currents would fluctuate with time, as shown by curve 1 of Fig. 6. This same result could be obtained by combining full wave rectification with non-rectified current of the same peak value, as shown, by adding curve 2 to curve 3 of Fig. 6. For observing upon sustained oscillations of constant amplitude it might be advisable in some instances to insert low pass filters in the output circuits of the rectifiers 24 to 27, inclusive, of Fig. 3, the purpose of which would be to smooth out the fluctuating rectified currents flowing through resistances 39 to 42, inclusive, into steady direct currents, as shown in Fig. 7. The resultant filtered direct current through resistances 28 to 31, inclusive, would impress constant potentials across deflector plates 33 and 34. The resultant constant voltage acting upon the electron stream would cause it to impinge constantly upon a given point of the screen, the distance of which point from the origin, that is, the center of the screen, would be proportional to the magnitude of the impressed raido wave train, and the line through the point and the origin would make an angle θ with the horizontal, indicating the direction of propagation of said wave train, the direction from which the wave impinged being indicated by the quadrant of the circle in which the point was located. Fig. 8 shows the manner in which the voltage impressed across the deflector plates varies with time when filtered rectified current is combined with non-rectified alternating current of the same maximum value.

What is claimed is:

1. In a circuit for determining the magnitude and direction of propagation of radio waves, the combination of three coaxially aligned antennæ comprising two identical loop antennæ, the planes of which are set at right angles to each other, and a vertical antenna, means for separately amplifying and demodulating the currents induced in the three antennæ circuits in such manner that the demodulated currents are in like time phase relation, means for combining in a first electrical circuit demodulated current from the vertical antenna in like time phase relation with similar current from a given loop antenna, means for combining in a second electrical circuit demodulated current from the vertical antenna with similar current from said loop antenna but in phase opposition thereto, means for similarly combining in a third and a fourth electrical circuit, respectively, demodulated current from the vertical antenna with similar current from the second loop antenna in like time phase relation and in phase opposition, rectifying means individual to said four electrical circuits adapted to impress upon identical resistances individual to the outputs of each of said rectifying circuits, fluctuating direct voltages proportional to the alternating voltages impressed upon said rectifiers, a cathode ray oscillograph having associated therewith two pairs of deflecting plates set at right angles to each other, means for impressing upon one pair of deflecting plates a voltage proportional to the difference of the two rectified currents first mentioned, and means for impressing upon the second pair of said deflecting plates a voltage proportional to the difference of the two rectified currents last mentioned.

2. In a radio receiving circuit for determining the magnitude and direction of propagation of radio waves, the combination of three coaxially aligned antennæ comprising a vertical antenna and two identical loop antennæ the planes of which are set at right angles, electrical circuits individual to said antenna, amplifiers in each of said electrical circuits, a source of locally generated oscillating current, means for applying said locally generated current directly to each of the electrical circuits associated with the loop antenna, means for applying the locally generated oscillations through a phase shifting device to the vertical antenna circuit, said phase shifting device being adapted to cause said currents, applied to the vertical antenna, to differ in phase by 90 degrees as compared to that applied to the loop antenna circuits, demodulating and amplifying circuits individual to the three antenna circuits, a system of interconnected transformer associated with the output circuits of the amplifiers last mentioned, said transformer circuits being adapted to combine in a first electrical circuit demodulated current from the vertical antenna circuit in like time phase with similar current from a given loop antenna circuit, said transformer circuit being further adapted to simultaneously combine in a second electrical circuit demodulated current from the vertical antenna circuit with similar current from said loop antenna circuit but in phase opposition thereto, said transformer circuit being further adapted to similarly combine in a third and a fourth electrical circuit, respectively, demodulated current from the vertical antenna circuit with similar current from the second loop antenna circuit in like time phase relation and in phase opposition thereto, respectively, rectifying circuits individual to each of said four electrical circuits adapted to furnish in the output circuits fluctuating direct currents proportional to the alternating current impressed upon the inputs, a cathode ray oscillograph having associated therewith two pairs of deflecting plates, one pair of which is set at right angles to the other, means for impressing upon one pair of said deflecting plates a voltage proportional to the difference of the two rectified currents obtained from the vertical and a given loop antenna, and means for impressing upon the second pair of deflecting plates a voltage proportional to the difference of the two rectified currents obtained from the vertical and the second loop antenna circuits.

3. In a radio receiving circuit for determining the magnitude and direction of propagation of radio waves, the combination of three coaxially aligned antennæ comprising a vertical antenna and two identical loop antennæ, the planes of which are set at right angles, electrical circuits individual to said antenna, amplifiers in each of said electrical circuits, a source of locally generated oscillating current, means for applying said locally generated current directly to each of the electrical circuits associated with the loop antenna, means for applying the locally generated oscillations through a phase shifting device to the vertical antenna circuit, said phase shifting device being adapted to cause the current applied to the vertical antenna, to differ in phase by 90 degrees as compared to that applied to the loop antenna circuits, demodulating and amplifying circuits individual to the three antenna circuits, a system of interconnected transformers as-

sociated with the output circuits of the amplifiers last mentioned, said transformer circuits being adapted to combine in a first electrical circuit demodulated current from the vertical antenna circuit in like time phase with similar current from a given loop antenna circuit, said transformer circuit being further adapted to simultaneously combine in a second electrical circuit demodulated current from the vertical antenna circuit in like time phase with similar current from a given loop antenna circuit, said transformer circuit being further adapted to simultaneously combine in a second electrical circuit demodulated current from the vertical antenna circuit with similar current from said loop antenna circuit but in phase opposition thereto, said transformer circuit being further adapted to similarly combine in a third and a fourth electrical circuit demodulated current from the vertical antenna circuit with similar current from the second loop antenna circuit in like time phase relation and in phase opposition thereto, respectively, rectifying circuits individual to each of said four electrical circuits adapted to furnish in the output circuits fluctuating direct currents proportional to the alternating current impressed upon the inputs, low pass filters inserted in the output circuits of said rectifiers and individual thereto, said low pass filters being adapted to transform the fluctuating direct current to a steady direct current, a cathode ray oscillograph having associated therewith two pairs of deflecting plates, one pair of which is set at right angles to the other, means for impressing upon one pair of said deflecting plates a voltage proportional to the difference of the two rectified currents obtained from the vertical and a given loop antenna, and means for impressing upon the second pair of deflecting plates a voltage proportional to the difference of the two rectified currents obtained from the vertical and the second loop antenna circuits.

4. The method for determining the magnitude and direction of propagation of radio waves, which comprises, detecting components thereof which vary in accordance with said direction of propagation, detecting other components which are independent of said direction, combining said dependent with said independent components and rectifying the same, deflecting an electronic stream in accordance with said rectified components to give an indication of the magnitude and also the absolute direction of propagation of said waves.

5. The method for determining the magnitude and direction of propagation of radio waves, which comprises detecting components thereof which are independent of said propagation direction and detecting other components which are dependent thereupon, combining said dependent with said independent components and rectifying the same, deflecting an electronic stream in accordance with said rectified components to give an indication of the magnitude of said waves and the direction of the source thereof.

6. The method for determining the magnitude and absolute direction of propagation of a radio wave train, which comprises, detecting a first component thereof which varies in a certain manner in accordance with said direction of propagation, detecting a second component thereof which varies in a different manner in accordance with said direction, detecting a third component thereof which is independent of said direction, independently combining said first and third and said second and third components, rectifying said combinations, deflecting an electronic stream in accordance with said rectified combinations, and causing said deflected stream to indicate the magnitude and absolute propagation direction of said wave train.

7. The method for determining the magnitude and absolute propagation direction of a radio wave train, which comprises, detecting a first component thereof which varies in a certain manner in accordance with the direction of said propagation, detecting a second component which varies in a different manner in accordance with said direction, detecting a third component which is independent of said direction, combining said first and third components in like phase relation and in phase opposition, similarly combining said second and third components, rectifying said combinations, deflecting an electronic beam in accordance with the difference of said first two rectified combinations and at an angle thereto deflecting said beam in accordance with the difference of said last two rectified combinations, and causing said deflected beam to indicate the magnitude and absolute direction of propagation of said wave train.

8. The method for determining the magnitude and absolute direction of propagation of a radio wave train, which comprises, independently detecting components of said wave train which are proportional to the sine and also to the cosine of the angle between said propagation direction and an arbitrarily chosen direction. as well as a component thereof which is independent of said propagation direction, combining said independent component in like phase relation and also in phase opposition with said sine component, similarly combining said independent component in like phase relation and in phase opposition with said cosine component, rectifying said combinations, deflecting a concentrated electronic beam in accordance with the difference of said first two rectified combinations, and at right angles thereto deflecting

said beam in accordance with the difference of said last two rectified combinations, and causing said deflected beam to indicate the magnitude of said wave train and also the direction from whence it issues.

9. The method for determining the magnitude and absolute direction of propagation of a radio wave train, which comprises, independently detecting components of said wave train proportional to the sine and also to the cosine of the angle which the propagation direction makes with an arbitrarily chosen direction, and also a component independent of said propagation direction, independently combining said sine component in like phase relation with said independent component and also in phase opposition thereto, similarly combining said cosine component with said independent component, separately rectifying the four combinations thus obtained, deflecting a concentrated electronic beam with a voltage proportional to the difference of said two rectified currents containing said sine components, and at right angles thereto deflecting said beam with a voltage proportional to the difference of the two rectified currents containing said cosine components and causing said deflected beam to visibly indicate the magnitude of said wave train as well as the direction from whence it issues.

10. Means for determining the magnitude and absolute direction of propagation of radio waves, comprising in combination, a vertical antenna and coaxial therewith two loop antennæ set at an angle to each other, means for combining in like phase relation and also in phase opposition, currents from said vertical and a first loop antenna, means for similarly combining currents from said vertical and said second loop antenna, means for rectifying said current combinations, a cathode ray oscillograph having one pair of deflecting plates set at an angle to the second pair, means for applying to said first pair of plates a voltage proportional to the difference of said two rectified currents first mentioned, and means for applying to said second pair of plates a voltage proportional to the difference of said two rectified currents last mentioned, whereby said oscillograph indicates both the magnitude and the absolute direction of propagation of said wave train.

11. Means for determining the magnitude and absolute direction of propagation of radio waves, which comprises in combination, a vertical antenna and coaxial therewith two loop antennæ the planes of which are set at right angles to each other, means for combining in like phase relation and also in phase opposition currents from said vertical and a first loop antenna, means for similarly combining currents from said vertical and said second loop antenna, means for rectifying said combined currents, a cathode ray oscillograph having a first pair of deflecting plates set at right angles to a second such pair, means for applying to said first pair of plates a voltage proportional to the difference of said two rectified currents first mentioned, and similar means for applying to said second pair of plates a voltage proportional to the difference of said two rectified currents last mentioned.

12. Means for determining the magnitude and absolute direction of propagation of radio waves, which comprises in combination, a vertical antenna and coaxial therewith a first loop antenna set at right angles to a second identical loop antenna, amplifying and heterodyne detecting means individual to said antennæ for adjusting the magnitudes of the detected currents therein to the same value and also for adjusting said currents in like phase relation, means for combining in like phase relation and also in phase opposition detected currents from said vertical and a first loop antenna, means for similarly combining currents from said vertical and said second loop antenna, means for independently rectifying said current combinations, a cathode ray oscillograph having one pair of deflecting plates set at right angles to a second pair, means for applying to said first pair of plates a voltage proportional to the difference of said two rectified current combinations first mentioned, and means for applying to said second pair of plates a voltage proportional to the difference of said two rectified current combinations last mentioned, whereby said oscillograph indicates both the magnitude and the absolute direction of propagation of said wave train.

13. The method of determining the magnitude and absolute direction of propagation of radio waves, which consists in detecting components thereof, combining one of said components with a second one of said components and a third one of said components with said second one, rectifying said combinations, deflecting an electronic beam in accordance with the difference of said first two rectified combinations, deflecting said beam at an angle thereto in accordance with the difference of said last two rectified combinations and causing said deflected beam to indicate the magnitude and absolute direction of propagation of said waves.

14. Means for determining the magnitude and absolute direction of propagation of radio waves comprising in combination a vertical antenna, two loop antennæ set at an angle to each other, means for combining currents from said vertical and a first loop antenna and currents from said vertical and second loop antenna, means for rectifying said current combinations, means for producing an electronic beam, and means for apply-

ing said rectified current combinations to said latter means to deflect said beam and cause it to indicate the magnitude and absolute direction of propagation of said waves.

In testimony whereof, I have signed my name to this specification this 23rd day of April, 1928.

AUSTIN BAILEY.