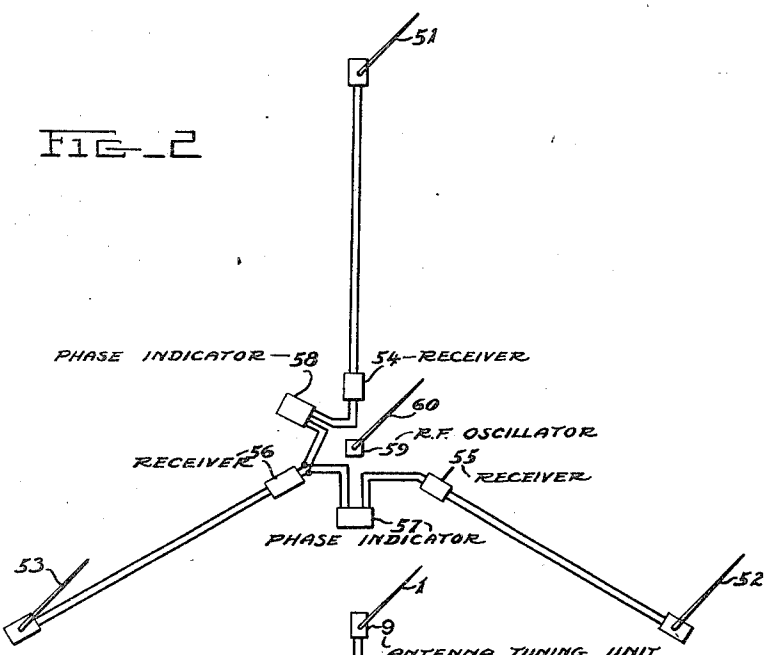
Feb. 4, 1947. E. N. DINGLEY, JR 2,415,088

RADIO DIRECTION FINDER

Filed Dec. 16, 1938

FIG. 2



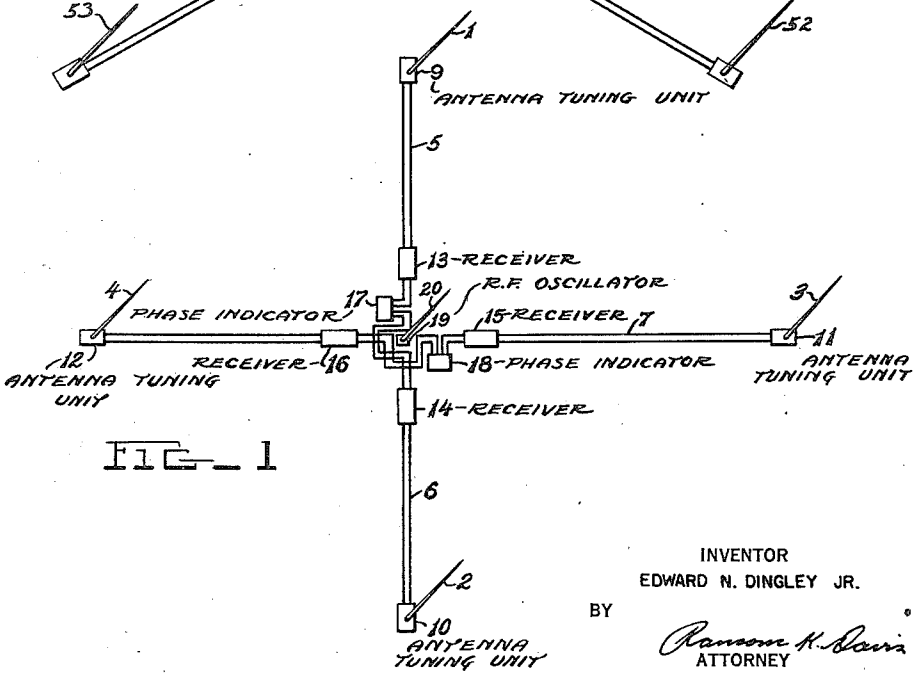


FIG. 1

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RADIO DIRECTION FINDER

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My invention relates broadly to radio direction finder systems by means of which the direction of arrival of radio waves may be determined accurately.

My invention relates chiefly to circuit arrangements in which the phase differences between the voltages induced in a plurality of immobile wave collector systems is indicated.

One of the objects of my invention is to provide a radio direction finder system by means of which the direction of arrival of radio waves may be determined regardless of the polarization of such waves and regardless of the vertical angle of incidence of such waves.

Another object of my invention is to provide means by which the phase differences of the voltages induced in a plurality of collector systems is indicated thus making it possible to determine both the true azimuth and the vertical angle of incidence of the wave which induced the said voltages in the said collectors.

Still another object of my invention is to provide a radio direction finder system which will be capable of determining accurately the direction of arrival of radio waves having any frequency used in radio communication and to achieve this objective without the necessity of rotating or moving the collector system.

Other and further objects of my invention will be understood from the following specification and by reference to the accompanying drawing in which:

Fig. 1 diagrammatically illustrates a fundamental circuit arrangement of my invention.

Fig. 2 diagrammatically illustrates a modified circuit arrangement of my invention.

Fig. 1 illustrates one embodiment of my invention wherein the vertical antennas, or collectors 1, 2, 3, 4 and 20 are mounted in fixed relation to the earth. Antennas 1, 2 and 20 lie in a vertical plane which is perpendicular to the vertical plane containing the antennas 3, 4 and 20. Antennas 1, 2, 3 and 4 are equidistant and not more than one-half wave length from antenna 20 and are respectively connected to the antenna tuning units 9, 10, 11 and 12, which are respectively connected to the radio receivers 13, 14, 15 and 16, by means, respectively of the transmission lines 5, 6, 7 and 8. The audio output circuits of receivers 13 and 14 are connected to the phase indicating device 17 and the audio output circuits of receivers 15 and 16 are connected to the phase indicating device 18. The source of radio frequency energy, oscillator 19, is connected to the antenna 20 which serves to radiate said energy.

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The circuits of radio receivers 13, 14, 15 and 16 are not shown for the reason that any type of radio receiver such as a common broadcast receiver used for home entertainment capable of receiving a modulated radio frequency signal and of delivering at its output terminals the detected audio frequency component thereof will serve the desired purpose and such receiver circuits are well known to the radio art.

The audio frequency amplifier circuits of the radio receivers should be matched, that is, a signal of any audio frequency between the approximate limits of 300 to 4000 cycles per second should encounter equal phase shifts in transversing each audio frequency amplifier. This requirement may be fulfilled by means well known to the art. The circuits of the antenna tuning units 9, 10, 11 and 12 are not shown for the reason that any type of tuning unit will serve the purpose, or the tuning units may be omitted with some sacrifice of signal strength, and such tuning units are likewise well known, as for example those described in the Proceedings of the Institute of Radio Engineers, volume 23, November 1935, pages 1268 to 1307. The circuits of the oscillator 19 are not shown for the reason that any well known type of oscillator capable of delivering a few microwatts of radio frequency energy to the antenna 20 will serve the desired purpose.

The antennas 1, 2, 3 and 4 may be at distances greater than one-half wave length from antenna 20 but such spacing results in multiple bearings. As used herein, "at two spaced points" is defined as meaning approximately one-half wave length but preferably less than one-half wave length of the highest operating frequency.

In the following, the wave originating at a distant point, the azimuth of which is to be determined, will be termed the "distant wave."

In order to demonstrate the advantages of my invention as compared to well known types of direction finders utilizing immobile antennas, it is desirable to show wherein large errors are produced in the well known types, by waves which arrive not along the ground but at angles considerably elevated above the horizon.

In practically all of the well known types of direction finders using four immobile antennas, as for example those described in the Proceedings of the Institute of Radio Engineers, volume 17, March 1929, pages 425 to 478; the transmission line 5 is transposed and connected in parallel with transmission line 6 and a means is provided to measure the voltage produced at their junction. This voltage is proportional to

the difference between the voltages induced in antennas 1 and 2 provided that the impedances of the two antennas and of the two transmission lines are identical, a condition difficult of achievement. In the same manner, the voltage between the junctions of transmission lines 7 and 8 is measured. In the following let:

E_1, E_2, E_3, E_4=Peak voltages induced in antennas 1, 2, 3 and 4 respectively.

e_1, e_2, e_3, e_4=Instantaneous voltages induced in antennas 1, 2, 3 and 4 respectively.

θ=Electrical degrees spacing between antenna 20 and antennas 1, 2, 3 and 4.

z=Azimuth of arriving wave measured clockwise from antenna 1 with antenna 20 as a center.

h=Vertical angle of incidence of arriving wave above the horizon.

wt=Instantaneous phase of the arriving wave at the antenna 20 at the time t.

Then:

$$e_1=E_1 \sin (wt+\theta \cos z \cos h) \quad (1)$$
$$e_2=E_2 \sin (wt-\theta \cos z \cos h) \quad (2)$$
$$e_3=E_3 \sin (wt+\theta \sin z \cos h) \quad (3)$$
$$e_4=E_4 \sin (wt-\theta \sin z \cos h) \quad (4)$$

Then, assuming $E_1=E_2=E_3=E_4=E$

$$e_1-e_2=2E \sin (\theta \cos z \cos h) \cos wt \quad (5)$$
$$e_3-e_4=2E \sin (\theta \sin z \cos h) \cos wt \quad (6)$$

And the ratio of:

$$\frac{e_1-e_2}{e_3-e_4}=M=\frac{\sin (\theta \cos z \cos h)}{\sin (\theta \sin z \cos h)} \quad (7)$$

Equation 7 indicates that if the spacing θ is fixed, if the azimuth z is fixed, and if the angle of incidence h is variable, the ratio M will not be a constant except when the azimuth z is 45 degrees or any multiple thereof. In the well known types of direction finders utilizing the aforestated principle, the azimuth of the wave is determined by the ratio M. It has been demonstrated that for a given azimuth other than multiples of 45 degrees, M varies with the angle of incidence h and because h is unknown, the direction finder cannot be calibrated to eliminate these errors.

This variation results in serious errors of indicated azimuth unless the spacing θ is made very small under which conditions the voltages e_1-e_2 and e_3-e_4 become very small and the sensitivity of the direction finder is thereby greatly reduced. Furthermore, Equations 1 through 7 are based on the assumption that the impedances of all four antennas and of all four transmission lines are equal. Since this condition is not usually attainable over wide tuning ranges, the magnitudes and phases of the voltages delivered from the transmission lines will not be equally proportional to the magnitudes and phases of the voltages induced in the antennas. Equations 1 through 7 demonstrate that such a lack of proportionality will produce large errors in the value of M and corresponding large errors in the indicated azimuth or bearing.

My invention, as described hereinafter, eliminates the errors and disadvantages, as above set forth, by providing a direction finder system which does not require that the antennas and transmission lines have identical characteristics. This is accomplished by introducing the energy derived from the heterodyning oscillator 19 into the antenna of each radio receiver instead of into the receiver itself. Introducing the heterodyning signal at the antenna subjects the heterodyning signal to essentially the same attenuation and phase shift as is encountered by the distant wave or signal in traversing the antenna and transmission line because the two signals differ in frequency by only a fraction of a percent or by 300 to 4000 cycles per second in a total of 1000 to 100,000 kilocycles per second.

If two waves or signals such as $E_h \sin (wt+\phi_1)$ and $E_d \sin (pt+\phi_2)$ are combined and detected or demodulated, their difference-frequency signal will be

$$\frac{E_h E_d}{2} \cos (wt-pt+\phi-\phi_2)$$

It is to be noted that the phase of the difference-frequency signal is determined by $\phi_1-\phi_2$. If ϕ_1 and ϕ_2 are both increased or decreased by the same number of electrical degrees, the phase of the difference-frequency signal remains unchanged. It is for this reason that the antenna, the transmission line or the radio receiver, being traversed simultaneously by the heterodyning signal (E_h) and by the distant wave or signal (E_d), may be tuned entirely through resonance without increasing or decreasing the phase of the difference-frequency signal from the value it would have had if both radio frequency signals had encountered no phase shift at all. The only result of mis-tuning the antenna, transmission line or radio receiver is a loss of detected signal magnitude as would be expected.

The last-stated formulae also prove that if the phase (ϕ_2) of the distant signal in increased or decreased by a given amount, due to a change in azimuth of the distant source, while ϕ_1 remains fixed, then the phase of the difference-frequency signal is increased or decreased by the same amount.

In my invention the phase (ϕ_1) of the heterodyning signal is held constant and equal at each of the four antennas 1, 2, 3 and 4 of Fig. 1 by radiating the signal from an antenna (20 of Fig. 1) which is located at a point equidistant from the aforesaid four antennas.

If all time and space phases are measured with respect to the central antenna 20 of Fig. 1 or 60 of Fig. 2, then ϕ_1 becomes zero and the phase difference between the difference-frequency signals (audio output signals) of two receivers such as 13 and 14 of Fig. 1, will be exactly equal to the phase difference between the radio frequency voltages induced, on their antennas 1 and 2 of Fig. 1, by the distant wave or signal.

In consequence of the foregoing, Equations 1 through 4, which were defined in terms of the radio frequency voltages induced in antennas 1, 2, 3 and 4 by the distant wave, apply with equal rigor to the audio output voltages delivered by the receivers 13, 14, 15 and 16, except that the magnitudes of the audio voltages will be altered and will not necessarily be equal to each other and except that wt is now taken to represent the instantaneous phase at the time t of the audio output of a receiver which might be connected to antenna 20. No receiver is connected to antenna 20; this point is used solely for reference phase.

In my invention, the voltages e_1 and e_2 are not connected together so as to subtract in a common circuit. Neither are voltages e_3 and e_4 so connected. In my invention, the voltages e_1 and e_2 are delivered to a phase indicating device 17 which indicates the phase angle between e_1 and e_2 regardless of their relative magnitudes. In the same manner, the phase indicating device 18 indicates the phase angle between e_3 and e_4.

In Equations 1 through 4, the instantaneous phase of e_1 is $\phi_1=(wt+\theta \cos z \cos h)$ and the instantaneous phase of e_2 is $\phi_2=(wt-\theta \cos z \cos h)$ and therefore the phase difference between e_1 and e_2 is:

$$\phi_{12}=2\theta \cos z \cos h \quad (8)$$

And the instantaneous phase difference between e_3 and e_4 is:

$$\phi_{34}=2\theta \sin z \cos h \quad (9)$$

And the ratio of ϕ_{34} to ϕ^{12} is:

$$\frac{\phi_{34}}{\phi_{12}}=\frac{\sin z}{\cos z}=\tan z \quad (10)$$

Equation 10 demonstrates that when using my invention, it is only necessary to observe the phase angle ϕ_{34} as indicated by the device **18**, and to observe the phase angle ϕ_{12} as indicated by the device **17**, to divide ϕ_{34} by ϕ_{12} and to find the angle z whose tangent is equal to this quotient in order to determine the azimuth z with great accuracy. The values of the spacing θ and of the angle of incidence h, do not enter into this determination. Furthermore, having thus determined the azimuth z, its value may be substituted in either Equation 8 or in Equation 9 and the value of the angle of incidence h may thus be determined if desired.

Figure 2 illustrates another embodiment of my invention wherein the vertical antennas **51**, **52**, **53** and **60** are mounted in fixed relation to the earth. Antennas **51**, **52** and **53** are equidistant from antenna **60** and are spaced 120 arc degrees from each other. The antennas **51**, **52** and **53** are connected to the radio receivers **54**, **55** and **56** respectively by means of transmission lines and antenna tuning units which are identical to those described in connection with Figure 1. The audio output circuits of receivers **54** and **56** are connected to the phase indicating device **58** and the audio output circuits of receivers **55** and **56** are connected to the phase indicating device **57**. The source of radio frequency energy (oscillator) **59** is connected to the antenna **60** which serves to radiate said energy. The oscillator **59** is identical to the oscillator **19** of Figure 1. The radio receivers and phase indicating devices of Figure 2 are identical to the radio receivers and phase indicating devices described in connection with Figure 1.

The equations for the voltages induced in the antennas **51**, **52** and **53** (or for the audio voltages delivered by the receivers) are somewhat similar to Equations 1 through 4 as follows:

$$e_1=E_1 \sin (wt+\theta \cos z \cos h) \quad (11)$$

$$e_2=E_2 \sin (wt+\theta \cos [z-120°] \cos h) \quad (12)$$

$$e_3=E_3 \sin (wt+\theta \cos [z+120°] \cos h) \quad (13)$$

The phase difference between e_1 and e_3 is:

$$\phi_{13}=\theta \cos h \ (1.5 \cos z+0.866 \sin z) \quad (14)$$

And the phase difference between e_2 and e_3 is:

$$\phi_{23}=\theta \cos h \ (1.732 \sin z) \quad (15)$$

And the ratio of ϕ_{13} to ϕ_{23} is:

$$\frac{\phi_{13}}{\phi_{23}}=\frac{1.5 \cos z}{1.732 \sin z}+\frac{0.866 \sin z}{1.732 \sin z}=\frac{0.866}{\tan z}+0.5 \quad (16)$$

or

$$\tan z=\frac{0.866}{\frac{\phi_{13}}{\phi_{23}}-0.5} \quad (17)$$

Equation 17 demonstrates that when using my invention, it is only necessary to observe the

phase angle ϕ_{13} as indicated by the device **58**, and to observe the phase angle ϕ_{23} as indicated by the device **57**, to divide ϕ_{13} by ϕ_{23}, to subtract 0.5 from this quotient and to divide the resultant into 0.866 in order to find the tangent of the azimuth z and from the tangent to determine the azimuth z with great accuracy. The values of the spacing θ and of the angle of incidence h, do not enter into this determination. Furthermore, having thus determined the azimuth z, its value may be substituted in either Equation 14 or in Equation 15 and the value of the angle of incidence h may be thus determined if desired.

The phase indicating devices **17**, **18**, **57** and **58** may be of any kind or type. The use of certain types requires that the magnitudes of the two voltages must be closely identical. This requirement can be fulfilled by the use of well known types of automatic volume control circuits in conjunction with the radio receivers. Certain other types of phase indicating devices require that the frequencies of the voltages must be nearly constant. This requirement can be fulfilled by the use of well known types of automatic frequency control circuits in connection with the radio receivers.

The invention herein described and claimed may be used and/or manufactured by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

I claim:

1. A method of determining the azimuth angle between a selected line and the path of an incoming distant radio wave, comprising the steps of collecting energy from said wave at two spaced points on said line, determining a first phase angle between the waves at the two said points of collection, collecting energy from said wave at two other points spaced from each other the same distance as are the first mentioned two points and on a line normal to said selected line midway between the first mentioned two points, determining a second phase angle between the waves at the second mentioned two points, determining the ratio between the said second phase angle and said first phase angle, which ratio evaluates the tangent of said azimuth angle, and from said tangent determining said azimuth angle.

2. A method of determining the azimuth angle between a selected line and the path of an incoming distant radio wave, comprising the steps of collecting energy from said wave at first, second and third points symmetrically disposed about a central point, said selected line passing through said first point and said central point, determining a first phase angle between the wave at said first point and that at said second point, determining a second phase angle between the waves at said second point and said third point, determining the ratio of said first phase angle to said second phase angle, which ratio evaluates the tangent of said azimuth angle, and from said tangent determining said azimuth angle.

3. A method of determining the azimuth angle between a selected line and the path of an incoming distant radio wave, comprising the steps of collecting energy from said wave at a plurality of points symmetrically disposed about a central point, said selected line passing through said central point and at least one of said collection points, determining a first phase angle between the wave at one of said collection points and the wave at a second collection point, likewise deter-

mining a second phase angle between the waves at a different two of said collection points, determining the ratio between the said phase angles, which ratio evaluates a function of the said azimuth angle, and from said function determining the said azimuth angle.

4. A method of determining the azimuth angle between a selected line and the path of an incoming distant radio wave, comprising the steps of collecting energy from said wave at a plurality of points symmetrically disposed about a central point, said selected line passing through said central point and at least one of said collection points, radiating from said central point energy of a frequency to beat with said incoming wave to produce audio frequency, determining a first phase angle between the audio frequency waves derived from energy collected at two respective said collection points, likewise determining a second phase angle between the audio frequency waves derived from energy respectively collected at a different two of said collection points, determining the ratio between said phase angles, which ratio evaluates a function of the said azimuth angle, and from said function determining said azimuth angle.

5. A system for determining the azimuth angle between a selected line and the path of an incoming distant radio wave, comprising means to radiate a local wave at a frequency to produce an audio beat frequency with said incoming wave, two collectors equidistantly spaced from said local radiating means on said selected line, means respectively connected to each of said collectors to detect the beat frequency derived from energy of said distant wave collected at each of said collectors, means connected to indicate a first phase angle between the said two beat frequencies, two other like collectors equidistantly spaced from said local radiating means on a line through said local radiating means perpendicular to said selected line, means respectively connected to each of said two other collectors to detect the beat frequency derived from energy of said distant wave collected at each of said two other like collectors, and means connected to indicate a second phase angle between the beat frequencies from said two other collectors, the ratio of said second phase angle to said first phase angle being the tangent of said azimuth angle.

6. A system for determining the azimuth angle between a selected line and the path of an incoming distant radio wave, comprising means to radiate a local wave at a frequency to produce an audio beat frequency with said incoming wave, a first, a second and a third collector disposed equidistantly from said local radiating means and from each other, one of said collectors and said local means lying on said selected line, means respectively connected to each of said collectors to detect the beat frequency derived from energy of said distant wave collected at each of said collectors, means connected to indicate a first phase angle between the beat frequencies from said first and second collectors, and means to

indicate a second phase angle between the beat frequencies from said second and third collectors, the ratio of said first phase angle to said second phase angle evaluating the tangent of said azimuth angle.

7. A system for determining the azimuth angle between a selected line and the path of an incoming distant radio wave, comprising means to radiate a local wave at a frequency to produce an audio beat frequency with said incoming wave, a plurality of collectors symmetrically disposed around said local radiating means, said local radiating means and at least one of said collectors lying on said selected line, means to detect the beat frequency derived from energy of said distant wave collected at each of said collectors, means connected to two of said detecting means to indicate the phase angle between the beat frequencies detected thereby and means connected to another two of said detecting means to indicate the phase angle between the beat frequencies detected thereby, the ratio of one of said phase angles to the other evaluating a function of said azimuth angle.

8. A system for determining the azimuth angle between a selected line and the path of an incoming distant radio wave, comprising means to radiate a local wave at a frequency to produce an audio beat frequency with said incoming wave, a plurality of collectors disposed around said local radiating means equidistantly from said radiating means and from each other, said local radiating means and at least one of said collectors lying on said selected line, means to detect the beat frequency derived from energy of said distant wave collected at each of said collectors, means connected to two of said detecting means to indicate the phase angle between the beat frequencies detected thereby, and means connected to another two of said detecting means to indicate the phase angle between the beat frequencies detected by said other two detecting means, the ratio of one of said phase angles to the other evaluating a function of said azimuth angle.

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