CHART POSITION INDICATING APPARATUS

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Fig. 1.

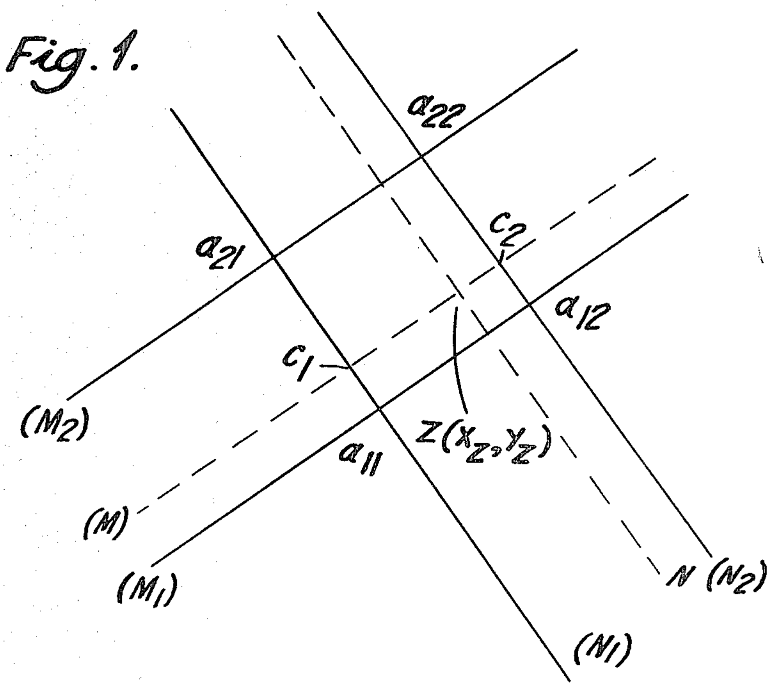

Fig. 2.

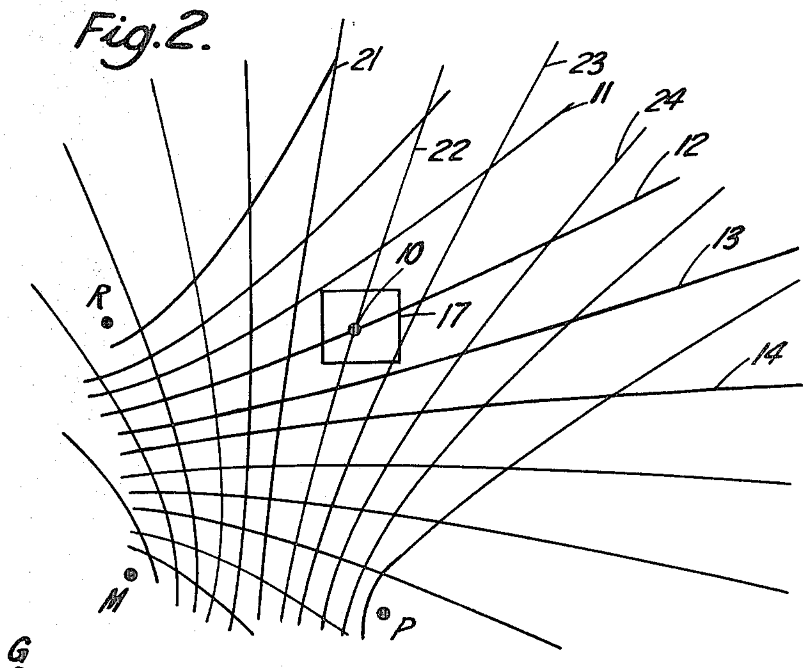

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CHART POSITION INDICATING APPARATUS

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Fig. 3.

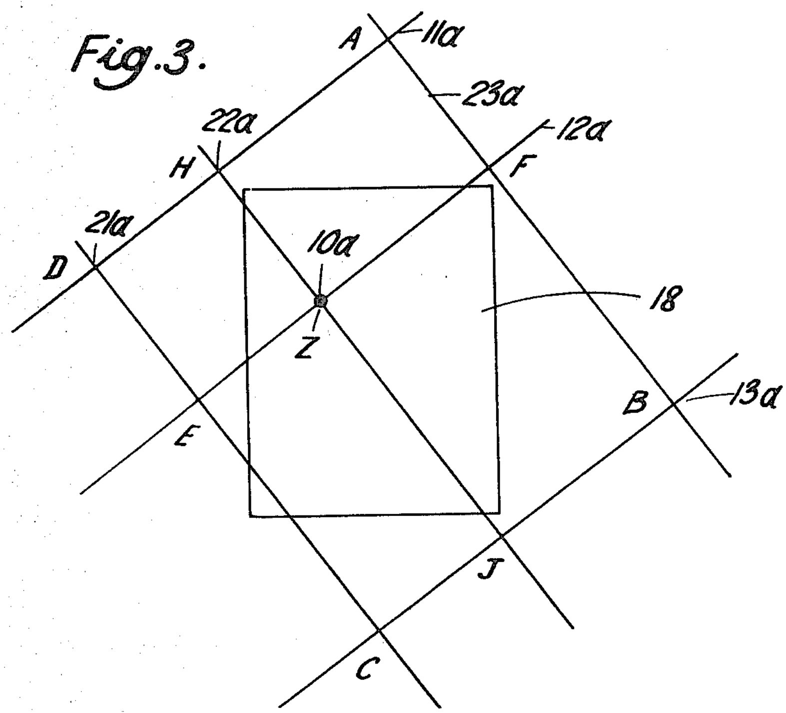

Fig. 5.

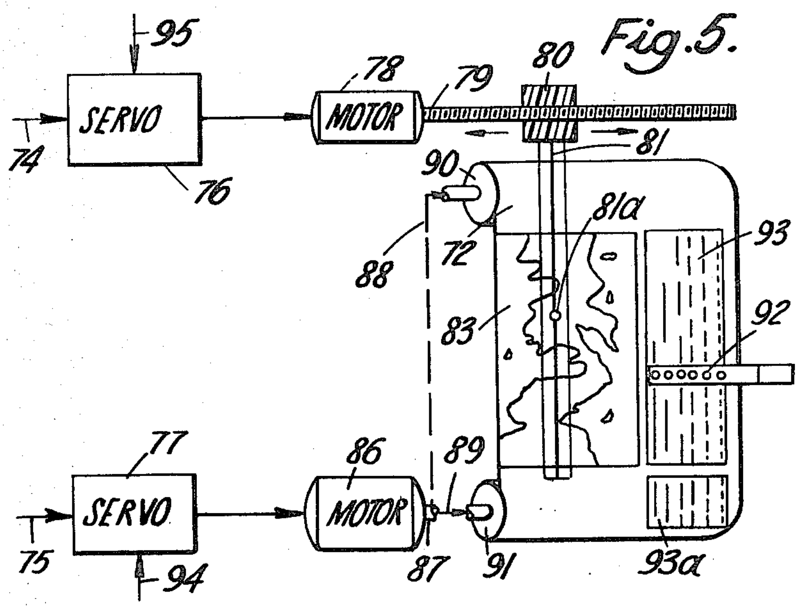

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CHART POSITION INDICATING APPARATUS

Filed April 12, 1968 3 Sheets-Sheet 3

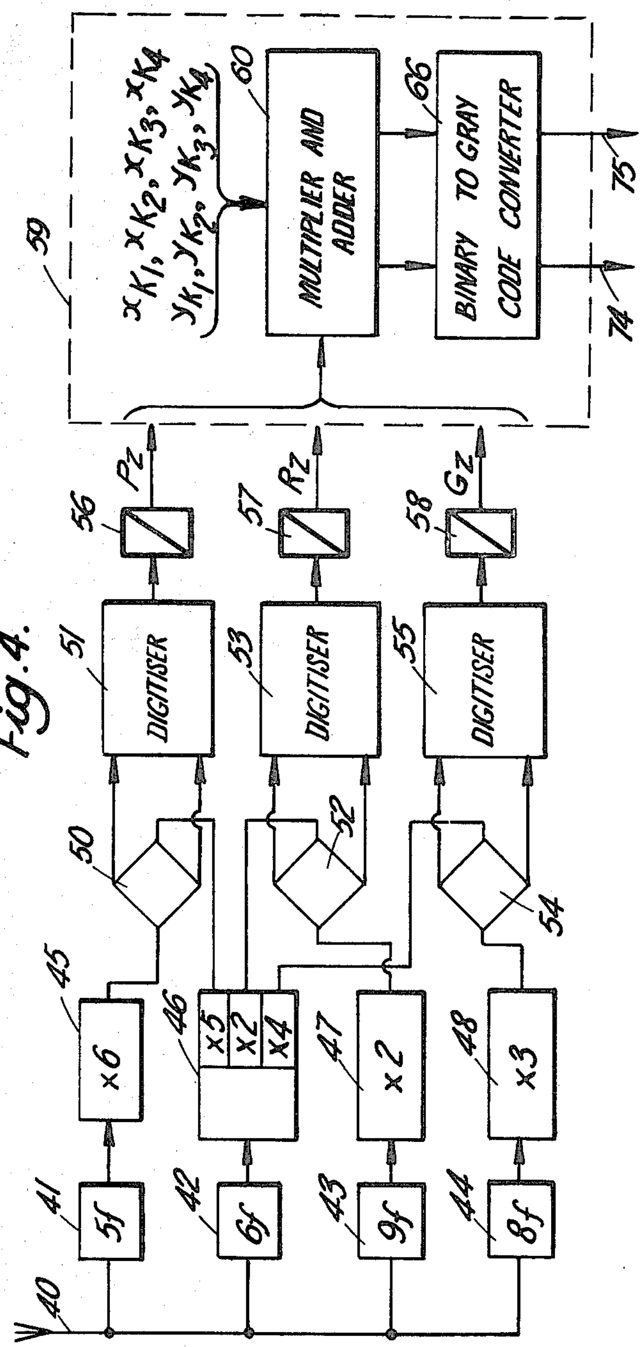

Fig. 4.

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CHART POSITION INDICATING APPARATUS

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Int. Cl. B43l 5/00
U.S. Cl. 33—1 5 Claims

ABSTRACT OF THE DISCLOSURE

A chart position indicating apparatus in which input signals, each representing one out of a family of hyperbolic position lines in a radio navigation system, are used to drive an index relative to a chart in two cartesian coordinate directions. The chart is distorted so that each family of position lines is represented on the chart by a family of straight lines inclined to both the cartesian coordinate directions and the apparatus is specially constructed to effect an associated coordinate transformation of the signals.

This invention relates to chart position indicating apparatus.

Chart position indicating apparatus is commonly used in conjunction with a radio navigation system in order to indicate on a chart a geographical position using signals obtained at a receiver which may be, for example, arranged to compare the phases of signals radiated by various pairs of stations in the radio navigation system to obtain outputs respectively representing one of two or more position lines whose intersection defines the geographical position of the receiver.

In order to display the aforementioned geographical position, the chart position indicating apparatus commonly includes an index which is relatively movable in two coordinate directions with respect to a chart, the relative movement of the index and chart being controlled in each direction from an output or outputs of the receiver (that is, using at least one signal or set of signals representing a determined position line). In general, however, the coordinate system of the movement of the chart and index (usually cartesian) is different from that of the radio navigation system, whose position lines are commonly hyperbolic but may be elliptical or circular. It is necessary therefore to effect a co-ordinate transformation of the receiver's outputs before they can be used to control the relative movements of the index and chart. Although it is possible to do this with a suitably programmed or constructed computer, it is in many ways simpler and cheaper to draw the chart with a projection that effects the required co-ordinate transformation and to use a simplified computer. This introduces some distortion of the geographical features of the chart and in the past the distortion has often been excessive. It is one of the objects of the present invention to provide chart position indicating apparatus for which the charts can be less distorted than hitherto and be at the same time easily prepared.

According to the present invention, apparatus for indicating on a chart the geographical location represented by the intersection of two position lines which are respectively members of two families of position lines of a radio navigation system adapted to provide outputs identifying a position line in each family, comprises a chart of a geographical area embracing said location, the chart being distorted such that the two families of position lines are each representable on the chart by a set of lines such that the rates of change of position, with respect to the respective output of the radio navigation system, of the intersections of a line in a set with all the lines in the other set are all constant, an index relatively movable in two orthogonal co-ordinate directions over the surface of the chart, the lines in at least one set being inclined to both the two orthogonal directions; and computing means adapted to obtain the orthogonal co-ordinates of the geographical location with respect to the chart by solving two equations which have the aforementioned outputs as variable quantities using a programme that relies on the constancy of the aforementioned rates of change, means being provided for displacing said index relative to the chart in the two orthogonal co-ordinate directions in accordance with the values of said orthogonal co-ordinates determined by said computing means.

Although the chart is used with an index movable in an orthogonal co-ordinate system, the particular manner of drawing the chart makes it possible, in general, to produce a chart with very little distortion from a geographical chart, using conventional navigational charts which are usually drawn with polyconical or mercator projections. This may be seen from the following considerations. If the "lattice" lines of the radio navigation system are drawn on a conventional navigational chart, they are usually curved, but for a small region it is possible to draw straight lines approximating very closely to these "lattice" lines. With chart position indicating apparatus heretofore it has been necessary to distort the chart so that the lattice lines are co-ordinate lines in a cartesian co-ordinate system: with the apparatus of the present invention on the other hand, the charts are arranged so that although at least the lines in one set are normally straight, the lattice lines need not be co-ordinate lines in a cartesian co-ordinate system and in practice they may be arranged so that distortion only arises by assuming the constant nature of the aforementioned rates of change. It is found that the approximation can for most practical purposes be very good.

Thus, one of the usual features of the invention is that the position lines in both families are when represented on the chart inclined to both the orthogonal directions of relative movement between the index and chart.

The present invention may be better appreciated if the most usual form of it is discussed in some detail. Preferably both families of lines are representable on the chart by a set of straight lines and preferably the aforementioned orthogonal co-ordinate directions are cartesian. With this form of the invention, the conversion of the navigation system's outputs into the cartesian co-ordinate system of the chart and index may proceed as follows, reference being made to the accompanying FIG. 1, in which M and N represent the values of two intersecting position lines (and for convenience denote the lines themselves).

It is possible to define, in each set of lines, two "reference" lines, M_1, M_2 and N_1, N_2 whose intersections a_{11}, a_{12} etc. (where a_{11} is the intersection of M_1 and N_1) and the parts of M_1, M_2, N_1 and N_2 between the intersections form a quadrilateral when drawn in the said cartesian co-ordinate system. If, for example, c_1 and c_2 are the points at which the line M intersects respectively the lines joining a_{11}, a_{21} and a_{12}, a_{22}, then, by simple ratio, the x co-ordinate of c_1 divides the x co-ordinates of a_{21} and a_{11} in the same ratio as M divides M_1 and M_2 and in the same ratio as the x co-ordinate of c_2 divides the x co-ordinates of a_{22} and a_{12}. A similar equality is true for N and thus it is possible to express X_z and Y_z, the cartesian co-ordinates of Z, the intersection of the lines M and N, by equations in which only the cartesian co-ordinates of the a_{rs} (r, s=1 or 2), the navigation system outputs corresponding to position lines through the a_{rs} (all known constants) and M and N appear. Thus the computing means need only be fed with a few constants and M, N and the values of X_z and Y_z may easily be computed to control the displacing means for the index. It should be made clear, and will be explained in more detail hereinafter, that the resultant expressions for X_z and Y_z can be more conveniently stated in the form $k_1MN+k_2M+k_3N+k_4$ and $k'_1MN+k'_2M+k'_3N+k'_4$ where all the k are constant for any point on the chart and each are *derived* from the cartesian co-ordinates of the a_{rs}. This leads to a simplification in the computation of X_z and Y_z.

According to this aspect of the invention, chart position indicating apparatus for use with a radio navigation system adapted to provide, at a mobile receiver, two outputs, M and N, each identifying a position line in a respective one of two families of intersecting position lines, comprising a chart drawn by assuming the position lines all to be straight computing, in cartesian co-ordinates with respect to the chart, the co-ordinates of the four intersections of a pair of position lines in one family with a pair in the other family and plotting the chart such that for any point on the chart, either position line through the point divides either selected position line in the other family in the same ratio as the cartesian co-ordinates of said point divide the respective cartesian co-ordinates of the intersections lying on said selected position line in the other family; an index relatively movable in the two cartesian co-ordinate directions over the surface of the chart, means for displacing said index relative to the chart to indicate the chart position (X_z, Y_z) of said location automatically in accordance with two outputs, defining X_z and Y_z respectively, of a computing means responsive to the navigation system outputs, said computing means being arranged to compute X_z and Y_z as the values of expressions of the form $k_1MN+k_2M+k_3N+k_4$ and $k'_1MN+k'_2M+k'_3N+k'_4$, or expressions which can be stated in that form, wherein k_1, k_2, k_3 and k_4 and k'_1, k'_2, k'_3 and k'_4 are constant for any point on the chart and are derived from the cartesian co-ordinates of the intersections.

The aforementioned intersections would normally lie outside the area covered by the chart; although it is possible to use directly the values of the co-ordinate defining the positions of the intersections to obtain the values of the cartesian co-ordinates of any other point, it is preferable (as already mentioned) to define various constants comprising combinations of the co-ordinates of the intersections to obtain simple expressions for calculating X_z and Y_z. These various "constants" are peculiar to a chart and signals defining them would usually be automatically fed to the computing means when a particular chart was in use. They are usually called "chart constants."

The present invention is particularly applicable but not restricted to radio navigation systems of the hyperbolic phase comparison kind. In such a system, the position lines are families of confocal hyperbolae each having two transmitting stations in the navigation system at their foci. It is well known that if one of the two stations is common to two pairs of stations it is possible to define intersecting families of hyperbolae and to define the position of a receiver as the intersection of two members of each family. For convenience, the present invention will be particularly described with reference to such a system but it will be understood that the present invention is also applicable to other navigation systems. For example, it may be used with a "two range" system which would provide outputs defining one each in two families of concentric circular position lines the intersection of the defined position lines determining the location of the receiver. Furthermore, the invention might also be used with time displacement radio navigation systems which, like phase comparison radio navigation systems, possess position lines in the form of families of confocal hyperbolae.

A preferred, but not essential feature of the invention is accordingly its use in conjunction with a radio navigation system of the kind having at least three radio transmitting stations arranged to radiate phase-locked radio frequency signals of different but harmonically related frequencies and in which a mobile receiver is arranged to compare the phases of signals received from two pairs of stations, one station being common to the two pairs, so as to obtain two outputs each representing a different position line through the location of the receiver.

The invention includes within its scope a chart for use in chart position indicating apparatus of the kind which is controlled by two outputs of a radio navigation system, each output representing a position line in one of two families of intersecting position lines and which co-operates with the chart to provide relative movement of an index and the chart in two orthogonal co-ordinate directions so that the index and chart together indicate the geographical location defined by the intersection of the position lines defined in turn by said outputs, the chart comprising a chart member bearing markings representing a geographical area that includes said location, the chart being distorted so that the two families of position lines are each representable on the chart by a set of straight, parallel lines, at least the lines in one set being inclined to both said co-ordinate directions.

It is convenient to arrange (as previously indicated), that the chart provides the constants necessary for the programme used by the computing means; accordingly, the member may carry sensible indications of at least some of a plurality of constant terms which are normally required by the apparatus for providing a conversion of the said outputs into signals appropriate for effecting relative movement of the index and chart, whereby the chart in use can co-operate with sensing means to provide signals defining the constant terms.

In the following, reference will be made to the rest of the accompanying drawings in which:

FIGS. 1 and 2 illustrate in part transmitting stations and position lines in a hyperbolic phase comparison navigation system;

FIG. 3 illustrates the arrangement of a chart in accordance with the present invention; and

FIGS. 4 and 5 illustrate in simplified block diagram form a receiver and chart position indicating apparatus, constructed in accord with the invention and for use with a radio navigation system of the kind shown in FIG. 2.

Before explaining the various approximations and mathematical computations contemplated by the present invention it is appropriate to describe by way of example a typical radio navigation system that is suitable for the present invention in order that the features of the present invention may be fully appreciated. In FIG. 2 is shown the configuration of four transmitting stations in a typical hyperbolic phase comparison radio navigation system. The four transmitting stations are spaced apart and are arranged in a star-shaped pattern with the master station M near the centre of the pattern, the "red," "green" and "purple" slave stations R, G and P being disposed around the master station. For the purposes of the present invention it may be assumed that these stations transmit continuous radio frequency signals on different but harmonically related frequencies.

The transmissions from the slave station are locked in phase to the signals from the master station further, for example, by measurement at a mobile receiver **10** of the phase relationship between signals from the master M and the slave station R a position line **12** through the geographical location of the receiver is determined. If as is usual, the frequencies radiated by the two stations are different it is necessary to bring them to a common comparison frequency before measuring their phase relationship. The position line **12** is one of a family of confocal hyperbolae having the master and slave stations M and R as foci. Some others of these hyperbolae are shown at **11**, **13** and **14**. By using a further phase comparison between the signals radiated from the same master station M and the slave station P a further hyperbolic position line **22** is obtained, the intersection of lines **12** and **22** defining the location of the receiver **10**. The position line **22** is one of a family of confocal hyperbolae having the master and purple slave stations as foci, other position lines in this family being **21**, **23** and **24**. The other halves of the position lines in the master-red set have been omitted and the position lines for the master-green set have been entirely omitted for convenience. It is common practice to refer to the results of the phase comparison between the master-red signals as the red co-ordinate and to that between the master and purple signals as the purple co-ordinate and thus they will be called hereinafter.

Also shown in FIG. 2 is an area **17** which is to be covered by a chart and which embraces the geographical location of the receiver **10**. The area shown is approximately rectangular but in practice it may deviate slightly from rectangular. It will be understood, however, that the chart itself is in normal practice always rectangular. It will be noted from FIG. 2 that the two families of position lines are divergent over the area covered by the chart; this will not always be so, the lines in a family being parallel if the chosen area is on a base line of the navigation system. It will also be noted that at least over the area covered by the chart the various position lines are approximately straight.

In FIG. 3 is shown a chart **18** having some of the position lines of FIG. 2 projected on it in accordance with the present invention.

In FIG. 3, the position lines **11**, **12**, **13** etc. are shown as the straight lines **11***a*, **12***a*, **13***a* etc. The latter lines form sets of lines which are not, of course, families of position lines, but which represent the families of the respective position lines. It will be appreciated that it is not necessary to draw lines corresponding to the aforementioned position lines actually on the chart but it is necessary to be able to calculate them so that the chart is suitable for use with the computing apparatus to be described later and so that the positions of the various geographical features on the chart may be properly located.

For each chart, it is convenient to choose from each family of position lines two reference position lines which are for the "red" set, the lines **11** and **13** and for the "purple" set are the lines **21** and **23**. The present invention places no particular restriction on the choice of the two lines except that the four points A, B, C and D which are defined as the intersections of the two pairs of reference position lines (or their corresponding lines in the chart's co-ordinate system), are preferably outside, but enclose, the area represented by the chart. It is at this point convenient to recall that in a hyperbolic phase comparison system it is usual to make a phase comparison at a high frequency in order to define a number of possible position lines (which differ by integral multiples of a complete cycle of phase change at the appropriate comparison frequency) and then to make a further, coarse comparison at a much lower frequency in order to define which of the possible position lines is the one passing through the position of the receiver. It is usual to call a complete cycle of phase change at the lower frequency a "zone" whereas it is usual to call a complete cycle of phase change at the higher comparison frequency a "lane." It will be seen that a "zone" comprises a number of lanes, the number being equal to the ratio between the upper and lower comparison frequencies. Since a chart position indicating apparatus and modern-day computing means are digital in nature it is desirable that constant terms defining the reference position lines or the intersections thereof are chosen to have as few digits as possible and it is with the present invention quite possible to chose the various points A, B, C, D so that their co-

ordinates (or, as will be seen, constants derived therefrom) associated with them are integral powers of two or numbers having only a few digital places.

A chart would be associated with an index (not shown in FIG. 3), the chart and the index being relatively movable in two orthogonal directions which will be called the X and Y (cartesian) co-ordinate directions hereinafter. These directions are for convenience chosen to be parallel to a respective edge of the chart but this restriction is not essential to the present invention. It is normally only essential when one of the movements in a co-ordinate direction is effected by movement of the chart whereas the movement in the other co-ordinate direction is effected only by movement of an indicator carrying a marker to define the index. However, such considerations will be discussed in detail hereinafter.

Referring again to FIG. 3: for calculating the position of the point which is the intersection of the two determined position lines it is necessary to make use of the special manner in which the charts are drawn. As has been mentioned, the chart is drawn so that (for example) equal changes in the "red" hyperbolic co-ordinate produce equal changes in the positions of the intersections of the line relating to that co-ordinate with all the lines representing position lines in the "purple" family and vice versa. With this assumption it will be seen (for example) that the ratio *EC/DC* is equal to the ratio *ZJ/HJ* and also equal to the ratio *FB/AB*. Similar relationships hold for the "purple" position lines. The assumption can only be exactly true and produce no distortion if the lines **11** to **13** (in FIG. 2) were parallel and evenly spaced, and the lines **21** to **23** were evenly spaced and parallel, with lines defining intermediate co-ordinates also parallel to the other members in the respective family.

In the following, for any point Q, R_q, P_q, X_q and Y_q define respectively the "red" co-ordinate, the "purple" co-ordinate, the X cartesian (chart) co-ordinate and the Y cartesian (chart) co-ordinate of point Q. The "red" and "purple" co-ordinaes relate to the radio navigation system whereas the X and Y co-ordinates relate to the co-ordinate system of the chart.

It will be understood that R and P are examples of the M and N lines mentioned hitherto.

For the time being, it will be assumed that it is possible to consider that the "red," "purple," X and Y co-ordinates of the points A, B, C and D are defined and that the "red" and "purple" co-ordinates of the point Z are known. Although this would appear to require 16 fixed quantities and two variable quantities, there are in fact, only 12 known quantities since (for example) $R_a=R_b$ etc.

The X co-ordinate of point E, i.e., X_e divides the interval X_c-X_d in the same proportions as the co-ordinate interval P_c-P_d is divided by point E. Thus, it may be assumed that

$$\frac{P_e-P_d}{P_c-P_d}=\frac{X_e-X_d}{X_c-X_d} \text{ and } \frac{P_f-P_a}{P_b-P_a}=\frac{X_f-X_a}{X_b-X_a}$$

But $P_e=P_f=P_z$ and $P_d=P_h=P_x$ and $P_c=P_j=P_b$ therefore

$$\frac{P_z-P_d}{P_c-P_d}=\frac{X_e-X_d}{X_c-X_d}=\frac{X_f-X_a}{X_b-X_a} \quad (1)$$

It may similarly be assumed that:

$$\frac{R_h-R_d}{R_a-R_d}=\frac{X_h-X_d}{X_a-X_d} \text{ and } \frac{R_z-R_e}{R_f-R_e}=\frac{X_z-X_e}{X_f-X_e}$$

But $R_h=R_j=R_z$ and $R_a=R_f=R_b$ and $R_d=R_e=R_e$: therefore

$$\frac{R_z-R_d}{R_a-R_d}=\frac{X_h-X_d}{X_a-X_d}=\frac{X_z-X_e}{X_f-X_e} \quad (2)$$

From Equation 1

$$X_e=\frac{P_z-P_d}{P_c-P_d}(X_c-X_d)+X_d \quad (3)$$

and

$$X_f=\frac{P_z-P_d}{P_c-P_d}(X_b-X_a)+X_a \qquad (4)$$

From Equation 2

$$X_z=\frac{R_z-R_d}{R_a-R_d}(X_f-X_e)+X_e$$

Substituting Equations 3 and 4 in Equation 2, there is obtained

$$X_z=\frac{R_z-R_d}{R_a-R_d}\left[\frac{(P_z-P_d)}{P_c-P_d}(X_b+X_d-X_a-X_c)+X_a-X_d\right]+\frac{(P_z-P_d)}{P_c-P_d}(X_c-X_d)+X_d \qquad (5)$$

It will be seen that Equation 5 defines the unknown X co-ordinate of the point Z in terms of the X co-ordinates of the points A, B, C and D, the "red" and "purple" co-ordinates of the same points (all known quantities) and the respective inputs, R_z and P_z, from the radio navigation system; a similar equation holds true for the Y co-ordinate for the point Z but for convenience only the manipulation and solving of Equation 5 will be discussed in detail.

One way of handling Equation 5 is to make provision (as hereinafter explained) for the storage of all the constant terms appearing therein and when it is required to compute the required value of X_z to perform the various additions, subtractions and multiplications defined in Equation 5. However, it is appropriate to simplify the computation by, instead of storing the values of the co-ordinates X_a, X_b etc., to store various combinations and derivations thereof as will now be explained.

It is convenient to recognise a particular set of constants in Equation 5 which are as follows:

$C_1=X_d$
$C_2=X_c-X_d$
$C_3=X_a-X_d$
$C_4=X_b+X_d-X_a-X_c$
$C_5=P_c-P_d=2^p$ where $p=$ any integer between +5 and 0
$C_6=R_a-R_d=2^r$ where $r=$any integer between +5 and 0
$C_7=P_d=$any integer (the units being ¼ zone)
$C_8=R_d=$any integer (the units being ¼ zone)
C_5 and C_6 are in the same units as C_7 and C_8.

Equation 5 then reduces to:

$$X_z=(2^{-(r+p)})(R_z-C_8)(P_z-C_7)C_4+(2^{-r})(R_z-C_8)C_3+(2^{-p})(P_z-C_7)C_2+C_1 \qquad (5a)$$

Since the multiplication by an integral power of 2, where digital computing apparatus is being used, only amounts to a right- or left-shift by a number of digital places, it is convenient to define this in one of the constant terms. This is equivalent to using new constants defined as follows:

$K_1=C_4(2^{-(r+p)})$
$K_2=C_3(2^{-r})$
$K_3=C_2(2^{-p})$ and thus Equation 5a reduces to

$$X_z=K_1(R_z-C_8)(P_g-C_7)+K_2(R_z-C_8)+K_3(P_z-C_7)+C_1 \qquad (5b)$$

When the corresponding equation for Y_z is written, the constants C_7 and C_8 reappear in the same role; in fact, R_z is never used by itself: only R_z-C_8 is used. Similarly, P_z is never used by itself. New values are required for the other constants and the total list of constants required is When the corresponding equation for Y_z is written, the constant C_7 and C_8 reappear in the same role; in fact, R_z is never used by itself: only R_z-C_8 is used. Similarly, P_z is never used by itself. New values are required for the other constants and the total list of constants required is ${}^xK_1$, ${}^xK_2$, ${}^xK_3$, ${}^xC_1$, ${}^yK_1$, ${}^yK_2$, ${}^yK_3$, ${}^yC_1$, C_7 and C_8 which is only ten constants.

Because C_7 and C_8 are common to X and Y, it may be convenient to form R_z-C_8 and call it $-R$. This can be stored and used for both X and Y determinations. The subtraction of C_8 consists mainly of zeros when expressed as a binary number.

If $R_z-C_8=R$ and $P_z-C_7=P$, then

$$X_z={}^xK_1RP+{}^xK_2R+{}^xK_3P+{}^xC_1 \qquad (6)$$

and

$$Y_z={}^yK_1RP+{}^yK_2P+{}^yK_3P+{}^yC_1 \qquad (7)$$

if C_7 and C_8 are quoted in the negative form, no subtractions are needed, i.e., —R becomes $R_z+(-C_8)$ and it will be seen that the solution of Equations 6 and 7 require only eight multiplications and eight additions.

It will be seen that although the constants in Equations 6 and 7 are related to and are defined by the various co-ordinates of the points A, B, C and D, the connection between the two is complex. It might be possible to simplify Equation 5 in other ways but essentially the computation of the values X_z and Y_z relies on the fact that the programme for solving X_z and Y_z must always rely on the constancy of the aforementioned rates of change. This is the basis of the Expressions 1 and 2 from which the Equations 6 and 7 are derived. It is by the same token a measure of the distortion present in the chart.

From the foregoing explanation of FIG. 3 it will be appreciated that in order to move an index and a chart relatively in the X and Y co-ordinate directions it is necessary to provide computing means for solving, using the appropriate outputs from the navigation systems and constants, Equations 6 and 7. How the outputs are derived and the constants may be stored for use in a computation and how the chart and index may be driven will now be explained.

For convenience of explanation it will be assumed that the stations P, M, G and R in FIG. 2 radiate continuous radio frequency signals of frequencies 5*f*, 6*f*, 9*f* and 8*f* respectively, *f* being (for example) in the region of 14 kHz. In a mobile receiver as shown in FIG. 4, to determine the hyperbolic co-ordinates the signals are picked up by an aerial **40** and are amplified by amplifiers **41** and **44** tuned respectively to the frequencies 5*f*, 6*f*, 9*f* and 8*f*. The outputs of the amplifiers are fed to frequency multipliers **45** to **48**. The frequency multiplier **46** associated with the 6*f* signal from the master station separately multiplies the received 6*f* signals by factors of 3, 4 and 5 to provide outputs of 18*f*, 24*f* and 30*f*. The 30*f* output from the multiplier **46** is fed to one input of a phase discriminator **50** to other input of which is fed a 30*f* output from the multiplier **45** which multiplies the received purple 5*f* signal by a factor of 6. The discriminator **50** provides two outputs representing the sine and cosine of the phase angle beween the master and purple slave station signals at the receiver. The outputs are fed to a digitiser **51** which provides a digital output representative of the phase angle, that is, it defines the master-purple slave hyperbolic co-ordinate of the receiver. The 18*f* output from the multiplier **46** is fed to one input of a discriminator **52** to the other input of which is fed an 18*f* output from the multiplier **47** which multiplies the received 9*f* green slave signal by a factor of 2. The outputs from the discriminator **52** are fed to a digitizer **53** to yield an output in digital form representative of the phase difference between the 18*f* signals from the multipliers **46** and **47**, i.e. the master-green slave hyperbolic co-ordinate. A 24*f* output from the multiplier **48**, which multiplies the frequency of the received red slave signals by a factor of 3, is fed to one input of a discriminator **54** to the other input of which is fed the 24*f* output from the multiplier **46**. The outputs from the discriminator **54** are fed to a digitiser **55** to provide an output in digital form representative of the phase difference between the 24*f* signals from the multipliers **46** and **48**, i.e. the mastered slave hyperbolic co-ordinate. A hyperbolic phase comparison navigation system of the above kind is with the exception of the provision of digitisers more fully described in the specification of British Pat. No. 620,479 and reference may be made to that specification for further explanation of the construction and manner of operation of such a system. The digitisers **51**, **53** and **55**, which might readily be replaced by a single time-shared digitiser or other digitisers capable of being driven by the sine and cosine signals from the discriminators, accordingly provide indications with respect to three sets of confocal hyperbolae, each set having a master station and the appropriate slave station as its two foci. The positional information in binary digital form from the digitisers **51**, **53** and **55** is fed through gates **56**, **57** and **58** which are controlled as required by a computer **59** to feed the positional information into the computer.

The computer **59**, which is not illustrated in detail since its manner of construction will be readily apparent to those skilled in the art, essentially comprises a multiplier and adder **60** to which are fed at appropriate times two hyperbolic co-ordinates obtained from the phase comparisons and the constants hereinbefore mentioned, binary to Gray code converter **66** receiving the determined values of X_z and Y_z and providing two digital outputs in Gray code defining X_z and Y_z. The computer is programmed to feed to the multiplier and adder the signals at appropriate times so that the multiplier and adder yields X_z and Y_z by solving Equations 6 and 7.

The description of the invention so far has been concerned with the drawing of a chart to conform with this invention and with the obtaining of signals which define with respect to the chart the position of the receiver as determined by the phase comparisons between signals received from various stations in the navigation system. The X_z and Y_z signals, fed out from the computer on lines **74** and **75** are to be used to control the displacement of an index with respect to a chart automatically so that a chart display can automatically indicate the geographical location of the receiver.

A number of ways of controlling the displacement of the index are possible. It is possible to provide means for storing determined values of X_z and Y_z and comparing these stored values with further values of X_z and Y_z obtained from a succeeding determination, the displacement of the index being made in accordance with each change in X and Y from the stored to the further values. Such a chart display is known as an "integrating" display since after an initial setting the index and chart are relatively displaced by the integral of the changes in the X and Y cartesian co-ordinates of the chart and index system. However, with such a system it is necessary to set the display initially to indicate the correct position of the receiver at the instant of setting, which for obvious reasons may not always be possible. It is preferable to provide, for each co-ordinate direction of displacement of the index a servo system which responds to the respective (X or Y) co-ordinate determined from the phase comparisons and to the actual position indicated by the index relative to the chart for that co-ordinate direction and to effect relative displacement of the chart or index in accordance with any difference between the actual and indicated co-ordinates. For this purpose, the chart may be movable to and fro relative to the index to indicate one co-ordinate direction and the index may be movable to and fro in the transverse direction to indicate the other co-ordinate, there being associated with both the chart and the member bearing the index a separate set of digitally coded tracks arranged to co-operate with a respective sensing means to provide coded signals defining the co-ordinate indicated by the chart or member, a respective servo mechanism being arranged to compare the respective coded signals with a respective value of X or Y from the navigation system and to drive the chart or member to the co-ordinate position defined by said value of X or Y. Such a system is more particularly described and claimed in the specification of British Pat. No. 914,185 or the corresponding U.S. Pat. No. 3,113,313 and reference may be made to the specification of that patent for further details of the construction and manner of operation of such a system; it will be understood, however, that what follows, which is given by way of completeness, is by no means essential to the present invention and considerable variations, which will be pointed out as they occur, may be made.

Referring to FIG. 5, the signal on line **74** is fed to a servo system **76** together with another input on a line **95** obtained in a manner to be described. The servo system **76** is arranged to produce an error signal, which is fed to a motor **78** to drive a lead screw **79** on which is mounted a carriage **80**. Rotation of the motor moves the carriage **80** transversely with respect to a chart **83** so that one co-ordinate of the position of the receiver (for the sake of example, the Y co-ordinate) is determined by the position relative to the chart of an index line **81** on a transparent cursor **82** which is carried by the carriage **80**. On the line **81** there is an index cross or circle **81*a*** which serves as a reference for the other co-ordinate and hence is to indicate when used with a chart the position of the receiver.

The servo **76** drives the carriage **80** until the value of the co-ordinate indicated by the line **81** is the same as that determined for the receiver by the computer **59**. This type of drive and automatic drive display is fully described in the aforementioned British patent specification No. 914,185.

A similar servo system **77** is responsive both to an input on a lead **75** from the computer and to an input on a lead **94** which indicates the position of the chart with respect to the index **81*a***. The chart is one of a number on a chart roll **72** mounted for movement between the two spools **90** and **91** which may be driven to move the chart in its longitudinal direction by a motor **86**. The output from the servo **77** is fed to the motor **86** via a shaft **87** and links **88** and **89** (which have been illustrated diagrammatically for convenience) and thus the index **81*a*** is movable relative to the chart in the two orthogonal X and Y directions.

It is not essential to use a movable chart; in particular two cursors carried on respective carriages may be movable in orthogonal directions across the chart, which for this purpose would be fixed in position. Also, as is disclosed in the specification of British Pat. No. 1,090,-153 it is possible to use an index which is formed as the intersection of two orthogonal lines drawn on respective flexible members which are movable in the longitudinal direction with respect to the chart. One line would be drawn in an oblique direction on one transparent flexible member and the other drawn on the other member but at right angles to that on the first member. Reference may be made to the specification of that patent for further details.

For controlling the servo mechanism, the chart and the carriage are each associated with digital tracks which co-operate with sensing means to define the actual co-ordinate indicated by the chart and carriage. Along the sides of the chart member **72** parallel to and along one side of the chart **83** is a plurality of tracks of opaque digital markings **93** performing two functions. Firstly, a number of tracks are arranged in a repetitive cyclic code such as Gray code so that a corresponding number of photocell sensing means **92** may provide an output indicating the actual position of the chart. The digits sensed by the individual photocells **91** are fed on line **94** to the servo system **77** to enable the necessary comparison between the actual and required chart positions to be made. However, further markings **93*a*** are provided to supply the aforementioned constants which are used by the computer to define the X and Y co-ordinates. It will be appreciated that the constants defining the various coordinates and constants are peculiar to each chart and when a chart is inserted in the apparatus, the photocells read the respective constants and feed them to a temporary store from which they are fed out at appropriate times by a gating system to the multiplier and adder. It will be apparent that the photocells are indicated only diagrammatically and typically there may be several rows of them since each constant in general comprises a plurality of digits. As will be made clear, however, the extreme latitude in the choice of the reference position lines that is provided by the present invention enables the number of digits in each constant to be kept to a minimum.

For the other co-ordinate direction, the carriage **80** is associated with plurality of wipers **84** co-operating with digitally coded tracks **85** to provide on the line **95** Gray code signals representing the position of the carriage and therefore the index **81***a* in the Y direction. The servo **76** forms the difference between the signals on the lines **74** and **95** and drives the motor **78** to move the carriage **80** to the correct position in the known manner.

I claim:

1. Apparatus for indicating on a chart the geographical location represented by the intersection of two position lines which are respectively members of two families of position lines of a radio navigation system adapted to provide outputs identifying a position line in each family, comprising a chart of a geographical area embracing said location, the chart being distorted such that the two families of position lines are each representable on a display surface of the chart by a set of parallel lines, the rates of change of position, with respect to the respective output of the radio navigation system, of the intersections of a line in a set with all the lines in the other set being all constant; an index and the chart being movable relative to each other in two orthogonal co-ordinate directions parallel to the display surface of the chart, the lines in at least one set being inclined to both the two orthogonal directions whereby each orthogonal co-ordinate of the geographical location with respect to the chart is determined by a respective one of two equations which each have the aforementioned outputs as variable quantities; and computing means for forming said two equations and thereby determining each said orthogonal coordinate; drive means being provided for displacing said index and chart relative to each other in the two orthogonal co-ordinate directions in accordance with the values of said orthogonal co-ordinates determined by said computing means.

2. Apparatus as claimed in claim **1** in which the chart is distorted such that both families of position lines are representable on the chart by a set of straight, parallel lines.

3. Apparatus as claimed in claim **2** in which the two orthogonal co-ordinates are cartesian.

4. Chart position indicating apparatus for use with a radio navigation system adapted to provide, at a mobile receiver, two outputs, M and N, each identifying a position line in a respective one of two families of intersecting position lines, said outputs defining thereby two position lines through the location of the mobile receiver, said apparatus comprising a chart drawn by assuming the position lines all to be straight, computing, in cartesian co-ordinates with respect to the chart, the co-ordinates of the four intersections of a pair of position lines in one family with a pair in the other family and plotting the chart such that for any point on a display surface of the chart, either position line through the point divides either selected position line in the other family in the same ratio as the cartesian co-ordinates of said point divide the respective cartesian co-ordinates of the intersections lying on said selected position line in the other family; an index and said chart being movable relative to each other in the two cartesian co-ordinate directions which directions are parallel to the display surface of the chart, means for displacing said index and chart relatively to each other to indicate the chart position (X_z, Y_z) of said location automatically in accordance with two outputs, defining X_Z and Y_Z respectively, of a computing means responsive to the navigation system outputs, said computing means being arranged to determine X_z and Y_z by computing the values of expression of the form $k_1MN+k_2M+k_3N+k_4$ and $k'_1MN+k'_2M+k'_3N+k'_4$ wherein k_1, k_2, k_3 and k_4 and k'_1, k'_2, k'_3, and k'_4 are constant for any point on the chart and are derived from the cartesian co-ordinates of the intersections and a representation on the chart of a position line in either family of position lines is inclined to both the orthogonal co-ordinate directions of relative movement between the index and chart.

5. Apparatus as claimed in claim **4** in which the radio navigation system is of the kind having at least three radio transmitting stations arranged to radiate phase-locked radio frequency signals of different but harmonically related frequencies and in which a mobile receiver is arranged to compare the phases of signals received from two pairs of stations, one station being common to the two pairs, so as to obtain two outputs each representing a different position line through the location of the receiver.

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