(2) Automatic Direction Finders ~~&~~ (ADF) ~~&~~ (Powell / Hofman-Wellenhof)

& Nondirectional Beacons (NDBs).

- Earliest use of radio waves in navigation

Principle: A receiving antenna has directional properties

Early DFs were simply a loop antennae that the pilot rotated till he got a null ~~beam~~ signal from a ~~sta~~ tuned station. The ~~di~~ orientation of the antenna gave the ~~bear~~ relative bearing of the station.

Current ADFs consists of a pair of orthogonal coils. The relative strengths of currents induced in the two coils gives a measure of the relative bearing of the broadcast station, which is usually a NDB.

An NDB is a omnidirectional transmitter continuously broadcasting ~~a~~ a radio signal (along with a 3-letter Morse code for id).

Distance Measuring Equipment (Powell, Hofman-Wellenhof)

Principle: To determine slant range between a/c & a beacon by a two-way runtime measurement. in a interrogation-reply mode.

The DME transmits a pattern of paired pulses ~~at~~. The beacon receives the pulses and retransmits after a fixed known delay.

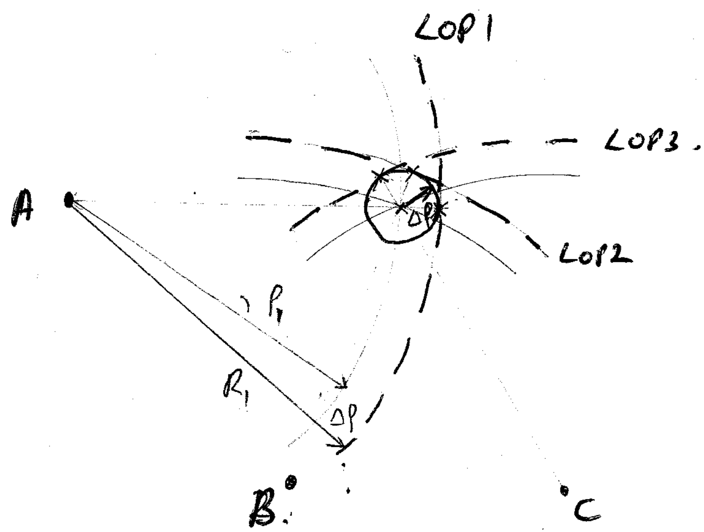
Position fixing by using ~~difference of distances~~ pseudorange

Range measurements made using run time measurements in radio navigation may be subject to a bias caused by a bias in the receiver clock.

Such a biased range measurement is called pseudorange. $R = \rho + \Delta\rho$.

In case of a constant but unknown bias, pseudorange measurement can be used for position fixing in two ways.

(A) 3 pseudorange measurements can be used to fix 2 position coordinates and ~~find~~ find the unknown scalar bias.

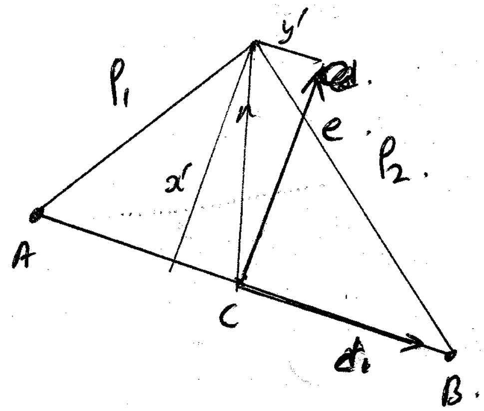


(Hoffman-Wellenhof).

(B) Hyperbolic positioning:

<u>Principle:</u> Eliminate the bias by taking the difference between the two ranges.

~~The~~ The difference in ranges to two stations gives an LOP which is a hyperbola.



$$\rho_1 - \rho_2 = l.$$

Let $x = \begin{bmatrix} x \\ y \end{bmatrix}$, $r_A = \begin{bmatrix} x_A \\ x_B \end{bmatrix}$, $r_B = \begin{bmatrix} y_A \\ y_B \end{bmatrix}$.

Then $$\sqrt{(r-r_A)^T(r-r_A)} - \sqrt{(r-r_B)^T(r-r_B)} = l.$$

Let $c = \frac{1}{2}(r_A + r_B)$, $d = \frac{1}{2}(r_B - r_A)$.

Then $$\sqrt{(r-c+d)^T(r-c+d)} = l + \sqrt{(r-c-d)^T(r-c-d)}$$

$$\therefore \cancel{(r-c)^T(r-c)} + 2(r-c)^T d + \cancel{d^T d} = l^2 + 2l\sqrt{(r-c-d)^T(r-c-d)}$$

$\therefore \quad l\sqrt{(r-c-d)^T(r-c-d)} = 2(r-c)^T d - l^2.$

~~Let $\hat{e}$ be a unit vector orthogonal to d.~~

Then. $l^2(r-c)^T(r-c) - \cancel{2l^2(r-c)^T d} + l^2 d^T d$

$$= l^4 - \cancel{2l^2(r-c)^T d} + 4[(r-c)^T d]^2.$$

~~Let~~ Let e be a unit vector orthogonal to d.

Let $\quad x' = (r-c)^T d \dfrac{1}{\sqrt{d^T d}} \qquad y' = (r-c)^T e$

Then. $\quad l^2(x'^2 + y'^2) + l^2 d^T d$

$$= l^4 + 4(d^T d)\, x'^2.$$

$\therefore \quad x'^2(4d^T d - l^2) - l^2 y'^2 = l^2(d^T d - l^2) \rightarrow$ eqn. of a hyperbola

Note that triangle inequality implies that $l < 2\sqrt{d^T d}$.

Note that $\quad \begin{bmatrix} x' \\ y' \end{bmatrix} = \underbrace{\begin{bmatrix} \frac{d^T}{\sqrt{d^T d}} \\ e^T \end{bmatrix}}_{\text{rotation}} \underbrace{(x - c)}_{\text{shift of origin}}$

$\therefore$ The eqn. of the LOP is of the form.

$$(x - c)^T Q (x - c) = 1.$$

$$Q = \begin{bmatrix} \frac{d^T}{\sqrt{d^T d}} \\ e^T \end{bmatrix}^T \begin{bmatrix} \frac{4d^T d - l^2}{l^2(d^T d - l^2)} & 0 \\ 0 & -\frac{l^2}{d^T d - l^2} \end{bmatrix} \begin{bmatrix} d^T/\sqrt{d^T d} \\ e^T \end{bmatrix}$$

To get a position fix, a minimum of 3 range / pseudo range readings are required. to get two LOPs, of the form.

$$(x - c_1)^T Q_1 (x - c_1) = 1$$

$$(x - c_2)^T Q_2 (x - c_2) = 1.$$

Radio navigation systems based on hyperbolic positioning:

LORAN - C. (for LOng RAnge Navigation). Low frequency

~~Cosi~~ Made up of several chains of transmitting stations. Each chain consists of a master & 2-3 secondary transmitters placed 1000 - 1200 km. apart.

The master transmits a sequence of 8 pulses following which each secondary transmits the same sequence of pulses one after the other, each with its own nominal emission delay. The whole group repeats the sequence in a group repetition interval that serves to identify the chain.

The time differences between corresponding pulses ~~of the~~ received from the master & slave minus the NED of the slaves gives the difference in the ranges to the two transmitters & thus gives a hyperbolic LOP.

Older systems - ~~Omeg~~. (Powell)

Omega - a VLF long range navigation system consisting of 8 stations worldwide transmitting continuous radio signals in a synchronized manner. The receiver measures phase differences between signals received from various transmitters. Since ~~several pairs~~ different combinations of ranges ~~can yield~~ ~~different~~ differing by integral multiples of wavelength can yield the same phase difference, a phase difference measurement gives several LOPS, one in each "lane". A lane is the set of points, all of which have the same integral no. of wavelengths ~~phase difference~~ difference in the ranges to two transmitters. Hence lanes have to be counted starting from ~~the~~ some known position fix.

Decca: Consists of chains of stations, each chain containing a master & a slave, all transmitting synchronized continuous waves at LF. Phase difference between received master & slave transmitters are displayed on Decometers. The observed phase differences identify hyperbolic lines marked on a chart. ~~The~~ After initial setting, the Decometers carry out the lane co...