ANDREJ NOVAK, D. Sc.
E-mail: Andrej.Novak@fpedas.utc.sk
University of Zilina, Faculty of Operation and Economics
of Transport and Communications
Univerzitná 8215/1, 010 26 Žilina, Slovak Republic

Traffic Engineering
Review
U. D. C.: 654.165:351.841.31
Accepted: Apr. 11, 2005
Approved: Sep. 6, 2005

RADIO DIRECTION FINDING IN AIR TRAFFIC SERVICES

ABSTRACT

The paper analyses the Radio Direction Finding principle for navigation and surveillance system. Radio Direction Finding involves locating the bearing of a transmitter called a radio beacon. A radio beacon's signal is received aboard a vehicle by a device called radio direction finder (RDF). The navigator turns the antenna of the radio direction finder to find the direction of the radio beacon. The RDF shows when the antenna is pointing towards the beacon. Radio direction finding is one of the oldest electronic navigation systems for aircraft and ships. It is generally used as a piloting aid along coastal waters. The range of a radio direction finding signal depends on the type of radio beacon.

KEYWORDS

Radio Direction Finding, doppler direction finder, interferometer

1. INTRODUCTION

Radio Direction Finding for navigation purposes (cooperative direction finding) is losing in importance due to the availability of satellite navigation systems, the requirement for determining the location of emitters' increasing with the mobility of the communication equipment:

- In radio monitoring in line with ITU guidelines
  - Searching for interference sources
  - Localization of non-authorized transmitters
- In security services
  - Fighting organized crime
- In military intelligence [1]:
  - Detecting activities of potential enemies
  - Gaining information on enemy's order of battle (signal intelligence)
- In intelligent communications systems
  - Space **D**ivision **M**ultiple **A**ccess requiring knowledge of the direction of incident waves [2]
- In research
  - Radio astronomy
  - Earth remote sensing

Another reason for the importance of Radio Direction Finding lies in the fact that frequency-spreading techniques are increasingly used for wireless communications: this means that the spectral components can only be associated with a certain emitter if the direction is known. Direction finding therefore is an indispensable first step in radio detection; the more as reading the contents of such emissions is usually impossible.

The localization of emitters is often a multistage process. Direction finders spread across a country allowing the transmitter to be located to a few kilometres by means of triangulation (typically 1% to 3% of the DF distances). The emitter location can be determined more precisely with the aid of direction finders installed in ground or air.

2. DOPPLER DIRECTION FINDER

If an antenna element rotates in a circle with the radius R, the received signal with the frequency is ω_0 frequency-modulated with the rotating frequency ω_r of the antenna due to the Doppler effect: if the antenna moves towards the radiation source, the frequency increases; if the antenna moves away from the radiation source, the received frequency is reduced.

From the instantaneous amplitude the

$$u(t) = a * \cos\left(\omega_0 t + \frac{2\pi R}{\lambda_0}\cos(\omega_r t - \alpha) + \varphi\right)$$

instantaneous frequency is derived by differentiation

$$\omega(t) = \frac{d\Phi(t)}{dt} = \omega_0 - \frac{2\pi R}{\lambda_0}\omega_r \sin(\omega_r t - \alpha)$$

After filtering out the DC component ω_0, the demodulated Doppler signal is obtained as

$$S_D = \frac{2\pi R}{\lambda_0}\omega_r \sin(\omega_r t - \alpha)$$

The phase of the demodulated signal compared to a reference signal of equal centre frequency derived from the antenna rotation $S_r = -\sin\omega_r t$ yields the bearing α.

Since mechanical rotation of an antenna element is in practice neither possible nor recommendable, several elements (dipoles, monopoles, crossed loops) are arranged on a circle (Fig. 1) and electronically scanned with the aid of electronic switches.

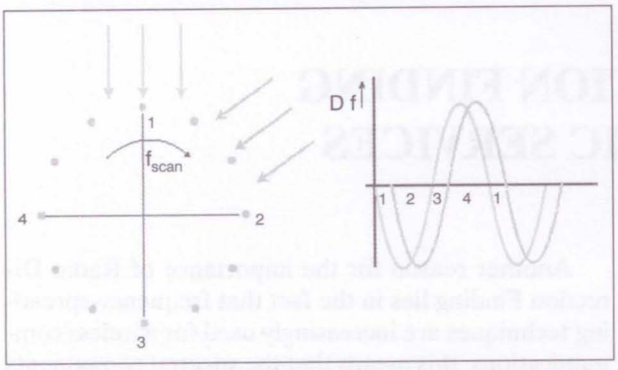

Figure 1 - Principle of Doppler direction finder

To obtain unambiguous DF results, the spacing between the individual antenna elements must be smaller than half the operating wavelength; in practice a distance of about one third of the minimum operating wavelength is usually selected. Fig. 13 shows an example of a Doppler direction finder for portable use in the frequency range 20 MHz to 1000 MHz.

If this rule is adhered to, Doppler DF antennas of any size are possible so that wide aperture systems featuring:

- high immunity to multi-path reception and
- high sensitivity can be implemented in a simple way.

A disadvantage of the Doppler method is the time required, since at least one antenna scanning cycle is needed to obtain a bearing. With a typical rotating frequency of 170 Hz in the VHF/UHF band one cycle takes about 6 ms.

3. INTERFEROMETER

The interferometer direction finder determines the angle of incidence of a wave by directly measuring the phase difference between the signals picked up at different points on the received wave front by the elements of the antenna array (Fig. 2).

Unambiguous determination of the azimuth and elevation with the aid of three antenna elements is only possible if the spacing between the antennas is not greater than half a wavelength. If Φ_1, Φ_2, Φ_3 are the phases measured at the antenna element outputs, the azimuth is calculated as

$$\alpha = \arctan \frac{\Phi_2 * \Phi_1}{\Phi_3 * \Phi_1}$$

The elevation angle is obtained as

$$\varepsilon = arccos \frac{\sqrt{(\Phi_2 - \Phi_1)^2 + (\Phi_3 - \Phi_1)^2}}{2\pi a / \lambda}$$

In practice, the 3-antenna configuration is usually enhanced by further antenna elements so that the antenna spacing can be optimally adapted to the operating frequency range and antenna spacing of $a > \lambda / 2$ be used to increase the accuracy of small-aperture DF systems.

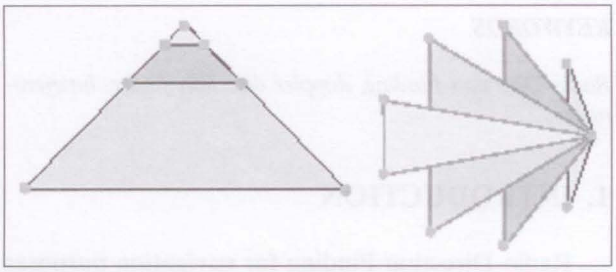

Figure 3 - 3-element interferometer enhanced to form a multi-element interferometer

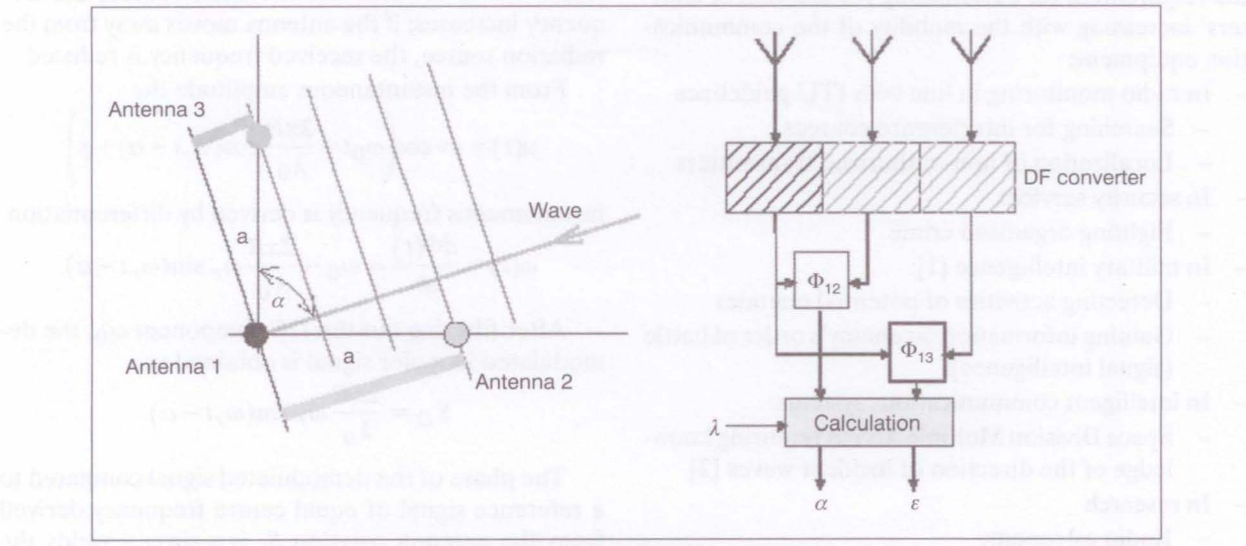

Figure 2 - 3-element interferometer

Frequently used antenna arrangements include the right-angled isoceles triangle and the circular array (Fig. 3). Triangular arrays are usually restricted to frequencies below 30 MHz.

At higher frequencies it is recommended to use circular arrays since these ensure the following:

- equal radiation coupling between the antenna elements,
- minimum coupling with the antenna supporting mast,
- direction-independent characteristics at different positions due to the symmetry about the centre point.

Special considerations are to be given to avoiding ambiguities that result from the fact that unambiguous measurement of the phase is only possible in the range of $\pm 180°$. As already mentioned before, the spacing between the elements of a 3-element (small--aperture) interferometer is therefore limited to half the minimum operating wavelength. For multi-element interferometers there are the following possibilities:

- *Use of "filled" antenna groups*: phase differences between neighbouring elements are always smaller than 180°; ambiguities can thus be avoided;
- *Use of "thinned out" antenna groups*: at least one neighbouring pair of elements with a phase difference >180°.

The following approaches exist to resolve ambiguities:

- Coarse direction finding using a small aperture system ($\alpha < \lambda / 2$);
- Use of circular arrays with at least one antenna pair having a phase difference of less than 180°.

A very effective means of eliminating the ambiguities of thinned out circular arrays is the correlation method. Fig. 16 shows a direction finder designed according to the correlation principle. The antenna array covers the frequency range 20MHz to 3000MHz.

The basic principle of the *correlative interferometer* entails a comparison of the measured phase differences with those obtained for a DF antenna system of known configuration at a given wave angle. The comparison is made by calculating the quadratic error or forming the correlation coefficient of the two data sets. If different azimuth values of the comparison data set are used, the bearing is obtained from the data for which the correlation is at a maximum.

This is illustrated by the example of a 5-element antenna as shown in Fig. 4: each column of the lower data matrix corresponds to a wave angle ⟨ and forms a comparison vector. The elements of the comparison vectors represent the expected phase differences between the antenna elements for this direction of incidence. The upper 5x1 data matrix contains the currently measured phase differences (Measurement vector).

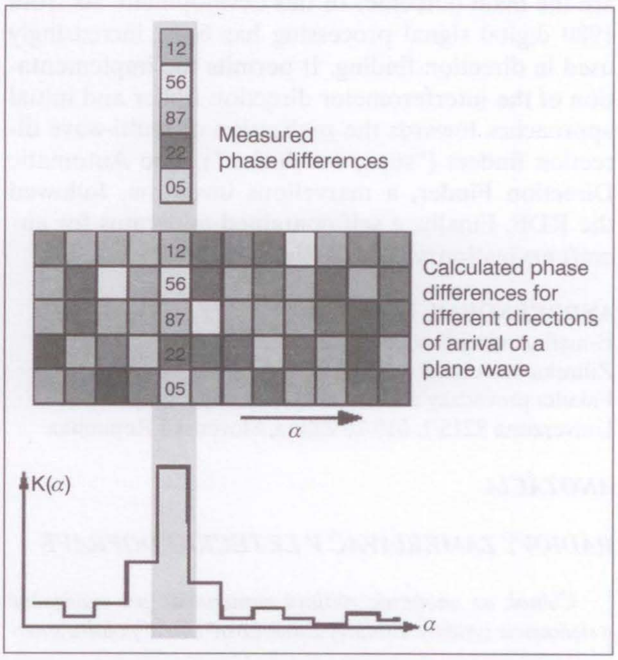

Figure 4 - Principle of correlation evaluation

To determine the unknown direction of incidence, each column of the lower reference matrix is correlated with the measurement vector by multiplying and adding the vectors element by element. The result is the correlation function[###EMBEDDING###], which reaches its maximum with the optimum coincidence of comparison vector and measurement vector. The angle associated with the comparison vector is the wanted bearing.

This method is a special form of a beamforming algorithm [2], which is described in detail in the following section on direction finding using sensor array processing.

4. CONCLUSION

As from 1931 camouflaged direction finders were available for use in vehicles and as portable direction finders for detecting spies. The first shortwave direction finder operating on the Doppler principle was built in 1941. The rapid progress in the development of radar in Great Britain made it necessary to cover higher frequency ranges: in 1943 the first direction finders for "radar observation" at around 3000 MHz were delivered. As from 1943 wide-aperture circular-array direction finders (Wullenweber) were built for use as remote direction finders. Since 1950s, airports all over the world have been equipped with VHF/HF Doppler direction finding systems for air--traffic control. In the early 1970s, digital technique made its way into direction finding and radiolocation; digital bearing evaluation and digital remote control are the main outcomes of this development. As from 1980 digital signal processing has been increasingly used in direction finding. It permits the implementation of the interferometer direction finder and initial approaches towards the realization of multi-wave direction finders ("super resolution"). The Automatic Direction Finder, a marvellous invention, followed the RDF. Finally, a self-contained apparatus for aircraft navigation was available.

ANDREJ NOVAK, D. Sc.
E-mail: Andrej.Novak@fpedas.utc.sk
Žilinská univerzita
Fakulta prevádzky a ekonomiky dopravy a spojov
Univerzitná 8215/1, 010 26 Žilina, Slovenská Republika

ANOTÁCIA

RÁDIOVÝ ZAMERIAVAČ V LETECKEJ DOPRAVE

Článok sa analyzuje rádiový zameriavač pre navigačné a sledovacie systémy. Rádiový zameriavač zmerá polohu smerníka vysielajúceho rádiového majáka. Vysielaný rádiový signál je primaný na palube auta, lietadla zariadením, ktoré sa nazýva rádiový zameriavač (RDF). Navigátor otáča anténu prijímača rádiového zameriavača do smeru, kde sa nachádza vysielaný signál. Rádiový zameriavač patrí k jedným z najstarších elektronických navigačných systémov pre lietadlá a lode. Obvykle sa používa ako pomocný riadiaci systém v oblasti pobrežných vôd. Dosah prijímača rádiového zameriavača je závislý od typu rádiového vysielania.

KĽÚČOVÉ SLOVÁ

Rádiový zameriavač, Dopplerovský rádiový zameriavač, Interferometer

REFERENCES

[1] **Godara, L. C.**: *Application of Antenna Arrays to Mobile Communication*, Part I Proceedings of the IEEE, Vol. 85, No. 7, July 1997, Part II No. 8, August 1997

[2] **Demmel, F.**: *Einsatz von Kreisgruppen zur echtzeitfätzung im Mobilfunkkanal*. ITG-Fachbericht 149 VDE-Verlag 1998