Introduction into Theory of Direction Finding

1 Introduction

1.1 Radio direction finding applications

While 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 increases with the mobility of the communication equipment:

- In radiomonitoring 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:
  - **S**pace **D**ivision **M**ultiple **A**ccess requiring knowledge of the direction of incident waves [2]
- In research:
  - Radioastronomy
  - 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 radiodetection, the more as reading the contents of such emissions is usually impossible.

The localization of emitters is often a multi-stage process. Direction finders spread across a country allow the transmitter to be located to a few kilometers by means of triangulation (typically 1% to 3% of the DF distances). The emitter location can more precisely be determined with the aid of direction finders installed in vehicles. Portable direction finders moreover allow searching within the last 100 meters, for instance in buildings.

1.2 Historical development

The DF technique has existed for as long as electromagnetic waves have been known. It was Heinrich Hertz who in 1888 found out about the directivity of antennas when he made his investigations in the decimetric wave range. An application of this for determining the direction of incidence of electromagnetic waves was proposed in 1906 in a patent of Scheller on a homing DF method.

The initial DF units were polarization direction finders. They consisted of a rotatable electric or magnetic dipole whose axis is brought to coincidence with the direction of the electric or magnetic field. The knowledge about the polarization direction then led to the direction of incidence. The rotating-loop direction finder is one of the best known direction finders of this type. In 1907 Bellini and Tosi discovered the DF principle that was named after them: a combination of two crossed directional antennas (eg loop antennas) with a rotatable coil goniometer for determining the direction Despite this invention, rotating-loop direction finders were mostly used in the First World War (Fig. 1).

The invention of Adcock meant a great step in the improvement of the DF accuracy of skywaves in the shortwave range. The pharmacist by profession realized in 1917 that with the aid of vertical linear antennas (rod antennas or dipoles) directional characteristics can be generated that correspond to that of loop antennas but do not pick up any interfering horizontally polarized field components (G. Eckard proved in 1972 that this does not hold true without any restrictions [3]). It was not until 1931 that Adcock antennas were first employed in practical applications in Great Britain and Germany.

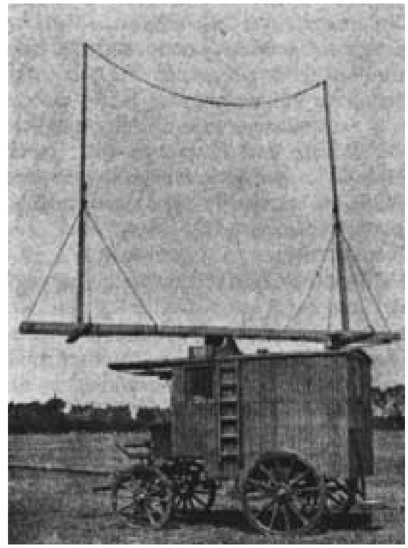

Fig. 1: Mobile rotating-loop direction finder for military use (about 1918)

Sir Watson-Watt made in the years 1925/26 the step from the mechanically moved goniometer direction finder to the electronic visual direction finder. As from 1943 British naval vessels were equipped with crossed loops and three-channel Watson-Watt direction finders for the shortwave range ("huff-duff" for detecting German submarines).

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 the 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 multiwave direction finders ("super resolution"). The first theoretical considerations were made much earlier, eg in [4].

Another important impulse for the development came from the requirement for direction finding of frequency-agile emissions such as frequency-hopping and spread-spectrum signals. The main result of this development was the broadband direction finder which is able to simultaneously carry out the search and DF process on the basis of digital filter banks (usually with the aid of **F**ast **F**ourier **T**ransform) [5].

1.3 Tasks of radio direction finding

The task of a radio direction finder is to estimate the direction of an emitter by measuring and evaluating electromagnetic field parameters.

Usually the **azimuth** α is sufficient to determine the direction; measurement of the **elevation** ε is of interest for emitters installed in flying platforms and especially for direction finding of shortwave signals (Fig. 2).

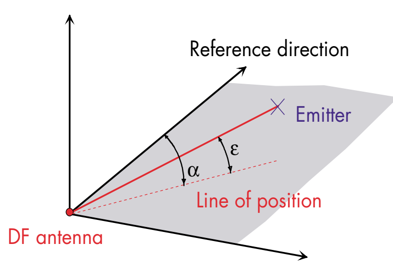

Fig. 2: Definition of emitter direction

Only in the case of undisturbed wave propagation is the direction of the emitter identical with the direction of incidence of the radio waves. Usually there is a large number of partial waves arriving from different directions and making up a more or less scattered field. The direction finder takes from this wavefront spatial and temporal samples and supplies in the ideal case the estimated values $\hat{\alpha}$ and $\hat{\varepsilon}$ for the most probable direction of the emitter observed.

The bearing can be referred to the following reference directions (Fig. 3) (see also DIN 13312 [6]):

- True north (true radio bearing)
- Magnetic north
- Vehicle axis or relative radio bearing

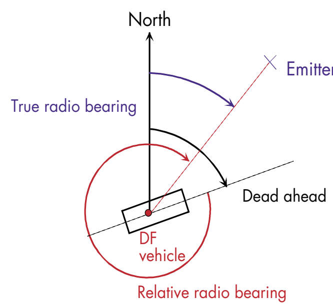

Fig. 3: Reference directions