In addition to the usual receiver settings such as frequency and bandwidth, the following settings and displays are made for direction finders:

- Averaging mode (if the signal level drops below the preset level threshold, averaging – depending on the averaging mode – is either stopped and restarted upon the next exceeding of the threshold or continued)
- Averaging time
- Output mode (refresh rate of display; output as a function of exceeding the signal threshold)

Multichannel direction finders are implemented with the aid of digital filter banks (FFT and polyphase filters). Depending on the outlay, these direction finders allow quasi-simultaneous direction finding in a frequency range from some 100 kHz up to a few MHz. Scan mode is additionally provided to cover larger frequency ranges (Fig. 28).

With a multichannel direction finder it is essential that the individual events can quickly be recognized and the activities taking place in different channels correctly assigned. Usually the following display modes are therefore provided:

- DF values versus frequency
- DF values versus frequency and time (eg by using different colours for the DF values)
- Level versus frequency (power spectrum)
- Level versus time and frequency (using different colours for level values)
- Histograms

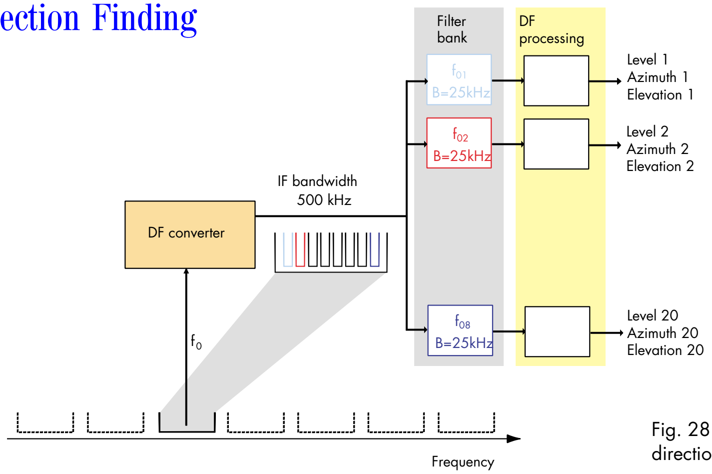


Fig. 28: Multichannel direction finder

6 Error Sources

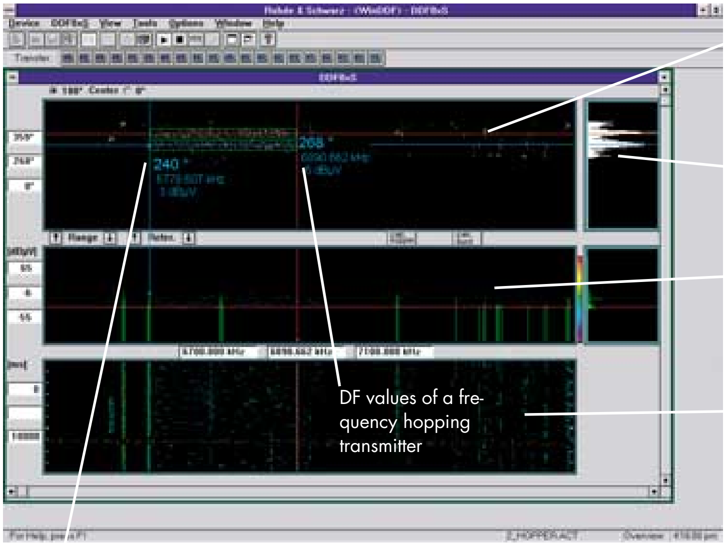
The DF accuracy is affected by a number of influences:

- Wave propagation (usually disturbed by obstacles)
- Signals radiated by the emitters are modulated, limited in time and their carrier frequency is often unknown
- Received field is additionally superimposed by noise, co-channel interferers
- Tolerances and noise in the DF system

6.1 Multiwave-related problems

As already mentioned in the introduction, the simple case of a plane wave occurs seldom in practice. In a real environment, further waves have usually to be taken into account which result

- from other emitters in the same frequency channel (incoherent interference) or
- from secondary waves (caused by reflection, refraction, diffraction – see Fig. 30) (coherent in-channel interference)[1]



DF value of selected signal

Fig. 29: Multichannel (broadband) display

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[1] A prerequisite is that the delay differences are small relative to the coherence lengths defined by the bandwidth B (see also 5.3)

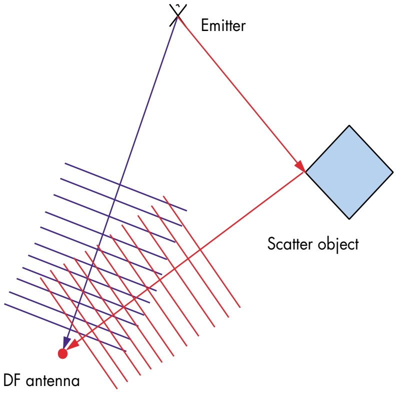

Fig. 30: Coherent secondary waves caused by reflection

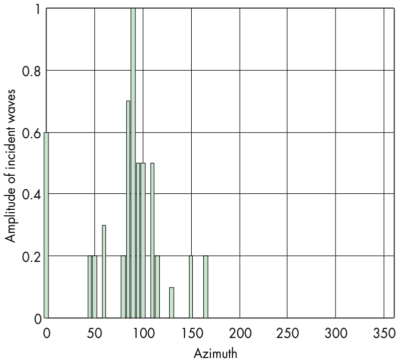

Fig. 31: Azimuth distribution of waves radiated by an emitter in built-up area

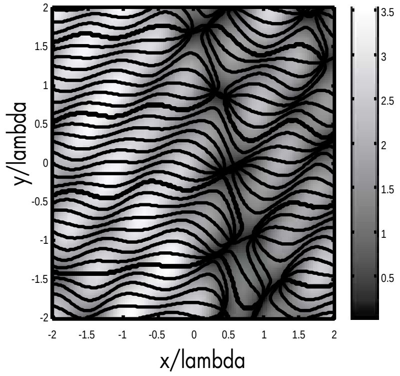

Fig. 32: Resulting field within a range of 4 x 4 wavelengths (the amplitudes are grey-level-coded, the lines represent isophases with π/4 spacing)

A large number of waves is involved [18]; Fig. 31 shows for example the azimuth distribution of the waves generated by a mobile transmitter in a built-up area. The direct wave component with the amplitude 1 arrives from an angle of 90°. Fig. 32 shows the resulting wavefront in form of a contour display for phase and amplitude [11].

If the majority of waves arrives from the direction of the emitter, the DF error can be sufficiently reduced by increasing the aperture of the antenna system. This effect is shown in Fig. 33 for an interferometer direction finder.

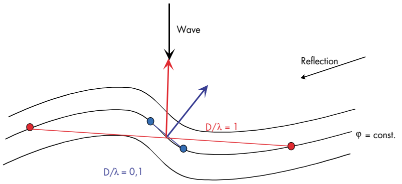

Fig. 33: Reducing bearing error of interferometer direction finder by increasing antenna aperture

6.2 Synchronization tolerances

Different gain and phase in the receive sections cause DF errors that are the greater the smaller the antenna aperture referred to the wavelength. This is illustrated in Fig. 34 for a 2-element interferometer.

As already mentioned, the receive sections of most multireceiver direction finders are calibrated for synchronism with the aid of a test generator prior to the DF operation. The transmission parameters in each section are measured in magnitude and phase and the level and phase differences are stored. In the DF process the measured values are corrected by the stored difference values before the bearing is calculated.

Special attention is to be given to the frequency response of the filters since synchronism is not only to be ensured in the middle of the filter passband but also at the band limits. Digital filters have the decisive advantage that they can be implemented with absolutely identical transfer characteristics.

6.3 Modulation

Usually the carrier signal (angular frequency ω) of the emitter to be DFed is modulated with the complex modulation function

$$m(t) = r(t)\, e^{js(t)}$$

(complex envelope).

The electric field strength at the spacing D is

$$E(t, D) = k_E\, r(t - D/c_0)\, e^{j(s(t - D/c_0) + \omega t)}$$

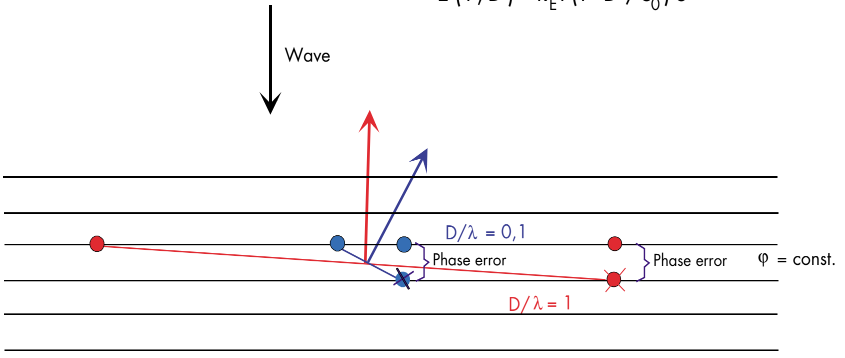

Fig. 34: Effects of phase synchronization tolerances on the bearing error when using different antenna apertures

The modulation can affect the DF result in several aspects:

- Different envelope delay distortion in the DF channels (see 3.2)
- With sequential antenna scanning: modulation function is not sufficiently stationary for the duration of the measurement or cannot be compensated by other measures prior to DF evaluation
- Possible decorrelation between the antenna elements if the spacing between the elements is greater than the coherence length $L_k = B/c_0$, where B is the bandwidth of the signal. The instantaneous values of the amplitudes and the phase differences between the elements are then no longer independent of the scanning point in time.
  Typical coherence length:
  B= 100 kHz L_k=3000 m
  B= 10 MHz L_k=30 m

6.4 Noise

Leaving aside intermodulation distortion, interference caused by noise has a limiting effect on the sensitivity of a DF system.

Sensitivity is to be understood as the field strength at which the bearing fluctuation remains below a certain standard deviation.

Noise can be in the form of

- external noise (atmospheric, galactic, industrial noise)
- internal noise produced in the system (antenna amplifier, DF converter, A/D converter)

The following considerations refer to the internal noise. The 2-element interferometer is used again as a mode, the same as in the examination of multiwave problems; for the complex case of a 3-element interferometer see [19].

Uncorrelated noise in the two receive sections causes statistically independent phase variations of the two test voltages according to the signal-to-noise ratio (Fig. 35).

In narrowband systems the noise voltage becomes approximately sine-shaped with slowly varying amplitude and phase so that – assuming large signal-to-noise ratios – the phase variation is given by the following equation [20]

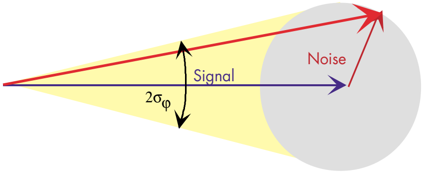

Fig. 35: Effect of noise on phase variation of measured voltages

$$\sigma^2_\varphi = \frac{1}{2S/N}$$

Mapping of the phase variation to virtual variations of the DF antenna positions (Fig. 36) yields for the bearing error

$$\sigma_\alpha \cong \frac{\sigma_\varphi}{\sqrt{2}} \frac{\lambda}{\pi D}$$

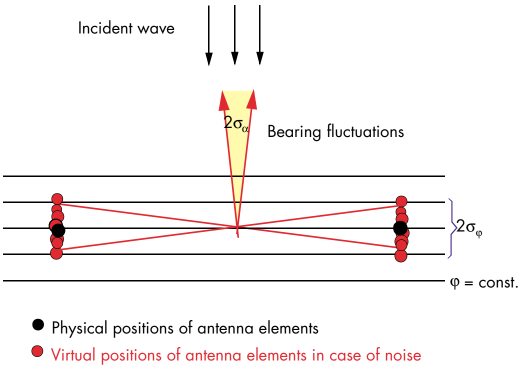

Fig. 36: Effect of phase noise on bearing error

This shows again the importance of the relative antenna aperture D/λ to be as large as possible.

Given a sufficiently long observation time, the variations caused by noise can be reduced by averaging. If the data used for averaging are uncorrelated, the variation is improved through averaging over K values in accordance with [21].

$$\sigma^2_{av} = \frac{\sigma^2}{K}$$

In Fig. 37 the two effects are combined. The shown curves of the signal-to-noise ratio in dB achieve a bearing fluctuation of 1 ° (standard deviation).

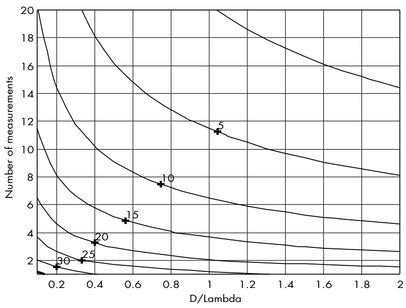

Fig. 37: Effect of antenna aperture and number of measurements on signal-to-noise ratio (in dB) required for a bearing fluctuation of 1 ° (standard deviation)