Distance Measurement by means of Radio Waves
Comparison of Classical and High-Resolution Spectral Methods

Lambda:4 Entwicklungen GmbH, Hamburg, Germany

Comparison of the Two Methods FFT and HiRes

For the measurement of the distance between receiver and transponder, two different methods were implemented by Lambda:4. These are the implementation of the classical spectral method of radio direction finding technology which measures the distance of the main energy between two points on the one hand, and a high-resolution spectral method, which determines the shortest distance contained in a distance spectrum on the other hand.

For both methods, measurement areas were implemented, one measurement area lying down the maximum distance which by such setting can be measured. Since one component of the measurement error depends on the measurement area, such measurement area should be selected as ideally as possible.

A Classical Methods of Radio Direction Finding

In the classical methods of radio direction finding, the angle of incidence of the signal portion with the highest energy is measured by means of spectral methods.

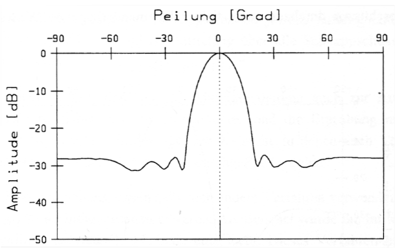

figure 1: simulated direction finding of a wave of 0°, linear group with 9 antennas, d = λ/2, S/N = 20 dB, 100 snapshots, bearing value determined –0,1°, |: pre-given direction of incidence ⋮: calculated direction of incidence [1]

If two signal portions providing approximately the same energy almost coincide, the two can hardly or not at all be differentiated. An identification of a signal by using Fast Fourier Transformation becomes difficult already for a difference of 10 dB or less as compared to the signal sum. This problem is observed, if there is no line of sight (LOS) and if many different reflections within the buildings are possible.

If there is LOS, the measurement results are very close to the distance in reality. In measurements with no LOS, the measurement results always are higher than the real distance, - and depending on the conditions of the environment or on the materials used, they may be even much higher.

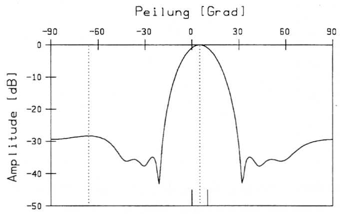

figure 2: simulated direction finding of two waves of 0° and 10°, linear group with 9 antennas, d = λ/2, S/N = ∞, 1 snapshot, bearing values determined 5° and –66°, |: pre-given direction of incidence ⋮ : calculated direction of incidence [1]

B High-Resolution Spectral Methods

In high-resolution spectral methods, as shown here in the example of MUSIC, a high-resolution distance spectrum is measured.

The MUSIC algorithm is a high resolution MUltiple SIgnal Classification technique based on exploiting the inherent structure of the input covariance matrix. It provides information about the number of incident signals, direction of arrival of each signal, strengths and cross correlations between incident signals, noise power, etc. [2]

Even if the portion providing the shortest distance, does not contain the highest power level, this portion can still be identified. The resolution capacity of such method with the present hardware structure provided by Lambda:4 amounts to ca. 20 dB. All signal portions which are weaker by up to 20 dB than the signal sum, can be resolved.

By means of the MUSIC-algorithm, even two almost coinciding signals can be differentiated and individually evaluated.

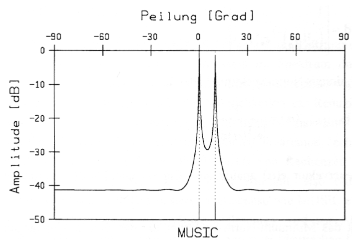

figure 3: incidence of two waves of 0° and 10° on a linear group with 9 antennas, d = λ/2, S/N = 20 dB, 100 snapshots, calculation of the angular spectrum by means of the MUSIC-estimator, directions of incidence determined 0° and 10°, |: pre-given direction of incidence ⋮: calculated direction of incidence [1]

If there is LOS, the measurement results are very close to the distance in reality as well. In measurements with no LOS, the measurement results always are somewhat higher than the real distance, however, usually only by a small amount.

EVALUATION / PERFORMANCE / LIMITS

To compare the two methods, the data of distance measurements from several field tests were recorded. A test subject moved around on a floor in an office building at walking pace, and continuous distance measurements were taken at ca. 1.5Hz.

Route points located on the way were measured – with an accuracy of +/- 10cm. By means of these route points the distances measured were put in relation to the real distances. The real distances between transponder and station were interpolated by means of the route points over the elapsed period of time. In this method, an additional error of up to +/- 25cm is to be expected.

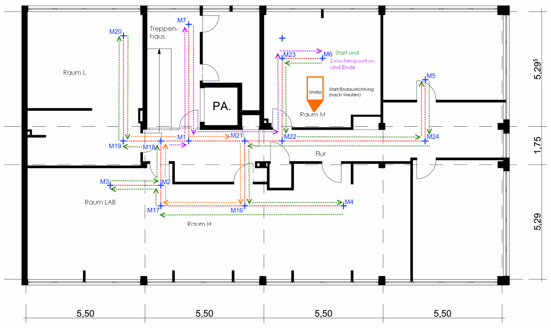

figure 4: floor plan showing route covered and route points (for example „M20“)

By means of a test we have considered the distribution of absolute errors in ca. 2000 distance measurements in a time period of 24 minutes. In such test, distances of 0 to 11 meters between transponder and station were reached. Figure 5, 6 and 7 show the frequency of errors occurring in three distance ranges.

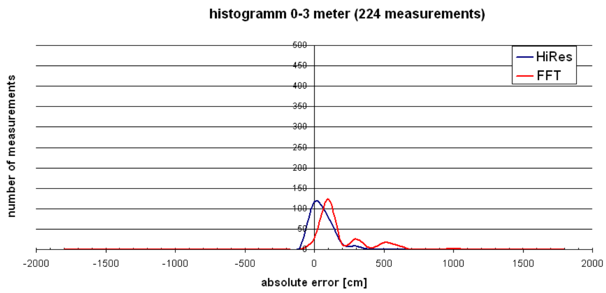

figure 5: Comparison of FFT and HiRes, 224 distance measurements in the range between 0 and 3 meter,

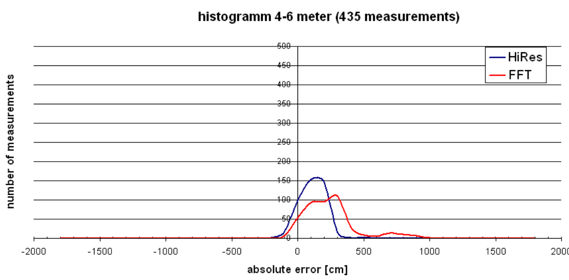

figure 6: Comparison of FFT and HiRes, 435 distance measurements in the range between 4 and 6 meter,

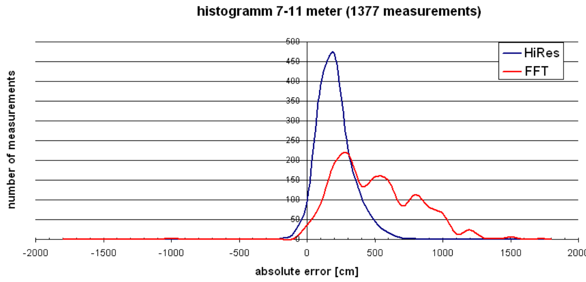

figure 7: Comparison of FFT and HiRes, 1377 distance measurements in the range between 7 and 11 meter,

By means of these charts, the quality of the HiRes method as compared to the FFT method becomes very clear. In all three distance ranges, the HiRes method shows superior results and a clear majority of measurements with small errors becomes apparent – even with larger distances.

The general performance of the technology was tested in different environments. With an unobstructed line of view, a range of ca. 1500m was achieved in the city park of Hamburg [3], in other, non-documented tests in the Alps, up to 5 km.

Indoor tests were run in airports, subway stations, in office buildings and underground parking garages. Here the ranges obtained very much depend on the structural conditions. In one office building a vertical range of ca. 7-8 floors was reached [4]. On the airport pier in Hamburg a reach of 550m horizontally, and three floors vertically was obtained [5]. In underground parking garages, a transponder was reliably located through 2-3 parking levels [6].

The accuracy of the distance measurement inside buildings typically amounts to 1-5m, depending on the wall materials and other conditions of the environment (for example, many people moving around). With an unobstructed view over distances of 100-500m, the maximum error typically lies around 10 to 20 meters. In the case of very long distances or strong signal attenuation respectively, a distance measurement is not always possible.

References

[1] Mewes, H.: *Theoretische und experimentelle Untersuchungen von Peilverfahren für Mehrkanalempfänger im HF-Bereich*, Verlag Shaker, Aachen, 1994

[2] R.O. Schmidt, *Multiple Emitter Location and Signal Parameter Estimation*, Proc. IEEE Trans. On Antennas and Propagation, Vol. AP-34, No.3, Mar. 1986.

[3] John, F., *Protokoll Feldtest Reichweite SW 1.76*, Lambda:4-interne Feldtestprotokolle, Hamburg, 23. Mai 2012

[4] John, F., *Protokoll Feldtest L4 Bürogebäude über X-Stockwerke*, Lambda:4-interne Feldtestprotokolle, Hamburg, 10. Mai 2012

[5] Ernst, M., John, F., *Protokoll Feldtest Flughafen Hamburg*, Lambda:4-interne Feldtestprotokolle, Hamburg, 19. April 2012

[6] John, F., *Protokoll Feldtest Tiefgarage, Lambda:4-interne Feldtestprotokolle*, Hamburg, 2. März 2012

If you have any questions, please feel free to contact us:
Arne Bestmann: bestmann@lambda4.com, Mirjam Ernst: ernst@lambda4.com