Practical Aspects of the Direction Finding Accuracy of Compact Wideband Arrays for V/UHF Frequencies

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Abstract – **The paper discusses some advanced topics of direction finding (DF) of communication signals and respective antenna arrays in the frequency range from 20 to 3000 MHz. There are a number of issues contributing to potentially severe performance degradation of an installed system in its typical operational environment compared to the same system operated under the well-defined test conditions on an antenna test site. It is shown that especially polarization aspects deserve more attention than traditionally paid.**

1 INTRODUCTION

Radio communications is a ubiquitous technology. Many radio standards exist throughout the world and are used by a multitude of individuals and organizations. Wideband direction finding systems enable the detection and determination of the line of bearing (LoB) of virtually arbitrary radio emissions and are thus important for security applications, in spectrum regulations enforcement as well as in military operations.

The three main components that make up most of the current digital DF systems are a specialized DF antenna, a set of DF receivers digitizing the antenna signals and the numerical algorithms. Typically, DF antennas need a certain aperture (and size) to enable appropriate performance. From an installation point of view there exists however a strong desire to minimize the size. So we refer to compact arrays in a dual sense as (a) being much smaller than the wavelength (e.g. diameter of 0.5 m at 15 m wavelength) and (b) packing the elements of multiple antenna array bands into a compact overall volume.

In particular, it is pointed out that although under idealized conditions on an antenna test range the DF accuracy might be high, the compactness gives rise to all sorts of rapid degradation when installed in a non-ideal operational scenario. The deviations arise from non-compliance with the typical assumption of a pure single wave scenario, from non-compliance with a pure vertical source polarization, from parasitic effects of the mounting, e.g. currents on parts of the structure, as well as from insufficient calibration methods for scenarios where elevation angles are also important.

The paper starts in Section 2 with a discussion on general aspects and methods on the calibration of DF antenna arrays. Calibration complexity, measurement errors and modeling errors are considered.

Section 3 is dedicated to some experimental findings about the sensitivity of an array of loop antennas to its mounting conditions. Loop arrays are an attractive solution to build very compact arrays for very low frequencies even down to ~ 1 MHz, but require great care for calibration and installation.

Section 4 presents a review of observations made during the evaluation and calibration of another compact antenna system which is only 500 mm in diameter and 900 mm high [1]. This system covers the HF, VHF and UHF frequency range from nominally 300 kHz to above 3 GHz. There are four sub-bands each covered by separate antenna arrays comprising suitable antenna elements. These antenna elements are interleaved as well as being stacked above each other leading to undesired mutual coupling and cross polarization effects not normally observed in less compact arrays. In addition, some of the sub-bands use internal mounting structures within the arrays not only to support the antenna elements but also to generate omni-directional patterns for monitoring applications. Specialized calibration techniques were developed to mitigate these undesired effects and to achieve the specified system performance.

2 DF CALIBRATION FUNDAMENTALS

DF and High-Resolution-Parameter-Estimation are in general highly dependent both on the choice of a suitable antenna array as well as precise knowledge about the array characteristics. In essence direction of arrival is estimated by comparing the actual measured signals at the array output with some a priori knowledge about the expected signal given a certain direction. This knowledge is either obtained by an analytical model of the antenna array response or by calibration measurements. The first approach requires that the actual antenna array behaves exactly as the analytical model assumes. This method leads to quite efficient algorithms but the requirements on the layout/geometry of the antenna array and the patterns

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of the individual elements are high. Some algorithms require a uniformly spaced array where the elements are exactly equidistant and the radiation patterns are exactly equal for all elements. This cannot be guaranteed with practical antenna arrays, thus, leading to severe estimation artifacts. In particular the interactions between different elements of the array (mutual coupling) are often neglected.

Another, more practical approach is to measure the response of the antenna array for all directions of interest and to use this information for direction finding. The data is obtained using calibration measurements either in an anechoic chamber or on a suitable test range. Usually the antenna array is mounted on a positioner and illuminated by a source antenna. Using the positioner the antenna response can be measured for arbitrary angles. By using calibration measurements it can be ensured that arbitrary spacing of the elements as well as mutual coupling and non-uniform radiation patterns are properly accounted for.

However, the quantity of measurement data is very large. This is so since the measurements need to be done for all directions of interest. These directions are unknown and it requires a virtually infinite number of measurements. This problem is solved by measuring only a limited set of directions and using an adequate interpolation algorithm to obtain the antenna response for arbitrary directions. One interpolation method that also reduces the number of samples necessary is the “Effective-Aperture-Distribution-Function” (EADF) [2]. It is the 2D-Fourier transform of the sampled radiation pattern and, therefore, provides a low interpolation error (given that the sampling theorem is met).

The calibration measurement is affected by the test positioner and the general measurement environment. The purpose of the calibration measurement is to obtain the antenna responses as would be the case in actual field operation. Therefore, the array should be mounted as it would be in its final operational environment. During calibration this cannot always be assured because the antenna positioner and the mounting fixture may disturb the measurement since they are not part of the actual operational antenna installation. Parasitic reflections inside the anechoic chamber or on the test range can also affect the accuracy of the calibration measurements. Fortunately, this can be detected and to some extent corrected with the help of the EADF [2]. Parasitic reflections can cause a broadening of EADF especially in the elevation domain and can be compensated by cutting out the affected samples.

However, it can be said that besides the above mentioned challenges of the calibration measurement this approach is superior to the use of analytical array models as it characterizes the properties of antenna arrays more accurately.

Another aspect of the accuracy of direction finding is the data model used. Often the direction of interest is only characterized in the azimuthal plane and it is assumed that the incident wave or the individual array elements are single-polarized (either pure vertical or horizontal). These assumptions may then define the way in which the calibration measurement is conducted. For example, if the elevation angle is of no interest the calibration is done only for an “azimuthal cut” (fixed elevation angle). Depending on the type of antenna array this may lead to biased or even completely distorted results [2]. The same is true for the polarization characteristics of the source antenna. Even if a particular antenna appears to be single-polarized in the main-beam direction this may not be true anymore outside the main-beam. Furthermore, while an individual antenna may be single-polarized this might not be the case if it is mounted within an antenna array. Due to the mounting of the array and the interaction between different elements the polarization characteristics may change.

3 LOOP ANTENNAS FOR DF

Most DF antenna concepts exploit phase and amplitude difference measurements between geometrically displaced radiation elements, thus representing spatial samples of an incoming wave front. The extent of the measurable phase differences is a function of the element spacing over the wavelength. Thus, “small arrays” at “large wavelengths” yield only small measureable phase differences and thus poor DF accuracy and sensitivity. Using loop antennas as the basic element is the only solution to partly get around this fundamental relation. Loop antennas are effectively sensing the magnetic field component of the incoming wave and thus inherently create a phase and amplitude response that depends on the angle of incidence.

The ideal pattern of a loop element has two main lobes perpendicular to the plane spanned by the loop and two deep nulls 90° off the main lobes. Figure 1 illustrates a significant deviation in the antenna patterns of a small loop antenna being part of a more complex compact DF antenna. It has been found that the large deviations from an ideal loop in free-space are mainly related to currents on the antenna mast and cable shielding. The suppression of these currents is needed in order to avoid dependency on a particular mast setup. In this example the optimized configuration (b) is achieved by using a non-conductive mast section plus a high number of ferrite cores around the feed cables. The vanishing of the secondary main lobe towards 100 MHz is due to the presence of a large concentric support structure made of metal.

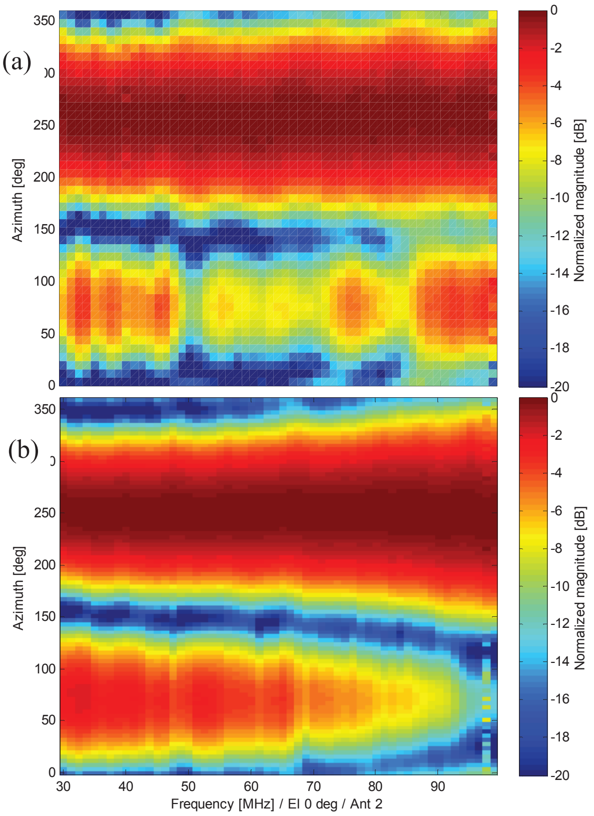

Figure 1: Magnitude antenna patterns of a loop antenna inside a compact DF array. (a) original setup giving strong deviations from free-space loop patterns and (b) the same antenna in a greatly improved measurement setup yielding patterns closer to a loop in free space.

4 SOURCE POLARIZATION

Wideband DF systems are commonly specified to operate only on vertically polarized (Vpol) incoming waves. This seems to be a reasonable selection for systems using monopole-type antennas (whips, blades, etc.) at low and medium frequencies, the adoption of Vpol for higher frequencies is less clear. Yagi antennas are often used with horizontal polarization (Hpol), and portable uses of monopole or patch antennas seldom create a pure Vpol but result in mixed polarization.

Three approaches to cope with the practical challenges of mixed source polarization are: 1) the use of a polarizer which acts, as a physical filter to reflect and keep the “undesired” polarization from the actual antenna elements, 2) use of antenna elements that are insensitive to source polarization, e.g. circularly polarized spiral antennas, and 3) dual-polarized antennas where each antenna element provides two ports to measure the Vpol and Hpol field components individually.

4.1 Polarization and DF stability

During the prototyping phase of a new compact antenna it was observed that at certain frequency sub-bands there seemed to exist some instability in the measured DF antenna patterns. Short term stability was good but during the course of days changes in the data built up, leading to serious degradation of the DF performance. A large Vpol LPDA was used as a source at that stage and the hypothesis was made that this setup might create a significant amount of Hpol, mainly from the ground reflection which may change with ground conditions. Therefore, an experiment was conducted with the aim to improve the cross-polarization discrimination (XPD) of the receive array by putting a polarizer filter over the antenna (Figure 2). The polarizer consists of an etched grid of horizontal strips 2 mm wide and 20 mm apart. The ends of the individual strips are soldered together to form continuous strips. The polarizer made almost no change to the Vpol DF but did not have the desired effect of eliminating the Hpol. Contrary to theoretical predictions of between 20-25 dB [3], the Hpol attenuation was only improved by about 7 dB (See Figure 3). After additional tests it was concluded that the polarizer was so closely spaced to the array that there were additional parasitic interactions with the array.

The final resolution of the instabilities involved a number of improvements in the DF antenna and ferrites on cables as well as changing to a different type of source antenna (caged rod conical monopole), providing a better source polarization purity because it directly launches only a ground wave.

Figure 2: Test setup with a polarizer filter covering the radome of a compact DF antenna.

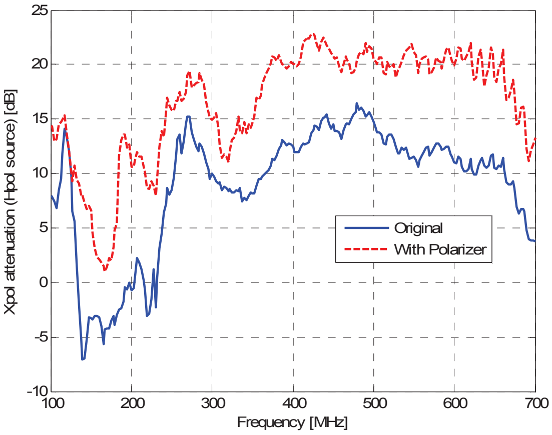

Figure 3: Improvement of the cross-polarization attenuation for Hpol signals from the polarizer filter.

4.2 HPol DF using Vpol elements

Having a sophisticated DF system that unknowingly provides wrong LoBs if the source polarization does not match the specified Vpol is a major drawback. For an operator it is normally impossible to recognize this situation. Figure 4 depicts the effect for a large number of frequency lines, where the conventional DF (blue) comes up with almost random bearings. The correlative interferometer at least provides reliability information on the LoB that can be used to exclude the unlikely bearings.

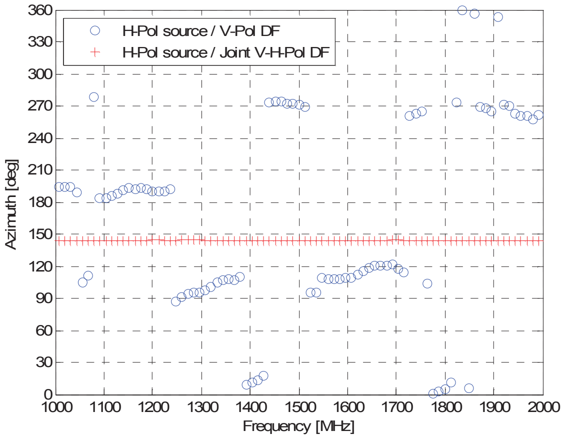

Figure 4: Illustration of the DF failure for Hpol signals (blue circles, true LoB at 144°). The joint V-H-Pol DF results are correct also for Hpol (red plus signs).

Rather than changing an existing antenna design to include fully multi-polarized DF arrays using dual or circularly polarized elements the feasibility of an intermediate solution was experimentally addressed. A solution to provide accurate DF results for both Vpol and Hpol signals including the discrimination between the two was devised.

There are three principal questions to be looked at: 1) Are the Vpol elements sensitive enough for Hpol excitation? In a compact array with rather small elements this has been shown to be true, since the XPD is only 10-15 dB. 2) Are the Hpol antenna patterns "well-behaved" in order to enable correlative DF processing at reasonable SNR? Measurements and analysis of the Hpol patterns have proven this especially for the more interesting higher frequency bands. 3) Are the correlation properties of the Vpol and Hpol patterns sufficiently orthogonal to discriminate between the two? There clearly exists some frequency dependence on the degree of cross-correlation between Vpol and Hpol patterns. This in turn means that reliable discrimination requires for some frequencies a higher SNR than for others, and also the susceptibility to mixed polarized situations varies. More effort is required to derive a clear set of parameters quantifying these effects but for the considered antenna reliable operation could be demonstrated even while preserving DF capabilities for Vpol sources with very high elevation.

5 CONCLUSIONS

The paper elaborated on some of the consequences which very compact DF arrays have on the installed performance of a system. Loop antennas are good for DF at low frequencies but need special attention to minimize electromagnetic interactions with the mounting structure.

Robust DF performance in operational scenarios requires measures to mitigate against mixed polarized incident fields. Some effects were illustrated by a number of dedicated test measurements on existing compact arrays. In addition, some measures to minimize the problematic effects in compact arrays were described.

Acknowledgments

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