HF direction finding with a vertical array of collocated loop antennas

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ABSTRACT

The use of antenna diversity and (or) space diversity in HF (3 to 30 MHz) system has been investigated in numerous studies, a synthesis about some methods and applications is described in [1].The purpose of this paper is to present a particular application in the HF radio wave direction finding. The knowledge of propagation effects and antenna effects allowed particular array configurations to provide DOA estimation. The effect of introducing a small vertical diversity in a collocated antenna array (regarding to the wavelength) is to improve the elevation measurements. The paper describes the collocated array and presents the first experimental results of direction finding related to this new array structure.

INTRODUCTION

In the HF band, the propagation channel is related to the presence of several ionospheric layers, which act as reflectors for sky waves propagating in one or more hops. It generates signals issued from multipath propagation. In addition, the anisotropic nature of the ionosphere imposes a multimode propagation. This complex propagation channel needs the use of a high resolution algorithm such as MUSIC to discriminate angles of arrival. In a such method of signal processing, the contribution of antenna effect and propagation effects on the incoming wave have to be known. Depending on the type of antenna array, AOA estimation can be affected.

A GENERAL VECTORIAL EXPRESSION OF THE ACQUIRED DATA

The vectorial expression of the data at the output of the antennas can be written as:

$$X(t) = F(Az, El).S(t) + N(t)$$

where :

X(t) denotes the observation vector obtained on the collocated antennas,
S(t) is the signal vector corresponding to the different modes,
F(Az,El) represents the steering vector matrix, it is the complex responses of each antenna for the several paths of the signal. This function includes the spatial diversity.
N(t) is an additive noise vector. The components of this vector are assumed to be temporally and spatially white.

MUSIC ALGORITHM OPERATING ON A HETEROGENEOUS ARRAY.

The MUSIC parametric method [2] aims to estimate parameters which are bound by incident sources such as angles of arrival, signal strength and by computation of complex responses F(Az,El). An original method operating on an array, which is made up different sensors, has been proposed [3]. The different antenna patterns need computation of each antenna complex response in respect to the array configuration. Therefore, antenna characteristic functions are assumed to be known. Antenna complex responses can be obtained from computational method of moment (NEC 2 D). The responses take into account the following parameters:

- Angle of arrival(azimuth and elevation)
- Location of the received station,
- Frequency of the carrier

- Type of antenna
- Height of the antenna,
- Characteristics of the ground,
- Electrical characteristics of amplifiers and cables.

The two first sets of parameters include the polarization characteristics (function of the geomagnetic field) of the incoming waves. In the HF band and for ionospheric propagation, the polarization for the two possible incoming modes can be determined by the limit conditions of Budden [4].
The type and the height of antenna are two interesting parameters because the system designer can change them depending on ambiguities of collocated array.
When the complex antenna responses are obtained, the pseudo spectrum can be computed. The method takes into account the two possible polarization modes, so we have to compute two pseudo spectrum (PSSPx et PSSPo).

$$PSSP_T(Az,El) = \left[\sum_{p=NSE+1}^{NC} \left| v_p^T b_T(Az,El) \right|^2 \right]^{-1}$$

where:

- b_T represents the normalized steering vector for T mode,
- v_P is the set of vectors defining the noise subspace
- T is an index for each mode O or X.

Simulations are performed by implementing a bi-vectorial HF signal model, proposed by [5] which includes antenna and space diversities.

DESCRIPTION OF THE COLLOCATED ANTENNA ARRAYS

The collocated HF antenna array using vertical diversity is set up with the same type of antenna, but with different heights. The array uses two sets of sensors placed on a vertical mast of 18 meters high. Each sensor is composed with three active loop antennas oriented in the east west, north south and horizontal directions. The first set of sensors is set at 2 meters high; the second is positioned at 12 meters high.

Figure 1: 2 sub arrays set up on the same mast : first sub array at 2 meters high, the second at 12 meters

The method to determine the height of the higher sub array is based on the inter-correlation product of the steering vectors. Steering vectors are computed at frequencies from 3 to 20 MHz and for height of the highest sub array between 4 to 18 meters high. The two sub arrays have the same orientation.

Coupling can be an important limitation, in [6], it is shown that receiving loop antennas are uncoupled enough. All channels are relatively well uncorrelated. Generally, the level of the intercorrelation product is lower than 0.9 and give a guarantee for a good estimation of the AOA with Music algorithm, however antennas oriented in the same direction are the most correlated.

EXPERIMENTAL RESULTS.

The experimental system is located in Monterfil (about 25 km from Rennes, 48° N 2°W, France). Results presented in this paper have been obtained in the following conditions.

- Bandwidth 3 kHz
- Frequency sampling 40kHz
- Acquisition duration 205 ms
- Number of snapshot 65

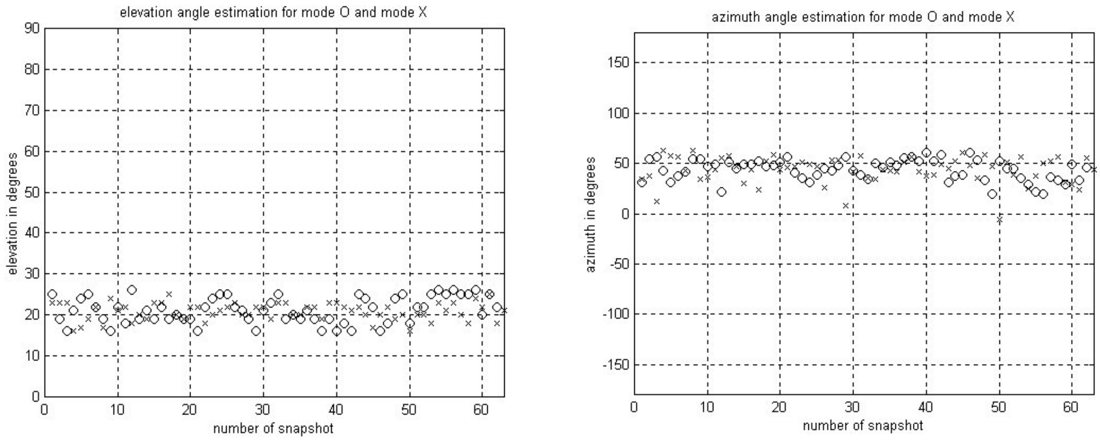

Figure 2 : angle estimation for azimuth and elevation for each mode propagation (O and X)

On figure 2, the O mode path is represented by “o” and the X mode path is represented by “x”

The link is Hamburg (Germany)-Monterfil (France)

- Carrier frequency 10.101 MHz
- Distance 1070 km
- Geometrical azimuth 47° 59’
- Modulation type AFSK

Measurements have been acquired on March 25 2002 from 16h30 to 16h50 UT. These measurements take into account only the main path : this path corresponds to the absolute pseudo-spectrum maximum, secondary peaks are in this case occulted.

	O mode		X mode	
	mean	σ	mean	σ
Elevation	21.29	3.2	21.06	2.16
Azimuth	43.6	10	46	13

Table 1 : statistical results for the Hamburg-Monterfil link

These estimations agree with the values computed by LOCAPI [7].

The accuracy of azimuth measurements needs to be improved. In this way, vertical loops could have different directions and so, the complex responses will be different with azimuth and therefore the ambiguity should decrease.

CONCLUSIONS

The use of antenna effects and the space diversity in a collocated antenna array allows the estimation of direction of arrival with the MUSIC algorithm. Experimental results have shown the availability of the technique using slightly correlated signals. For the elevation estimation angle, the spatial diversity increases the accuracy of measurements compared to a single collocated sensor.

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