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A Low Complexity Method for HF Direction Finding

F. Marie, M. Oger, D. Lemur, Y. Erhel, G. Le Bouter, L. Bertel, C. Brousseau

This paper presents a new algorithm with a low complexity for HF (3-30 MHz) direction finding (DF). This method is applied to different types of signal and to different configurations of circular arrays (homogeneous or heterogeneous).

Introduction: In order to check or calibrate HF receiving antenna arrays we proposed [1] to compare the estimated differential responses of an array with the theoretical values for a given direction of arrival (DOA) of the incident wave. In this letter, this idea is generalized to the determination of directional vectors which minimize the differences between the phases of the estimated and theoretical values of the array responses. This criterion is the basis of a simple DF method. After a short description of the proposed method, some experimental results involving different types of signal and different configurations of array are presented.

A method to estimate the differential responses of an array: Let us consider a receiving array. In the case of one incoming path, the signal at the output of an antenna can be expressed as:

$$X_n(t) = a_n(\theta)Sr(t) + N_n(t) \quad (1)$$

$X_n(t)$: acquisition at the output of the channel n,

$Sr(t)$: signal corresponding to the received wave,

$N_n(t)$: additive noise,

θ : angle of arrival (azimuth, elevation).

The components $a_n(\theta)$ combine the antenna responses $F_n(\theta)$ and the values of the phases $\varphi_n(\theta)$ calculated with respect to the array geometry [2]:

$$a(\theta) = (F_1(\theta)e^{j\varphi_1(\theta)}, \dots, F_{NC}(\theta)e^{j\varphi_{NC}(\theta)})^T \quad (2)$$

NC : number of channels,

T : transposed

In the case of a homogeneous array, all the sensors have a common antenna response $F(\theta)$; the vector is simplified as:

$$a(\theta) = F(\theta)(e^{j\varphi_1(\theta)}, \dots, e^{j\varphi_{NC}(\theta)})^T \quad (3)$$

On the basis of equation (1) and neglecting the additive noise, the signals existing at the outputs of the channels can be expressed as:

$$\begin{pmatrix} X_1(t) \\ \cdot \\ X_n(t) \\ \cdot \\ X_{NC}(t) \end{pmatrix} = \begin{pmatrix} a_1(\theta) \\ \cdot \\ a_n(\theta) \\ \cdot \\ a_{NC}(\theta) \end{pmatrix} Sr(t) \quad (4)$$

One channel is considered as a reference with $a_{ref}(\theta) = 1$ so that $Sr(t) = X_{ref}(t)$

From these equations the estimated differential response \tilde{a}_n of channel n is extracted by the following expression:

$$\tilde{a}_n = \frac{X_{ref}^*(t)}{X_{ref}^*(t) \cdot X_{ref}(t)} \cdot X_n(t) \quad (5)$$

*: conjugated

In order to compare the theoretical and estimated differential responses (a_n^{th} and \tilde{a}_n), the first ones must be normalized with respect to a channel of reference:

$$a_n^{thnor}(\theta) = \frac{a_n^{th}(\theta)}{a_{REF}^{th}(\theta)} \quad (6)$$

We can choose the same channel of reference as in equation (5) ($REF = ref$), if not the estimated responses have to be also normalized

$$\tilde{a}_n^{nor} = \frac{\tilde{a}_n}{\tilde{a}_{REF}} \quad (7)$$

For the measurements presented in the next paragraph, channel 1 is the reference ($REF = ref = 1$). The choice of the channel of reference is not critical for a circular array; for a heterogeneous array made up of very different antennas, however the choice would be less evident. It is desirable to choose a well modelled antenna giving a good signal to noise ratio.

The DOA of the sources are estimated by searching the directional vectors which minimize the differences between the phases of the estimated and those of the theoretical array responses. These correspond to the angular values which maximize a directional function expressed as:

$$L_{PSSP}(\theta) = \frac{1}{\sum_{n=1}^{NC} (\arg(a_n^{thnor}(\theta)) - \arg(\tilde{a}_n^{nor}))^2} \quad (8)$$

In the case of a heterogeneous array, the theoretical responses [2] for the ordinary (denoted O) mode and for the extraordinary (denoted X) mode are computed, providing two directional functions (one for each expected polarization) and thus two pseudo-spectra (Fig. 4).

The experimental array. It contains eight active loop antennas equally spaced on a horizontal circle with a 25 m radius. If all the antennas are oriented in the same direction, the array is homogeneous (Fig. 1 a). If the antennas are oriented in different directions, the array is heterogeneous (Fig. 1 b shows practical configuration): the heterogeneous array combines diversity of the spatial responses (different antennas orientations) and space diversity.

Measurements on the homogeneous circular array. The antennas are set up along the East-West axis. The first acquisition concerns an AM transmitter located in Moosbrunn (Austria: latitude: 48°N; longitude: 16°28E, frequency 13.730 MHz [3]) with a geometrical azimuth of 83.4° from Rennes (France). The sample rate and the analysis duration are equal to 24 ksamples/s and 21.85 s respectively. The DF (Fig. 2) provides as estimated angles of arrival : azimuth = 82°, elevation = 10°. (For comparison, the multiple signal classification method MUSIC with an estimated number of sources $p = 2$, gives: azimuth = 82°, elevation = 27°.)

The second acquisition concerns a DRM (Digital Radio Mondiale) transmitter located in Junglister (Luxembourg: latitude: 49°40N; longitude: 6°19E, frequency 6.095 MHz [3, 4]) with a geometrical azimuth of 70° from Rennes (France). The sample rate and the analysis duration are equal to 48 ksamples/s and 10.9 s respectively. The DF (Fig. 3) provides the following angles: azimuth = 69°, elevation = 50°. (MUSIC with $p = 2$ gives: azimuth = 68°, elevation = 54°.)

Measurements on the heterogeneous circular array: In this experimentation, the array responses contain both the geometrical phase and the antenna responses [2]. The DF functions are calculated jointly for an O and an X mode. The acquisition is relative to the Moosbrunn's transmitter [3]. The sample rate and the analysis duration are equal to 24 ksamples/s and 21.85 s respectively. The results (Fig. 4) show the presence of only an X mode incoming with the following angles: azimuth = 82°, elevation = 24°. (MUSIC with $p = 2$ gives: azimuth = 83°, elevation = 22° for an X mode and azimuth = 84°, elevation = 3° for an O mode three times weaker than the X mode)

Conclusion: This article introduces a new simple and fast DF method based on the minimization of the differences between the measured and the theoretical responses of an array. Measurements on different types of signals (AM and DRM) using different array configurations (homogeneous and heterogeneous) demonstrate the potential of the proposed technique.

Additional studies will consider the performances (angular resolution, computing time...) compared with other DF methods (Interferometry, Standard Beamforming, CAPON, MUSIC...).

References

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3 www.hfcc.org

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Figure captions:

Fig. 1: Homogeneous (a) and heterogeneous (b) circular array

Fig. 2 AM broadcast from Moosbrunn (13.73 MHz, March 30, 2006)
Spectrum for channel 1 (a) and pseudo-spectrum with scale in dB (b)

Fig. 3 DRM broadcast from Junglister (6.095 MHz, June 1, 2006)
Spectrum for channel 1 (a) and pseudo-spectrum with scale in dB (b)

Fig. 4 AM broadcast from Moosbrunn (13.73 MHz, March 2, 2004)
Pseudo-spectrum for O mode (a) and pseudo-spectrum for X mode (b) (scale in dB)

Figure 1

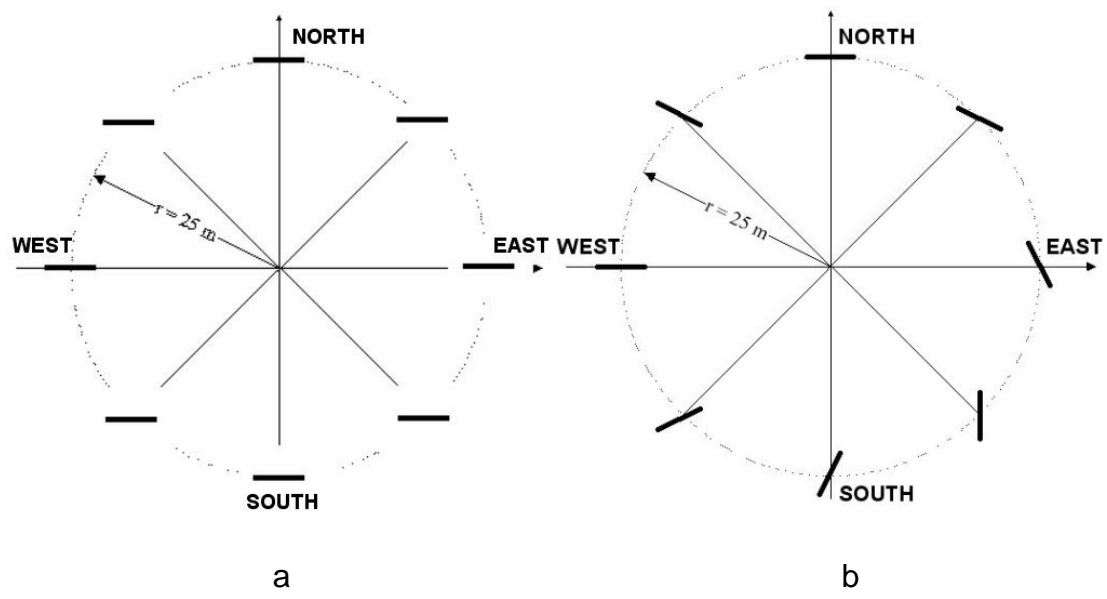


Figure 2

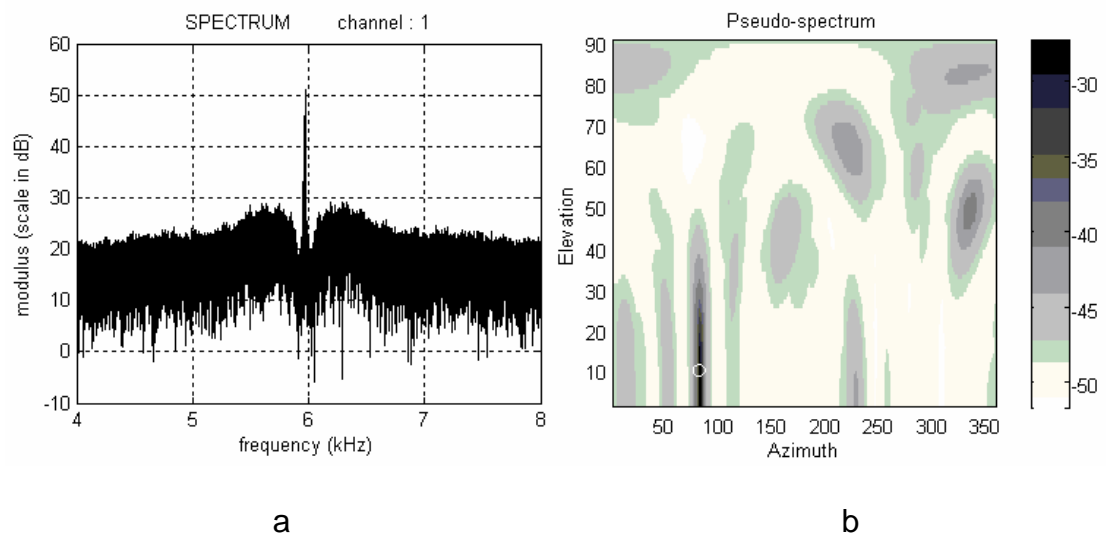


Figure 3

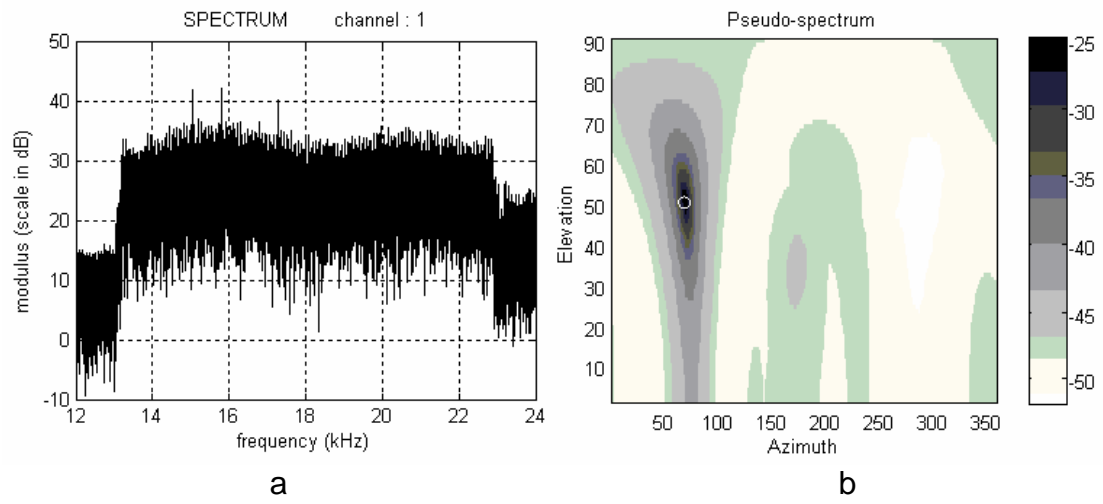


Figure 4

