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A Low Complexity Method for HF Direction Finding

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Beam Forming Techniques Operating on HF Collocated Antennas

F. MARIE, L. BERTEL, Y. ERHEL, D. LEMUR, M. OGER

Abstract: This paper presents theoretical aspects and experimental results of beam forming techniques operating on an array of HF collocated antennas without the need for space diversity. This original application achieves the separation of two propagation modes associated with a given path on the ionospheric channel. A specific device, based on different types of active antennas has been developed and experimental results validate this concept.

Introduction: As a rule, beam forming techniques are based on the space diversity of arrays using simple geometry (linear or circular). In the HF band (3-30MHz), decametric wavelengths generally need to be set up in a large space. This paper proposes a derivation of these techniques for active collocated antenna arrays: the sensors being associated with the same phase centre, the system is set out in a limited volume corresponding to a sphere with a 2 meter diameter. Following a description of this device, some theoretical and experimental results are presented, showing the significance of this original system.

The collocated antennas array design: The prototype [1] is designed with four loops and four dipoles. Antennas of the same type are oriented in different directions so that their spatial responses are also different. Antennas are small (compared with the wavelength) and their preamplifiers provide an optimal connection to the coaxial lines. Fig. 1 shows the

constructed prototype. All the amplification elements are located in the centre of the system. In the experimental configuration, the array is placed several meters above the ground, not shown in the photograph.

Antennas' responses: To determine the relation between the incident electromagnetic field and the output signal of the antennas, each of them was described by an electromagnetic simulation code (NEC2D). The computation was modified to include the Magneto-ionic theory applicable in this frequency band (Appleton-Hartree formula, presence of the ordinary and extraordinary modes). This results in the calculation (for a mode denoted k) of the electric field at the exit of ionospheric plasma by using Budden's boundary conditions [2] :

$$\mathbf{E}_k(t) = E_{0k} \cdot [0 \quad 1 \quad \pm j\eta_k]^T,$$

where E_{0k} is a function of time and space which includes also a term of modulation. η is the polarization ratio, the \pm signs correspond to the O and X polarisation modes.

Then the signal at the output of antenna i can be written in the form:

$$S_{ik}(t) = \mathbf{M}_i \cdot \mathbf{E}_k(t),$$

where \mathbf{M}_i is a matrix which characterises the i antenna in its environment, including the transfer function (modulus and phase) of the preamplifier [3].

Using the polarisation relation [1], for each antenna and each polarisation mode (O or X), this calculation provides a complex valued function $F_{ik}(Az, El)$ named antenna spatial response and the output signal S_{ik} takes the following form [4]:

$$S_{ik}(t) = F_{ik}(Az, El) \cdot E_{0k}(t)$$

For the following computations, the angular resolution has 1° in elevation and 1° in azimuth. The selected method takes the ground effect (average ground) into account through Sommerfeld integrals.

Beam-forming technique: The beam forming technique is carried out with acquisitions at the 8 collocated antennas' outputs. There are two possible methods. The first one uses a “phase only” technique with a mathematical expression given by (first technique):

$$S_{BA,k}(t) = \sum_{i=1}^8 \text{Arg}(F_{i,k}^*(Az,El)) \cdot S_{i,k}(t)$$

where $F_{i,k}^*$ is the i antenna conjugate response for the k mode and $S_{BA,k}(t)$ is the signal at the output of the beam-former.

In the second one, each antenna signal is multiplied by the complex coefficient corresponding to the considered conjugate antenna response. The corresponding expression can be put in the following form (second technique):

$$S_{B,k}(t) = \sum_{i=1}^8 F_{i,k}^*(Az,El) \cdot S_{i,k}(t)$$

It should be noted that these expressions are related in both O and X modes. Fig. 2 shows an example of a 3D beam-forming diagram relating to the second technique and in the O mode. The receiving station is in Monterfil (lat 48°N, long 2° E) and the azimuth (Az) and the elevation (El) expected are respectively $Az = 116^\circ$ and $El = 30^\circ$, Fig. 3 plots, for a given elevation, the gain of the beam former (first method) regarded as a function of the azimuth. Its values are compared to the vertical dipole gain which is constant in these conditions. A maximal difference of approximately to 8 dB can be noted as an advantage of the beam former. Moreover, the front to back ratio is about 9 dB at this elevation (30°). To obtain the same result with a classical uniform linear would require five to six antennas

15 meters distant ($\lambda / 2$). This implies that the array would require a total length of 75 meters.

Experimentation: Measurement campaigns have been carried out on several links. The following results involve the Rome HF broadcast (transmission with AM modulation). Acquisitions were recorded during a period of twenty seconds on the 5 kHz IF, the sampling frequency being equal to 25.6 kHz. In the first step of the processing, the Angles Of Arrival (AOA) were estimated with a computation of the MUSIC algorithm: the corresponding values were close to 30 degrees for the elevation and 110 degrees for the azimuth (the theoretical azimuth is equal to 116° for a single hop propagation mode). The second step used the beam-forming technique (O mode and X mode) to improve the signal to noise ratio in the expected direction. The two techniques described in the previous section were applied to experimental data in order to filter the O and X modes. Fig 4 gives the Fast Fourier Transform of: (i) the IF acquisition corresponding to the vertical antenna, (ii), the O filtered signal resulting from the “phase only” technique and (iii) the associated X filtered signal. The first spectrum (i) contains four peaks (presence of four incident signals) which could correspond to the superimposition of single hop and two hop propagation modes. The two other spectrums (ii and iii) illustrate the separation of the incident sources with a gain of approximately 8 dB after application of the O and X beam-forming technique. These results show good matches with simulations although no calibration was processed to optimise the collocated antenna array.

Conclusion: This paper demonstrates that antenna diversity can, in the particular context of ionospheric transmission, replace space diversity in beam-forming techniques. However, spatial filtering efficiency is directly dependent on the accuracy of the computation of the antenna responses. Assuming a reliable electromagnetic model, this original method can enhance digital communications in the HF band.

References

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4. Collocated antenna array (Patent: PCT/FR00/03544)

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Figure captions:

Fig. 1 Collocated antennas array (Patent: PCT/FR00/03544)

Fig. 2 3D beam forming representation, using second technique and for the O mode

Fig. 3 2D beam-forming representation, using the first technique

Fig. 4 the Fast Fourier Transform signal (vertical, O mode and X mode)

Figure 1



Figure 3

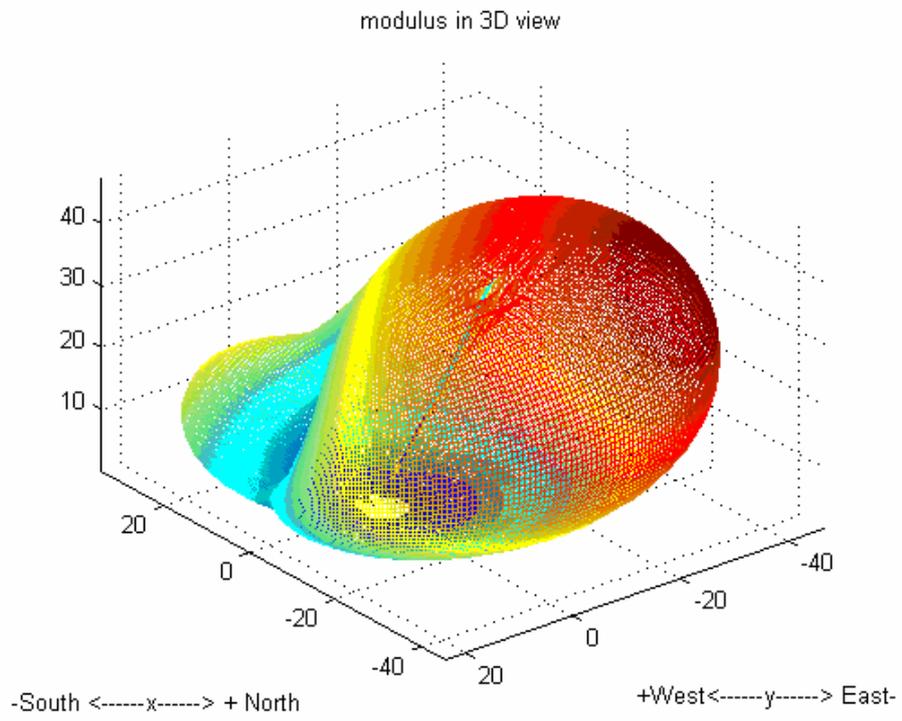


Figure 4

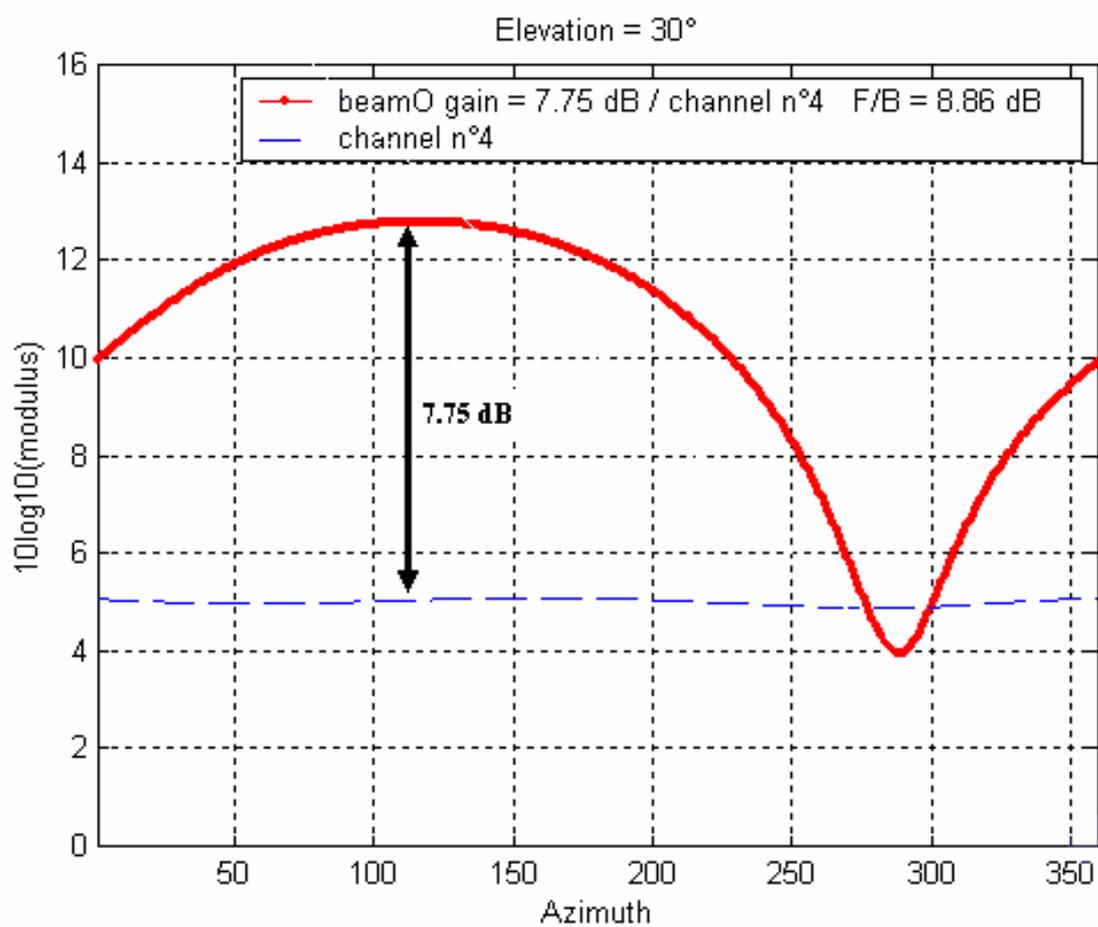


Figure 5

