ANTENNA EFFECTS ON HF SYSTEMS

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ABSTRACT

In the HF band (3-30 MHz), the equipment used for transmission or for location finding, rely on the antenna system which can be very varied, using antenna diversity and/or space diversity. The roles of these antennas or antenna arrays are presented in this paper using a bi-vectorial model related to ionospheric links. This narrow band model includes propagation effects, transmitting and receiving antennas effects via their complex responses and the characteristics of the link geometry. After a quick description and analysis of the model, typical applications are shown in the fields of direction finding, simulators, channel analysis and digital transmissions.

I INTRODUCTION

A bivectorial model, has been defined in [1], [2], [4]. This narrowband model takes into account the following :

- the effect of ionospheric propagation, introducing the attenuation, propagation time and Doppler for each identified mode (O or X) and path.
- the transmitting and receiving antennas via their responses to the different field components. Two responses can be defined for each receiving antenna, in correlation with the two modes of propagation [5]
- the geometry of the link and the relative position and/or orientation of the transmitting and/or receiving antennas [5].

In the first part of the paper the model is presented. This model can be applied to systems with single or multiple antennas at the transmitter and/or at the receiver. Space diversity, antenna diversity and polarisation diversity are introduced in the analysis. In the second part the limits of such model are also outlined. Some applications of the model are presented in the last part of the paper.

II THE BIVECTORIAL MODEL

The scalar model of propagation for HF links (3-30 MHz) is based on optical geometry [3]. If the transmitted signal is assumed to be written as $e(t) = m(t)e^{j\omega_0 t}$ where $m(t)$ represents the modulation of the signal and ω_0 is the carrier angular frequency, the received signal, for narrow band and for the k^{th} mode ($1F_2O$ for example) of propagation, can be expressed as [1], [2], [3] :

$$s_{rk}(t) = A_k\, m(t-\tau_{gk})e^{j\omega_{rk}(t-\tau_{pk})} \qquad (1)$$

where A_k is the attenuation related to the k^{th} mode, $\boldsymbol{\tau_{gk}}$ is the group delay corresponding to the k^{th} mode, $\boldsymbol{\omega_{rk}}$ is the received angular frequency including the Doppler shift, $\boldsymbol{\tau_{pk}}$ represents the phase delay for the considered mode. The modelling of all these parameters can be deduced from ionospheric propagation and prediction software (attenuation, group delay or angles of arrival) such as LOCAPI [6] or from physical considerations and measurements (Doppler shift) [1].
A narrow band model is then defined as a model for which the parameters $\boldsymbol{A_k}$, τ_{gk}, ω_{rk}, and τ_{pk} can be considered as constant in the band. Typically this band is situated between 50 KHz and 200 KHz [6].

For HF propagation the relation between an incoming wave and the signal s(t) at the output of an antenna receiving this field has been expressed as : $s(t) = F(\theta).E(t)$ where $E(t)$ is the electric field vector and $F(\theta)$ represents the antenna response [4], [5], [7]. $F(\theta)$ is a complex function of the general angles of arrival θ.

The inhomogeneity and the anisotropy of the ionosphere induce multipath and multimode propagation. The formula mentioned above for a receiving antenna can also be applied for a transmitting antenna ; thus, a general expression for the received signal on the antenna i, transmit by the antenna l, can be written as :

$$X_{rli}(t) = \sum_{k=1}^{ns} G_{lk}\, F_{ik}\, s_{rk}\,(t) + n_i(t) \qquad (2)$$

where k identifies the O or X propagation paths and ns the number of paths ; G_{lk} and F_{ik} are the complex functions of the transmitting antenna l and the receiving antenna i ; these functions are determined for the O and X propagation modes and depend on the angles of arrival [4], [5], [9] ; $n_i(t)$ is the additive noise.

III APPLICATION TO SEVERAL CASES

SIMO systems (single input, multiple output)

For a receiving antenna of type i at the position p in an array using antenna and space diversity the general expression of the received signal is :

$$X_{rli}(t) = \sum_{k=1}^{ns} G_{lk}\, F_{ik}\, e^{j\delta_{ik}}\, s_{rk}\,(t) + n_i(t) \qquad (3)$$

where δ_{ik} indicates the phase shift regarding a reference for the wave k. The G_{lk} and F_{ik} functions characterise both the antenna diversity and the polarisation effect [1]. The term containing δ_{ik} is related to space diversity which can occur at the receiving site.

For the **particular case of an array of NC collocated antennas**, omitting the transmitting antenna effect, the vectorial expression of the received signal becomes [14] :

$$X_{li}(t) = \sum_{k=1}^{ns} c_k\, F_{ik}\, s_{rk}\,(t) + n_i(t) \qquad i = 1,\dots, NC \qquad (4)$$

c_k is an arbitrary complex coefficient.

MIMO systems (multiple input, multiple output)

In this case the signal expression must include space and antenna diversity at the transmitting and receiving site. The general expression becomes :

$$X_{rli}(t) = \sum_{k=1}^{ns} G_{lk}\, e^{j\gamma_{lk}}\, F_{ik}\, e^{j\delta_{ik}}\, s_{rk}\,(t) + n_i(t) \qquad (5)$$

where γ_{lk} indicates the phase shift regarding a reference at the transmitting site.

In the expression (5), antenna diversity and space diversity effects are clearly identified via the F_{ik} and G_{lk} functions or via the δ_{ik} and γ_{lk} terms. In the relations (2) to (5), the complex functions G_{lk} and F_{ik} act as weights for the signals corresponding to the different waves. So the signals at the output of the antennas appear with uncorrelated envelopes as shown in figure 1.

IV LIMITATIONS OF THE MODEL

The model is based on several hypotheses. The first one is related to the determination of the “scalar” parameters, which are deduced from forecast software. Numerous simulations and comparisons with data show that the obtained parameters are correct [4], [6]. In the bivectorial model the antenna responses must be obtained with accuracy to avoid errors [6]. The determination of these functions are correlated to :

- the application of the limit conditions of Budden [8],
- the modelling of the antenna transfer functions. In the HF band and for active antennas several methods have been used [5], [7], [9] they show that the ground effect is still important and that a calibration sequence is necessary to avoid diverging results [10].

The model is a narrow band model as defined in paragraph 2. The relation 5 supposes that the spatial size of the transmitting and receiving arrays conserves the spatial coherence of the waves. A good agreement is then found between simulated and experimental data if the received antennas are decoupled [4], [10].

V POSSIBLE APPLICATIONS

The model has been used to simulate and develop new techniques in filtering [4], direction finding [10], [11], [13] as well as in digital transmission [6], [12]. Results of such applications can be found in several papers given in the references, some of them are shown in figures 2, 3, 4, and 5 respectively for :

- a direction finding technique using an heterogeneous arrays [13],
- a direction finding technique using a collocated array,
- defining a method to characterise the channel transmission during a digital transmission [2], [12],
- defining a process to improve the performances in digital transmission [12].

VI CONCLUSION

The presented model and its applications show the great interest to include antenna effects in the conception of systems. Several examples showed how these effects can be used to improve direction finding or transmitting systems. New simulators can also be defined from the proposed equations [14]. The use of both space and antenna diversity is now carried on in the laboratory [15].

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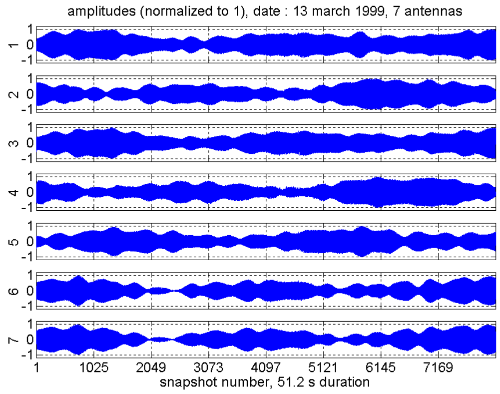

Figure 1 : Observed signals at the output of 7 colocated antennas over 50 seconds

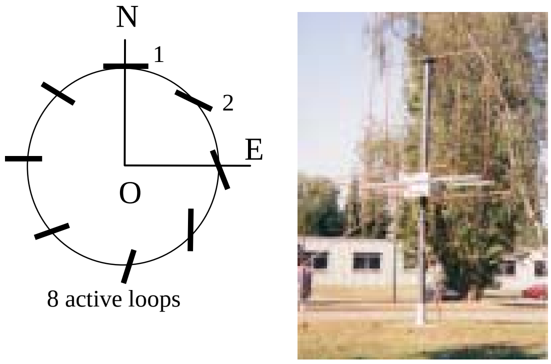

Figure 2 : heterogeneous circular array and a collocated array prototype made of 7 small antennas used in [4], [9], [10], [11], [12], [13].

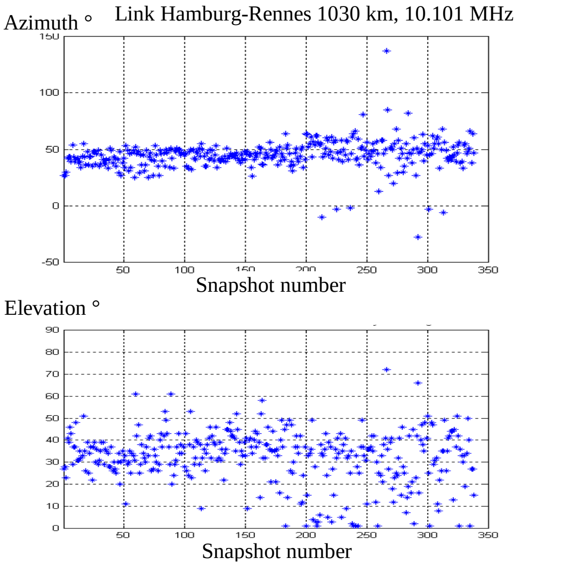

Figure 3 : HF DF on an heterogeneous circular array of loop antennas (from [13]).

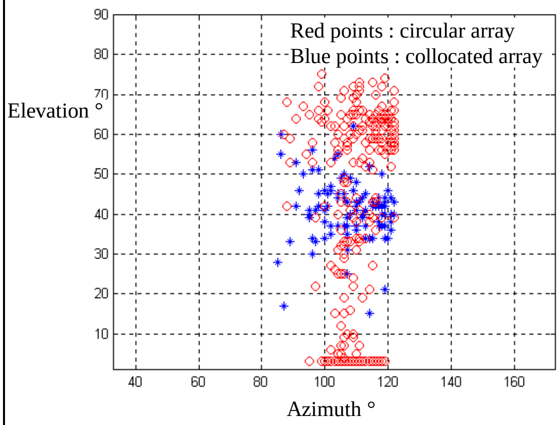

Figure 4 : HF DF estimation comparison between a circular heterogeneous array and a collocated sensor (from [13]).

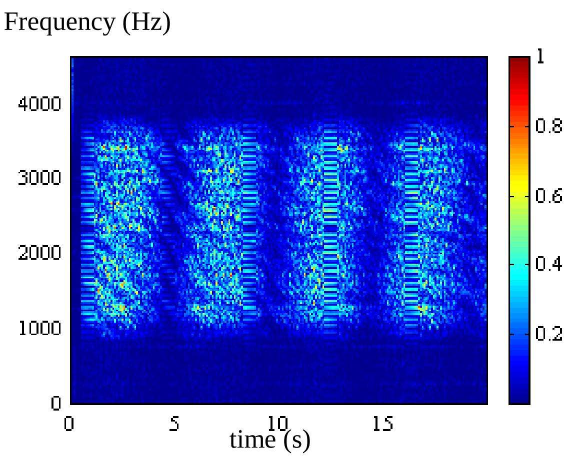

Figure 5 : channel characterization using time-frequency analysis (from [12]).

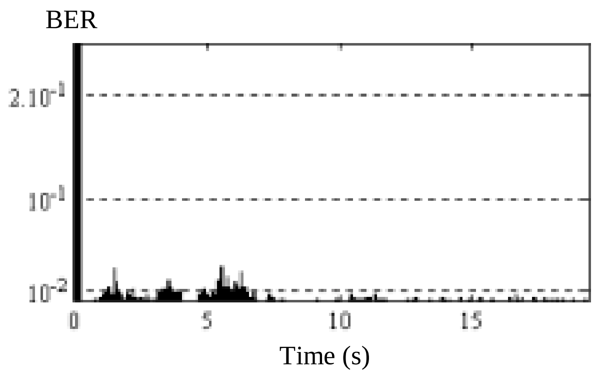

Figure 6 : Binary error rate (from [12]) obtained with 4 antennas from the collocated sensor (see figure 2)