A radar oriented ionospheric channel model based on ray-tracing theory

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***Abstract*— A ionospheric channel model based on raytracing theory is here proposed. Several HF ionospheric channel models based on statistical approach have been presented [1]-[3]. The here proposed model combines the statistical method with the deterministic method, using a raytracing approach. By means of raytracing we are able to simulate any ionospheric channel condition by varying the transmission frequency in the HF band, the elevation angle, the transmitter geographical coordinates, the season, the time of day and the solar activity. The here proposed model is a useful tool to simulate a signal received by an OTH (Over-The-Horizon) radar, that uses the ionosphere as transmission channel.**

I. Introduction

In order to simulate the signal received by an OTH sky-wave radar is necessary to develop a ionospheric channel model. Several ionospheric channel simulators, based on the narrowband channel model firstly proposed by Watterson [1] have been developed. The Watterson model is representative of the HF channel only when the channel can be considered to be both stationary and stable, for this reason Watterson assumes that the propagation delay in a narrowband model is frequency independent. On the contrary, using a ray-tracing technique, the propagation delay of a ray depends not only on the transmitted frequency, but also on the transmitted elevation angle, the solar activity, the transmitter geographical coordinates, the season and the time of day. The here proposed wideband ionospheric channel model is a useful tool to simulate a signal received by an OTH sky-wave radar, in order to test or to develop signal processing techniques. The use of a ray-tracing technique allows to simulate a more realistic channel, specifically:

- The time delay calculation of a ray travelling in the ionosphere is more accurate thanks to a physic-based approach in the ray path evaluation.
- The simulated electromagnetic paths have their own effective losses and phases, resulting from travelling from the radar transmitter to the reached point on the Earth's surface.

The ray tracing algorithm here proposed works under the assumption that terrestrial magnetic field and electron collisions can be neglected. Accordingly, the ionosphere will be modelled as an isotropic plasma without collisions, where only the ordinary magneto-ionic component exists.

II. Raytracing Theory

The aim of the ray-tracing algorithm is to reconstruct the real path of the electromagnetic wave travelling from the transmitter to the reached point on the Earth's surface. The electromagnetic wave is gradually bended through the ionosphere and sometimes it is fully reflected. To better deal with the mentioned problem, a polar geometry is introduced, where the elevation angle used in transmission is defined as β and the entry angle in ionosphere is θ_0 . Because of the simplifying assumption of horizontally stratified ionosphere, it is worth noting that the angle of incidence into the ionosphere θ_0 is equal to the reflected angle. As a consequence, the ray path is symmetric with respect to the reflection point T , and the total ray-path length is double of the $Tx-T$ path length. Fixing the transmission frequency, the elevation angle, the transmission site and the ionospheric conditions (i.e.: Sun Spot Number, month and hour of the day), the raytracing algorithm allows the estimation of the electromagnetic ray-path. The evaluation of the $Tx-T$ path, shown in Fig. 1 can be decomposed into the evaluation of two different paths.

1) $Tx-A$ quasi free space propagation
2) $A-T$ ionospheric propagation

It is clear that these two paths have different refraction indexes. The first path has a refraction index equal to one, therefore the electromagnetic wave travels along it with a velocity approximately equal to the speed of light in a vacuum (c). On the contrary, the speed of the electromagnetic wave (i.e.: group velocity v_g) varies with height while travelling along the path *A-T*. We are referring to the geometry shown in Fig. 1 where a polar coordinate system with the origin in the centre of the Earth is considered.

The position of a generic point P_i is defined by r_i and ψ_i, respectively the distance from the centre of the Earth and the angle between P_i and the transmitter with respect to the centre of the Earth; moreover ϑ_0 is the angle wherewith the wave enters in the ionosphere. The angle ψ_i can be evaluated by means of the following equations [4]:

$$r_i = R_E + h_i \tag{1}$$