A method to test HF ray tracing algorithm in the ionosphere by means of the virtual time delay

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As well known a 3D ray tracing algorithm furnishes the ray's coordinates, the three components of the wave vector and the group time delay of the wave along the path. This last quantity can be compared with the real group delay to check the performance of the algorithm. **Simulating a perfect reflector at an altitude equal to the virtual height of reflection the virtual delay is assumed as a real group delay**. For a monotonic electronic density profile we find a very small relative difference between the calculated and the simulated delay both for analytic and discrete 3D electronic density models.

REFLECTOR SCENARY

We employed a simple method to test a ray tracing algorithm exploiting the following relations:

$$f_v = f_{ob}\cos\varphi \qquad h'_v = h_{ob} \qquad t_{virt} = t_{calc}$$

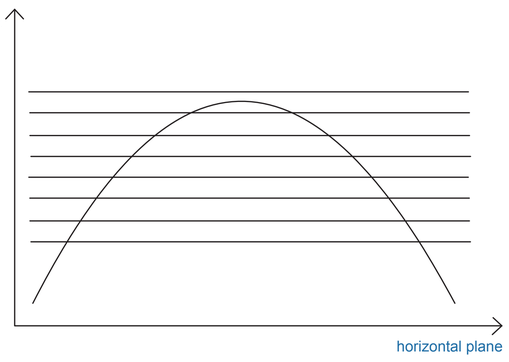
where f_v is the vertical incidence frequency, f_{ob} is the oblique incidence frequency, h_{ob} is the oblique virtual height of reflection and h'_v is the vertical virtual height of reflection.

The first relation comes from the **secant law**, the second is related to **Martyn's theorem**, while the third one is the **Breit and Tuve theorem** that assures that the real group time delay t_{calc} of the wave propagating in the effective path at group velocity is equal to the virtual time delay t_{virt} of the wave propagating along the oblique virtual path at the speed of light in vacuum (c_0).

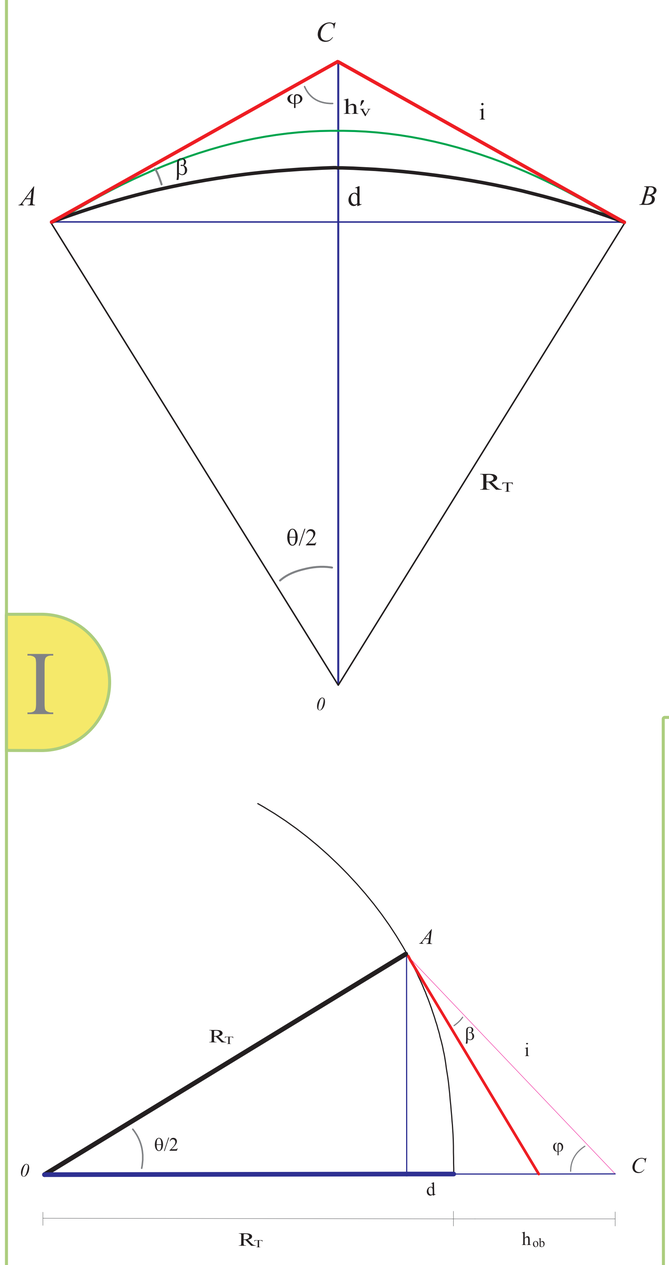
I The ray tracing algorithm furnishes in output the arrival point *B* and the calculated time delay t_{calc} .

II All the parameters necessary to calculate the virtual delay t_{virt} are derived from the formulas on the bottom left.

III For more realistic scenary we employed both analytic and numerical models and the results of these simulations are presented below.



In a **flat layering ionosphere**, without horizontal gradient, and in a **monotonically increasing electronic density profile,** the virtual group delay t_{virt} and the calculated group delay t_{calc} are theoretically equal.
These conditions are not valid anymore when the electronic density profile has a valley between E and F layers.



I

The virtual group delay t_{virt} can be obtained very easily using a pure geometrical relation (t_{virt} = ACB / c_0).

$$i = R_T[\sin(\theta/2)/\sin(\varphi)]$$

$$\varphi = \pi/2 - (\theta/2 + \beta)$$

$$h_{ob} = i\cos(\varphi) - d$$

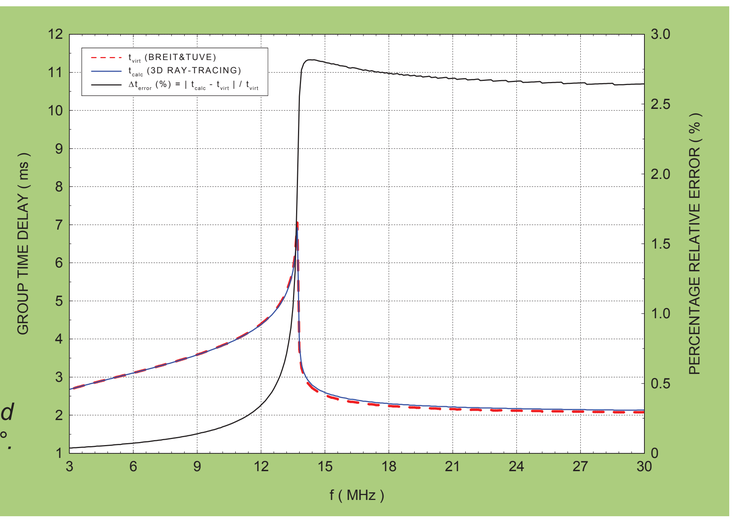
$$d = R_T[1 - \cos(\theta/2)]$$

II

ANALYTIC CHAPMAN PROFILE

The relative Δt_{error} does not exceed 0.5% when the frequencies are relatively low.

The error increases when the ray penetrates deep in the ionospheric plasma since numerical integration meets the discontinuity in the refractive index next to the critical frequency.

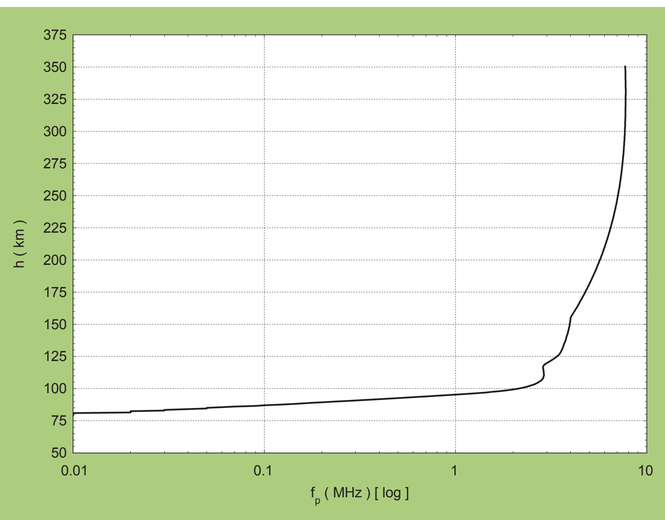


Time group delays (calculated and virtual) and percentage relative error with elevation angles of 30°.

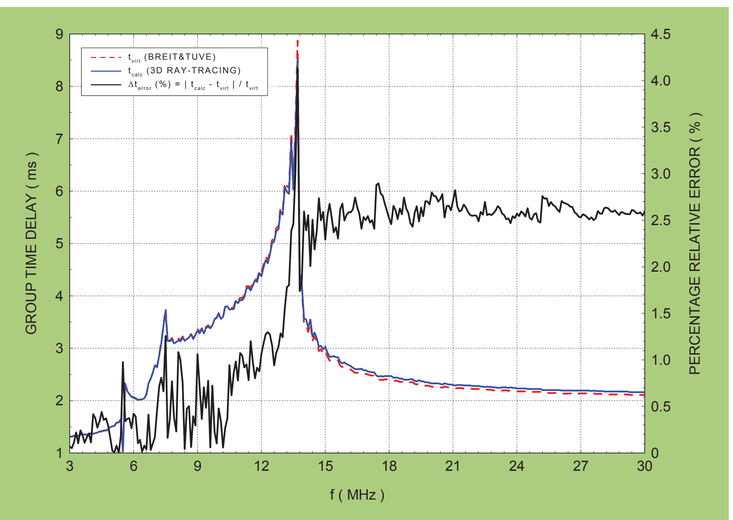
III

NUMERICAL PROFILE

The general trend is analogous to the analytic Chapman model except for the more irregular behavior due to the discrete values in the electronic density profile with step of 0.5 km.



Numerical electronic density profile defined by the parameters like critical frequency and height of the maximum electronic density.

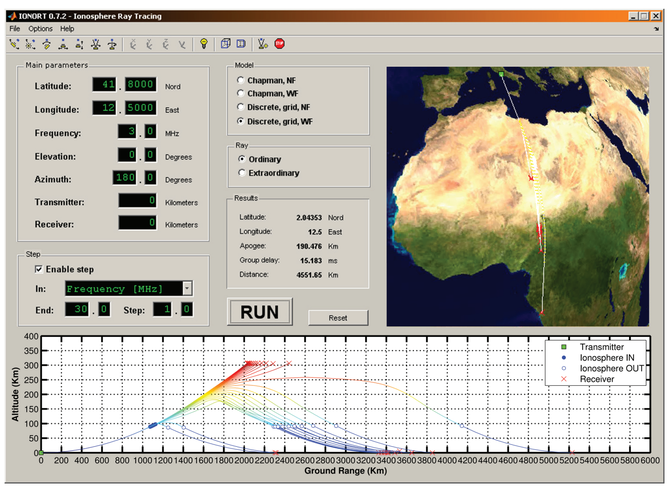


Time group delays and percentage relative error simulating a numerical electronic density profile with elevation angle of 30°.

$$h'_v(f_v) = h_0 + \int_{h_o}^{h_r} n_g(h, f_v)\,dh$$

where n_g is the refractive group index.

For monotonic electronic density profile we found a very small relative error between the calculated and the simulated delays both for analytic and discrete 3D electronic density models. Such errors are mainly due to the discrete step of the numerical integration of the differential equations of the ray tracing algorithm and to discrete electronic density profile. **A further analysis has been performed checking the resulting virtual height h'_v of the simulated reflector and the virtual height calculated by means of the relation on the left**. The percentage errors between the two values were always less than 1%.



IONORT - The ionospheric ray tracing program here employed that is still developing.

This program allows calculating the ray path that is shown in 2D azimuth plane and in 3D geo-referenced map.
Transmitter parameters are user inserted as input. A real discrete profile grid is used.

- Bianchi, C., Settimi, A., Azzarone, A., IONORT - Ionosphere Ray-Tracing (Programma di ray-tracing nel magnetoplasma ionosferico), INGV Technical Report N. 161, INGV Printing Office, Rome, Italy, 2010.
- Davies, K., Ionospheric Radio Propagation, National Bureau of Standard Monograph 80, U. S. Government Printing Office, Washington, U. S., 1965.
- Davies, K., Ionospheric Radio, Peter Peregrinus Ltd., London, UK, 1990.
- Jones, R. M., Stephenson, J. J., A versatile three-dimensional ray tracing computer program for radio waves in the ionosphere, OT Report, 75-76, U. S. Department of Commerce, Office of Telecommunication, U. S. Government Printing Office, Washington, U. S., 1974.