Impedance Probe Analysis of Ionospheric Properties Using a Finite Difference Time Domain Model (SM13A-0350)

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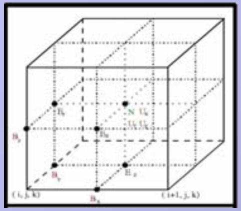
Overview

Swept impedance probe analysis of the ionospheric parameters using a Plasma Fluid Finite Difference time domain (PF-FDTD) model is undertaken . The simulation results are compared to data from the Sudden Atom Layer (SAL) rocket to validate the model . The parameters to be determined are the plasma frequency , collision frequency , gyro frequency and the ambient magnetic field. The study can be divided into the following sections:

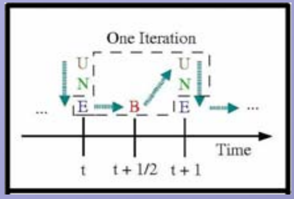
- Description of the Plasma Fluid Finite difference time domain model.
- SAL rocket – Swept impedance probe description
- Comparison of results.
- Scaled simulations

Finite difference Time Domain Model

- The traditional analytical analysis using plasma probes requires the use of extensive in-situ approximations while the numerical methods need the use of equivalent dispersive media.
- Both of these result in non-trivial analysis of the plasma environment.
- The Finite difference time domain method is used to more accurately model the ionospheric plasma environment. Decoupled boundary conditions are used to deal with instabilities of the plasma at the boundaries.



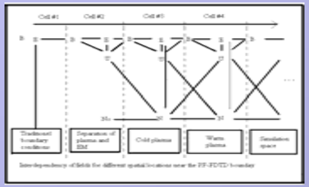
- The Model uses traditional methods to determine the impedance. By obtaining the feed current and a known input voltage , we obtain the impedance of the antenna in plasma.
- The Advantage of this method over traditional methods is that additional complex geometries can be analyzed.
- Also , by discretizing the probe into additional Yee cells , we can the use leap frog technique to perform a time domain analysis , as indicated in the figures above and below.



The Ionospheric plasma parameters derived from the PF-FDTD simulations are

- Plasma frequency
- Collision frequency
- Gyro frequency
- Electric and magnetic fields
- Impedance

The boundary conditions used by the PF-FDTD model



The equations used to characterize the environment are

$$\frac{\partial n}{\partial t} + \nabla \cdot (n\vec{U}) = 0$$ — Basic continuity equation

$$mn\frac{\partial \vec{U}}{\partial t} = nq(\vec{E} + \vec{U} \times \vec{B}_0) - \nabla P - mn\nu(\vec{U})$$ — Momentum equation

$$P = nkT$$ — Ideal gas law

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

Maxwell's equation

$$\nabla \times \vec{B} = \varepsilon_0 \mu_0 \frac{\partial \vec{E}}{\partial t} + \mu q n \vec{U}$$

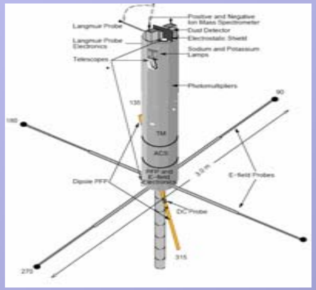
The characteristic frequencies are known by standard formulas. From those values. From them , the charge density , electric and magnetic field values are determined

$$no = \frac{\omega_{pe}^2 m}{e^2}$$

$$B = \frac{\Omega_c \varepsilon_o}{e}$$

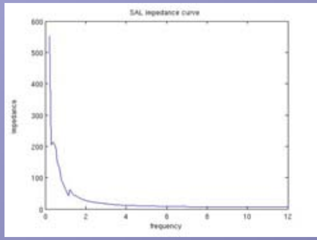
SAL Rocket

The NASA Sudden Atom Layer (SAL) sounding rocket was launched as a part of the COQUI II campaign from Puerto Rico on 19 February 1998 at 2009 LT. The rocket's main scientific purpose was the probing of sporadic sodium layers (Nas). These are thin (1 km) layers of neutral atomic metal that form in the mesosphere (as observed by lidar), roughly within an altitude range of 90–100 km. Besides the three instruments, the payload also included a charged dust detector, a Langmuir probe operating as Fast Temperature Probe to measure electron temperature, telescopes to measure sodium airglow, and photometers and lamps to measure neutral sodium density. Figure 1 depicts the payload instrument configuration.



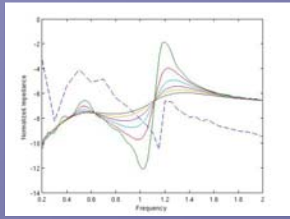
The Impedance probe consisted of two booms deployed 180 degrees apart with a 2-m tip-to-tip length and a 2.54 cm diameter and used the last 52.5 cm of the booms as active elements of the antenna. The antenna was differentially driven with a 1-Volt sinusoidal signal, with a frequency sweep at 40 fixed frequencies ranging over 0.2–12 MHz, at the rate of 96 sweeps per second. Although the impedance probe was driven in a dipole configuration, the current was monitored on only one half of the antenna. The antenna was electrically short at the driving frequencies.

Comparison of impedance curves between SAL and simulations.



SAL rocket data at a height of 90 – 115 kms . Plasma frequency = .565Mhz , Gyro frequency = 1.06 MHz (3)

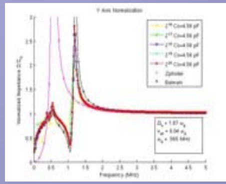
Simulations were run with parameters matching the characteristic frequencies of the ionosphere at the altitude where the SAL recorded the data



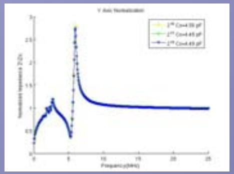
PF-FDTD simulations for collision frequencies values ranging from 10%-60% of plasma frequency (.565 MHz)

Scaled simulations of the FDTD Model

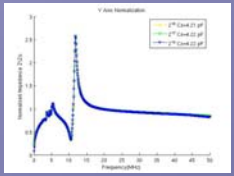
- Simulations of the FDTD model were run with scaled values of plasma frequency , gyro frequency and the upper hybrid frequency
- It was found that that all the three frequency values maintained their relative positions in the curves obtained.



Plasma frequency = .565 MHz , Gyro frequency = 1.06 MHz, Collision frequency = .0026 MHz



Plasma frequency = 2.825 MHz , Gyro frequency = 5.3 MHz, Collision frequency = .013 MHz



Plasma frequency = 5.65 MHz , Gyro frequency = 10.6 MHz, Collision frequency = .226 MHz

Conclusion

- The simulations results of the FDTD model were compared with the impedance curves from the SAL rocket and were found to be in reasonably close agreement with each other
- The characteristic frequencies maintained their relative positions on the curve when their values were scaled
- The PF-FDTD model will be used to study data from future rocket missions

Reference

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[3] A.Barjayta, C.Swenson , “Observations of triboelectric charging effects on langumir-type probes in dusty plasma", Journal of geophysical research, VOL 111, A10302