The Current Distribution along a Short Dipole Antenna in Magnetized Plasma via a Finite Difference Time Domain Model

Jeffrey D. Ward
Weber State University. Ogden, UT, 84408
E-mail: jeffreyward@weber.edu

Introduction

The complete interaction between an antenna and a magnetized plasma environment has always presented some challenging complications. While at relatively high operating frequencies antennas can be modeled using free space equivalent models, the closer the operating frequency becomes to matching any of the natural plasma resonances, the more the input impedance deviates from the free space value. It is this discrepancy between free space and plasma that has been utilized to measure the plasma environment via RF probes for the past 40 years [1], [2]. However the complexity of the problem has prevented a complete and accurate representation of the plasma effects on the antenna input impedance at low operating frequencies. To make this problem tractable, researchers have had to limit their analysis to electrically short dipole antenna, where triangular or exponential current distributions could be prescribed [3], [4]. This paper applies the Plasma Fluid Finite Difference Time Domain (PF-FDTD) model to an electrically short dipole in order to explain some of the discrepancies between the analytical theories and experimental data.

The Plasma Fluid Finite Difference Time Domain Model

To overcome many of the analytical limitations the five moment Maxellian distributed plasma fluid equations are incorporated into a Finite Difference Time Domain (FDTD) model, to create the Plasma Fluid Finite Difference Time Domain (PF-FDTD) model [5]. Similar to Young's and Olakangil's models [6], [7], the PF-FDTD treats the plasma density/pressure and velocity as independent variables. However, unlike the previous models, the PF-FDTD models the density and the velocity to the centre of the FDTD cell. This increased the stability of the PF-FDTD, enabling simulations to run for 100,000+ iterations. It is this increased stability that has also enabled the PF-FDTD to analyze the lower frequency region where the plasma physics plays an important role, see Fig. 1.

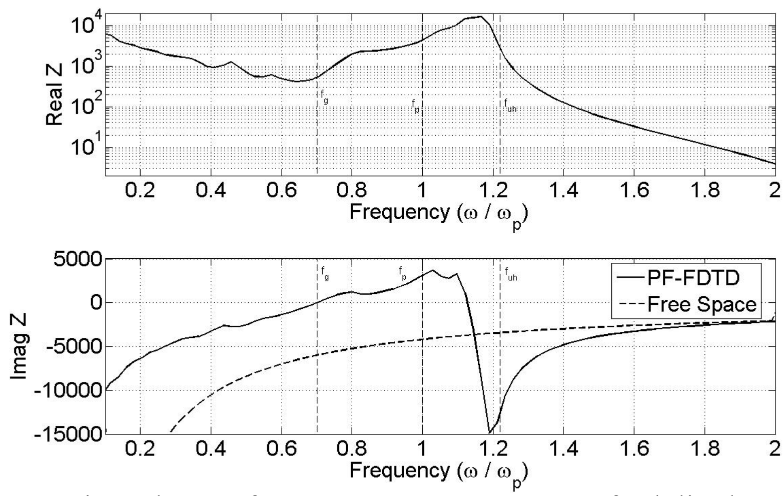

Fig. 1. Input impedance of a 1.04 m x 0.004 m center feed dipole antenna in a magnetized plasma (normalized to the plasma frequency)

Calculated Current Distribution

As the PF-FDTD data more closely recreates experimental data, additional questions are raised as to the reasoning behind the failure of the analytical models. It has long been known that the current distribution along a short dipole immersed in magnitized plasma was not purely triangular (standing wave) or exponential (evanescent) as research have prescribed in the analytical models [8]. In fact the PF-FDTD agrees with Ishizone etal. in that there exist both a standing and evanescent current distribution, depending upon the operating frequency and the plasma parameters, see Fig. 2. However, the resulting phase variations in the current distribution have not been documented, see Fig. 3.

Besides the traditional spike in the magnitude that corresponds to the series resonance condition present at the plasma cyclotron frequency (f_g), there is also the expected global minimum in the magnitude near the upper hybrid frequency (f_{uh}). However a closer look reveals that the minimum in magnitude also corresponds with the operating frequency at which the phase distribution is no longer constant. In fact, it appears that it is also at this point that the evanescent distribution begins to dominate the magnitude. This also corresponds to the frequencies at which the plasma behaves more reactively, with the natural resonance structures being more oscillatory as opposed waves.

In addition, in this region of reactive coupled energy the current distribution phase variations appear to take on a concave fundamental shape, with the valley of the curve appearing to be a function of the plasma density and antenna geometry. It is as if the natural plasma oscillations have an effective radius and any small amount of energy organizes as opposed to its traditional random nature.

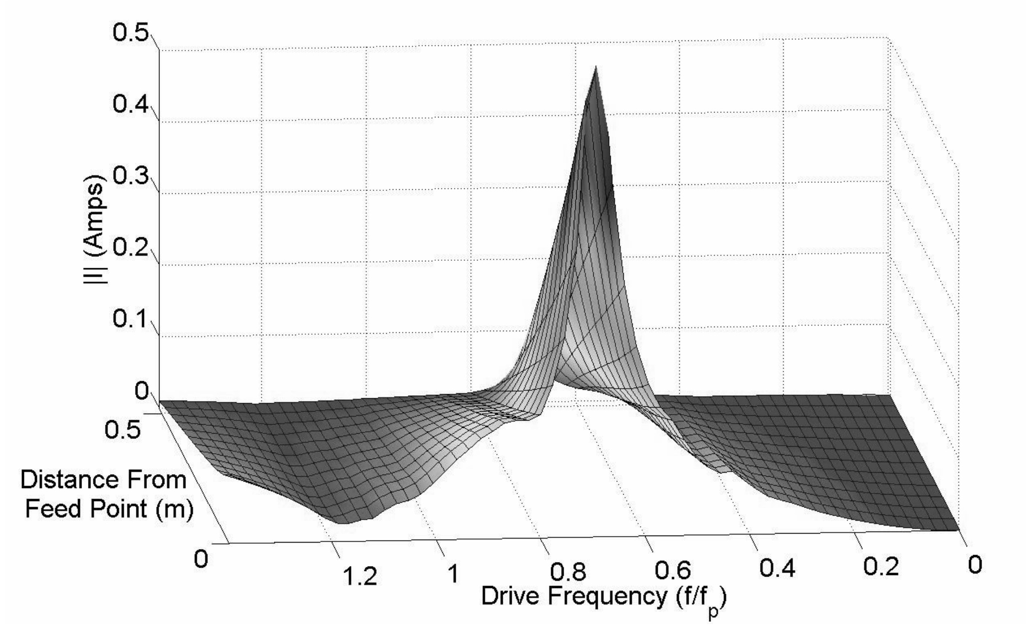

Fig. 2. Magnitude of the current distribution along a 1.04 m x 0.004 m center feed dipole immersed in magnetized plasma for various drive frequencies

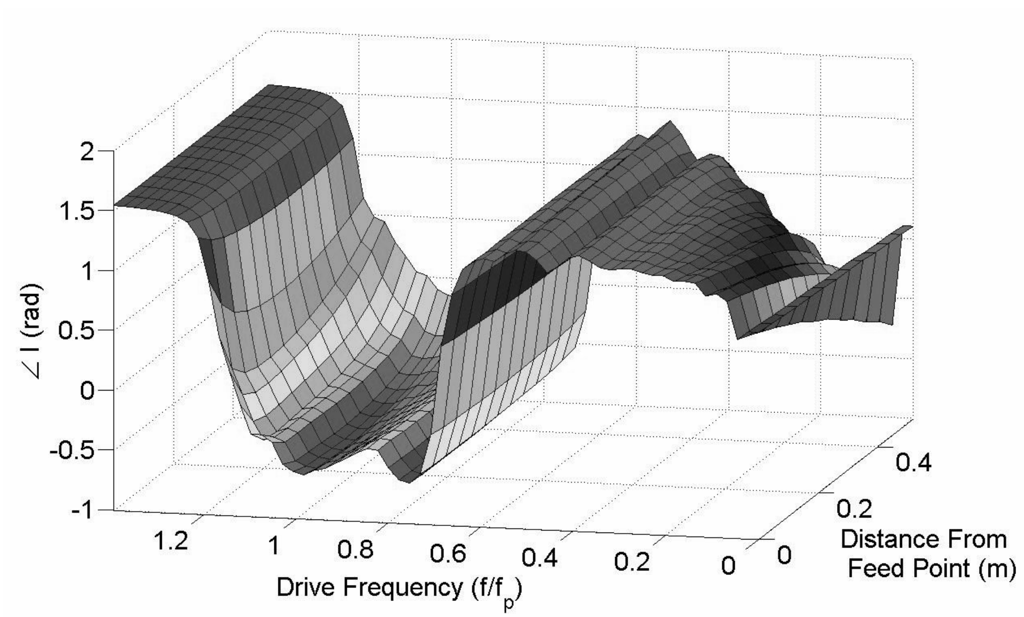

Fig. 3. Magnitude of the current distribution along a 1.04 m x 0.004 m center feed dipole immersed in magnetized plasma for various drive frequencies

Conclusion

These variations from non standard current distributions may help explain why experimental data never exactly matches the theoretical models of RF plasma probes for any operating frequency near or below the natural plasma resonances. In fact if the PF-FDTD is correct, the non constant phase distribution delays the parallel resonance condition and down shifts the zero phase point below the frequency at which the dip in magnitude is seen. This has large ramifications as it has always been assumed that these two points directly correlate, as in traditional electrical circuits. This offsets in the apparent parallel resonance, from the upper hybrid, yields a false plasma density measurement for non calibrated RF plasma probes. Unfortunately to date no RF probe has had this offset factored into its measurements.

References:

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