Magnetic Field Pattern Effects on Surface Impedance for Late-Time HEMP and Geomagnetic Disturbances

James Gilbert
Metatech Corporation
Goleta, California, United States of America
quantmec@charter.net

Abstract—In this presentation, we discuss the effect of the magnetic field pattern on the electric fields. Earlier calculations calculated the electric field from the local magnetic field using a one-dimensional multilayer conductivity calculation. Newer calculations use a multi-dimensional calculation including both horizontal and vertical variations of conductivity. To quantify the effect of two-dimensional variations in the magnetic field, we separate the magnetic field into irrotational and divergence-free portions and show that they have the opposite effect when the skin depth becomes longer than the characteristic length over which the magnetic field varies.

Keywords-Late time HEMP, Geomagnetic Disturbance, Surface Impedance,

I. INTRODUCTION

In this presentation we will examine an arbitrary surface magnetic field at the upper surface of a uniformly conducting half space and look at solutions for the electric field on the same surface in the frequency domain by expanding the surface fields into modes and examining the electric field for each mode. The separation into modes can be done in various coordinate systems for the ease of calculation. We first examined this for sinusoidal variations along a single direction and noted that the result at low frequencies greatly depended on whether the variation was in the direction parallel or perpendicular to the magnetic field. To generalize this, we took the general form for the magnetic field variation and noted that the separation into TE and TM modes explained the different behavior of the surface impedance as the frequency varied.

II. TECHNIQUE

The decomposition of an arbitrary surface magnetic field into TE and TM modes may be done using the Helmholtz decomposition for suitably behaved field – the only TEM mode is a spatially uniform magnetic field which is inconsistent with a localized field. With z in the vertical direction and $\nabla_\perp$ the two-dimensional gradient operator on the surface, the magnetic field of a TE mode has

$$\nabla_\perp \times H_\perp = 0 \quad \nabla_\perp \cdot H_\perp \neq 0 \qquad H_z \neq 0 \quad (1)$$

and a TM mode has

$$\nabla_\perp \times H_\perp \neq 0 \quad \nabla_\perp \cdot H_\perp = 0 \qquad H_z = 0 \quad (2)$$

The surface impedances of the two types of modes are identical at high frequencies and equal to the result for a uniform magnetic field

$$Z_{TE},\ Z_{TM} \rightarrow \sqrt{\frac{-i\mu_0\omega}{\sigma}} \quad (3)$$

but separate when the planar skin depth is equal to the characteristic horizontal length of variation and at low frequencies the surface impedance for TE modes behaves as

$$Z_{TE} \rightarrow \frac{-i\mu_0\omega}{|k_\perp|} \quad (4)$$

which is inductive and the surface impedance for TM modes behaves as

$$Z_{TM} \rightarrow \frac{|k_\perp|}{\sigma} \quad (5)$$

which is purely resistive In these formulae, σ is the conductivity, μ_0 is the permeability of free space, ω is the angular frequency and

$$k_\perp = \sqrt{k_x^2 + k_y^2} \quad (6)$$

is the transverse wave number of the mode (in this example in Cartesian geometry).

III. RESULTS

The surface magnetic field of Surface Burst EMP is TM by symmetry. E3A (Blast Wave MHD) and Sudden Storm Commencement GMD vary in time so rapidly that the pattern effect is small. E3B (Heave MHD) and Electrojet GMD are predominantly TE and the electric field is reduced by the pattern effect. We will show numerical calculations of the effect in the presentation.