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Influence of a multi-layered planetary ground on the propagation of ELF electromagnetic field pulses

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Electrical discharges in planetary atmospheres generate short electromagnetic field pulses that propagate in ground-ionosphere waveguides over long distances as TEM waves. Due to waveguide dispersion the waveform of the ELF (Extremely Low Frequency) electromagnetic field pulses change significantly with the distance.
Planetary crusts with a low electric conductivity have a particularly strong influence on ELF radiowave propagation in the ground-ionosphere waveguides due to the penetration of the ground by the wave's electromagnetic field. For a known distance from the source the waveform's shape allows investigating waveguide propagation properties. When the model of the lower ionosphere is known, contribution of the ground to the propagation parameters of the waveguide can be derived. A method based on this principle can be useful in a study of electrical properties of the ground especially on planets where the atmospheric discharges are not frequent enough to continuously generate Schumann resonances.
In this work we present and analytical model of the ELF radiowave propagation in ground-ionosphere waveguides with multi-layered ground. We have developed equations that enable us to include different ground models in propagation equations using the concept of complex altitude.
The model let us conclude that the influence of the ground on the ELF radiowave propagation is particularly strong when the field penetrates through a low conductivity layer of a planetary crust into a higher conductivity layer or the mantle, and a distinct boundary between the two layers leads to interferences in wave propagation in the upper layer and to a significant change in the propagation parameters of the ground-ionosphere waveguide. We envisage technical possibility of measurement of the magnetic field component of the electromagnetic waves generated by short electric discharges in the Martian atmosphere.
The presented model can be useful in studies of ELF radiowave propagation on Mars, Venus, Titan and planets that have a low conductivity ground.