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Radio Scintillation Modelling for the Deep Venus Atmosphere

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The Venus atmosphere is dense and turbulent, and so might be expected to exhibit significant effects on electromagnetic propagation. Indeed, the very first radio transmission from within another planet's atmosphere – that from the Venera 4 probe at Venus in 1967 - was reported to exhibit very strong signal fluctuations. Strong scintillations have also been routinely observed in radio occultation experiments by Venus orbital and flyby spacecraft.

A new generation of Venus missions is in development, notably the NASA DAVINCI probe which will use a two-way adaptive radio link to maximize the returned data volume, enabling imaging during descent. To optimize the rate control logic, an estimate of the likely signal power fluctuations is needed, and a bottoms-up physical scintillation model has been developed using the classic theory of Tartarskii.

The refractive variations which cause scattering and scintillation are principally due to gravity waves, and have temperature fluctuation amplitudes reaching up to ~4K at about 65km altitude, as measured in many radio occultation temperature profiles. Although temperature fluctuations deeper in the atmosphere towards the surface (where only a single high-resolution in-situ profile is available, from the VEGA-2 lander : at altitudes below about 38km superrefraction makes it impossible to use occultation methods) are smaller, the atmosphere is much denser, and the refractive index structure constant C_n increases from about 10^{-7} $m^{-1/3}$ at 65km to 10^{-6} $m^{-1/3}$ at the surface.

According to theory, signal power fluctuations contributed by each increment of propagation path scale with C_n^2, with wavelength to the -7/6 power, and with the 5/6 power of distance from the transmitter. The resultant scintillation amplitude can then be estimated from the C_n profile and the given transmission geometry. For a typical descent probe with a carrier/relay spacecraft, the scintillation history can be non-monotonic, as initially the ray path is very shallow, grazing the horizon, yielding initially strong scintillations which then weaken as the ray becomes progressively more vertical as the relay rises in the sky. This change is convolved with the increasing local refraction changes, and the altitude range that the signal must traverse, effects which eventually win out.

The model is compared with the scintillations observed in radio occultations, and with the modest power fluctuations observed on the Venera 5-8 missions and Pioneer Venus. The model predicts scintillations of the order of ~1dB for DAVINCI's S-Band link when the probe is near the surface.