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Design and performance of the compact five-channel VLF receiver for the CANVAS CubeSat mission

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Very-low-frequency (VLF) waves from ground-based sources impact the lower ionosphere and magnetosphere through their interaction with the local plasma and energetic particle environments. Understanding of the multiple impacts of these waves, however, requires an accurate assessment of the propagation and attenuation of these waves. The Climatology of Anthropogenic and Natural VLF wave Activity in Space (CANVAS) mission is designed to measure VLF waves from low Earth orbit originating from ground-based sources such as lightning and VLF transmitters. The mission aims to characterize the VLF environment in low Earth orbit to address two main goals: i) constrain the VLF wave injection from the ground into the magnetosphere, and ii) improve models of VLF wave attenuation during propagation through the ionosphere.

The CANVAS payload includes a three-axis magnetic search coil and two-axis electric field dipole antennas. The search coils are 9.5 cm in length and optimized for the VLF frequency range from 0.3–40 kHz. The instruments are designed to measure electric field wave components with sensitivity of 10^{-6} V/m/$\sqrt{\text{Hz}}$ and 50 dB dynamic range, and magnetic field wave components with sensitivity of 10^{-4} nT/$\sqrt{\text{Hz}}$ and 50 dB dynamic range. They are integrated into a 3D-printed Carbon PEEK holder, provided by Roboze, Inc. The holder incorporates the magnetic field preamplifier board. The search coil and holder are deployed 1 meter from the spacecraft using a carbon fiber deployable boom, designed and fabricated by Composite Technology Development (CTD), Inc. Cabling integrated into the boom provides power to the preamplifiers and sends analog signals back to the spacecraft. The search coil system is deployed by a stepper motor upon command from the ground.

The electric field system is composed of four 40 cm monopole antennas, which form two orthogonal dipole pairs. Each monopole antenna is connected to a preamplifier circuit integrated into the spacecraft "crown" which also serves as the antenna hinge base.

Signals from the electric and magnetic field preamplifiers are sent to a single analog receiver board, which provides appropriate amplification, anti-alias filtering, and centering for the ADCs. Data from the 16-bit ADCs are sent to a digital board, which includes an FPGA for onboard signal processing. Data are converted to spectral matrix components with $<10\%$ frequency resolution between 0.3–40 kHz, with extra bins for known VLF transmitter frequencies. Spectral matrices are saved at 1-second cadence, providing a single "fast survey" data mode continuously for the duration of the mission.

This paper presents an overview of the CANVAS mission with a focus on the instrument design and performance. Performance characterization includes assessment of sensitivity, gain, spurious-free dynamic range (SFDR), and linearity over the required frequency range, as well as mutual orthogonality between components. The instrument is now completed and undergoing functional testing and performance characterization, and will be integrated into the spacecraft in Spring 2022. The CANVAS mission is expected to launch in early 2023 and a one-year mission duration is planned.