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Active Amplification of VLF Plasma Waves in the Ionosphere to Reduce Radiation Belt Particle Fluxes that can Damage Satellite Electronics

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The number of satellites launched into low Earth orbit (LEO) is increasing at an exponential rate. Launches support deployment of multi-satellite constellations for many applications. Experiments with electric field sensors on Swarm-E in conjunction with dedicated and serendipitous rocket burns in space have been conducted to amplify whistler waves from ground transmitters and reduce the fluxes of energetic particles that can destroy satellite electronics. Active reduction of radiation belt particles is now possible with selective injection of exhaust into the F-region ionosphere over ground VLF transmitters that are connected by magnetic field lines to the inner and outer radiation belts.

Currently, there are about 7000 operational satellites in orbit around the Earth that provide services including communications, internet, and weather by Earth observations. These satellites have to avoid impacts by energetic particles that can damage solar panels and electronic components. Whistler and electromagnetic ion cyclotron (EMIC) waves can scatter trapped radiation into the atmospheric loss cone and, thus, reduce energetic particle fluxes. Many methods have been proposed to generate these whistler waves using both ground and space-based sources. For example, amplitude of the whistlers from ground VLF transmitters, satellites with large antennas, HF electrojet modulation and electron beam injections from rockets provide signals with 5 pT or less. All existing VLF sources produce weak signals that are not effective to remove radiation belt particles. A new technique has been developed to amplify these waves as they pass through the ionosphere using artificial injection of lower hybrid waves. The firing of a small rocket motor in space yields neutral exhaust moving up to 10 km/s with power over 1 MW. After charge is exchanged with the ambient oxygen ions in the ionosphere, the resulting ion ring-beam distribution excites a lower hybrid parametric amplifier that transfers the kinetic energy of the ions whistler or EMIC waves passing through this region.

Measurements of 30 to 60 dB gain for waves through the F-layer have been observed experimentally. If these intense whistler waves are captured by field aligned ducts and guided to the radiation belts, this can lead to rapid reduction of the harmful particle fluxes. The LH waves provide a pump for a whistler traveling wave parametric amplifier (WTWPA) that intensifies the VLF signals. Satellite measurements of the VLF wave amplitudes in the ionosphere have reached values between 200 pT and 1000 pT using amplification by the Cygnus BT-4 rocket motor of the NML VLF transmitter in North Dakota. Each VGA-C launch from French Guiana place an Attitude Vernier Upper Module (AVUM) burn of 800 grams/second at the peak of the F-layer, within 300 km of the NAA VLF transmitter in Cutler, Maine, USA. Over 20 launches of the Falcon 9 from Canaveral has been detected with deployment module deorbit burns over west Texas are recorded by enhanced F-layer 630 nm emissions at the McDonald Observatory. Experiments by the University of Alaska are also conducted to see if the HAARP, high-power HF transmitter in Alaska can both modulate the electrojet to generate whistlers and to amplify these whistlers with HF pumped lower hybrid waves. Modeling has been demonstrated by rapid radiation belt remediation can occur in minutes with rocket exhaust driven amplification (REDA) rather than days under with unamplified sources.

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