TERSat: Trapped Energetic Radiation Satellite

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Mission Background

Radiation harms satellites
- Natural: High energy particles from solar wind are trapped in Van Allen Belts
- Man-made: high altitude nuclear activity

Lightning causes gap in Van Allen belts; safer zone for satellites

Can we scatter radiation particles by emitting VLF waves, like lightning?
VLF Experiment Overview

When TERSat radiates VLF waves...

Can the transmission overcome the impedance of the plasma around the antenna?

How do the VLF waves propagate?

Could another satellite receive our signal?

AFRL DSX
AFRL VPM
VLF Experiment Overview

TERSat
- 550 km
- 32W, 3–50 kHz, 600 V transmitter
- 0.1–50 kHz VLF receiver
- 2x2.5 m booms

DSX
- Related AFRL mission
- 6000–12,000 km
- > 1 kW, 3–50 kHz, 10 kV transmitter
- 0.1–50 kHz VLF receiver
- 2x40 m booms

TERSat will answer critical questions about VLF wave propagation
Can we use VLF waves to clear particles?

- **VLF energy couples to the energetic electrons**
  - Spacecraft + plasma form circuit
- Scatters the electrons out of their “trapped” trajectory and into the atmosphere
- Can’t do it well from the ground
  - Plasma cutoff frequency blocks direct, efficient VLF wave transmission through the ionosphere
TEERSat Overview

- **VLF Transmitter (Payload)**
- **VLF Receiver (Payload)**
- **5m Dipole (Payload)**
- **Body-mounted Solar Panels**
- **Cubesat Bus Electronics**
- **NiCd Batteries (for bus and payload)**
### Concept of Operations

**Phases of Operation**

1. **Pre-launch** (2+ weeks)
   - Systems checks and equipment prep.
2. **Launch** (5 minutes)
   - Nominal orbit at 550 km altitude, 20°
3. **Commissioning** (1 month)
   - Lightband separation, De-tumbling, and Stabilization
   - Antenna Deployment, Second Stabilization
4. **Operations** (~1 year)
   - Experiment Operations
5. **Decommissioning** (~4 minutes to shut down, ~14 years to de-orbit)

Falcon 9 image from spaceflight101.com, nationaldefensemagazine.org
Payload Design Analysis

Plasma and spacecraft form a circuit

Built Matlab model of circuit behavior
  – Loops through different inductance values
  – Plots $P_{\text{rad}}$ vs. Frequency

Determined final design parameters

Final Design Parameters

- Antenna Length: 5 m
- Peak Voltage: 600V
- Frequency Range: 3–50 kHz
- Inductance Range: 0.2–3 Henry

Power Radiated at $L = 0.3$ H
Payload Transmitter

Flight Computer → Inverter → H Bridge Circuit → Transformer, RLC → Dipole Antenna
Payload Transmitter

STACER Deployable Antenna
Payload Receiver

Dipole Antenna

Stanford WIPER VLF Receiver

- LNA
- Filter
- Trans-conductor
- Op-Amp
- Capacitors

FPGA

Flight Computer
Bus Electronics

Pumpkin Cubesat Motherboard
*Image Credit: Pumpkin Inc.*

Cubesat Board Stackup with 2U Adaptor
Bus Electronics

Customized Clyde Space Cubesat EPS

Image Credit: Clyde Space Inc.

NiCd Battery Box
ADCS Block Diagram

Hardware Abbr.
CSS: Coarse Sun Sensor
MTM: Magnetometer
MTQ: Magnetorquer
RWA: Reaction Wheel Assy.

Actuators

Plant

Environment
Satellite Nonlinear Dynamics

Controller
Filter
Attitude Estimator
ADCS Watch Dog

Software

Sensors

MTM
IMU
CSS

Ground Command

System State
Bus Mechanical Design

- 6061-T6 Skinned Isogrid Structure
  - Low weight
  - High strength
  - Simplified assembly
- Multiple internal and external attachment points

16inx16inx12in
(40.64 cm) X (40.64 cm) X (30.48 cm)

- Supports satellite structurally and thermally
- Thermal and Structural FEA validated the design
Path Forward

Protoqualification Unit (PQU) Environmental Testing

PQU revisions, Flight assembly

Flight testing (Environmental, EMI, Functional)

Prepare to Ship

Shipping, Launch Vehicle Integration

PQR, Small Sat

FCR

Flight TRR

Flight SAR

Flight PSR

Launch

2012

2013

2014
Questions?