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TSAT VLF and Electric Field Sensor on Boom System

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Abstract

The Earth's Electric Field (ThEEF) sensor is a critical component on the Taylor Satellite (TSAT) nanosatellite project. Outfitted with a pair of sensors, a Very Low Frequency (VLF) sensor and an Electric Field (E Field) sensor, this instrument is designed to collect ground breaking data from the lower reaches of the atmosphere, roughly between 300 km and 100 km above sea level. This is a cross section of the atmosphere which, surprisingly, is not that well understood presently. As TSAT orbits the earth, it will obtain information about VLF wave propagation characteristics in the region, providing potentially new insights into the Sun/Earth coupling. It also measures the vertical voltage per meter, giving the vertical E Field of the Earth. The sensor is flown on a new boom system. Unlike the boom structures of past satellites, the current TSAT arms are designed to be electronically controlled from a remote location on the ground and will be fully retractable. Additionally, the booms serve as an isolated collection surface for the VLF sensor, while doubling as aerodynamic stabilizers much like the steadying effects that feathers have on an arrow in flight.

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Introduction

The Taylor satellite (TSAT) is a powerful student designed nanosatellite that will be commissioned for probing space weather data (see Figure 1). It provides a unique observation platform in the relatively unexplored lower atmosphere and ionosphere (120-300 km region). TSAT contains VLF electromagnetic wave sensors, electric field sensors, particle detectors[1], and UV radiation sensors[2]. The on-board instruments and the ground support equipment (GSE) are designed to process, record, and display the information[3]. TSAT is designed to orbit from altitudes of 100 km to 300 km, with up to 1000 full orbits as anticipated over the course of five weeks. The ThEEF Sensor provides the major measurement capabilities of TSAT. The role of the ThEEF sensor on this satellite is twofold. First, it makes VLF wave measurements in the low-altitude ionosphere where the Earth/magnetosphere VLF coupling is not well understood and high precipitating signal-to-noise fluxes are very high. Second, TSAT measures the vertical E Field of the Earth in order to verify the current atmospheric models[8]. Previous satellites have also been flown which take measurements of VLF wave activity[5,6,7,8] and E fields[9,10,11].

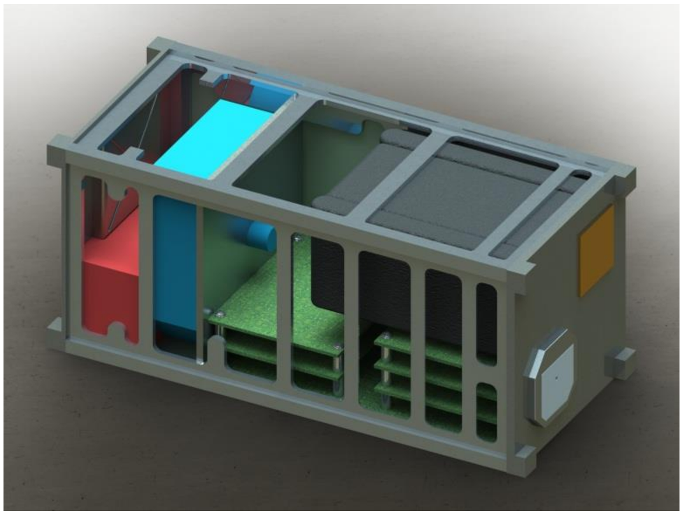

Figure 1. System level diagram of TSAT with ThEEF Sensor and retracted booms (not shown) colored in blue as situated behind the EMI shield.

The ThEEF Sensor consists of two probes mounted on opposing booms, perpendicular to the face of the earth. These sensors measure the differential voltage that exists between them, and then passes this data to the main signal processor on the student sensor board. The received signal is then split into its AC and DC components and processed. The block diagram of the ThEEF Sensor is shown in Figure 2.

This paper describes the designs of both the external and internal components of TSAT. A description of the sensors is followed by the boom system; the internal instrumentation ofthe main electronics on the student sensor board are also presented.

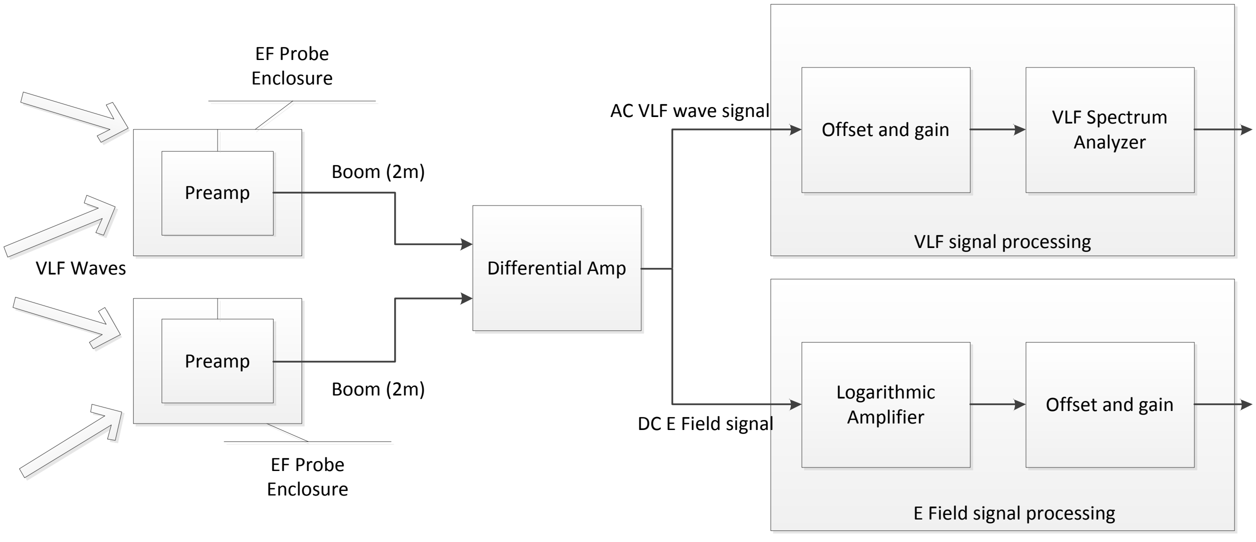

Figure 2. Block Diagram of ThEEF Sensor showing the signal flow path through booms to signal processing following the AC/DC split.

Sensors

Each probe is mounted on the end of a flat-pressed boom. The probes pick up a combination of DC and AC charges from, respectively, the voltages in the atmosphere and those incident from the electromagnetic waves. A reset is included to clear the collection surface of built up charges, once every second. The individual signals are processed through a low-pass filter to allow only the VLF electromagnetic waves of less than 30 kHz through in the DC E Field portion. The signals are then sent through a protection circuit and a preamplifier before being passed through the booms.

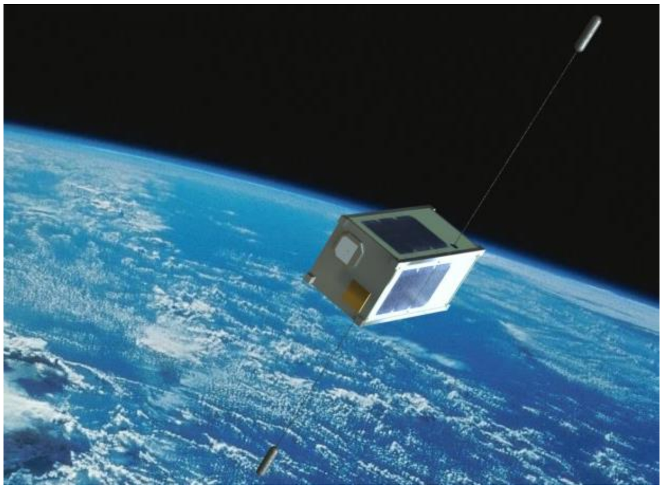

Figure 3. TSAT with ThEEF Sensor and booms with the Aquadag coated sensors mounted on the booms.

The VLF and E Field probe front-end amplifier is located with the probe enclosure at the end of the boom. A plasma gap around the antenna and spacecraft is the sheath, with a characteristic thickness given by the Debye length and depends on the inverse square root of the plasma density. The plasma density varies significantly in Low Earth Orbit but the nominal thickness is on the order of about 1 cm. The sheath impedance between the antenna and plasma is small because the antenna is short and estimated to be around 25 pf with a 2 MΩ resistance. The low antenna capacitance indicates that precaution is required on the release mechanism stray capacitance design. To significantly reduce the effect of stray capacitance, the preamp output is bootstrapped with a Mylar shield so that the grounded surfaces in the boom release mechanism are canceled. Antenna efficiency is increased as the stray capacitance is reduced by this design.

Besides improving the signal to noise ratio, the preamplifier presents a low impedance signal line back to the electronics box to reduce pickup. A protection circuit is also included on the front end to prevent voltage and current spikes in the plasma from destroying the input FET circuit. A temperature sensor is added for observation of the preamplifier. The capsule enclosing the front end circuitry on the boom is the actual collection surface itself which is covered with an Aquadag coating (i.e. a conductive carbon substance) allowing it to double as a capsule and a probe with a direct connection to the front end circuitry.

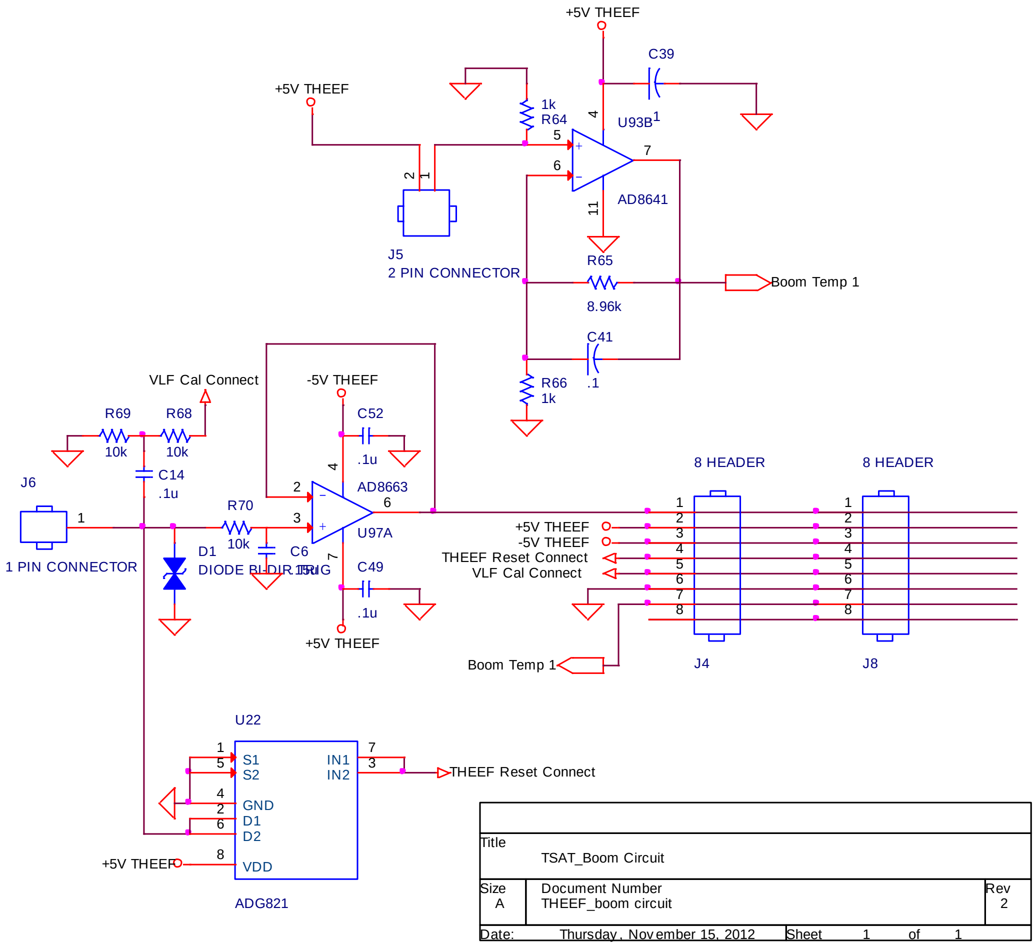

Figure 4. Front end circuitry contained within capsules mounted on booms.

Mechanical Booms

The present boom system is a novel design in cubesat technologies. Unlike other boom designs[12,13], the spooling feature of the carbon fiber booms for this project allows for these members to be extended and separated to a distance of up to 4 meters, while taking up minimal space within the satellite housing itself. Additionally, the booms provide an isolated collection surface for the VLF sensor, while doubling as an aerodynamic stabilizer much like the steadying effects that feathers have on an arrow in flight. This system allows for the retraction of the booms in order to take measurements at varying distances. A High torque space certified motor with encoder controls the boom extension and a state-of-the-art piezoelectric motor works to lock the probes in place for pre-deployment. A first generation conceptualization of the design is shown in Figure 5.

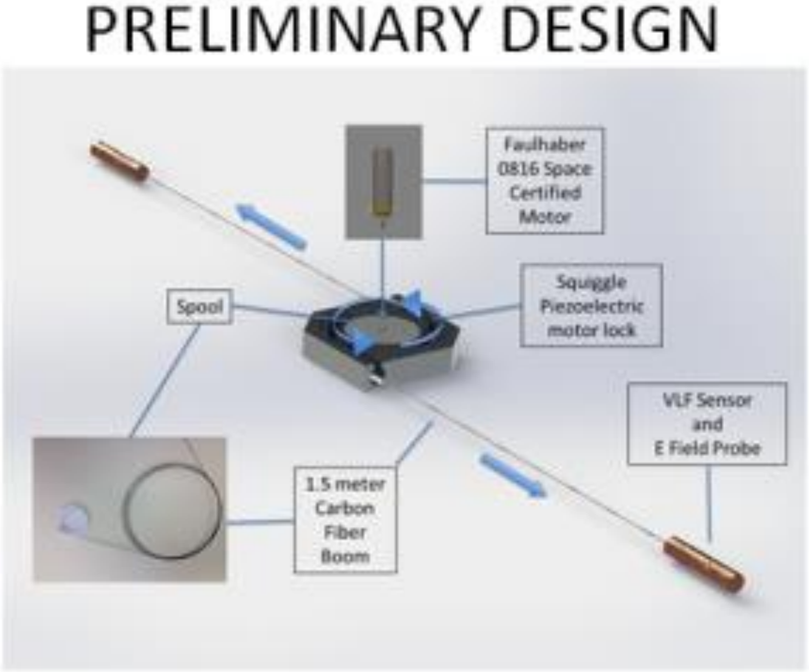

Figure 5. An early concept model of the boom release system.

In designing a boom system for outer space, environmental considerations require special attention, such as exposures to outgassing and extreme temperature conditions. Due to outgassing, lubrication cannot be used anywhere in the boom system. Because of this, very precise space certified motors must be used, and tolerances must be so tight in order to reduce frictional effects. In the design of the boom system, special considerations were given to account for anticipated thermal expansion effects of the materials while operating in space. The range in craft operating temperatures may fluctuate between 230 K and 350 K (i.e. between -45 °F and 170 °F) with typical expected temperature differentials (ΔT) of possibly 30 or 40 K (i.e. 60 or 70 °F). This temperature change was taken into consideration when determining the material and design of the present boom system. Additionally the spin of the spacecraft must be accounted for to ensure that the deployment of the booms is achieved in a tangle free manner.

To reiterate, the present boom system design consists of a spool with two flat carbon booms wrapped around it (see Figure 6). The booms are flat to allow for layers of conductive and insulating material to be pressed onto it to double as a coaxial cable. The spool and booms are placed in a case that aligns the two booms opposite one another (Figure 5). When the spool rotates, the booms extend outward in opposite directions.

Figure 6. Exploded view of the boom system with VLF sensors.

Because of the flat pressed design, cables are not required for extending out to the VLF sensors. The wire trace conductive plating on the boom acts as the cable, while the kapton serves as an insulator (see Figure 7); the carbon fibers add rigidity to the structure of the boom system. Once inside the spool, the cable feeds up into a compartment where additional loops of cable are loosely wrapped in the compartment, thus allowing for rotation of the mechanism upon deployment.

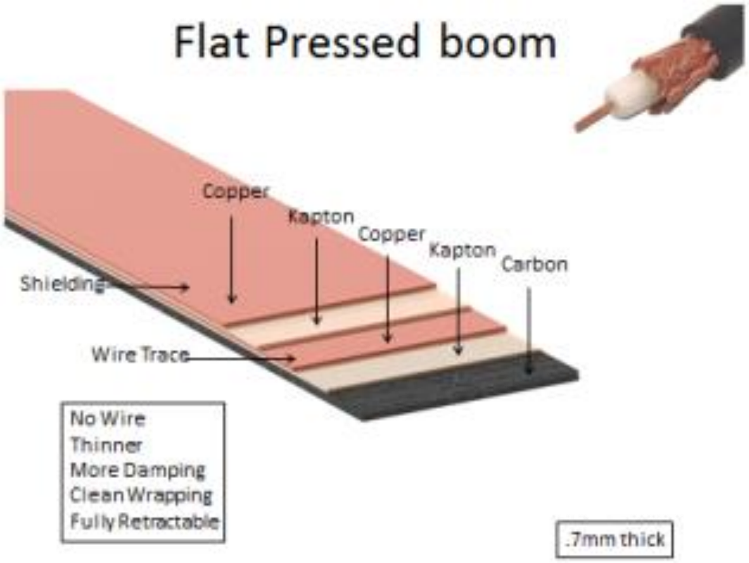

Figure 7. Boom materials resemble the construction of a coaxial cable.

A pair of state-of-the-art piezoelectric motors lock the VLF capsules in place inside of the boom system unit prior to launch. A space certified electric motor with a high ratio gear box turns the spool to extend the booms. The gear ratio selected for use on this mission is 4000:1 in order to provide maximum torque while keeping the deployment speed low and controlled. The deployment speed must be slow due to the rotation of the satellite during deployment. As the booms are deployed, they will naturally tend to retard the rotational speed of the satellite, however, if extended too quickly, the booms can then get entangled around the structure of the spacecraft.

Another novel feature of the present boom system is its design to extend or retract to any distance within the maximum length, on command, through remote control. An encoder is furnished on the deployment motor to indicate the position of the boom. This is useful for instruments that require a separation of a specified distance. Moreover, the whole boom deployment case, spool, and cover have been designed with 3D printing in mind. This makes prototyping, as well as manufacturing of the parts, both quick and simple.

Main Electronics

After the main electronics have received the signals from the booms, they are coupled by way of a differential amplifier on the student sensor board. An anticipated peak-to-peak input voltage around 1 mV is expected due to electromagnetic waves, with an offset of approximately 1 V due to the Earth’s electric field.

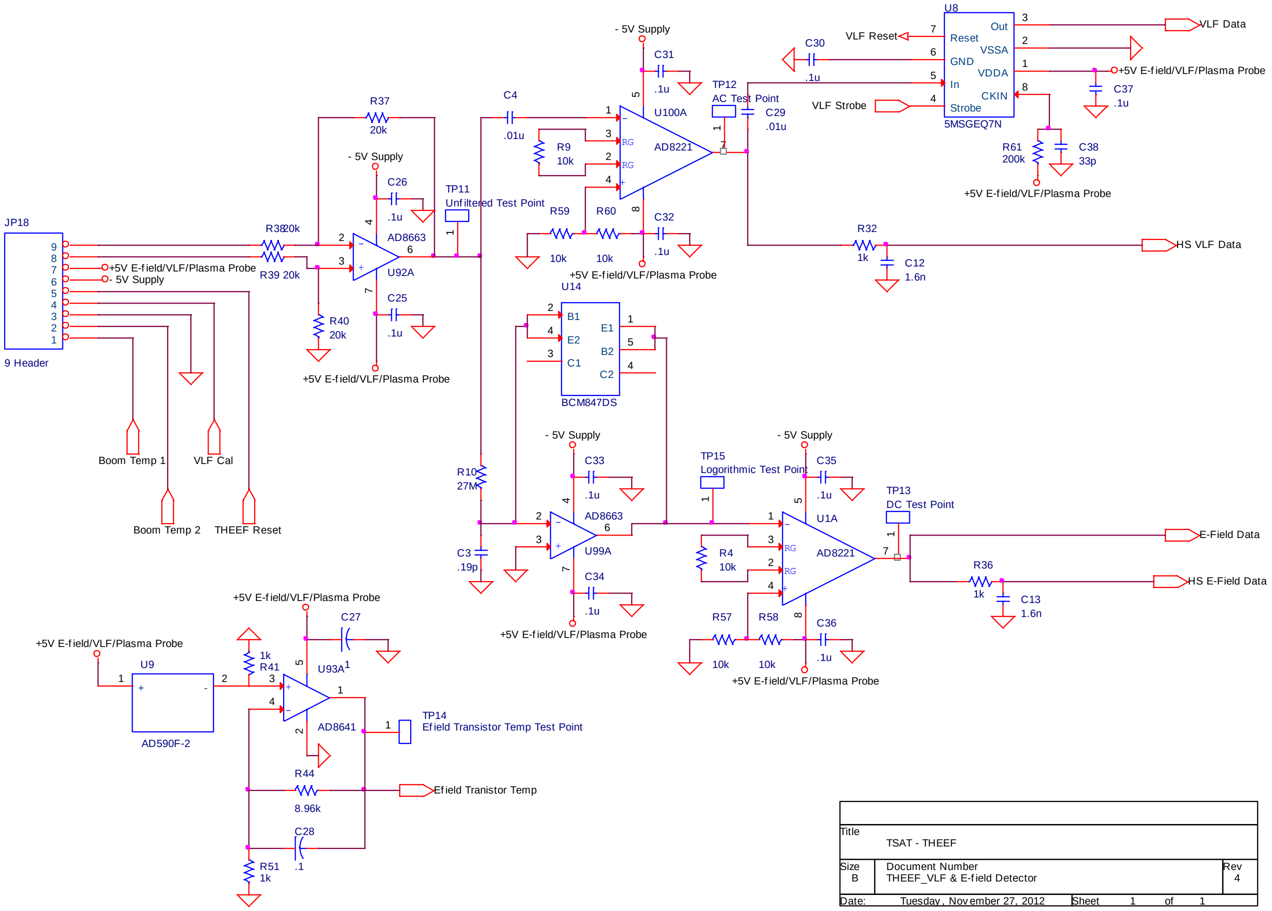

Figure 8. Main electronics showing the circuitry to receive the two boom signals, combine them into one via a differential amp, before splitting these into separate AC and DC current designations.

Using another low-pass filter, the signal is split into separate AC and DC forms (see Figure 8), prior to becoming decoupled into the VLF and E Field portions. The E field signal is passed through a logarithmic amplifier to make the output within the range of 0-5 V. The VLF signal is offset initially to prevent negative values from being introduced. This signal is then sent to the VLF spectrum analyzer which is a six-channel spectrum analyzer, converting data to the frequency domain and performing a six-point Fast Fourier Transform (FFT). Both sets of data are then sent to the student flight processor board for further processing. Following this, the information is relayed to the ground support equipment to be recorded and displayed.

Advanced parallel data processing with ACTEL-FPGA-firmware is used to change gain levels, add high level filters, convert data to the frequency domain, burst and survey data processing and final compression for telemetry transfer. A high speed output is expected for oscilloscope testing on the ground once the satellite is fully operational. A temperature sensor is included due to thermal sensitivity of the transistors in the logarithmic amplifier.

Conclusion and Further Research

TSAT is expected to provide groundbreaking data from a region of the atmosphere at an altitude of between 300 km to 100 km. This region of space is currently considered as being largely uncharted. The contribution of the ThEEF Sensor is to take sample measurements of the VLF electromagnetic waves and vertical E Field characteristics of this area to gain an understanding of the Earth/magnetosphere VLF coupling. These sensors are mounted on booms utilizing a novel design that provides an isolated collection surface and has the ability to extend and retract the boom system. TSAT is schedule to launch from Cape Canaveral on NASA’s upcoming Space-X mission to the International Space Station in the summer of 2013. The lessons gained from this project are hoped to set the foundation for the upcoming Extremely Low Earth Orbit NanoSatellite (ELEO-SAT), a nanosatellite approved for inclusion on the NASA Space-X manifest launch a year following in 2014[14]. Both of these projects will serve to enhance student learning through technological advances and innovation resulting in a deeper understanding of the relatively uncharted regions of the ionosphere.

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Bibliography

1. McClure, D., Foote, S., and Voss, H., "TSAT Solid State Detector and Plasma Probe Particle Detectors," in *Proceedings of the 2013 ASEE Annual Conference*, Trine U., Angola, IN, April 6, 2013.
2. Kilmer, A. and Boyajian, D., "Thermal and Ultraviolet Modeling, Balancing, and Sensing," in *Proceedings of the 2013 ASEE Annual Conference*, Trine U., Angola, IN, April 6, 2013.
3. Lew, D., Baranowski, J., and Min, R., "TSAT Student Flight Processor and Ground Support Equipment," in *Proceedings of the 2013 ASEE Annual Conference*, Trine University, Angola, IN, April 6, 2013.
4. Okada, T. and Iwai, A., *Natural VLF Radio Waves*, New York : Research Studies Press, 184 pp., 1988.
5. Clements, E., Alvisio, B., Babuscia, A., et al., "TERSat: Trapped Energetic Radiation Satellite," *in 26th Annual AIAA/USU Conf. Small Satellites*, 2012.
6. Jiricek, F., Triska, P., Vojta, J., and Fischer, S., "ELF and VLF Electric Field Measurements with the Interkosmos 10 Satellite," *Studia et Geophyisca et Geodaetica*, 20(*1*), 72-80, 1976.
7. Inan, U., Bell, T., and Anderson, R., "Cold Plasma Diagnostics Using Satellite Measurements of VLF Signals from Ground Transmitters," *J. Geophysical Res.*, 82(*7*), 1977.
8. Yamamoto, M., Ito, Y., Kishi, Y., et al., "k Vector Measurements of VLF Signals by the Satellite EXOS-D," *Geophysical Res. Letters*, 18(*2*), 325-328, 1991.
9. Fish, C., Swenson, C., Neilsen, T., Bingham, B., Gunther, J., Stromberg, E., Burr, S., Burt, R., Whitely, M., Crowley, G., Azeem, I., Pilinski, M., Barjatya, A., and Petersen, J., "DICE Mission Design, Development, and Implementation: Success and Challenges*," 26th Annual AIAA/USU Conf. on Small Satellites*, 2012.
10. Gurnett, D., "Satellite Measurements of DC Electric Fields in the Ionosphere," *Particles and Fields in the Magnetosphere*, B. M. McCormac (Ed.), pp. 239-246, 1969.
11. Pratt, J., "Native Earth Electric Field Measurements Using Small Spacecraft in Low Earth Orbit," *Master of Science Thesis, Utah State University*, 85 pp., 2009.
12. Mark, S., Ben, D., and Pete, W., "Development of a Deployable Gravity-Gradient Boom CubeSat," *CubeSat Developers' Workshop*, Cal Poly Pomona, San Luis Obispo, April 22-25, 2009.
13. Prashant, M., "Wire Boom Deployment Dynamics and Control System Model for Small Satellite," Master's Thesis, Utah State University, 75 pp. (2012) .
14. Voss, H., Kilmer, A., McClure, D., Lew, D., Baranowski, J., Seifert, K., Orvis, M., Foote, S., Dailey, J., Geisler, J., and Boyajian, D., "Extremely Low-Earth Orbit NanoSatellite (ELEO-Sat) for Student Learning and Research," in *Proceedings of the 2013 ASEE Annual Conference*, Trine U., Angola, IN, April 6, 2013.

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