Lightning Spectrometer for Ionospheric Disturbances

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***Abstract* – Students have had to become familiar with lightning propagation and ionospheric occurrences through analysis and research which revealed that lightning acts as an electric dipole antenna emitting radio wave propagation that affects the ionosphere. This property is being used to design a new low-cost ground/satellite observation capability to measure dispersion and total electron content. The signal path is determined by locating the lightning using time of flight to both the spacecraft and inexpensive ground stations. This specialized monitoring system involves a transformation of an alternating signal to a direct signal at which point the data is efficiently buffered and time stamped for convenient downlink. This will allow for a client to download the data and perform their own analysis of the ionosphere or for the engineered satellite-based monitoring system to perform detailed trending. The eventual goal of this project is to provide a nano-satellite package for low earth orbit with the capabilities described previously.**

Keywords – total electron content, spectrometer, ionosphere, antenna.

I. INTRODUCTION

Lightning is the means to which the Lightning Spectrometer (LS) will be engineered. The LS will be utilized to figure out the total electron content in the ionosphere. The ionosphere varies both seasonally and diurnally causing mass communication failure between ground stations and satellites. The spontaneity of lightning discharge proves to be problematic regarding location and time prediction of each lightning storm as well as the gauging of the ionospheric electron density. This project is difficult due to the complexity of the various components that make up the LS. The goal is to create a viable system to allow for inexpensive, compact, and efficient LS to negate communication error. Various components consist of use of Uman’s Model as a basis of gauging lightning, the Numerical Electromagnetics Code (NEC), the Analog–to–Digital Converter Board (ADC), the Field-Programmable Gate Array (FPGA), the Microcontroller, and the Global Positioning System (GPS).

II. LIGHTNING & IONOSPHERIC BACKGROUND

The ionosphere is the uppermost layer of Earth's atmosphere composed of ionized particles created by incoming solar radiation. It is a naturally occurring plasma whose frequency varies due to the diurnal and seasonal variations in the free electron number density. This plasma frequency creates the conditions for the passage and/or reflectance of electromagnetic waves of particular frequencies. Radio waves have a low enough frequency to be refracted by the ionosphere back to the ground, permitting communication throughout the world. This type of radiation forms a part of the electromagnetic spectrum with frequencies ranging from 30 kHz to 300 GHz and is crucial with respect to communication systems. A naturally occurring radio wave source is lightning—an electrical discharge that occurs between conducting media and positively or negatively charged cloud formations. Each lightning strike is seen as an impulse that on average has a lifetime of less than one second. When there is a lightning storm each impulse emits a signal at a particular frequency and the combination of these signals allows for the accumulation of frequencies into a frequency spectrum.

Idealistically each discharge is treated as an oscillating electric dipole antenna emitting electromagnetic radiation into the atmosphere [8]. This radiation emission is measured at far field using the dipole antenna that transmits these signals to an Analog-to-Digital Converter wherein the information is captured and transformed into Fourier Space.

III. NUMERICAL METHODS

Calculation of the electric and magnetic fields at near and far fields require the solution of the Electric Field Integral and Magnetic Field Integral Equations (EFIE/BFIE) as well as the physical parameters imposed by the lightning strike. It has been determined that for an oscillating electric dipole antenna the EFIE formulation is better suited for calculating the transient response [5]. Closed-form solutions cannot be obtained and thus a numerical analysis is necessary.

A. Numerical Electromagnetics Code (NEC)

The NEC is a publicly available computer code developed by Lawrence Livermore National Laboratories used to analyze the electromagnetic fields and frequency responses of antennas [5]. NEC solves the integral equations by the method of moments and an explanation and derivation can be found in [5].

The use of NEC to model lightning is well documented; see [6]. Using NEC, a lightning strike was modeled as a 3 km tall wire antenna with a current of approximately 10 kA through the antenna. These numbers were obtained through the United States Precision Lightning Network (USPLN) real time measurements of lightning strikes in the area and previous research in lightning modeling [8]. These simplifications, the near and far electromagnetic fields, can be calculated and their intensities can be found at any distance from the lightning strike. From these values frequency and power spectra can be determined at a location due to the hypothetical lightning strike. This process resembles the procedure by which the lightning spectrometer would measure, make calculations, and interpret lightning data acquired from a lightning event.

B. Real Time Data Acquisition/Analysis

Lightning strike data was also acquired through the use of a Com-Power AB900 Biconical Antenna with frequency range 30 MHz-300MHz. The reason for use of the Biconical Antenna is for its ability to gauge the electromagnetic field in various axes. This allows for a more complete understanding of the true signal in Fourier Space. The antenna was connected to a Tektronix MSO4054 Mixed Signal Oscilloscope by a coaxial cable and real time measurements of lightning strike data was saved using the oscilloscope's USB drive capabilities. Lightning strike data was sampled using 1 million data points for duration of 40 milliseconds. The data was saved as a comma separated value (CSV) file and imported into MATLAB for analysis. Using an m-file script, the lightning strike signal was transformed from the time-domain to the frequency-domain using a fast Fourier transform. The frequency-domain signal was filtered by adjusting for the antenna factor and background noise. The corrected frequency-domain signal is then used to produce a spectrogram of the lightning strike. The acquisition of data through techniques other than the actual LS allows the observer to have an idea of what the true lightning signal should look like when measured.
An example of a lightning spectrogram can be seen in the figure below.

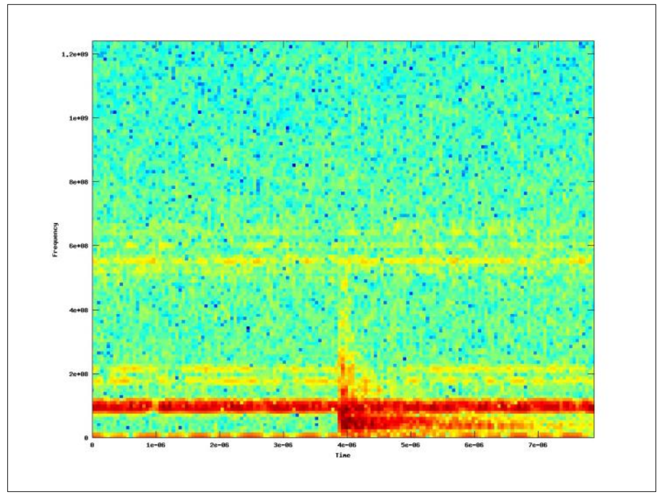

Figure 1 Lightning Strike Spectrogram

IV. LIGHTNING SPECTROMETER HARDWARE

A. Analog-to-Direct Current (ADC)

The first part of hardware of the LS is a board that receives the lightning signal and converts it into digital data. The Easily Applicable Graphical Layout Editor (EAGLE) 5.9.0 software is used to create the schematic and layout of the design. The board receives the lightning signal from an antenna via a BNC connector. At the front end of the design a Littlefuse PulseGuard Suppressor is placed to protect the ADC from high voltages [7]. Next, an operational amplifier is used to create a low-pass filter to cut out any signal beyond the range of the antenna. A potentiometer is included in this part of the design so that the gain of the op amp circuit can be chosen. As a further precaution, a comparator is built to test the signal against an on board supply of 3.3-V. If the signal exceeds this value, a set/reset latch sends a signal directly to the microcontroller, informing it to cut power to the system.

The primary function of transforming the signal is performed by the ADS5463, a very high-speed analog to digital converter chip. The ADS5463 is an 80-pin surface-mount component from Texas Instruments. It samples at a rate of 500 MSPS and has an input bandwidth of 2.3 GHz. Another valuable attribute of the ADC is a high analog input swing of 10-Vpp [11]. The signal is passed through a transformer in order for it to be changed into a differential signal for the ADC. The ADS5463 receives the differential input from the transformer and a clock signal from a 500 MHz voltage controlled oscillator [4]. The clock can be input to the ADC as a differential or single-ended signal. Since board space was more of a concern than timing jitter for this project, the application notes for a single-ended clock was followed. Both the rising edge and falling edge of the clock is used to propagate the analog sample through the ADC every half clock cycle. This gives the ADC a very low latency of 3.5 clock cycles.

The ADC requires power from both a 5-V and 3.3-V supply. At this stage in the project, adjustable DC power supplies were used. The supplies are set to 5.4-V and 3.7-V and these voltages are adjusted on the board by voltage regulators before they are sent to the ADC [1] [10]. In order to ensure clean power to the ADC we placed 0.1µF decoupling capacitors in line with each power pin. The ADC has an internal reference voltage of 2.4-V to manage the level of the inputs and outputs.

The output of the ADS5463 has a resolution of 12 bits. It also has a Data Ready Low Voltage Differential Signal (DRY LVDS) output and an Over Range Indicator LVDS output which indicates that the analog signal is outside of its range. These outputs go to a Z-Pack Tyco Electronics connector which joins the data sample with the rest of our system [12]. The sample eventually arrives at the microcontroller for processing after being buffered by the Field-Programmable Gate Array (FPGA).

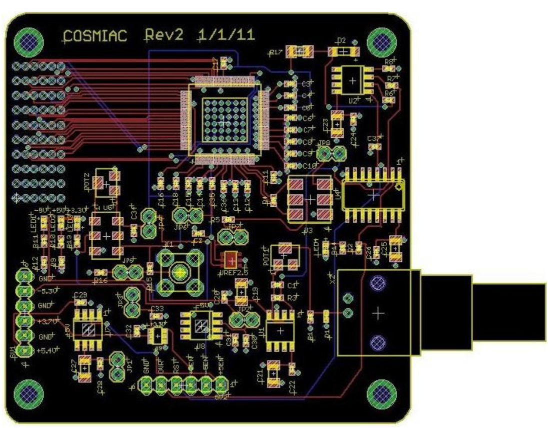

Figure 2 ADC Board in EAGLE

B. Field-Programmable Gate Array (FPGA)

Xilinx's ML403 FPGA Evaluation Platform is the FPGA based Evaluation Board used in this project for data transfer from the ADC board to the Microcontroller. The ML403 uses a Xilinx Virtex-4 XC4VFX12-FF668-10 FPGA chip. The ML403 has 100 MHz oscillator installed for a system clock as well as a Differential Sub-Miniature A (SMA) Clock input for multiple or greater clock speeds. The ML403 includes 16 differential signal inputs for high-speed data transfer as well as Universal Asynchronous Receiver/Transmitter (UART) connection to the FPGA's I/O. The application of the ML403 is to transfer the high speed data from the ADC board to the Microcontroller. Since the Microcontroller cannot handle the high-speed data rates that the ADC outputs, a First-In-First-Out (FIFO) buffer is introduced on the Virtex-4 FPGA. This is to store the high-speed data through the differential I/O pins from the ADC and then output the data in the correct order to the Microcontroller through the UART connection at a slower rate of transfer [13].

C. Microcontroller & Global Positioning System (GPS)

The GPS used in this project is the FV-M8, formerly documented as EB-85A. The purpose of the GPS implementation is to synchronize time in order to triangulate the position of lightning events as well as providing a timestamp to the lightning strikes. GPS and corresponding evaluation boards are utilized for power and simplification of the Universal Synchronous/Asynchronous Receiver/Transmitter (USART) and Pulse Per Second (PPS) signals from the actual GPS pseudo code [9]. From here, the GPS board is interfaced to the Atmel board. This prototyping board used is identified as the EVK1100 which consists of the microcontroller chip UC3A0512. The interface between the Microcontroller board and GPS board is via an RS232 transceiver cable and used with the provided USART hardware support. Also between such hardware assigned and configured, General Purpose Input/Output (GPIO) pins on the Atmel board were used to bring in some custom signals from the GPS to perform interrupt driven, real timing as well as provide a threshold from the ADC regarding data collection and system shutdown. AVR32 is the software being utilized to program the microcontroller chip and the various components such as the USART and USB. The 500MHz oscillator clock will help determine the order of data store from the FPGA along with properly time stamping the data using the GPS PPS signal [2].

V. CONCLUSION

The eventual goal regarding this project is to be able to apply a correction to communication systems for constant contact between ground stations and satellites by looking at the LS to determine the plasma discharges and to see the electromagnetic activity in the ionosphere. Thus by creating the LS, anyone can utilize it for research or correctional purposes. All the large scale components that make up the LS will help to provide communication and research capabilities. However, the small scale objective is to minimize these components to specific chips and boards that would allow for the transportation of this correction system on a CubeSat. Ultimately a network of CubeSats in space will be able to provide an accurate and precise spectrum for these correctional errors and research capabilities.

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