Abstract—In this paper, we present a low-cost and flexible high-speed data acquisition system based on software defined radio. An open-source software development toolkit, GNU Radio, is used to develop receiver’s functionality. The hardware is used to perform characterization of electric and magnetic fields from electromagnetic fields measurements. This characterization is an important tool for understanding characteristics of lightning related phenomena such as preliminary breakdown pulse (PBP), K-processes, J-processes, Narrow Bipolar Pulses (NBP), etc. Currently scientists have proven that the use of high-speed data acquisition systems produce important information on lightning processes. However, some commercial high-speed data acquisition solutions can be quite expensive, so their uses in some contexts are not viable. The total hardware cost of the proposed instrument is low compared to commercially available high-speed data acquisition systems.

Keywords—lightning; software defined radio; radio atmospherics (sferics); Very Low Frequencies (VLF).

I. INTRODUCTION

To improve our understanding of lightning phenomenon is essential to collect data of the lightning discharge and its related events. Lightning flashes generate wide-band electromagnetic pulses that goes from few Hz up to several GHz. Electromagnetic pulses from lightning in the 3 KHz to 30 KHz frequency band are known as radio atmospherics (also known as sferics). These sferics are lightning produced electric and magnetic fields, which propagate by way of multiple reflections in the Earth-ionosphere cavity. In this Earth-ionosphere waveguide, sferics are measurable at great distances from their source locations due to their low loss propagation typically 2-3 dB/1000 Km. An event related to the one aforementioned is Schumann resonances that are standing waves signals in the Earth-ionosphere waveguide at discrete frequencies (7.8, 14, 20, 26, 33, 39 and 45 Hz). Finally, whistlers are signals in the ELF and VLF bands that travel out through the ionosphere along the Earth’s magnetic field lines and back through the ionosphere into the atmosphere [1].

Other related events to lightning discharge are preliminary breakdown pulse (PBP), K-changes, J-processes or M-components. They are an important tool to improve the detail understanding of lightning physics. These events are present at some stage of the lightning flash at nanoseconds to milliseconds time scale [2]. All of these events have in common the need for high-speed data acquisition system in order to collect enough information about them.

In general high-speed data acquisition can be defined as the measurement, recording, analyzing and presentation of real world phenomena. Currently, some high-speed data acquisition commercial solutions can be quite expensive, so their uses in some contexts are not viable. Hence, in this paper the authors present preliminary design of a general purpose platform for digital signal processing. Based on software defined radio (SDR) technology, this kind of platform initially was aim to be use in the context of radio communication systems but here in a first stage, its capabilities are used for detecting sferics events.

II. RECEIVER ARCHITECTURE

SDR technology facilitates experiments and practical realizations of specific functions [3] [4] [5] [6]. This allows cheap manufacture, assembly, and testing of devices, despite fixed purpose hardware. Therefore this technology is suitable to collect and process lightning related electromagnetic signals. Fig. 1 is a conceptual block diagram of the complete platform.

A. General Architecture

1) VLF/LF antenna: VLF/LF antenna (loop antenna or a whip antenna). Preliminary tests have been done with an air core square antenna. This is a wideband antenna with a low gain. This antenna has 19 turns of 18 gauge wire. The square antenna has a side dimension of 0.64 meters so the area is 0.409 m².

2) Low Noise Amplifier: In order to improve the overall noise figure of the receiver, an external low noise amplifier
(LNA) was integrated. In this particular experiment, the LNA was installed at the coaxial output of the antenna. This amplifier has a wideband from 0.0025 to 500 MHz, typical gain of 25 dB.

3) Low Pass Filter: It is a coaxial low pass filter manufactured by Mini-circuits [7]. It has 50 ohms input impedance, and a frequency range from DC to 32 MHz.

4) USRP N210: The USRP N210 [7] module manufactured by Ettus Research (and its parent company National Instruments) The N210 module basically consists of an FPGA board for digital signal processing of baseband signals. It provides high-bandwidth and high-dynamic range processing capability. The USRP N210 includes a Xilinx Spartan 3A-DSP 3400 FPGA, dual 100 MS/s, 14-bit ADC, dual 400 MS/s, 16-bit DAC and Gigabit Ethernet connectivity to stream up to 50 MS/s to and from host processors. The module works in conjunction with a LFRX daughterboard for this application.

5) LFRX daughterboard: The LFRX daughterboard utilizes two high-speed operational amplifiers to provide two differential signals from SMA connectors. These signals can be processed by the USRP radio as passband signals, or combined to form a complex baseband signal. The operational amplifiers are configured as a low pass filter with a 30 MHz cut-off frequency. This provides up to 60 MHz of bandwidth if used in a complex baseband mode. Within the bandwidth of the low pass filters, the LFRX provides unity gain from the SMA connectors to the ADC.

6) GPSDO: GPS Disciplined Oscillator is a combination of a GPS receiver and a stable oscillator whose output is controlled to agree with the signals broadcast by GPS satellites, so this oscillator is used as a reference for timing applications. In this experiment this element is not use yet, but in future will be use to add GPS location and data time of the actual receiver.

7) GNU Radio: GNU Radio [9] is an open-source software development toolkit that provides versatile signal processing capabilities and several processing block. It allows the designer to extended capabilities through its own functions and blocks write in C or Phyton. Hence hardware circuits are replaced with signal processing blocks and complex systems can be represented as simple flow graphs.

B. Architecture Description

The architecture of the proposed platform is suitable to collect data from different sources (magnetic or electric sensors). For preliminary test the platform used an air-core loop antenna composed of two orthogonal square loops that senses horizontal magnetic field component.

In this stage, the platform can work from DC up to 30 MHz, but changing module’s daughterboard is possible to extend its scope. For example SBX daughterboard allows the platform to work up to 4.4 GHz or the UBX40 daughterboard up to 6 GHz.

Next to the antenna is placed the LNA that matches the impedance of the antenna and provides low-noise amplification. The LNA was used was the ZHL-6A+ (manufactured by Mini-circuits) that is a coaxial medium power amplifier delivers 22 dBm into a 50 ohms load on +24V supply. The amplifier next to the antenna passes the radio signal ranged from 0.25-500 MHz. In order to effectively collect ELF electromagnetic signals is required to change this amplifier with one starting from DC. To connect the amplifier output to VLF receiver was used RG58 coaxial cable.
Then a low pass filter is placed at the N210’s input to eliminated high frequencies interferences such as HF and VHF signals. The filter used was the SLP-30+ (manufactured by Mini-circuits). This filter has a passband width of 32 MHz and a stop band attenuation of 20 dB at 47 MHz.

The N210 module samples data at 100 MS/s, nominally facilitating direct signal detection up to 50 MHz without aliasing. Using daughterboard is possible to translate energy signals around IF values, extending the range of the platform, even up to several GHz. Furthermore, the 14-bit ADC sampling resolution nominally enables 86 dB of dynamic range. In this implementation prior to the sampling process, a decimation process is performed to reduce the number of samples from 100 MS/s to 50 KS/s, this is done to have better resolution with the results of the FFT. Additionally, anti-aliasing filter is used before sampling the signal to guarantee band limited signals. Then Fast Fourier Transform (FFT) is performed on the incoming samples. With a sampling rate of 500 KHz (decimation factor of 200) and a 4096-point FFT, the FFT bin width equals approximately 123 Hz. To show some of the results, the data is drawn using function blocks available in the GNU Radio toolkit.

Fig. 2 shows part of the measuring site with computer running GNU Radio on Linux Mint 7.5.7. On screen is shown a flow graph and a spectrogram. At the left is possible to see the USRP N210 module and a low pass filter connected at module’s input. To validate some measurements a spectrum analyzer is always used.

### III. PRELIMINARY RESULTS

In order to test the general purpose of this platform, different types of measurements were performed. The first test was to use the platform to detect transmission from some VLF transmitter around the world. Table I shows a brief list of some available VLF transmitters. This measurement is important because a continuous monitoring of those VLF signals serves as a mechanism to evaluate the behavior of ionosphere regions (e.g. changes in the conductivity). This is done correlating the detected level of those VLF transmissions with certain natural phenomena (e.g. solar flares, the presence of transitory lightning events -sprites, elves- or the presence of thunderstorms). Those changes in ionosphere conductivity play an important role in the propagation of electromagnetic waves. In Fig. 3 is shown some of the detected signals with special emphasis in the transmission detected from the Lualualei VLF transmitter in Hawaii, USA (21.4 kHz).

The second measurement was to detect the presence of whistlers and tweeks who serves to establish correlation between its occurrence and lightning activity. Whistlers are associated to lightning activity in magnetic conjugate. The third measurement was to detect the presence of tweeks who are disperse sferics near the cut off frequency of the Earth-ionosphere waveguide. Fig. 4 shown a small sample of tweeks detected with the platform.

In both experiments, the research is in its first stage so the platform is currently collecting data, so the authors expect to have enough data for give relevant results very soon.

### IV. FUTURE WORK

The proposed platform has shown its potential as a flexible high-speed data acquisition system so a set of measurements are going to take place next months. The authors want to develop a couple of associated projects based on this platform. First, authors are going to include electric field sensors, such as, whip and plate antennas to detect rapid and slow changes in the electric field to collect data about PBP, J-process, K-process to characterize and understand lightning activity in Colombia, at the high altitude of Bogota (2600 m.a.s.l).

Second the authors want to obtain a mathematical model to estimate changes in the conductivity of the ionosphere due to solar flares in Colombia. This project is based on long term measurements of several VLF transmissions detected by two orthogonal loop antennas. VLF measurements are going to be correlated with solar activity information to establish their relationship and create a mathematical model to estimate the conductivity ionosphere behavior in Colombia.

Third project is to use whistlers measurements with lightning location data to determine magnetic conjugate point for Colombia. This is challenging due to its geographical location near to equator where corrected geomagnetic coordinates definition are invalid so it is not easy to use mathematical models to find these points.
V. CONCLUSIONS

In this paper, a technology that comes from communications context has shown its potential to be used in a completely different context. SDR approaches show the advantages of exchange hardware to software to perform signal processing. It gives the possibility of simplify the development, in terms of cost, time and even effort. It makes viable in a simple way the test of prototypes. Additionally the advances in digital electronic circuits, such as high-speed ADC, makes possible to develop high performance data acquisition systems that were only possible through expensive specialized instrumentation.

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Figure 3. This VLF transmission detected in 21.4 kHz corresponds to a VLF transmitter located in Hawaii, USA.

Figure 4. Sample of tweaks detected using the proposed high-speed data acquisition system.