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Research Paper

A prototype data acquisition and processing system for Schumann resonance measurements

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ABSTRACT

In this paper, a cost-effective prototype data acquisition system specifically designed for Schumann resonance measurements and an adequate signal processing method are described in detail. The implemented system captures the magnetic component of the Schumann resonance signal, using a magnetic antenna, at much higher sampling rates than the Nyquist rate for efficient signal improvement. In order to obtain the characteristics of the individual resonances of the SR spectrum a new and efficient software was developed. The processing techniques used in this software are analyzed thoroughly in the following. Evaluation of system's performance and operation is realized using preliminary measurements taken in the region of Northwest Greece.

1. Introduction

The space between the earth and the terrestrial ionosphere forms a large electromagnetic waveguide, considering that the earth surface is a conducting sphere as the ionosphere boundary. It is experimentally proven that the earth-ionosphere waveguide permits the generation of electromagnetic standing waves in the range of extremely low frequencies (ELF), where the wavelength is related to the dimensions of the earth-ionosphere cavity (Balser and Wagner, 1960, 1962). Therefore, specific spectral resonant frequencies are observed. The existence of these resonances was first predicted by Schumann (1952) on a theoretical basis and since then we refer to this phenomenon by the term Schumann resonance (SR) (Schumann, 1952). The frequencies of the lower eigenmodes are approximately 7.8, 14, 21, 27, and 33 Hz. It is found that the main source of these electromagnetic waves is the lightning effect, occurring on the earth. Consequently, Schumann resonance measurements could be used to monitor the global lightning activity during day and seasons (Heckman et al., 1998; Nickolaenko and Rabinowicz, 1995; Nickolaenko, 1997). Several natural phenomena such as the climate variations, ionosphere disturbances, solar radiation, have an impact in the spectrum of Schumann resonances. Schumann resonance signals could be the global environmental signal absorbed by the human body (Palmer et al., 2006). Furthermore, the characteristics of the SR may be important in aerospace, marine applications (Tulunay et al., 2008). A number of corresponding researches have been conducted in order to investigate several types of natural events through spectral traces. To report some of them, global temperature variations, water vaporization, space weather and earthquake precursors could be monitored by SR spectrum measurements (Sekiguchi et al., 2006; Roldugin et al., 2001; Hayakawa et al., 2005; Hayakawa et al., 2010). The significance of Schumann resonance spectrum has attracted the scientific interest of researchers around the world. Until today, several scientific groups have taken measurements of the SR spectrum and stations have been installed in order to record the spectral variations in daily basis (Sierra et al., 2014; Toledo-Redondo et al., 2010). Besides the important role of SR spectrum measurements for the scientific community, there are additional motivations for this research:

- Firstly was the comparison of simulation results with preliminary measurements taken occasionally, from August 2013 to December 2014, on the field comparing in this way the functionality of the SR measuring equipment.
- Secondly was the implementation of a prototype portable low cost, scalable and effective data acquisition system (DAS) capable to capture signals in the extremely low frequency (ELF) and the lower portion of the very low frequency (VLF) band. Exploiting the benefits of adjustable sampling rate, it is feasible to oversample the lowest part of ELF between 0 and 30 Hz where

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SR frequencies lie around.

- Last but not least was to carry out measurements in a location that was never measured, like Greece.

The final objective of current research is the implementation of a fully autonomous SR recording station, as a part of SR network, able to capture continuously and monitor special characteristics of the spectrum, along with its variations over time. The SR detection system consists of three main parts that are the antenna the amplification and filtering and the DAS. The latter includes a prototype data logging device and a personal computer. The rest of this paper is organized into the following sections; Section 2 presents related works; Section 3 gives a brief description on the analog part of our system including the antenna used and the amplifier-filters chain. In Section 4 the DAS is described analytically. Section 5 is dedicated to the results and the signal processing carried out by the software. Conclusions and future work are drawn in Section 6.

2. Related works

Capturing of naturally occurring electromagnetic events such as Schumann resonances in the portion of ELF (0–3 KHz) and VLF (3–30 KHz) has not been widely covered (Hanna et al., 2009). There is still a lack of reliable, economical technologies for monitoring the RF of the lithosphere–ionosphere coupling processes (Yi and Liu, 2011). Focusing mainly on the data acquisition component of SR monitoring systems previously works are presented. At Modra observatory, the output signal is digitized by 16-bit ADC at a sampling rate of 200 Hz. Authors have made several measurements from sampling 180 up to 230 Hz to check possible aliasing effects (Ondrášková et al., 2009) A commercial DAS with an adjustable sampling rate up to 4 KHz was used as a part of a new observation system to measure magnetic fields in the extremely low frequency band at Moshiri, Hokkaido, Japan. The commercial data acquisition board is placed in a PCI slot of a PC 220 m away from the antenna (Ando et al., 2005). At a vast bare land near Kolkata two research teams from India are capturing the ELF signals at a rate 40,000 times per second using a 12-bit A/D. Information is lost in the sampling process only due to relatively small A/D's bit resolution (De et al., 2010). Schumann resonance frequency variations observed in the Himalayan region, India, at elevations between 1228 and 2747 electromagnetic field components, in the form of time series, were recorded at 64 Hz sampling frequency at a site located away from the cultural noise (Chand et al., 2009). One research team from the University of Electro-Communications, Japan and Usikov's Institute for Radiophysics and Electronics, Ukraine are digitized signals inside the ELF band at 350 Hz using 12-bit A/D (Shvets et al., 2009).

According to previous works, there is an extra need for portable, autonomous, low-cost, data acquisition systems capable of capturing signals in the ELF and VLF band. The present prototype data acquisition and processing system presented in this work as a part of SR measurement system. Data logger is completely autonomous for a time period of one month concerning either storage or battery power capacities. The adjustable sampling rate from 512 Hz up to 16,384 Hz enables oversampling of the 30 Hz Schumman bandwidth even with a 273 times ratio. Oversampling in combination with 16-bit resolution is giving efficient signal detection. Furthermore oversampling essentially reduces requirements to anti-aliasing filter at the analog front end after the antenna. Additionally the upper limit of sampling at 16,384 Hz gives the ability to capture signals inside the entire ELF band and at the lower band of VLF (up to 8 KHz). Operation of the system using preliminary measurements is presented in details in the next sections.

3. Antenna and signal conditioning

The architecture of the Schumann resonances detection system we used in experimental measurements is based on a magnetic field antenna and the corresponding signal conditioning system. The first implementation is an inductor coil with a ferromagnetic core material that exhibits relative magnetic permeability value of the order of 10^5. That core material is a mumetal which meets ASTM A753 Alloy 4 specifications. The proposed inductor coil has 40,000 number of turns on a mumetal core rod (length 300 mm and diameter 25 mm). The induced voltage amplitude at the inductor coil terminal exhibits extra low values due to the extra low magnetic field amplitudes (some tenths of pT) that provide Schumann resonances. In order to achieve signal conditioning on those low-level signal amplitudes ensuring efficient noise performance and less signal distortion and degradation we designed and implemented a number of amplifying and filtering circuitries that are embodied in cascading topology. That proposed signal conditioning system provides remarkable performance at a wide frequency range. Amplifying, filtering and noise aspects on electronic circuitries have in detail studied and investigated in order to achieve system performance optimization. The overall gain of the amplification is 118 dBV. The cutoff frequency (at −3 dB) is 27 Hz, whereas the rolloff is about 60 dB/octave. Moreover, we managed to eliminate the signal level of the 50 Hz parasitic single tone from household supply system at the signal conditioning system output. This is achived by using a hardware notch filter as part of the rest signal conditioning system. Additional information about the antenna and the signal conditioning are presented in our previous work (Votis et al., 2015). Fig. 1 depicts a photo of the Schumann resonances detection system.

4. Data acquisition system overview

4.1. Architecture

In order to analyze the analog signal captured by the magnetic sensor, this signal is recorded in digital form and then the new offline software processes it. The digitization and storage are carried out by a data logging device that has been designed and constructed for this purpose. The logger consists of three main parts, an analog to digital converter (ADC), a central processing unit; that is a microcontroller (MCU) and a storage device. A simplified block diagram is shown in Fig. 2. The ADC converts the received analog signal to digital and via the MCU it is stored in a non-volatile memory device. The storage device used is a Secure Digital High

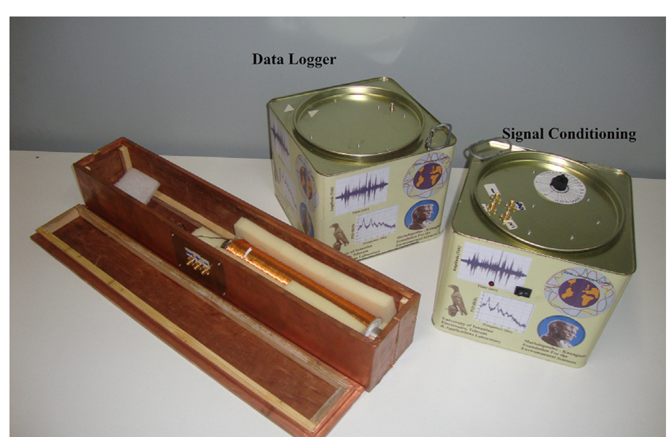

Fig. 1. Photograph of the proposed Schumann resonance detection system.