TESTING A NEW INSTALLED VLF/LF RADIO RECEIVER FOR SEISMIC PRECURSORS’ MONITORING IN ROMANIA

M. GHEORGHITA¹, E. SUCIU¹, A.S. MOLDOVAN², I.A. MOLDOVAN³

¹SC Elettronika Research SRL, Turnului Str. no. 5, RO-500152, Brasov, Romania
E-mail: m.gheorghita@elettronikaresearch.com;
E-mail: e.suciu@elettronikaresearch.com

²AZEL Designing Group Srl, P.O.Box MG-2, RO-077125 Bucharest-Magurele, Romania
E-mail: adrian@azel.ro

³National Institute for Earth Physics, P.O.Box MG-2, RO-077125 Bucharest-Magurele, Romania
E-mail: iren@infp.ro

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The paper presents the testing results of a new VLF/LF receiver for seismic precursors’ monitoring in Romania that is used, starting with March 2009, in the first phase of the Integrated System for the Forecast of Earthquakes in the European area. The system aims to capitalize and integrate numerous research results related to the statistical provisioning of seismic events and is consisting of a network of measuring stations, interconnected and organized through a distributed information system, which can allow consistently the availability of data acquired continuously. The acquired data refer to the amplitude of signals received in Romania and transmitted by high-power VLF and LF transmitters located in Europe. The paper shows why anomalous changes of the received signal level occur as an effect of modification of the characteristics of the ionosphere above the epicenter of an earthquake which is in its preparatory stage, if this is located inside the 5th Fresnel zone of the propagation path. Changes of the ionosphere’s altitude and composition, recorded as electromagnetic propagation anomalies, could be regarded as seismic precursors. This is accomplished with the help of ground-based network of receivers and appropriately located transmitters. The main contribution of the paper is that experimental data containing recordings of VLF/LF electromagnetic field monitoring in Romania are presented for the first time. Moreover, these data are consistent with data recorded in other countries.

Key words: VLF/LF antenna, VLF/LF receiver, seismic precursors, electromagnetic anomalies.

1. INTRODUCTION

The new VLF and LF radio receivers are currently used in the first phase of the Integrated System for the Forecast of the Seismic Events in the European area. The system aims to capitalize and integrate numerous research results related to the statistical provisioning of seismic events.

The development of activities is divided into two phases: first, implementing of an interconnected geographical network of data acquisition, for a comprehensive collection of useful information in the identification of an incipient seismic event; secondly, definition of the data acquisition system, efficient real-time processing and classification techniques for categorization of seismic precursors in order to realize the early warning system for seismic events within defined confidence intervals: the likely interest area of the incipient seismic phenomenon, the probable intensity of the seismic phenomenon and the period within which the event is expected.

2. GENERAL ASPECTS

For the above mentioned system there are six VLF/LF band receivers which are currently in use and are located in Italy (2 of them), Romania, Austria, Greece, and Turkey.

The system consists of a network of measuring stations, interconnected and organized through a distributed information system, which can allow consistently the availability of all data acquired continuously and the history from any remote station.

The prediction of seismic events is based on the effects induced on the propagation paths at frequencies within the band of 10–60 kHz (VLF). These electromagnetic anomalies, recorded prior to earthquake occurrence constitute seismic precursors. The detection of a seismic event is based therefore on the organization of a network of receivers in LF/ VLF band that monitors the transmission channels of stations which broadcast continuously, in order to determine the so called anomalies.

The detection of the electromagnetic anomalies is not regularly sufficient to either foresee by itself the incipient occurrence of a seismic event, or to define precisely the region of interest of the event, nor yet to provide indications about the time interval and the possible intensity of the phenomenon that is expected. It is therefore necessary to supplement this information with a set of other data such as possible variations in concentrations of certain gases in the areas affected by the phenomenon, the variation of level and acidity of the aquifer strata, the presence of radon in the area, etc.

3. SEISMIC PRECURSOR

A seismic precursor is an “anomalous” change in physical and chemical parameters before the advent of an earthquake and that is clearly connected to it.

The most recent research results indicate the existence of two different classes of precursors: terrestrial and atmospheric. The former are anomalies in physical-chemical parameters of the Earth, such as electrical resistivity of the soil, the gaseous and ionic content of groundwater, the earth’s magnetic field etc.; the latter are anomalies in physical and chemical parameters of the atmosphere, such as
temperature, gas composition, density etc. The terrestrial precursors are highlighted by measurements generally made in stations at ground level; the atmospheric precursors have been highlighted mainly through satellite measurements and their occurrence is determined by the atmosphere-lithosphere coupling, during the preceding/ preparatory phase of earthquakes.

The *radio precursors* consist of abnormal variations of amplitude and phase of the radio signals transmitted by high power-ground based transmitters and received on different points by terrestrial or satellite-based receivers. These variations are induced by modifications of the characteristics of propagation channel within the lower atmosphere. Radio anomalies are justified by changes in the physical and chemical parameters of the atmosphere and provide information that can be used for the development of a possible and effective analytical technique for forecasting seismic activities.

A significant contribution to the research on radio precursors comes from the analysis of satellite data. In June 2004, the French Spatial Agency has launched the DEMETER satellite to study the atmospheric precursors of earthquakes. The progress of research on the radio precursors is bounded, in the first place, to the extent of the measurement stations and to the coordination of the data collection.

The main objective is to create a measurement network to improve the detection of VLF/LF radio signals, centralized and operational in real time in Europe. The network will be quite dense and can also be enlarged with satellite observations. The network will be coordinated by the Italian research group operating in Bari and the data collection will be centralized in the operations center activated therein [1].

### 4. Earlier Studies in VLF and LF Monitoring

The researchers advanced the hypothesis that anomalies involving decreases of the signal are due to modifications of the troposphere and anomalies involving increases of the radio signals caused by modifications of ionosphere, both related to the preparatory phase of earthquakes. In [2], harmonics having a period of 0.5d, 1d, 14d, 28d and 365d in the spectral content of three LF radio signals recorded during a period of four years at a site located in central Italy indicated the fact that the atmospheric tides (linear action of gravity tides on atmosphere) are one of the factors affecting the propagation of LF radio waves. A pre-seismic enhancement of the atmospheric tides could justify the anomalous increase on the trend of one of the previous observed radio signals. It was advanced the hypothesis that such an enhancement was caused by a local decrease of the gravitational field as a consequence of the pre-seismic fluid diffusion in a wide area around the future epicenters. The proposed model makes use of gravity changes to justify the pre-seismic anomaly observed in the LF radio signal.
The results presented in [3] seem to confirm a good sensitivity of VLF-LF radio waves propagation to the seismicity. Moreover, the results seem to indicate a wider sensitivity that is to large tectonic processes as plate margin movements. Strong nighttime anomalies in amplitude and phase of a LF signal and significant evening shift in terminator times were found during a period of strong seismic activity [4]. From study [5] it can be inferred that the LF (200–300 kHz) radio signals recorded as far as 500–1000 km from the transmitter, contain information related to the ground-wave. In particular, anomalies appearing on this wave could be related to variations in some parameters of the ground and of the troposphere which control the ground wave propagation mode. Such variations can be produced by the processes which take place during the preparatory phase of earthquakes occurring inside the first Fresnel zone of these radio signals.

According to [6] there is a good possibility that the earthquakes with M ≥ 4.3 produce some decrease in the intensity of the VLF-LF radio signals, when the path is near enough to the epicenters. The decreases can represent a pre-seismic effect or a post-seismic one. The systematic measurement of the intensities of different VLF-LF radio signals in several points could increase the definition of the effect. From [7] it seems that the method of satellite monitoring by seismoninduced perturbations of the ionosphere using VLF signals is efficient as the ground monitoring of VLF subionospheric signals, in condition of a proper quality of the satellite data. The presented preliminary results encourage the intensification of the satellite monitoring. The thorough discussion of AGW seismo-associated influence upon ionosphere is presented by [8] including consideration of the source properties, AGW turbulence propagation into atmosphere, competition with natural atmospheric turbulence, and transformation in the plasma variations at the lower ionosphere. The observation results presented in [9] are more or less in compliance with the theoretical approach mentioned above.

In the previous years, seismic disturbances in VLF (3–30 kHz)/LF (low band, 30–80 kHz) radio signals, as well as in LF (high band, 150–300 kHz) radio broadcasts, have been presented. The disturbances in the VLF/LF radio signals seem to be produced by variations in the lower atmosphere/ionosphere of the area where the propagation of the radio signals happens. According to the most recent model these variations are due to turbulent atmospheric gravity waves of low amplitude that are generated near the ground surface by pre-seismic and post-seismic processes such as gas and water releases in seismic active regions. The typical temporal scales of such processes range from some minutes to few hours and a time from 1 to 10 h is needed for the energy to reach the lower atmosphere/ionosphere [10]. No connection of the anomaly with the geomagnetic activity or the meteorological condition stands up. On the contrary, the radio anomaly appears three days prior the occurrence of an earthquake (M=4.7). More precisely, it was verified that the epicenter is inside the 5th Fresnel zone of the one
of the paths [10]. A pre-seismic anomaly, with a duration of few hours, was revealed three days prior the occurrence of the offshore Anzio earthquake (M=4.7; 22 August 2005) in a VLF radio signal. Among the five radio signals recorded by the receiver, the anomaly appeared only in the signal, the 5th Fresnel zone of which contains the epicenter. This result was another evidence of the information on the location of a future earthquake, which the anomalies in the propagation of the VLF/LF radio signals can provide [10]

5. DESCRIPTION OF THE RECEIVER

The VLF/LF band receiver is a radio receiver working in VLF and LF bands. The equipment is produced by the Italian company Elettronika S.r.l.[1]. It monitors 10 frequencies distributed in the 15–50 kHz / 150–300 kHz bands and, for each of them, saves the power level detected on a non-volatile memory at a customizable sample time interval. The large amount of data collected by the VLF/LF radio receiver is organized in text files, one for each day.

![Fig. 1 – Inside view of the radio receiver.](image)

The configuration of the equipment, the check of its status and the download of the collected data are possible by a standard, powerful and ubiquitous Ethernet interface.

Another available feature is the internal GSM modem that can be used to control the VLF/LF radio receiver from remote, by making data calls. The interface and the possibilities during remote connection are the same as the local control by Ethernet.

6. OPERATION MODES OF THE RECEIVER

The VLF/LF radio receiver can be globally configured and controlled by a standard Ethernet connection. It is possible to make a direct connection between a computer and the receiver or to connect the receiver to a LAN hub, switch or router.
Inside the VLF/LF radio receiver a full operating system (Linux) and a web server run. All the operations can be done, by using a simple web browser, on a desktop computer. It's also possible to configure and monitor the receiver remotely by making a GSM data call to the GSM modem inside the receiver.

6.1. LOCAL, ETHERNET CONTROL

After powering on, the VLF/LF radio receiver starts monitoring 10 frequencies distributed in the two bands. Every Ts seconds (sample time), the receiver captures the voltage level associated to all the 10 frequencies. In the Receiver Settings web page, the user can choose the sample time in the range 20s to 600s and the frequencies in the range 15kHz to 50kHz (VLF band) or 150kHz to 300kHz (LF band).

In order to have an integer number of samples each day (so the samples are captured at the same time every day), the sample time Ts can be chosen in a collection of non-contiguous values (i.e., values that are divisors of 86400 seconds). On the other hand, the 10 frequencies can be set by 1Hz resolution.

The user can download all the files saved in the memory or only the files created in previous days. If requested, the web server compresses the requested files into a single archive file and sends it to the client. The user can delete all the files or only the files created in previous days (usually after successfully downloading them) to free memory space in the receiver.

6.2. REMOTE, GSM CONTROL

The receiver can be controlled also by GSM connection, useful if the installation site is far from the desktop computer or the Ethernet connection is not available. The GSM network is usually used for voice calls, but the GSM standard provides also data calls: CSD (Circuit Switched Data), different from GPRS connections. The speed of CSD connections is 9600bps. Usually the SIM card inserted in the GSM modem must be explicitly enabled for CSD data calls. Together with the web server, a PPP (Point to Point Protocol) server runs also. This server answers to GSM modem requests. The methods to perform a modem data call and a PPP connection can vary from computer to computer, mainly according to the operating system.

The GSM data connection has a low bit rate (only 9600bps) and is usually characterized by long delay. For that reason, the user should use this remote connection to download one file at a time, avoiding the download of large files.
6.3. NOISE MEASUREMENTS

Figure 3a and b depict the noise performance of the Elettronika receiver. It can be observed that 5 frequencies were chosen in each band: VLF and LF respectively. At these frequencies powerful, long range transmitters located in Europe, transmit regularly. In the VLF band (10 kHz – 50 kHz) the noise on the frequency channels corresponding to the transmitters from Table 1 have been monitored. As it can be seen, the noise level is below 3 dBmVpp, which is almost 1.41mVpp. This value is reached only on the 19.6 kHz channel. On the other channels, the noise level is lower, having a minimum of about 2 dBmVpp on the 23.4 kHz channel.

<table>
<thead>
<tr>
<th>Callsign</th>
<th>Frequency</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>HWU</td>
<td>18.3 kHz</td>
<td>N 46° 42' 47.26&quot;</td>
<td>E 001° 14' 42.89&quot;</td>
</tr>
<tr>
<td>GBZ</td>
<td>19.6 kHz</td>
<td>N 54° 43' 54.48&quot;</td>
<td>W 002° 52' 58.92&quot;</td>
</tr>
<tr>
<td>DHO38</td>
<td>23.4 kHz</td>
<td>N 53° 04' 44.04&quot;</td>
<td>E 007° 36' 54.00&quot;</td>
</tr>
<tr>
<td>NRK/TFK</td>
<td>37.5 kHz</td>
<td>N 63° 51' 1.31&quot;</td>
<td>W 022° 28' 0.38&quot;</td>
</tr>
<tr>
<td>NSY</td>
<td>45.9 kHz</td>
<td>N 37° 07' 32.37&quot;</td>
<td>E 014° 26' 11.10&quot;</td>
</tr>
</tbody>
</table>

All the measurements are made with the antennas being disconnected, such as the acquired noise levels represent the inherent noise of the receiver, on the specified channels. As it will be later seen, the noise level is below the usual signal level even during the day-time period, when the signal is weaker due to the propagation conditions. During the day-time period, the intensity of the signal is described by the propagation on a path which follows the surface of the earth (ground-wave).
During the night-time period, the signal’s level easily reaches 25–35dBmVpp. The signal-to-noise ratio in this period is large enough to allow a very good observation of ionospheric disturbances. In this period, the predominant electric field strength at the receiving station is due to the sky propagation (sky-wave). Modification of the ionosphere's composition or altitude can be easily observed during this interval, as changes in the received signal’s level.

6.4. FIRST RECORDED DATA AND PRELIMINARY RESULTS

First recorded data reveals a good correlation between the signals recorded by the receivers installed in Romania and Italy. An example of a 6 days recording period is illustrated in Figure 4. This figure represents the signal intensity which NSY (Niscemi transmitter, Italy) produces at the receiving station installed temporary in Bucharest (Romania). It can be observed that on 22.04.2009, at 08:25:00 UTC, the transmitters ceased to operate. It went back into operation at 11:15:00. The data are sampled at every minute, which produces 1440 points per day.
Figure 5 depicts the recordings of four transmitters, operating in the LF band, at 180, 183, 216 and 270 kHz, respectively. Good correlation between the first three of them can be observed, as well as similar disturbances on the first day of recording (20.04.2009), between 07:05 and 20:21 UTC. This may indicate a global disturbance of the ionosphere’s characteristics, as an intensified solar activity. Night-time and day-time propagation influences are clearly visible and appear on all recordings. However, in the case of the 270 kHz transmitter, these are not very visible.
7. CONCLUSIONS

The ground-based network of VLF/LF receivers constitutes an innovative approach, meant to reveal the connection between the ionosphere’s disturbances and the preparatory stage of earthquakes having their epicenter located inside the 5th Fresnel zone of the propagation path between VLF/LF transmitters and the receivers. The first results encourage the team to refine the research in this domain.

The advantage of a coherent, sustained and modern method of investigation, regarding the precursory character of the ionospheric disturbances induced by the preparatory stages of earthquakes must be exploited by future work, including the development of the system with complementary space techniques. As a first step, the ground-based real-time operated network is an important tool intended to lead to an efficient monitoring of the ionosphere-lithosphere coupled system. State-of-the-art techniques that are involved, including data manipulation and transfer are important arguments. Integrating the whole research system, embedding it with real-time data and automated recognition of electromagnetic anomalies is a challenge and the subject of future work. The paper presents experimental data recorded in Romania and regarding the VLF/LF electromagnetic waves propagation over different seismogenic zones in Europe. The paper’s main contribution is that not only depicts the advantages of a coherent investigation of electromagnetic propagation anomalies over large areas and different directions, but also demonstrates that data recorded in Romania are consistent with the data recorded in Italy, Austria, Greece and Turkey. Using such kind of multipoint monitoring system, correlations between recorded data are possible. The paper also shows that signals from the monitored transmitters reach high levels (30dBmVpp) while the system’s noise is quite low (approximately 3dBmVpp).

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REFERENCES


