

Reception of Natural Radio Emissions in the ELF Band



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The Radio Emissions Project (www.ltpaobserverproject.com) is an Italian independent project of scientific research established on February 2009 by Dr. Gabriele Cataldi and Dr. Daniele Cataldi, involved in the study of Seismo-Electromagnetic Precursors (S.E.P.) through geomagnetic background monitoring.

Historical Introduction

Scientists say that during some earthquakes (before generally, but sometimes also during the seismic activity) are emitted electromagnetic (E.M.) signals. This type of data have appeared in the literature for several decades (Parrot e Johnston, 1989; Park, 1993; Park, 1996; Johnston, 1997) and refer to a wide range and exceptional electromagnetic phenomena observed in the bands ELF, SLF, ULF, VLF e LF (0,001 Hz – 300 kHz).

For example, Gokhberg (1982) and Yoshino (1991) observed an increase in the amplitude of the radio signal at 81 kHz some time before (from minutes to hours) the occurrence of earthquakes at distances of hundreds of kilometers, and have attributed this phenomenon to a predictive meaning: seismo-electromagnetic precursors (S.E.P.).

The **first scientific use** of S.E.P. occurred in Greece (Varotsos, 1993a; Varotsos, 1993b) where low frequency waves of amplitude 20 mV/km were observed for several minutes using a dipole antennas of different lengths. Currently, their mechanism of generation is subject of debate (Lighthill, 1996; Pham, 1999).

Fifteen minutes prior to the great earthquake of 1960 in Chile (Warwick, 1982), radio emissions at 18 MHz were recorded on multiple receivers.

- The majority of S.E.P. were recorded serendipitously by radio detection systems used for other purposes.
- Early long term observations were made in Greece (Varotsos, 1993), Japan (Uyeda, 1998) and the United States (Johnston, 1989; Park, 1991).
- To allow easy monitoring of electromagnetic background, the Department of Geophysics, of Stanford University, California, has designed and built a transportable system for the registration of radio-anomalies (Summer 2000).

Possible physical explanations of the nature on ELF anomalies have been proposed by Draganov (1991), Fenoglio (1995), and Merzer and Klemperer (1997). It's almost certain that this type of emissions can be recorded at any point on the earth surface because of the limited attenuation that has been observed (M.E.M. project, I.N.G.V. - National Institute of Geophysics and Volcanology¹, L'Aquila, Italy). Propagation properties are different for emissions in the VLF band (Telford, 1990, Chp. 6), LF, MF, HF and so on.

Reception of Natural Radio Emissions in the ELF Band

The reports conducted in recent years have revealed that S.E.P. extend over a wide range of frequencies, to megahertz and above. Johnston and Mueller (1987) observed changes in the magnetic field of the geomagnetic background during the earthquake that occurred in 1986 in North Palm Springs (Southern California near the San Andreas fault), Johnston (1994) observed changes in the magnetic field of the geomagnetic background during the earthquake that occurred in Landers (in the same region) in 1992.

In the ELF band (precisely between 0.01-10 Hz), Fraser-Smith (1990) recorded anomalous fluctuations of the magnetic field of the geomagnetic background some time before the earthquake of October 17, 1987, with magnitude 7.1, which razed Loma Prieta in central California. In particular, an increase was observed in the amplitude of the electromagnetic background two weeks before the main shock, and continued to increase up to three hours before the earthquake.

Other abnormal ELF emissions possibly related to earthquakes have been recorded several hours before the magnitude 6.9 earthquake that razed Spitak, Armenia, on December 7, 1988 (Molchanov, 1992; Kopytenko, 1993). Other geomagnetic anomalies were observed between two weeks and few days before the earthquake magnitude 8 that was recorded in Guam, August 8, 1993 (Hayakawa, 1996).

¹ <http://www.progettomem.it>

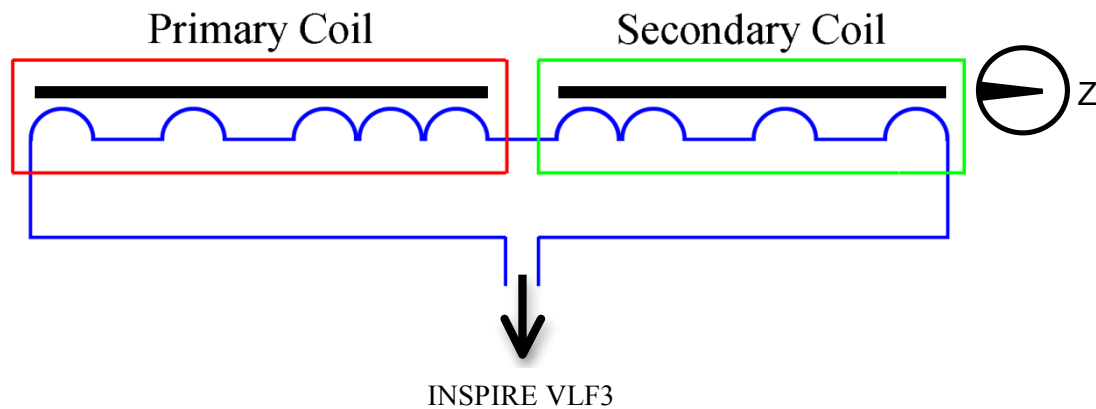
The Radio Emissions Project's Monitoring Station

The heart of our project is represented by a computerized radio-receiver that operates continuously and is specifically designed to monitor Earth's geomagnetic field at frequencies between 1 and 0.0013 Hz, with a resolution of 1.3 mHz. The geomagnetic pulsations (Pc1-5) are, in fact, observed in our receiver at frequencies below 5 Hz.

To achieve this purpose, the station uses a special antenna (magnetic sensor) which is formed by two inductors constructed with multiple overlapping spirals (multilayer), wound on a ferromagnetic core, connected in series and containing a total of 80,000 (60,000 + 20,000) turns and aligned with the vertical axis (Z axis). The total inductance of the antenna, greatly increased by the magnetic permeability of the ferro-magnetic cores used² (5.000x for 60,000 turns coil and 1.000x for 20,000 turns coil), exceeds 375,000 Henry (375+0,7 kH).

Structure of Primary Coil: The Axial inductor is made with 0.1 mm diameter enameled copper wire and that is wound on a core of tempered iron (produced specifically for components of large industrial power supplies, often 7.5 cm and 22.3 cm long). At the center of this core is a 14.4 cm long coil, divided into two 7.1 cm wide sectors separated by a layer of rubber with a thickness of 2 mm. To reduce the "distributed capacitance" of the coil, the windings have been divided into 2 areas for a total of 60,000 turns. The resulting inductance (ferromagnetic core relative magnetic permeability = 5.000x) is the 375 kHenry.

Structure of Secondary Coil: Axial inductor is made with 0.315 mm diameter enameled copper wire, wound on a ferromagnetic core (soft iron) with a diameter of 0.6 cm and length of 100 cm. The coil has been wound in the central part of the iron core for a length of 30 cm. To reduce the "distributed capacitance" of the coil, the windings have been divided into 3 areas for a total of 20,000 turns. The resulting inductance (ferromagnetic core relative magnetic permeability = 1.000x) is 700 Henry.



Simplified scheme of the magnetic induction sensor used for geomagnetic monitoring

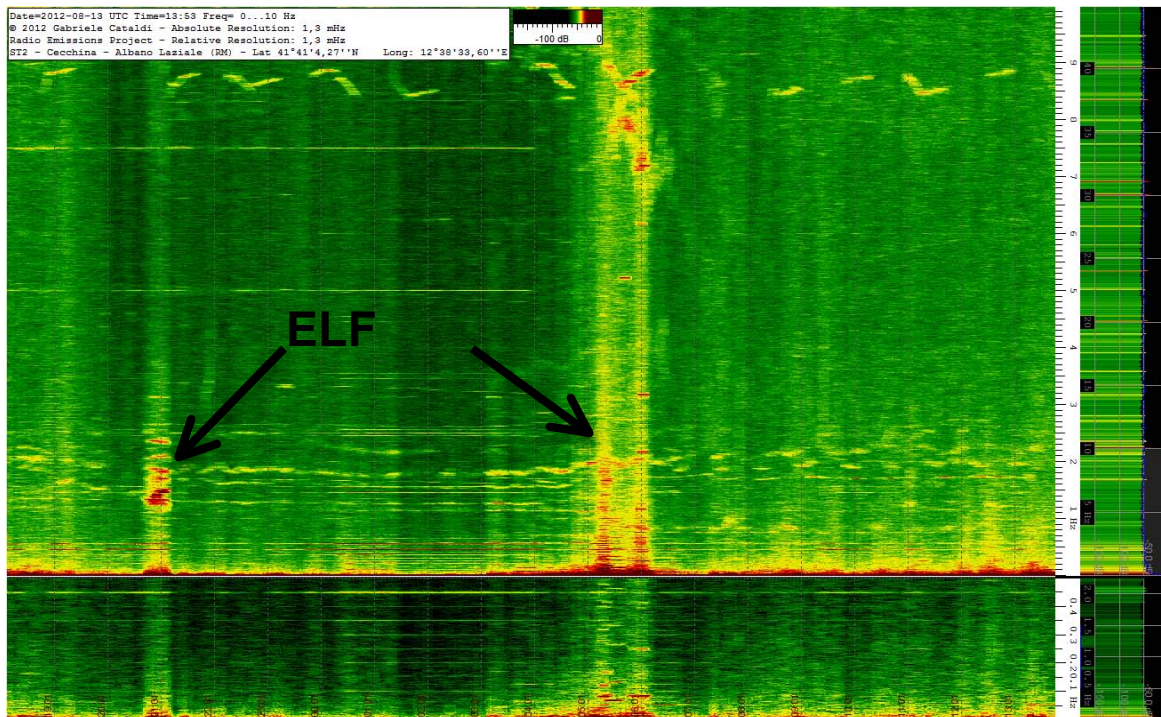
The natural radio waves classified as Geomagnetic Pulsations have a frequency between 5 and 0.002 Hz and a wavelength of between 60,000 and 300,000,000 Km. An omnidirectional, loop or Marconi antenna should be large to be useful at these frequencies. The problem can be solved easily using a coil antenna with high inductance. Our antenna, having an inductance of 375,700 Henry (calculated through the Wheeler's formula), is able to be sensitive to an electromagnetic wave which has a minimum frequency of 1.165 mHz.

The software used to produce spectrograms is "Spectrum Lab", the famous free FFT software that can be downloaded at <http://www.qsl.net/dl4yh/spectra1.html>.

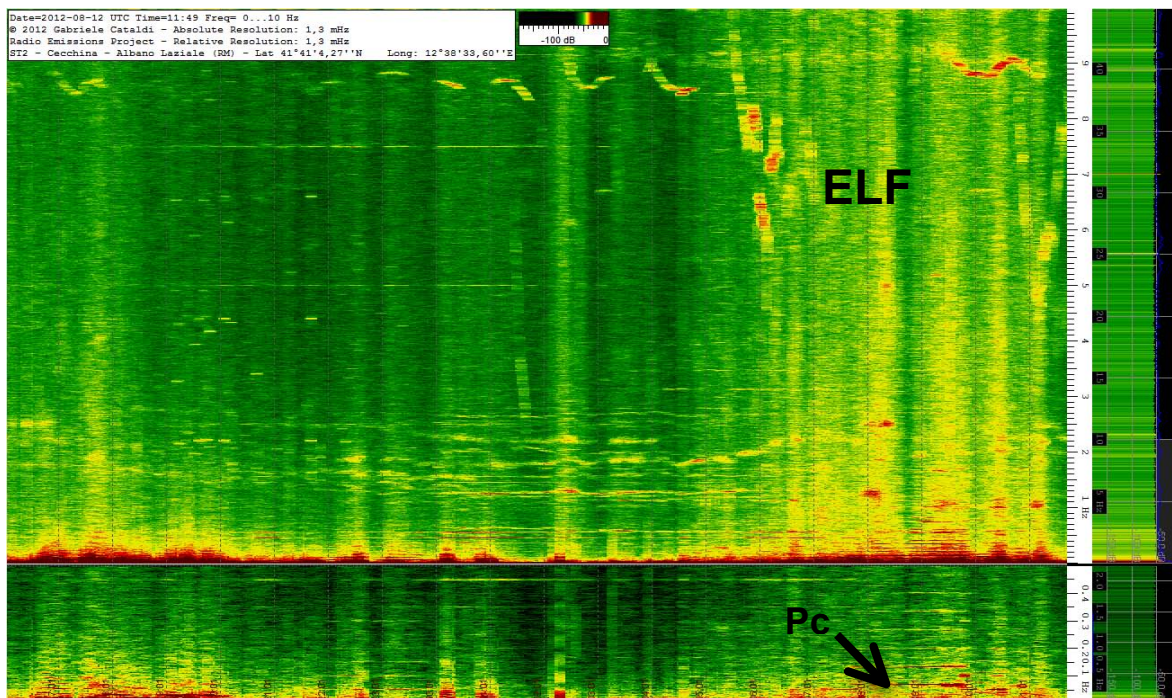
The spectrograms are a representation of time (X axis) of the intensity of the electrical signals transduced by the coil antenna and sent to the PC; in relation to their emission frequency (Y axis). The color of the signals changes in function of their intensity expressed in decibell (dB) (from black to dark red). Spectrum Lab, normally, is able to display electrical signals across a 180 decibell intensity range (180 orders of magnitude), but it is possible to choose a smaller range.

Another important feature of "Spectrum Lab" is the opportunity to choose the level of resolution (in Hz) that best suits the spectrograms. This is possible because the software is able to exploit the capabilities of the PC sound card directly, acting on the oscillator quartz. For monitoring the geomagnetic background it is necessary to reach a resolution of some mHz.

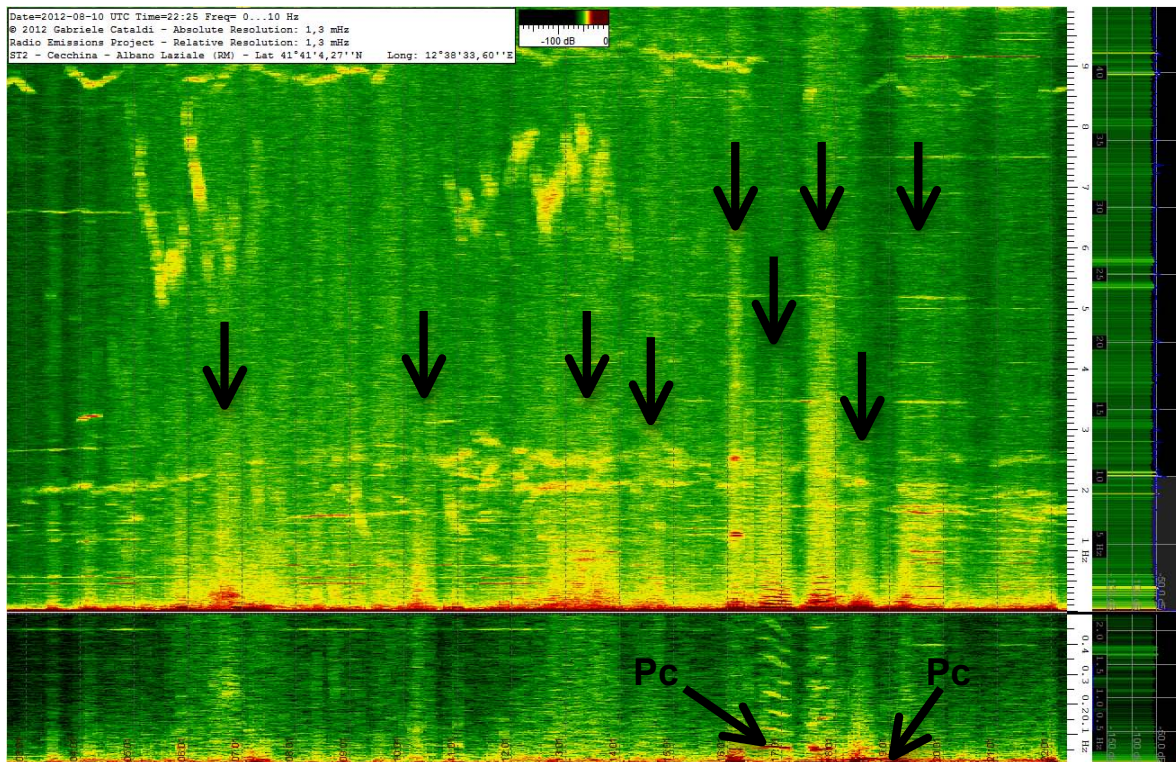
² For 60.000 turns coil: Steel used for the manufacture of electrical transformers. For 20.000 turns coil: Soft iron.



Typical modulation of a Geomagnetic Background – August 12-13, 2012



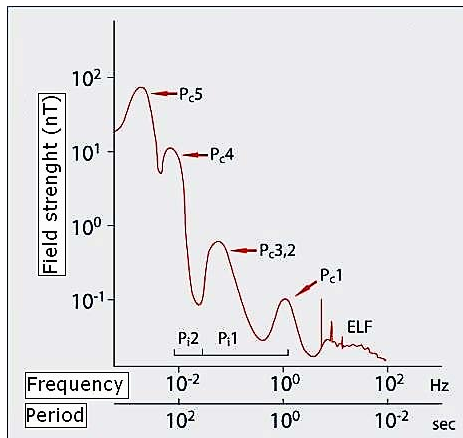
Big ELF Storm in Geomagnetic Background – August 12, 2012



Other ELF Storms (black arrows) – August 10, 2012

Using the INSPIRE VLF3 receiver for exploration a ELF Band

The Geomagnetic Pulsations and the Geomagnetic Background represent natural emissions, prevalently with a magnetic component. The coil antenna can capture, with better efficiency, these emissions because it is significantly permeable to magnetic fields. The INSPIRE VLF3 is available to study the VLF emissions, with a reported range of operating frequencies between 0 and 15 kHz with a gain of about 15 dB. Our studies have established that the



*Field strength of Geomagnetic Pulsation
Credits: National Institute of Geophysics
and Vulcanology (I.N.G.V.) L'Aquila, Italy*

INSPIRE VLF3 is able to amplify, with good intensity, radio signals that are located in the ELF band. This can be demonstrated by comparing the observations obtained with the VLF3 and those made by major geomagnetic observatories (HAARP, Kiruna, Licksele, Tromsø), or from satellites GOES/ NOAA. If it were not so, it would be impossible to produce spectrograms compatible with the real modulation of geomagnetic activity. Another important thing to consider is the high intensity of the geomagnetic background feature, which makes it possible to be detected by the INSPIRE VLF3 and other types of receivers designed to be used primarily for the study of VLF emissions. The intensity of Pc5 Pulsations reaches the strength (100-300 nT or 100-300 g) of Italian power line interference (220V/50Hz), which is detectable in a house located in the countryside (The intensity of the Pulsations Pc5 is indicated by I.A.G.A. classification of Geomagnetic Pulsations). The ELF storms visible on spectrograms are related to important variations in solar activity (changes in proton and electron density), changes in the interplanetary magnetic field (IMF) and variations of the Kp-Index. The spectrograms included above are an example of this. An example of this can be found between 10 and 13 August 2012, when the Earth's magnetic field was impacted by an intense burst of solar wind that caused major changes in the

geomagnetic field (www.noaa.gov). Moreover, geomagnetic activity undergoes diurnal variations in relation to the Earth's rotation: this variation can be observed on spectrograms (an overall reduction of geomagnetic background at night).

Classificazione IAGA delle pulsazioni geomagnetiche				
Continue	Nome	Durata	Frequenza	Intensità
	Pc1	0,2-5s	0,2-5 Hz	1 nT
	Pc2	5-10s	0,1-0,2 Hz	3 nT
	Pc3	10-45s	0,022-0,1 Hz	10 nT
	Pc4	45-150s 00:45-02:30	7-22 mHz	< 300 nT
	Pc5	150-600s 0230-10:00	2-7 mHz	300 nT
Irregolari	Pi1	1-40s	0,025-1 Hz	10 nT
	Pi2	40-150s 00:40-02:30	2-25 mHz	100 nT

I.A.G.A. classification of Geomagnetic Pulsations

From a graphical point of view, a Geomagnetic Storm can be seen as an overall increase of the magnetic signals that appear in the ELF band. The intensity of the increase is inversely proportional to the frequency of the signals, maximizing at the lowest frequencies observed.

In “*THE INSPIRE VLF-3 RECEIVER Theory of Operation*”³ it was specified that:

The inter-stage low pass filter of NASA INSPIRE VLF3 receiver, consisting of inductor L2 and capacitors C6 and C7. These components are located in the signal path between F1 and Q1. The inter-stage filter is needed because the input stage is broadband and capable of amplifying signals in the LF, MF and HF bands in addition to the VLF band. Even though the antenna circuit provides some filtering to reject signals in the MF and HF bands, a strong signal (for instance from an AM broadcast station) will get through and be audible in the receiver output. The low pass filter has an upper cut off frequency of about 12 kHz and strongly attenuates signals above about 20 kHz.

The fifth stage of VLF3 receiver is the 2nd audio amplifier/filter. This stage uses ½ of the LM358 integrated circuit (IC2) as an amplifier with a gain of about 15 dB and its frequency response is flat from about 300 Hz to well over 100 kHz. This is followed by the second part of the LM358 configured as a Sallen-Key second order low pass filter. This filter had unity gain and its frequency response is flat from about 300 Hz to approximately 20 kHz.

The VLF3 receiver uses a second order low pass filter to cut off the signals that have a frequency lower than 300 Hz. In theory, a second order low pass filter causes attenuation of radio signals corresponding to 12 dB/octave (40 dB/decade). Furthermore, that the receiver's documentation indicates that the “frequency response is flat from about 300 Hz,” referring to the LM358 integrated circuit.

In fact, we have been able to verify that the filters do not cause such a high attenuation of radio signals with a frequency <300 Hz, because the Italian power line interference (220V/50Hz) is always visible! The second order low pass filter should lead to an attenuation slightly less than 20 dB of radio signals having a frequency of 50 Hz and an attenuation of 40 dB at a frequency of 3 Hz (at 0.001 Hz the attenuation is 46 dB). The question then is how to explain the presence of the Italian power line interference (220V/50Hz)? This interference is not visible when the coil antenna is unplugged from VLF3 receiver. Thus, we know that the VLF3 receiver, is able to amplify frequencies < 300 Hz.

The spectrograms we have attached to this article contain traces of Geomagnetic activity that have an amplitude of -30 dB and -70 dB (dark green for -70 dB, dark red for -30 dB), for a total of 40 orders of magnitude. The color scale of the spectrograms can be modified to allow to view spectrographic traces that have a difference in amplitude corresponding to 180 dB or more. This feature allows view very weak spectral features in the observed signal.

³ http://theinspireproject.org/downloads/pdf/inspire%20Theory_of_Operations.pdf