Electromagnetic anomalies recorded before the earthquake of L'Aquila on April 6, 2009

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ABSTRACT Electromagnetic signals with frequencies from 10 to 100 Hz were recorded for four days before the earthquake of L'Aquila on April 6, 2009. Immediately before the earthquake, during the three and a half hours immediately preceeding the quake, the system detected also an increase of the electromagnetic emissions, with frequencies from 1 to 5.5 kHz. The radio receiving system was located ~10 kilometres from the epicenter, it was turned on April 2 and it recorded electromagnetic signals for up to two seconds immediately after the main shock when a power cut occurred. The low frequency emissions and the detected variation of the signals recorded in the higher frequency range are two anomalies that appeared before the earthquake of L'Aquila (M=6.3) and for this reason they could be related to this seismogenic process.

1. Introduction

This paper shows the electromagnetic anomalies recorded by a custom-made device in two different frequency ranges the days immediately preceeding the earthquake of L'Aquila. The detection of electromagnetic anomalies that could be identified as possible seismic precursors, is the main purpose of several research projects and experiments that are located in the most seismic areas of the world.

The possibility of receiving electromagnetic signals before or during earthquakes was already hypothesised in the past because of the luminous phenomenon which had been observed for centuries. This hypothesis was frequently confirmed because of the anomalies that seemed to appear on the telegraph lines before some big earthquakes; much later, many radio amateurs noticed the appearance of some disturbing noises during the conversations immediately before some seismic events.

More recently, a study shows that detectable electromagnetic emissions can be produced by rock fracturing in a laboratory experiment (Nardi and Caputo, 2009) and many other research projects are trying to reveal these anomalies using special radio receiving systems.

In this research, the development of the electronic device is a important part of the study that aims at estimating any possible variation of the electromagnetic signals which could eventually precede an earthquake in one or more specific frequency ranges in order to have a real time monitoring system of a seismic area such as the central Apennines near L'Aquila.

2. Description of the signal detection device

The apparatus used in this study has been designed to receive and record audio samples of signals below 16 kHz which can be emitted by rock fractures as previously shown by experimental laboratory studies as well as during rock extraction from a quarry (Nardi and Caputo, 2009). This is possible using a dedicated hardware that is able to select only the pulse sequences that overcome a fixed voltage threshold and fall within a fixed period range an N number of times during the acquisition period.

The hardware architecture is composed of three main functional blocks on a single board: the filter, the amplifier, and the signal discriminator.

The filter is a parallel connection of an inductor and a capacitor of 470 nF, where the inductor is actually a loop antenna which has a diameter of 0.5 m and forms a resonant filter at the frequency of ~5 kHz.

The voltage gain of the amplifier (G) is equal to 130; it has been calculated during a laboratory test using the following equation:

$$G = V_{out} / V_{in} \ . \tag{1}$$

The amplified signal is sent to the discriminator that gives a high level digital output, termed as trigger pulse only when the signal received is greater than a fixed threshold of 200 mV and its time width falls within a period range from 1 ms to 0.18 ms corresponding to the frequencies from 1 to 5.5 kHz.

The threshold has been defined to be equal to 200 mV, so that the output of the discriminator is normally equal to zero and cannot be triggered by any internal noise of the circuit itself.

The board is connected to the parallel port of a computer Pentium III where a 24-hour running software counts every single trigger pulse continuously and saves also the UTC time for each one of them.

A part of the amplified signal is also connected to the input line of the computer sound card so that the main acquisition software can record also digital samples of the received signal in wav format, only when the number of triggers is greater than a fixed value set by the software. Each audio sample has a length of 10 seconds and the main software does not allow more than six audio records per day for a total of 60 seconds only, in 24 hours of data acquisition.

The elapsed time T between two trigger pulses or trigger timing is actually the parameter given by the formula $T = T_2 - T_1$ where T_2 and T_1 are the times of the appearance of two consecutive trigger pulses; it allows the main software to exclude, even in real time, all the triggers that could have been caused by atmospheric events such as lightning or other slow discharging effects (Timing > 1 s) that can occur before or during thunderstorms, commonly termed as sferics, which usually can affect this kind of data acquisition of radio-receiving devices normally tuned into radio frequency bands below 16 kHz (Barr *et al.*, 2000).

The detector is located in the village of San Felice d'Ocre (~8 km from L'Aquila) when it took data from April 2 to April 6, 2009, then it was turned back on April 14 to April 23, 2009; the system is now acquiring data but the acquisition was resumed starting from October 2009.

In the past, it took data continuously from January 1, 2006 to August 31, 2007 in another place ~3 km from the present location; during that time it recorded some atmospheric signals in the range from 1 to 5.5 kHz.

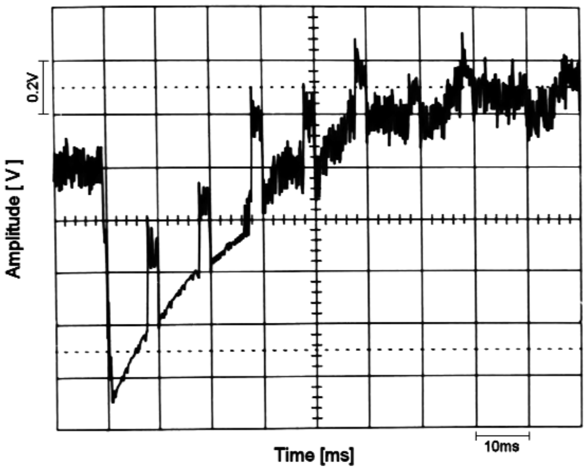

Fig. 1 - The waveform was captured from the screen of a digital scope. The signal was received on April 2, 2009 at 21:53 and shows an 880 mV main negative big pulse of 40 ms time width followed by a regular pulse sequence with a decreasing amplitude and a higher frequency of 100 Hz.

3. Anomaly recorded in low frequency band (10 – 100 Hz)

On April 6, 2009 at 1.32 UTC time, an earthquake with magnitude of 6.3 occurred; the epicenter was located ~5 km from L'Aquila. Some low frequency signals appeared from April 2, 2009 and were recorded up to one hour before the earthquake; the detected emissions are audio frequency signals, for this reason they were recorded as they were received.

With a digital scope, it is possible to display these signals which actually fall into the Extremely Low Frequency band (3 – 30 Hz) and Super Low Frequency band (30 – 300 Hz) as the ones shown in the following three plots (Figs. 1 to 3).

The plots shown in Figs. 1 to 3 have been displayed by connecting the output of the computer soundcard to the scope while a software was playing the audio sample. The audio files last only 10 seconds but they contain more than one pulse as the ones displayed in Figs. 1 to 3 show. In this analysis, we will show only three of them with higher amplitudes.

From Fig. 1, it is possible to measure about a 40 ms time width for the main negative pulse which is followed by a regular pulse sequence that is composed of 2 ms time width regular pulses at the frequency of 100 Hz. Fig. 1 also shows a signal amplitude of 880 mV. Since the amplifier has a total voltage gain equal to 130, according to the Eq. (1) the real amplitude of this pulse is 6.77 mV. Some signals in this low frequency range could be received before a seismic event, as shown on previous publications related to earthquakes with magnitudes greater than 4.5 that occurred on the central Apennines from August 2003 to September 2005 (Nardi and Caputo, 2006; Nardi *et al.*, 2007).

In Fig. 2 one can see another signal recorded just one day before the earthquake that has a negative and positive pulse for a total period of about 100 ms with an amplitude of ~1.2 V. Since, according to Eq. (1), the amplifier has a total voltage gain equal to 130, the amplitude of the pulse is equal to 9.23 mV.

The appearance of the three waveforms shown in Figs. 1 to 3 was random with random amplitudes, but from April 5 these signals were ~320 mV higher than the ones received on April 2.

Fig. 3 shows the waveform of the signal received just one hour before the earthquake and all

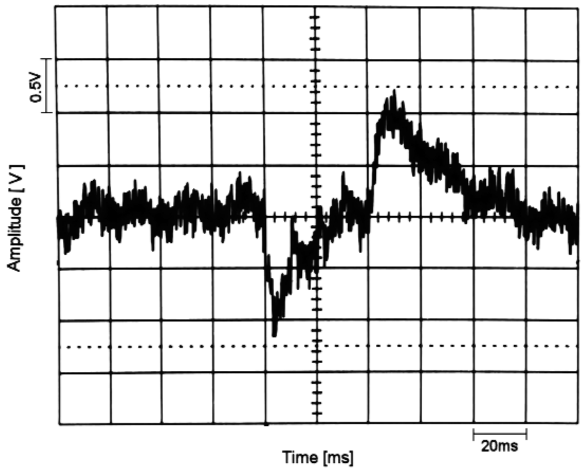

Fig. 2 - The waveform was captured from the screen of a digital scope. The signal was recorded on April 5, 2009 at 00:50 UTC and shows a negative and positive pulse with an amplitude of 1.2 Volt and a frequency of ~10 Hz.

parameters of the pulse look like the ones of the previous day with a frequency of 10 Hz and a slightly lower amplitude.

The waveforms shown in the first three figures do not show any man made modulation that could make sense in the case of radio transmissions, in fact they also appeared randomly with random amplitudes. They do not even match any known waveforms corresponding to natural radio signals like lightning discharges during thunderstorms or other known waveforms of sferics already pointed out in other publications (Barr *et al.*, 2000). It is very important to take into account the fact that the audio samples last 10 seconds and they are recorded by the system only when the number of triggers overcome a fixed number during the acquisition time for a total of six samples per day, but the number of triggers increases only when the signal received falls N times in the band 1 – 5.5 kHz. For this reason, the system recorded extremely low frequency

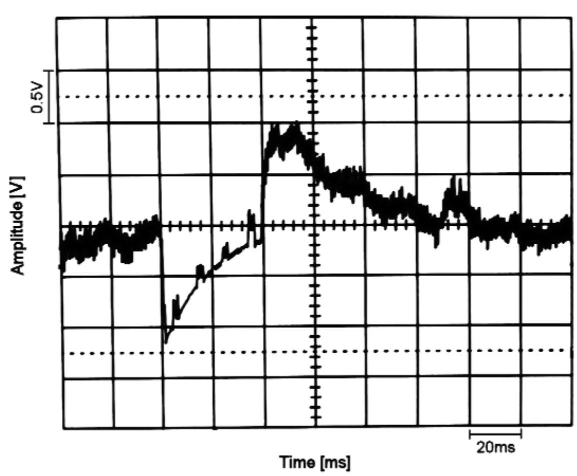

Fig. 3 - The waveform was captured from the screen of a digital scope. The signal was recorded on April 6, 2009 at 00:16 UTC and shows a negative pulse with an amplitude of ~1.2 Volt and a positive pulse with an amplitude of ~1 Volt and a frequency of ~10 Hz.

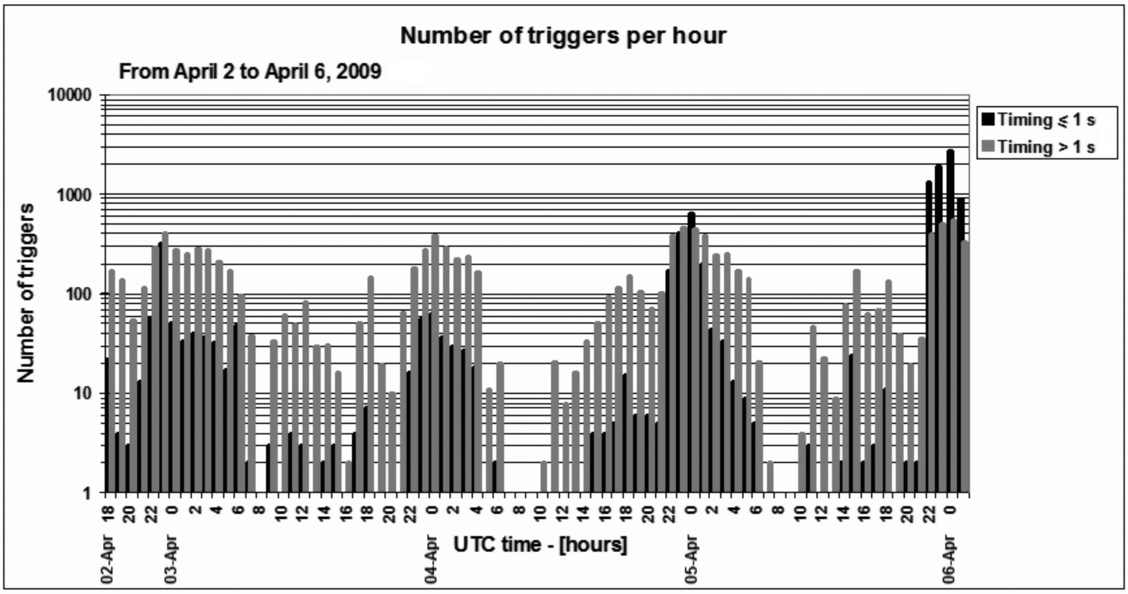

Fig. 4 - Distribution of the number of triggers per hour recorded from April 2 to April 6, 2009. The UTC time is on the abscissa, whereas the number of triggers is in the ordinate. The slower triggers (Timing > 1 s) in grey show a slight daily increase, the faster triggers (Timing ≤ 1 s) in black show a more significant and sudden increase starting from 22:00 which got the maximum of 2650 triggers from midnight to one o'clock.

signals from the soundcard while the same recording software was triggered by other kinds of signals with frequencies going from 1 to 5.5 kHz. In fact, from midnight on April 6 the software recorded 5 audio samples in only 16 minutes because of the high trigger rate caused by higher frequencies.

The efficiency of a loop antenna depends on its dimension which must be of the order of the wavelength of the radiation and its surface must be extremely large to receive extremely low frequency signals with the amplitudes varying from ~6 mV to ~9 mV as the ones shown in Figs. 1 to 3. In this case, the diameter of the loop antenna is only half meter long, for this reason it should not receive any pulse like the ones shown in the previous figures unless the source of these electromagnetic emissions was extremely powerful and very near the receiving system.

4. Anomaly in the higher frequency band (1 – 5.5 kHz)

Fig. 4 shows how the number of triggers per hour generated by signals with the frequencies from 1 to 5.5 kHz increased gradually day by day starting from April 2 but it shows also that the maximum was reached the same day as the earthquake. These triggers appeared more frequently and systematically during the night. The slower triggers, with a timing greater than 1 second, increased slowly and show a waveform which could be caused by an electric device which generates radio signals in the band from 1 to 5.5 kHz everyday at the same time from the same distance and presumably with the same power. On the contrary, the faster triggers, with a timing

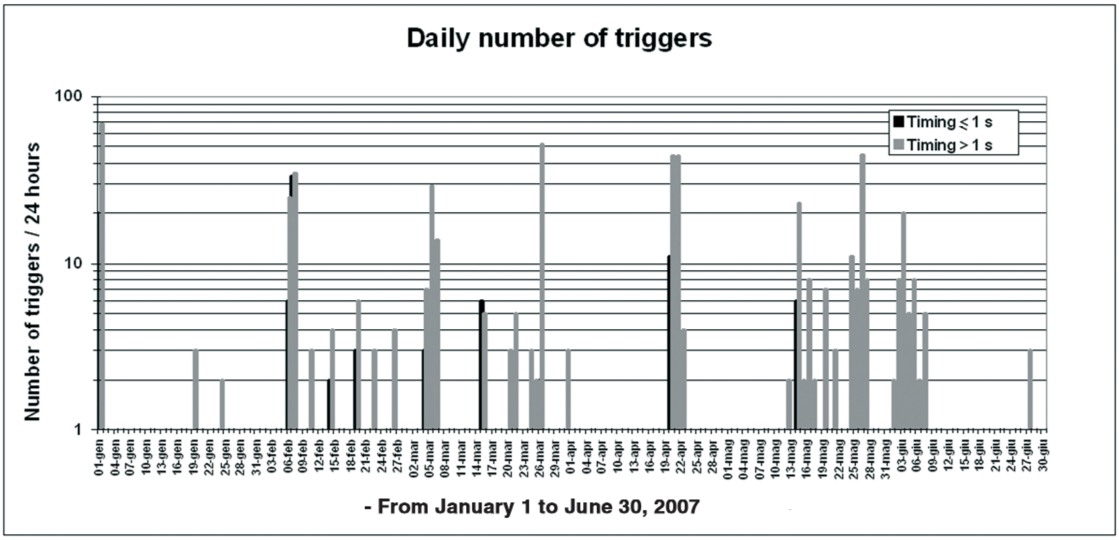

Fig. 5 - Daily distribution of number of triggers recorded in 181 days from January 1 to June 30, 2007. The daily numbers are in the abscissa the number of triggers divided by 24 hours are in the ordinate. Usually the counting rate of the system can be even equal to zero or the slower triggers (Timing > 1 s) in grey show a random daily appearance while the faster triggers (Timing ≤ 1 s) in black are quite rare.

lower than 1 second, appeared more frequently on a daily basis but their number increased suddenly and drastically starting from 22:00 on April 5 and rose continuously up to midnight of April 6. On April 5 the system counted a total of 7417 triggers in 24 hours, on April 6 in just 1.5 hours from midnight till 01:34 UTC the system recorded 4407 triggers, that means on April 6 the number triggers per hour became 9.5 times higher than the whole of the previous day.

Fig. 5 shows the normal data acquisition of the same radio wave detector, in the same area, for a period of six months from January 1 to June 30, 2007 for a total of 181 days. Fig. 5 clearly indicates that usually, during a longer data acquisition period, the number of daily triggers can be even equal to zero or that the slower triggers (Timing > 1 s) appear randomly, in fact they were usually generated before or during thunderstorms. The triggers that appear with a time lower than one per second are quite rare and their daily number is very low.

The highest peak of faster triggers (Timing ≤ 1 s) shown in Fig. 5 was recorded on the 38th acquisition day, corresponding to February 7, 2007.

5. Number of daily triggers

If we consider only February 6 and 7, 2007, we can display the number of triggers per hour as shown in Fig. 6.

From the comparison between Fig. 4 and Fig. 6, it is clear that the maximum number of faster triggers (Timing ≤ 1s) counted in one hour on April 6, 2009 (2650 triggers) is ~10 times higher than the peak of faster triggers recorded on February 7, 2007 (272 triggers). This can be identified as another anomaly detected before the earthquake because such a high number of fast triggers

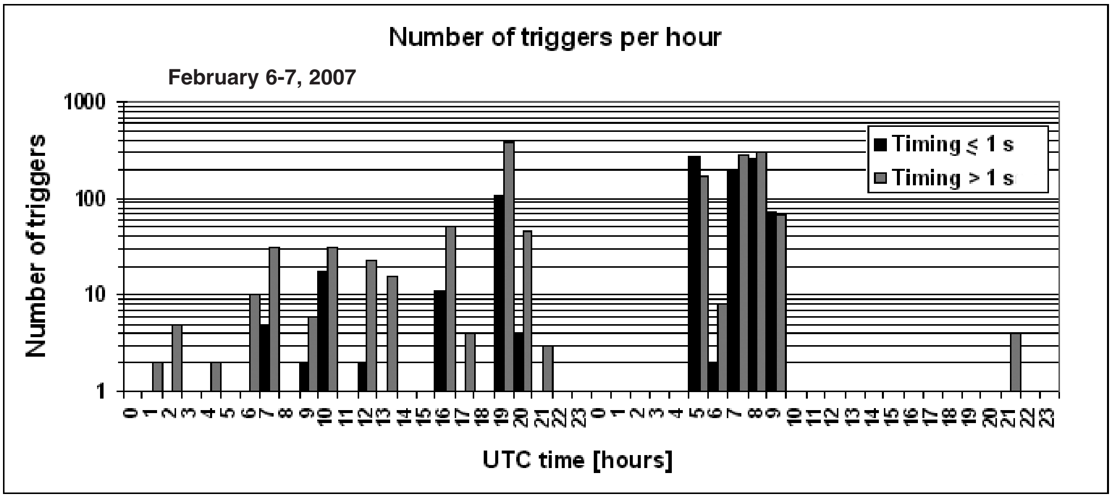

Fig. 6 - Distribution of the number of triggers per hour recorded in two days from February 6 to February 7, 2007. The UTC time is in the abscissa and the number of triggers in the ordinate. The maximum peak of faster triggers (Timing ≤ 1s) recorded on April 6 (see Fig. 4) is ~10 times higher than the maximum peak of faster triggers recorded on February 7, 2007.

was never recorded before in the same area.

The earthquake that occurred at 3:32 local time caused a general black out that interrupted the data acquisition process; the acquisition was resumed only starting from April 14 and from that time the detector did not record any other signal in the Extremely Low Frequency or Super Low Frequency range until April 23 when another power cut occurred thus stopping the acquisition process for six months. All radio waves received during the period from April 14 to April 23 are affected by other electromagnetic noises which were missing before the earthquake. In fact, the original radio cleanliness of the area was compromised because of the power generators of the camps, by some power cuts, by several radio signals mainly belonging to cell phones and radio transmitting apparatus which were disturbing the normal data acquisition, for all these reasons those data cannot be properly compared with the ones received before the earthquake.

Since October 2009, the detector has been acquiring data but the daily distribution of the number of triggers is similar to the one shown in Fig. 5 which did not record any other low frequency signals or other significant or fast increase of the electromagnetic emissions in the band 1 – 5.5 kHz worthy of reporting.

6. Conclusions

This paper shows that two electromagnetic anomalies appeared before the earthquake of L'Aquila in a lower frequency band (10 – 100 Hz) and in the higher frequency band (1 – 5.5 kHz). Both anomalies seem to be strictly correlated because the lower frequency signals were recorded automatically on the increase of the number of radio emissions detected in the higher frequencies range and they were received with a small loop antenna. Such anomalies were never detected before in this area, moreover they were received before the main shock of an earthquake with a magnitude of 6.3, for these reasons they should not be classified as simple coincidences.

Since these kinds of radio emissions in the low frequency bands were already observed in Taiwan (Akinaga *et al.*, 2001; Ohta *et al.*, 2001), California (Fraser-Smith *et al.*, 1990), and Japan (Nagao *et al.*, 2002), the two reported anomalies could be possibly related to the seismogenic process preceeding the earthquake of L'Aquila on April 6, 2009. The reported signals were received during a very short data acquisition time, for this reason the possible correlation of the two anomalies with the earthquake needs further investigation and more statistics for a better understanding of the phenomenon.

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