Overdamping geophones using negative impedances

Bernd Ulmann*
ulmann@vaxman.de

February 7, 2005

Abstract

The purpose of the following article is to describe an amplifier with negative input impedance to overdamp geophones thus extending their natural bandwidth by a considerable amount. Using a technique like the one described in the following even small teleseismic events can be detected employing quite cheap geophones as seismic sensors.

1 Introduction

In short, a geophone is a rather cheap instrument to measure ground motions. This is basically accomplished by a moving coil mounted to a mass with considerable inertia. Ground movements will cause the coil to move in the magnetic field of a surrounding magnet which is mounted on the geophone enclosure and thus follows the ground movement. These coil movements induce a voltage $U_{\texttt{ind}}$ which is proportional to the velocity of the moving coil in respect to the fixed position magnet. With x denoting the coil position relative to the magnet the resulting signal satisfies $U_{\texttt{ind}} \sim \frac{\mathrm{d}x}{\mathrm{d}t}$.

Figure 1 shows the structure of a typical geophone. The moving coil mounted to the mass is suspended by leaf springs. The natural period of this sensor is mainly determined by these leaf springs as well as the moving mass. Geophones with eigenfrequencies of i.e. 4.5 Hz are quite cheap and may be used in small experimental setups for teaching purposes. Instruments with natural frequencies down to 1 Hz are considerably more expensive but still within reach of most teaching institutions and hobbyists.

Like all passive instruments geophones have to be suitably damped to suppress slowly decreasing oscillations triggered by an initial ground movement. Normally this is accomplished by paralleling the induction coil with a damping resistor $R_{\texttt{d}}$. The overall damping resistance value is the sum of $R_{\texttt{d}}$ and $R_{\texttt{coil}}$, the resistance of the moving coil itself. Figure 2 shows this setup.

Clearly very low damping resistors are desirable – the better damping of the moving coil system by far outweighs the decreased signal amplitude. The limit of this damping scheme is reached for $R_{\texttt{d}} = 0\Omega$ leaving just $R_{\texttt{coil}}$ and no output signal at all.

If there would be a way to achieve a damping resistance significantly lower than $R_{\texttt{coil}}$ it would be possible to reduce the eigenfrequency of the geophone considerably, making a cheap instrument useful for the detection of teleseismic events which feature frequencies normally way below the natural frequency of even a 1 Hz geophone.

A damping scheme accomplishing this would clearly require $R_{\texttt{d}} < 0$ and is thus not possible using a real resistor for $R_{\texttt{d}}$. Instead a negative resistance (impedance being a better term) can be created using an operational amplifier in a circuit

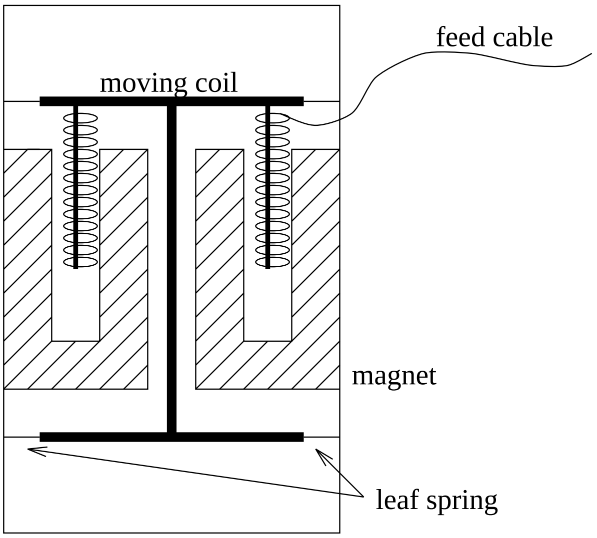

Figure 1: Principle of a geophone

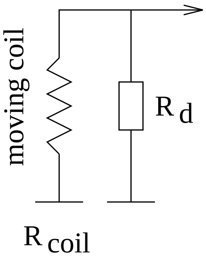

Figure 2: Damping a geophone

called *NIC* (short for *negative impedance converter*). Such a circuit is shown in figure 3. Parallel to the moving coil is a negative impedance created by employing an operational amplifier[1].

Using such a circuit, typical values for $R_{\mathtt{d}} \approx -\frac{4}{5}R_{\mathtt{coil}}$ can be easily achieved. Choosing a value like this results in extending the natural period of the moving mass/coil system by a factor of roughly 10 (even more can be achieved with careful tuning). Thus a 1 Hz geophone can be turned into a sensor with an eigenfrequency of approximately $\frac{1}{10}$ Hz which is very suitable for measuring teleseismic events and sometimes outperformes seismometers of the Lehman type.

2 The amplifier

The amplifier is divided into four independ subcircuits – the input stage with the negative impedance converter, a four pole butterworth low pass filter with a cut-off-frequency of approximately 10 Hz, the adjustable main amplifier and, finally, a simple dual power supply capable of delivering ± 5V.

Figure 4 shows the input stage – it consists of the negative impedance converter built around the OP27 operational amplifier[2] and the first amplifier stage which amplifies the input signal by a factor of about 100. For demonstration purposes or rather short measurement periods a cheap TL061 amplifier is suitable. If extreme stability is necessary, a chopper stabilized MAX430 should be used here (see

---

[1] This idea and a comparable circuit has been patented elsewhere – cf. [Lennartz].

[2] This amplifier was chosen for its capability to drive quite low impedances.

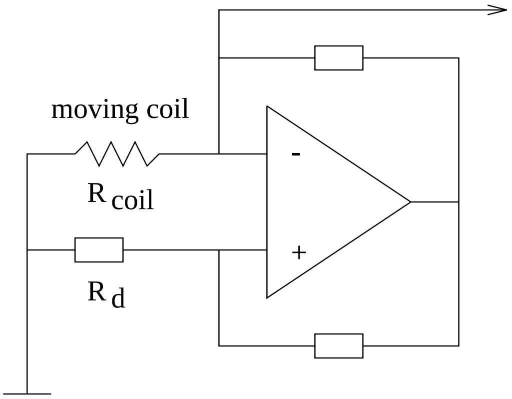

Figure 3: Damping a geophone using a negative impedance converter

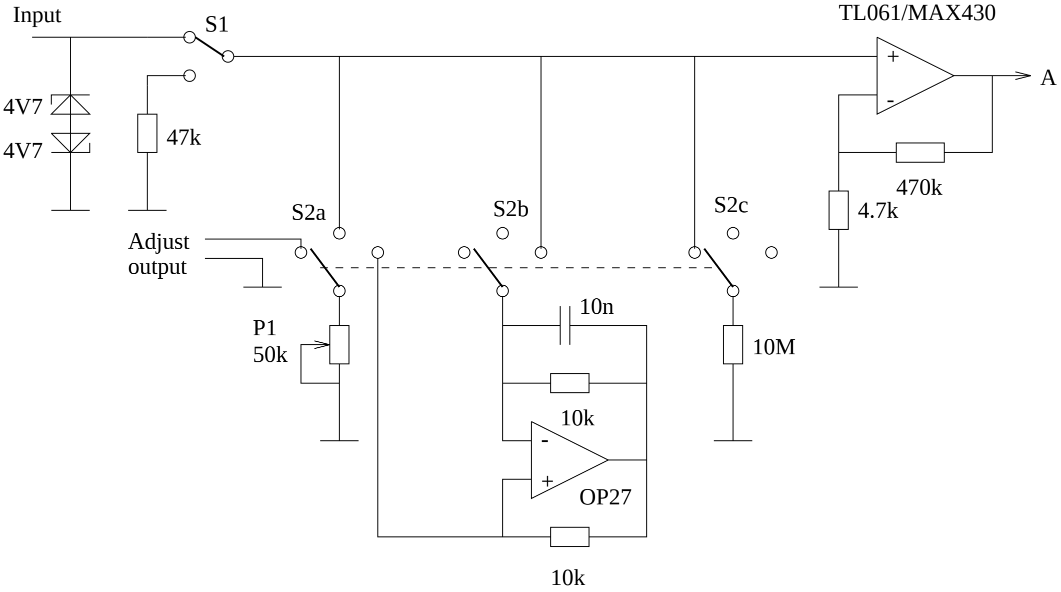

Figure 4: The negative impedance converter stage

[MAXIM]).

The input stage has three control elements:

S1: This switch may be used to short circuit the input of the amplifier which is quite useful for performing the necessary offset adjustment.

S2: This three position switch is used to select the desired mode of operation. In the left position the amplifier has a high input impedance of 10M[3], the middle position selects passive damping of the geophone using P1 as damping resistor, while the right position activates the negative impedance converter thus strongly overdamping the geophone.

P1: This 10-turn precision resistor is used to set the positive (S2 in its middle position) or negative (S2 in right position) damping resistance.

Normally, an equalization stage should follow this NIC converter to differentiate respectively integrate the raw signal generated by the sensor depending on its

---

[3] In this position P1 is routed directly to two 4 mm banana jacks which can be used to measure the value set at P1.

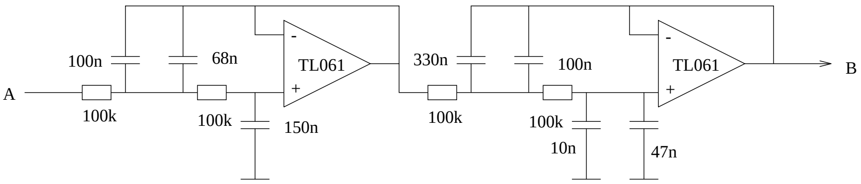

Figure 5: The four pole low pass butterworth filter

frequency to achieve a constant frequency response. This stage has been omitted from the following circuit due to simplicity reasons since it would strongly depend on the characteristics of the geophone used in conjunction with this input stage. To overcome this limitation digital postprocessing may be employed after the analog-digital-conversion of the output signal.

The next stage, shown in figure 5, is a four pole butterworth low pass filter which is sufficient to get rid of the 50/60 Hz hum of the power grid while not degrading the signal quality of the sensor.

The output stage can be seen in figure 6 – it is a very conservative design with switch selectable amplification factor ranging from 1 to approximately 700. The output stage is just an impedance converter to drive the following analog digital converter or a suitable plotter.

The simple power supply is shown in figure 7 – please note that it is crucial to feed this circuit with a prestabilized supply voltage! Using a simple rectifier with some electrolytic filter capacitors will leave too much hum on the supply lines which will capacitively couple into the amplifier stages and cause ripple on the output signal due to the very high amplification rate.

3 The prototype and its performance

Figure 8 shows the front panel of the prototype amplifier which has been continously in use for more than a year at the time of this writing.

On the left side of the panel the two 4 mm banana jacks for measuring the resistance set by P1 and the Lemo input connector can be seen. The toggle switch next to it is S1, the rotary switch below (with the black knob) is S2, currently set to the left position. Right to the toggle switch the offset adjustment potentiometer and below the damping potentiometer P1 (without a knob to avoid accidentally changing its setting) are located. On the right are the BNC output jack and the amplification selection switch.

3.1 Adjusting the amplifier

Adjusting the amplifier is a simple task – first of all keep in mind that it is always a good idea to let amplifiers like this one running for an extended period of time (at least half an hour, the more the better) before making any adjustments. To setup the amplifier follow these steps:

1. Connect the geophone to the Lemo input jack.[4]
2. Set S2 to the left position and connect an Ohm-meter to the two 4 mm banana jacks.
3. Adjust P1 so that the value displayed on the Ohm-meter is $\frac{4}{5}R_{\texttt{coil}}$ of the geophone used.

---

[4] If the geophone is in a seismic quiet area it is possible to set the toggle switch S1 to its open position thus creating a more realistic environment for the following adjustment procedure.

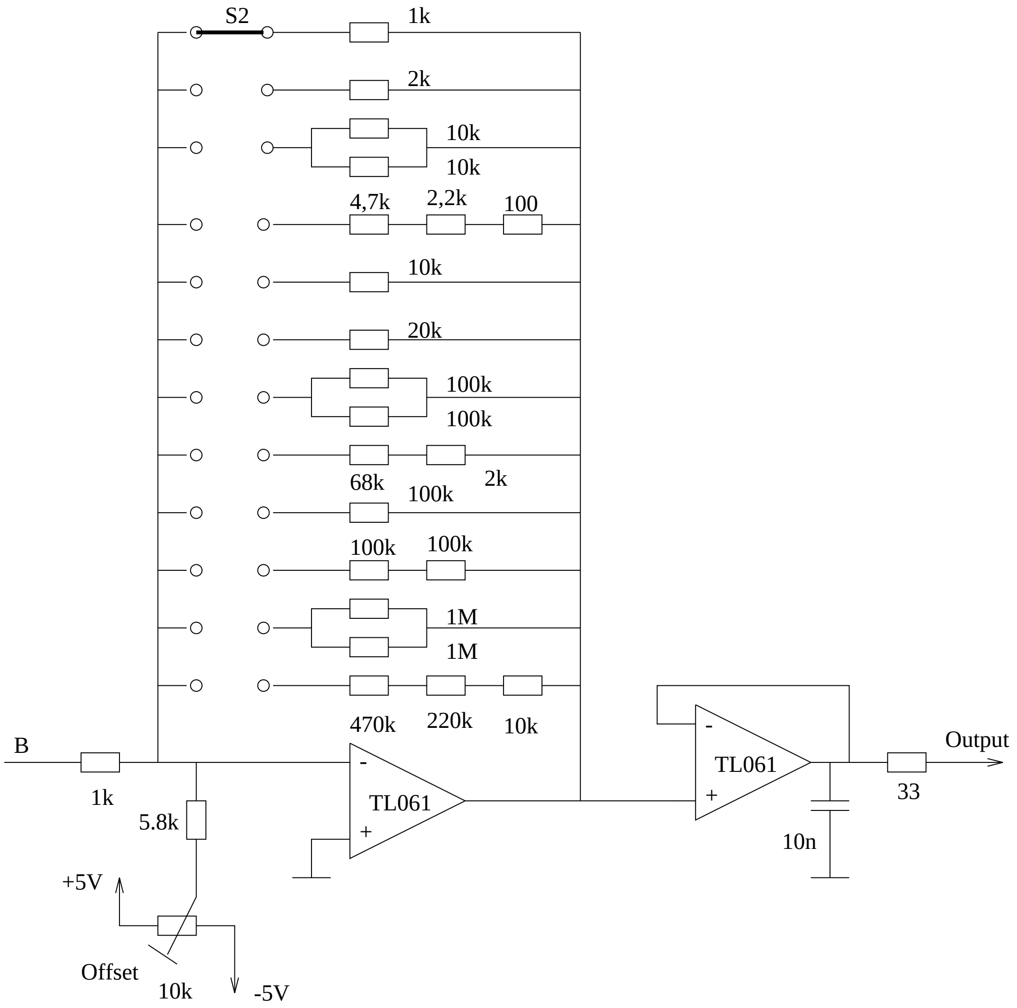

Figure 6: The main amplifier stage

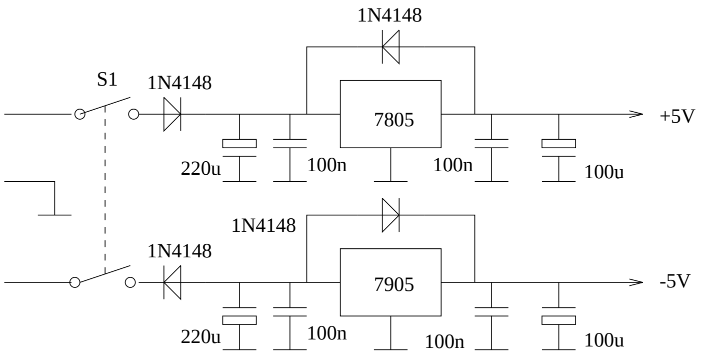

Figure 7: The dual power supply

Figure 8: The front panel of the prototype

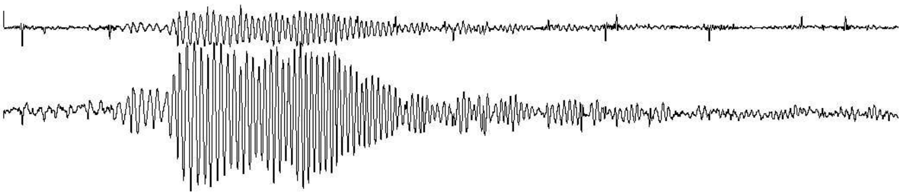

Figure 9: Guatemala, 3-MAR-2004, 05:12:40, magnitude 5.7 (Richter)

4. Set S2 to the right position and set the amplification select switch to a suitable high amplification rate (for example 10^4 or the like – keep in mind that the input stage already performs an amplification by a factor of 100).
5. Connect a voltmeter to the output BNC jack of the amplifier.
6. Slowly turn the offset control potentiometer until the output voltage reads zero (or as near at zero as possible).

3.2 A teleseismic example

The effect of extending the natural period of a geophone with strong overdamping by means of a negative impedance converter as in the prototype shown above can be seen in figure 9.

The two traces show the same seismic event, a magnitude 5.7 earthquake which happened in Guatemala on 3-MAR-2004, 05:12:40. Both traces were generated using two identical 1 Hz geophones and both traces were digitally low pass filtered with a critical frequency of $\frac{1}{5}$ Hz by employing a simple FFT based filter. Both geophones used have a coil resistance of $R_{\texttt{coil}} = 50k$.

The upper trace shows the output of a geophone with passive damping using a value of $R_d = 40$ k while the lower trace shows the same signal measured with a geophone connected to the amplifier described above with $R_d = -40$ k. The lower eigenfrequency of this device is clearly visible.

Further measurements of teleseismic events have shown the absolute superiority of this damping method over traditional passive damping schemes. The main advantage of this method is – in contrast to other active feedback mechanisms which employ capacitive position sensors, thus requiring alterations to the delicate instrument itself – that all damping circuitry is enclosed in the amplifier and may be easily adapted to very different geophones.

4 Conclusion

During the last year while the prototype described above was running without any necessary intervention it became clear that overdamping a geophone using a negative impedance for R_d is a very suitable way to convert a simple and quite cheap geophone into an instrument being very sensitive for even teleseismic events.

This turned out to be advantageous especially for stations with severe cost and floor space constraints as for example schools, university buildings, etc. Examining the raw data resulting in figure 9 which were gathered using a couple of instruments including a medium period Lehman seismometer, a simple 1 Hz geophone, a 1 Hz geophone with the amplifier described above extending its eigenfrequency down to $\frac{1}{10}$ Hz and a three axis geophone with an eigenfrequency of 4.5 Hz it was obvious that the 1 Hz geophone with strong overdamping generated the "best" data (concerning resolution and amplitude).

All in all the amplifier described above may be built for approximately 50 USD using a breadboard and an aluminium enclosure. The output signal can be converted to a digital data stream using any off the shelf analog to digital converter with at least 14 bit of resolution and a range of ±5 V.

References

[Lennartz] Lennartz electronic GmbH, *LE-xD Geophone Family*, Document Number: 990-0003.

[MAXIM] MAXIM, "MAX430 – ±15V Chopper-Stabilized Operational Amplifier", 19-0904, Rev. 2, 8/98.