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> Short notes

Commercial digital audio recorders: a new life for portable Lennartz PCM 5800 seismic stations

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Introduction

In the last two decades the use of mobile digital seismic stations has become more and more widespread both for active and passive seismological studies.
Many industries have designed and realized seismic stations suitable for portable use and characterized by small dimension and low power consumptions.
The modern portable seismic instruments are generally provided with 24 bit AD converter, GPS time code and acquisition on high capacity hard disk and/or continuous data stream for telemetry. These data loggers are generally equipped with high sensibility broad-band seismometers.

The PCM 5800 Digital Seismological System has been produced by LENNARTZ ELECTRONIC GmbH (Tubingen, D) since the middle Eighties. It became the first digital seismic equipment for many european and worldwide seismological institutions and laboratories, in many of which it is still in operation. This instrumentation, however, suffers of a weak point which is the acquisition based on a UHER magnetic tape recorder (13cm wheels) with low capacity (about 8 MB; 90 minutes of continuous recording at 4.75 cm/sec speed). This UHER recorder has high maintenance costs and it often needs expensive repairs.
We propose to replace the UHER recorders with an easy and cheap solution based on commercial digital recorders with removable media in order to continue to use the high number of instruments (Encoder and Decoder) still held by the seismological community, without any modification to the existing hardware and software.

The PCM 5800 System

The PCM 5800 System is based on a 12 bit Analog-to-Digital Converter reaching a dynamic range of 120 dB by means of a gain ranging amplifier. This seismological system has been produced in three configurations: Encoder (4-to-16 input), Mixer (up to 63 telemetered digital data streams from Encoders) and Decoder (for playback with analog output and/or IEEE-488 digital output). The most widespread acquisition system is the first one in four-channel configuration (for a three-component seismometer plus one free channel) recording on UHER 13cm magnetic tape recorder and equipped with a Decoder unit for the data playback (Figure 1).

In this paper we refer to this configuration as the standard equipment for portable use.

Software programming is realized through an alphanumeric display terminal (Figure 1). The acquisition is based on the classic STA / LTA (*Short Term Average / Long Term Average*) triggering algorithm. The software is easy to use and very adaptable. Standard time code is DCF-77 (77.5 kHz), however a GPS-DCF Time Code Receiver is also available. The PCM output of an Encoder acquired by an UHER recorder set at 4.75 cm/sec tape speed is 10kbits/sec. The playback of the data is performed by means of a Decoder PCM 5800 unit linked to a REVOX B-77 MK II tape recorder. An IEEE-488 interface allows the transfer of the recorded signals on a personal computer for analyses and storage.

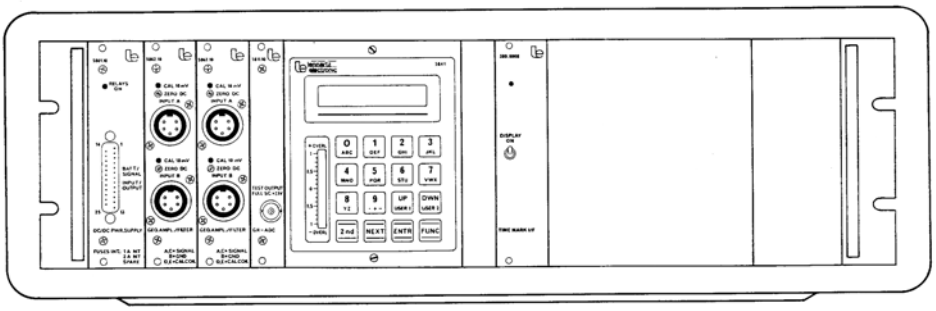

Figure 1. - A standard 4 channel PCM 5800 Encoder in a 19" rack (from Lennartz Electronic, 1983).

As mentioned before, the UHER recorder has been a weak point of the system because of its high maintenance costs. After about eight to ten years of intensive use, the motor of the recorders crashes and it can not be repaired! To solve this problem LENNARTZ ELECTRONIC GmbH introduced the so called "Digital UHER", that is based on a MarsLite/HD system recording on a 4.3 GB hard disk. Although this system allows the continuous data acquisition in a modern format, it forces to "leave" the existing and working instruments such as PCM 5800 Decoders, playback recorders and IEEE-488 interface cards. Moreover, the software for data playback and analysis must be changed.
We think that the alternative solution to the UHER recorder should fulfill some basis requirements:
• Quick implementation in the PCM 5800 System, with the use of simple electronic controls.
• Preservation of the recording and decoding data format, in order to use the existing instruments (encoder and decoder) and software.
• The use of commercial cheap digital recorders with removable media, for easy data recovery.

We suggest to use MiniDisc digital audio recorders as a simple solution to substitute the UHER recorders. These recorders are designed by SONY CORPORATION and also produced by other commercial firms.

The MiniDisc System

The SONY CORPORATION produced the first generation of MiniDisc recorders on 1992. This system allows to record the same amount of audio signals of a CD (650-700 MB) on a 2.5" magneto-optical disc of about 160 MB of capacity with practically the same audio quality.
This is possible using innovative ATRAC (Adaptive TRansform Acoustic Coding; "SP" at 292kbps) data compression system and its *ATRAC3* development (MDLP MiniDisc Long Play "LP2" at 132kbps and "LP4" at 66kbps). The recording duration is 60, 74 or 80 minutes according to the media format and the frequency response is 20 – 20.000 hz.
The ATRAC and ATRAC3 audio encoding technologies are based on psychoacoustic principles (Tsutsui et al., 1992; Sony Product, 2000). The audio signal in the time domain is converted in a signal in the frequency domain and then it is compressed by means of a psychoacoustic model of the human hearing. In the ATRAC coding (Figure 2) the signal is splitted in three sub-bands by means of two QMF's (Quadrature Mirror Filter). A gain control is applied to each band, which are then converted in the frequency domain using MDCT (Modified Discrete Cosine Transform). During the reproduction an IMDCT (Inverse MDCT) is applied for each band and the audio signal is generated using a band synthesis filter.

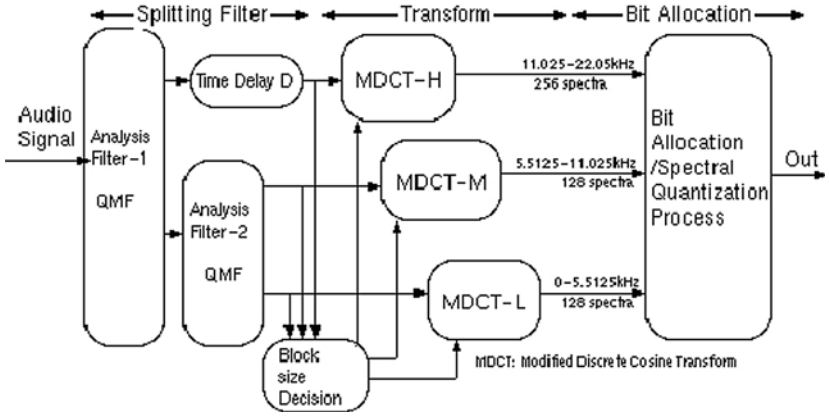

Figure 2. - Block diagram of ATRAC encoder (after Yoshida, 1994).

The *ATRAC3* coding achieves twice the frequency resolution of *ATRAC*, splitting the signal in four sub-bands and using longer MDCT conversion blocks. This allows us to increase the output frequency domain signals (Sony Products, 2000).
The compression ratio obtained with ATRAC SP is about 5:1, whereas with *ATRAC3 LP2* and *ATRAC3 LP4* it becomes 10:1 and 20:1 respectively.
The *ATRAC* "SP" encoding at 292 kbps is able to record the 10kbits/sec PCM data stream without loss of information. The frequency bands in which the input signal is splitted and compressed do not compromise the completeness of the seismic signals. Unfortunately, the time duration of the MD media (60, 74 or 80 minutes) is too short compared to the 13cm magnetic tape.
This problem has been overcome with the new generation of the MiniDisc, named Hi-MD and produced by SONY during 2004. The present SONY Hi-MD recorders/players use the new high capacity (1 GB) magneto-optical removable media. Hi-MD equipment enables uncompressed linear PCM recordings (16 bits / 44.1 kHz) and the up to date *ATRAC*3plus audio compression technology (Hi-SP: 256 kbps, Hi-LP: 64 kbps) with the same frequency response of the previous MD recorders (20 – 20.000 hz).
The recording duration with 1 GB media is 94 minutes in linear PCM encoding and 475 minutes (7h 55m; more than five times the 13cm magnetic tape duration!) in Hi-SP encoding (Table 1). Moreover, the Hi-MD recorder can reformat traditional 80 minutes MD media in Hi-MD media with 305MB of capacity. In this case the recording duration becomes 28 minutes in linear PCM and 140 minutes (2h 20m) in Hi-SP encoding (Table 1).
For our purpose both linear PCM and Hi-SP mode can be used to record PCM data in trigger configuration. The Hi-LP mode is not appropriate for our purpose, due to the data flow which is too low for the PCM data stream.

Hi-MD and Electronic controls

Not all the SONY Hi-MD models currently on the market are useful to record and reproduce PCM 5800 signals. In order to record, an instrument with LINE-IN input and remote control is enough, whereas to reproduce the data an apparatus provided with LINE-OUT output, characterized by an output level of 194 mV, is necessary. The only headphone output is not enough to decode PCM signals due to its too low output level (~ 1.4 mV).

Table 1. – Audio encoding and capacity on Hi-MD. (after Sony Corporation 2004, modified).

Encoding mode	Recording capacity	
	1GB Hi-MD media	**305MB Hi-MD formatted MiniDisc**
Linear PCM 1.4mbps	1h 34m	28m
ATRAC3plus 256kbps "Hi-SP"	7h 55m	2h 20m
ATRAC3plus 64kbps "Hi-LP" (not available for PCM 5800)	34h	10h 10m

Among the SONY Hi-MD production, we have selected, according to price-performance ratio, the MZ-NH700 and MZ-RH910 models to record data and the MZ-NH900 model to reproduce them linked with a Decoder PCM 5800 unit.
In order to use the Hi-MD recorders, instead of UHER tape recorders, we have designed and realized two electronic circuits: the first one for the Recording Control, the second one for the Link with the PCM 5800 Decoder unit.

Circuit for the Recording Control

The PCM signal is characterized by a 0 / +5V level. In order to record data on the Hi-MD recorder, the signal must be characterized by a 0 centred level. Therefore, the PCM signal is high-pass filtered (0.1 Hz) before the Hi-MD LINE-IN input.
The circuit for the Recording Control, as the following one realized by the Maintenance and Development of the Seismic Network Laboratory at OV-INGV, makes use of a characteristic of the MiniDisc "PAUSE" control. During a recording, the PAUSE command stops the recording itself and it leaves the apparatus in this stage indefinitely. A new PAUSE command restarts the recording **in a new file**, which is stopped with a further PAUSE command, and so on (see Table 2).

Table 2. – Block diagram of the control sequence and Hi-MD functions. Red controls are related to manual commands, the green ones are related to electronic circuit instructions. If the power supply decreases under 10V, the STOP command is enabled by the electronic circuit.

REC + PLAY	⟷	Begin Recording
⇓		⇓
PAUSE	⟷	Recording Pause – Closing File
	⇓	
TRIGGER ON	⟷	Pause OFF / Rec ON – Starting New File
⇓		⇓
TRIGGER OFF	⟷	Pause ON / Rec PAUSE – Closing File
⇓		⇓
TRIGGER ON	⟷	Pause OFF / Rec ON – Starting New File
⇓		⇓
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----------	⟷	----------
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⇓		⇓
STOP	⟷	DATA SAVE – SYSTEM FILE WRITING

Using the keys of the wired remote control, the electronic circuit enables the PAUSE command in correspondence with the TRIGGER ON and TRIGGER OFF impulses resulting from the trigger algorithm of the PCM 5800 station. The electronic circuit diagram for the recording control is shown in Figure 3A.

Note that the recorded data will be saved on disk only after the STOP command. To avoid that a too low power supply could cause the unexpected recorder switching off with the loss of the data, a voltage comparator is introduced in the electronic control circuit. If the power supply decreases under 10V, the circuit enables the STOP command on the wired remote control and the data will be saved on disk. The diagram of the voltage comparator is shown in Figure 3B.

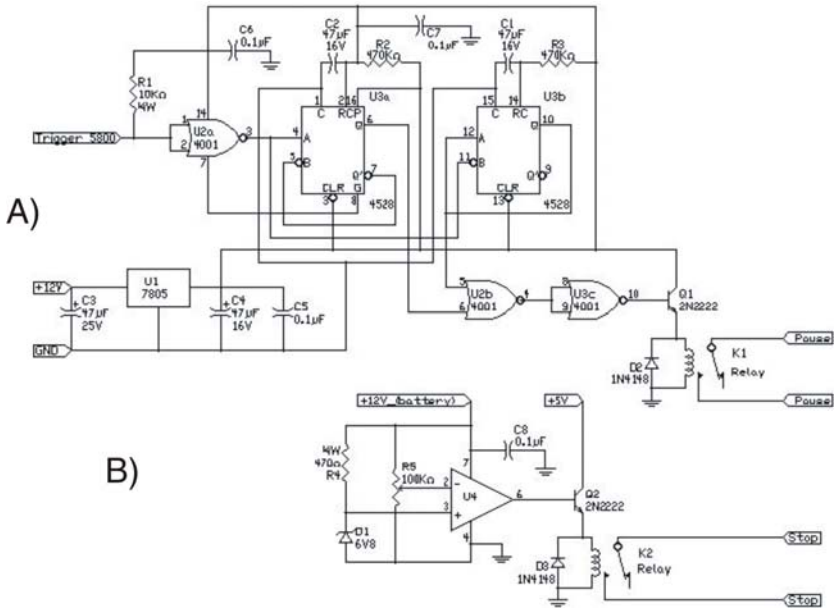

Figure 3. - A) Diagram of the electronic circuit for the recording control, B) Diagram of the voltage comparator circuit.

In Figure 4 the BKS (Mt. Vesuvius) PCM 5800 station equipped with a SONY Hi-MD (MZ-NH700 model) is shown. The power supply for the Hi-MD is taken from the DC/DC converter module of the PCM 5800 station.

Figure 4. - The PCM5800 station BKS (installed in a concrete bunker on Mt.Vesuvius) in 19" rack, equipped with SONY Hi-MD MZ-NH700. The black box on the left contains the circuit for the recording control.

Circuit for the Decoder Link

The output signal of a Hi-MD is an audio signal characterized by variation both in amplitude and frequency. A simple electronic interface that maximizes and normalizes the signal amplitude at a level of +5V is necessary to connect the Hi-MD output to the Decoder unit. In this way the original squared shape of the PCM signal is reconstructed and the Decoder unit is able to elaborate it.
The electronic circuit diagram for the Decoder link is shown in Figure 5.

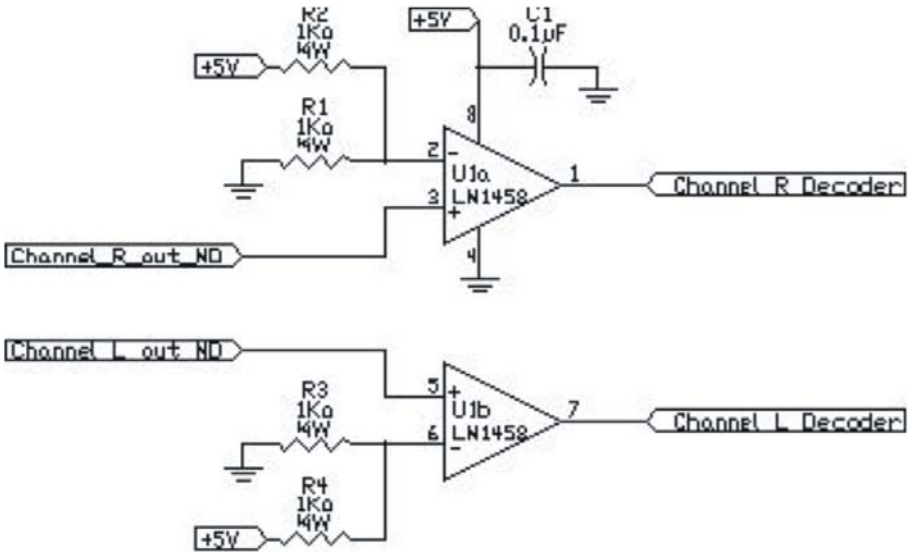

Figure 5. - Diagram of the electronic circuit for the Decoder Link.

Discussion and Conclusions

The PCM 5800 is an “old” system compared with the present available seismic instruments. Nevertheless, many seismological research institutes have a lot of these stations still working.
The SONY Hi-MD recorder is not a concurrent of the LENNARTZ “Digital UHER”, because it is not suitable for continuous recording, however it is a good solution to give a “new life” to the PCM 5800 digital stations in trigger configuration. The Hi-MD recorder is cheap, small, light and has low power consumption. The electronic controls are simple to realize. The capacity of the new 1 GB Hi-MD media is large compared with the old 13cm magnetic tape (more than five times). With recording windows of about 50-60sec (pre-event + coincidence + triggering + post-event) about 500 events can be recorded on a Hi-MD (*ATRAC3plus*, Hi-SP at 256 kbps).
In this case, we prefer removable media to hard disk recorders, as data recovery involves only a simple change of the media. Moreover, the magneto-optical media are rewritable for more than one million times without data deterioration (Yoshida, 1994).
We believe that PCM 5800 stations can be usefully deployed during temporary surveys and to improve local seismic network geometry with high-dynamic digital three component stations in local recording, without the typical problems of the radio links (direct visibility, interferences). With this objective, the STA/LTA triggering algorithm can be set up at high values (6 or 8). In such way, even if the low magnitude earthquakes may be lost, it is possible to reduce “false” triggers caused by human activity and noise
In Figure 6 an example of seismic recording with SONY Hi-MD, relative to a regional earthquake, is shown.

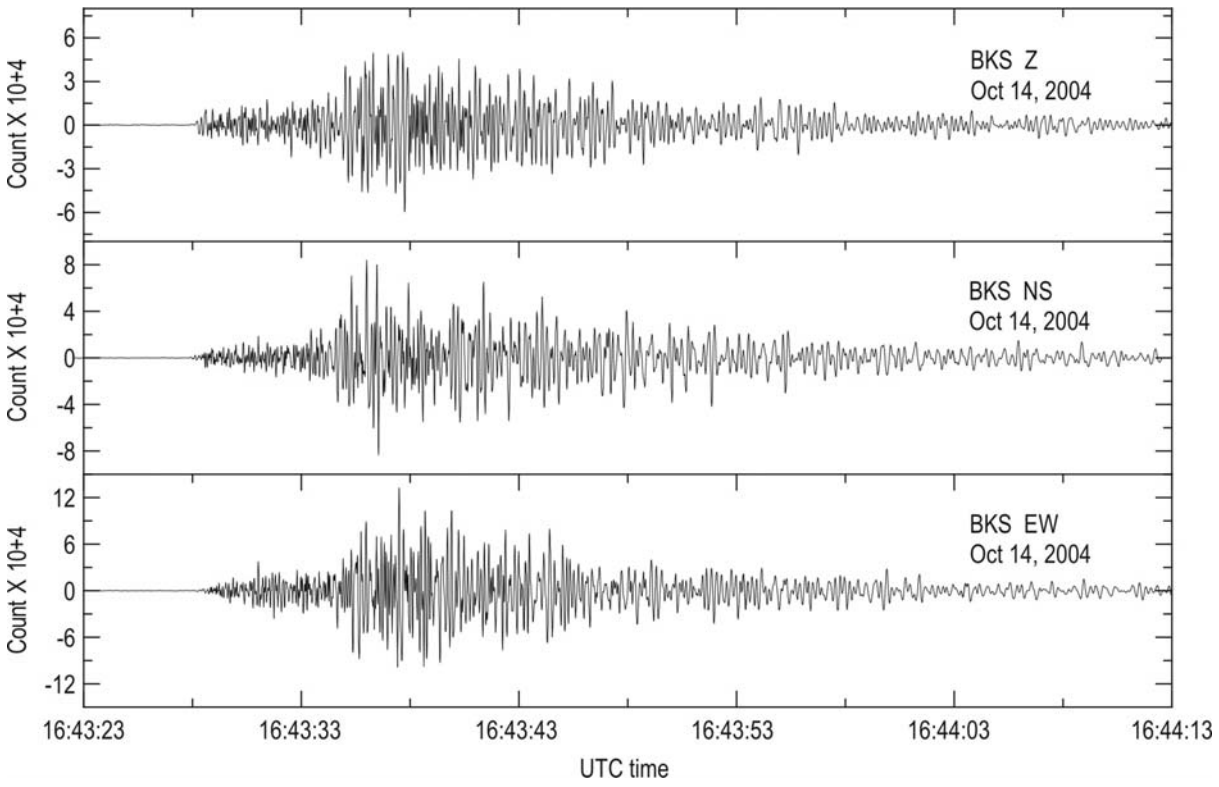

Figure 6. - M 3.3 regional earthquake (D=50km) of October 14th 2004 recorded at Lennartz PCM5800 station BKS (Mt.Vesuvius) equipped with Sony Hi-MD MZ-NH700 recorder and Lennartz Le-3D/1s seismometer. Trigger parameters: STA=1s, LTA=51s, STA/LTA=8.

Acknowledgments

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