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A NEW GENERATION OF MULTICHANNEL SEISMIC APPARATUS AND ITS PRACTICAL APPLICATION IN STANDALONE AND ARRAY MONITORING

Milan BROŽ and Jaroslav ŠTRUNC *

Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, v.v.i., V Holešovičkách 41, 182 09 Prague, Czech Republic
**Corresponding author's e-mail:* strunc@irsm.cas.cz

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ABSTRACT

A quantitatively new analog-to-digital converter (ADC) module has been developed during 2010, in co-operation with Tedia Ltd. The module has a 28-bit final resolution and uses 32-bit arithmetic. There are two versions, with four and twelve analog inputs. The 4-input module replaces the original 21-bit version, produced until 2009. The 12-input module is intended to be deployed in small-aperture seismic arrays. The whole set consists of four 3-channel detached modules that can be interconnected with the main module using a cable of up to 100 m in length. This design increases signal-to-noise ratio (SNR) by placing the A/D part as close to the seismograph as possible in order to transmit digital data for storage. All channels are sampled coherently so that all four sensors are automatically synchronised. It allows the detection of local events even though the sync-signal is absent. In other words, the 12-input module is suitable for ad-hoc field measurements even in places where there is no GPS signal. All arrays operated by the Institute of Rock Structure and Mechanics (IRSM) are going to be upgraded to use these modules and some new sites will also be set-up with this innovative equipment (e.g. Lazy in Western Bohemia and Dobrá Voda in Slovakia).

KEYWORDS: Analog-to-digital converter, seismic array, weak event, monitoring network, building

1. INTRODUCTION

The UDAQ-28xx analog-to-digital converter (ADC) module represents the latest instrumental development at the Institute of Rock Structure and Mechanics, ASCR. It is the direct successor of research that started more than thirty years ago with the development of an analog memory. Subsequent research developed the first digital devices, RUP93 and SARABA98, with 21-bit (Štrunc and Brož, 2004) and 28-bit resolutions. These devices provided cutting-edge technology. The latest instrumental development has been made in co-operation with our industrial partner, Tedia Ltd. This paper describes the main features of the 4-channel module, UDAQ-2804, and the 12-channel module, UDAQ-2812. Their implementation and experimental applications are also outlined.

The ADC modules are optimised for our proprietary seismological data-logging system RUP (Štrunc, 2005). The most recent version, RUP2011, was released in Autumn 2010.

All seismological measurements taken by the IRSM, whether for scientific or industrial purposes, are performed using the RUP system. Depending on the research objectives, the system uses a 14, 21, or 28 bit resolution. It may also be equipped with a precise time base (GPS) or GSM telemetry (Štrunc and Brož, 2006, 2007).

The 4-input module is dedicated to the classical three-component measurement, Z-N-E. The 12-input module is suitable for distributed measurements within a comparatively small area, such as circle with diameter of up to 200 metres (Málek et al., 2008; Štrunc and Brož, 2011). Such measurements are typical for small-aperture seismic arrays or for monitoring the response of a building to a seismological stimulus (Brož et al., 2008; Brož and Štrunc, 2009).

2. UDAQ-28XX

The UDAQ-28xx family is built around Texas Instruments high-resolution analog-to-digital converter ADS1282, each for one channel (Texas Instruments, 2009). This single-chip ADC has a programmable input gain amplifier, a Δ–Σ modulator, a selectable digital filter combination (FIR+IIR), and a 31-bit resolution with a 32-bit inner arithmetic. The UDAQ modules have all the advantages of an ADC; a wide range of input signals can be used (from ± 2.5 V down to ± 0.39 mV) and the sampling rate can be selected (from 250 Hz to 4 or 2 kHz, respectively). The achieved spurious free

Table 1 A comparison of the features in the ADC and UDAQ modules.

		ADS1282	UDAQ-2804	UDAQ-2812
Resolution	[bit]	31	28	
Full-Scale Input Voltage	[V]	±2.5	±2.2*	
Programmable Gain	[-]	1×, 2×, 4×, 8×, 16×, 32×, 64×		
Sampling Frequency	[Hz]	250, 500, 1000, 2000, 4000		250, 500, 1000, 2000
Bandwidth (-3 dB)	[Hz]	0.413 × Sampling		
Stop Band	[Hz]	0.500 × Sampling		
Stop Band Attenuation	[dB]	> 140		
Signal-to-Noise Ratio	[dB]	130 @250 Hz, ±2.5 V 103 @250 Hz, ±39 mV		
Spurious-Free Dynamic Range	[dB]	123 @250 Hz, ±2.5 V	120 @250 Hz, ±2.5 V 118 @250 Hz, ±625 mV 98 @250 Hz, ±39 mV 114 @1000 Hz, ±2.5 V	
Interface		SPI	USB 2.0	USB 2.0
Power	[V]	+5/±2.5	host powered	host powered & 24 V
Digital Input	[V]	SYNC/TTL	GPS/TTL	

* the maximal range ±2.5 V is implementary limited to ±2.2 V

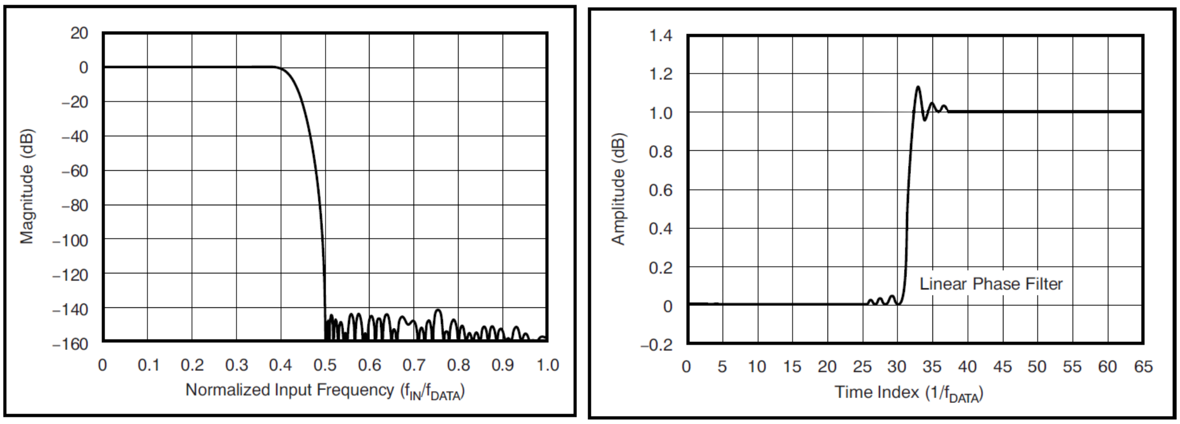

Fig. 1 FIR with linear phase. Transition band magnitude response & step response (TI, 2009).

dynamic range is 120 dB at 250 Hz and ± 2.5 V. Nyquist theorem is fulfilled by an internal FIR (finite impulse response) filter with the linear phase response (with constant group delay) and the stop band attenuation is more than 140 dB at the half sampling rate. There is also one digital input for GPS precise time synchronisation. All the parameters are shown in Table 1.

The magnitude response of the on-chip digital FIR with linear phase is shown in the left part in Figure 1. The effective suppression of signals above the Nyquist frequency is more than 140 dB. The linear phase filter causes constant group delay (i.e. constant delay time versus input frequency). The delay is always 31 samples irrespective of sampling (the right part in Figure 1) and is compensated by the UDAQ controller.

Figure 2 shows the block diagram for the UDAQ-2804. Notice the isolated GPS/Sync input and the isolation between the microcomputer (μC) and ADCs; this improves SNR and eliminates spurious signal influences. This module is powered by a USB host so that can be used with, for example, a notebook.

In contrast to previous 4-channel module, the 12-channel UDAQ-2812 is designed for measuring far from storage unit. It is suitable for seismic arrays or building monitoring. The distance between the measuring sub-module and the main module can be up to 100 metres (Fig. 2). For these reasons, it has

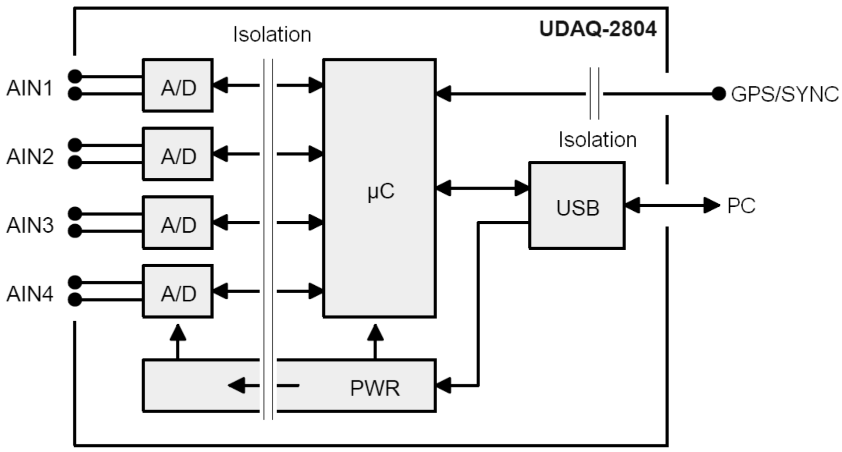

Fig. 2 A block diagram for the UDAQ-2804 (Tedia Ltd.).

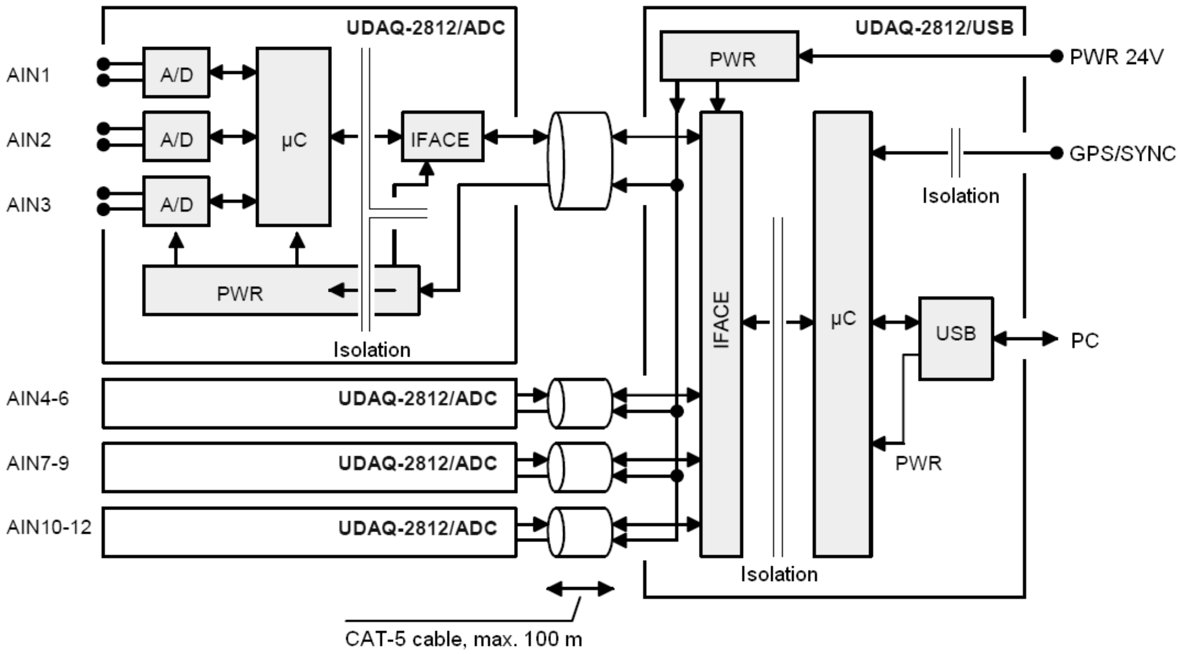

Fig. 3 A block diagram for the UDAQ-2812 (Tedia Ltd.).

specific requirements regarding the power supply. It is also possible to attach an auxiliary grounding wire to this module set

The UDAQ-2812 provides an isolated power supply for connection to the seismograph so that its differential output cannot be influenced by any temporary or permanent ground loop. Nevertheless, ground loops must be eliminated during the preparation and installation of the seismic station. The feature presented forms part of an additional protection.

The high resolution of the applied ADC means that the measured single has a high dynamic range. It is now able to store signals from active sensors with a low gain, such as the SM6b (Input/Output, 1999), without amplification. An apparatus with the same configuration can measure either a quarry blast or in-situ seismological noise whilst maintaining high signal fidelity. Figure 2 shows several combinations of sensors and input settings. The smallest measured value expressed considers the four lowest bits under the noise level. The real values depend on the site conditions and on the characteristics of each sensor, especially in case of measuring of very low velocities of seismic signal or seismic background noise.

Table 2 Sensor versus measurement dynamics.

		Sensor					
		SM6b	**LF-24**	**LE-3D**	**CMG-4T**	**STS-2**	
Input	**Eigenfreq.**	4.5 Hz	1 Hz	1 Hz	30 s	120 s	
	Sensitivity	28.8	15	400	800	1500	V/(m.s^{-1})
±2.2 V	min	5.2	9.9	0.37	0.19	0.1	nm/s
	max	76.4	146.7	5.5	2.75	1.47	mm/s
±1.25 V	min	2.6	5	0.19	0.1	0.05	nm/s
	max	43.4	83.3	3.125	1.56	0.83	mm/s
±0.625 V	min	1.3	2.5	0.1	0.05	0.02	nm/s
	max	21.7	41.7	1.56	0.78	0.42	mm/s

Table 3 ADC Modules: resolution, number of channels, and sampling.

		UDAQ-2804	**UDAQ-2812**	**UDAQ-2104**	**UDAQ-1408**	**UDAQ-1416**
Resolution	[bit]	28		21	14	
Analog Inputs		4	12	4	8	16
Digital Inputs		1/GPS	1/GPS	1/GPS	1/GPS	1/GPS
Sampling Frequencies	[Hz]	250, 500, 1000, 2000, 4000	250, 500, 1000, 2000	250, 500, 1000	125, 250, 500, 1000, 2000	125, 250, 500, 1000
Digital Filter Corner (Low Pass)	[Hz]	0.413 × Sampling, switchable		typically 0.4 × Sampling, other optional		
Sampling for Store	[Hz]	fully optional, typical 100 or 250				
Input Range	[V]	2.5		2	10	
Input Gain	[-]	1×, 2×, 4×, 8×, 16×, 32×, 64×		1×	1×, 2×, 5×, 10×, 20×, 50×	
Time Sync.		GPS Pulse per Second, RMC Sentense				
Telemetry		Ethernet, GPRS (TCP/IP); GSM-SMS				
Network Services		FTP, SFTP, Remote Desktop Protokol				
Native Data Format		GSE 2.0 (INT)				
Alternative Data Format		mSEED, plain ASCII				

All the features mentioned show that the UDAQ-28xx family allows the creation of a data-logger with the highest dynamic precision for seismology in the world (state in autumn 2010).

3. RUP2011

RUP is a set of programs and scripts running under Windows XP. As a hardware platform, a microcomputer based on a 686-core or later is sufficient. Depending on additional tools, such as telemetry (e.g. Ethernet or GSM) and auxiliary channels (e.g. SOH), it can work on battery or through an external power supply. There are many hardware variants derived according to the site and purpose of measuring. A GPS receiver forms the standard equipment for scientific experiments and this makes it possible to achieve time accuracy in the order of 1 μs. There are also cases when the exact origin time is not as important as the measured amplitude, e.g. measuring of quarry blast effects. In such situation the RUP-apparatus is often dedicated to work without GPS.

The presently supported data-loggers use 14; 21; and 28-bit ADC modules with 4; 8; 12; or 16 channels. All of them can be divided into two groups – scientific and industrial. Scientific instruments have resolution 21 of 28-bit. Possible combinations of these parameters are shown in Table 3. The latest version in

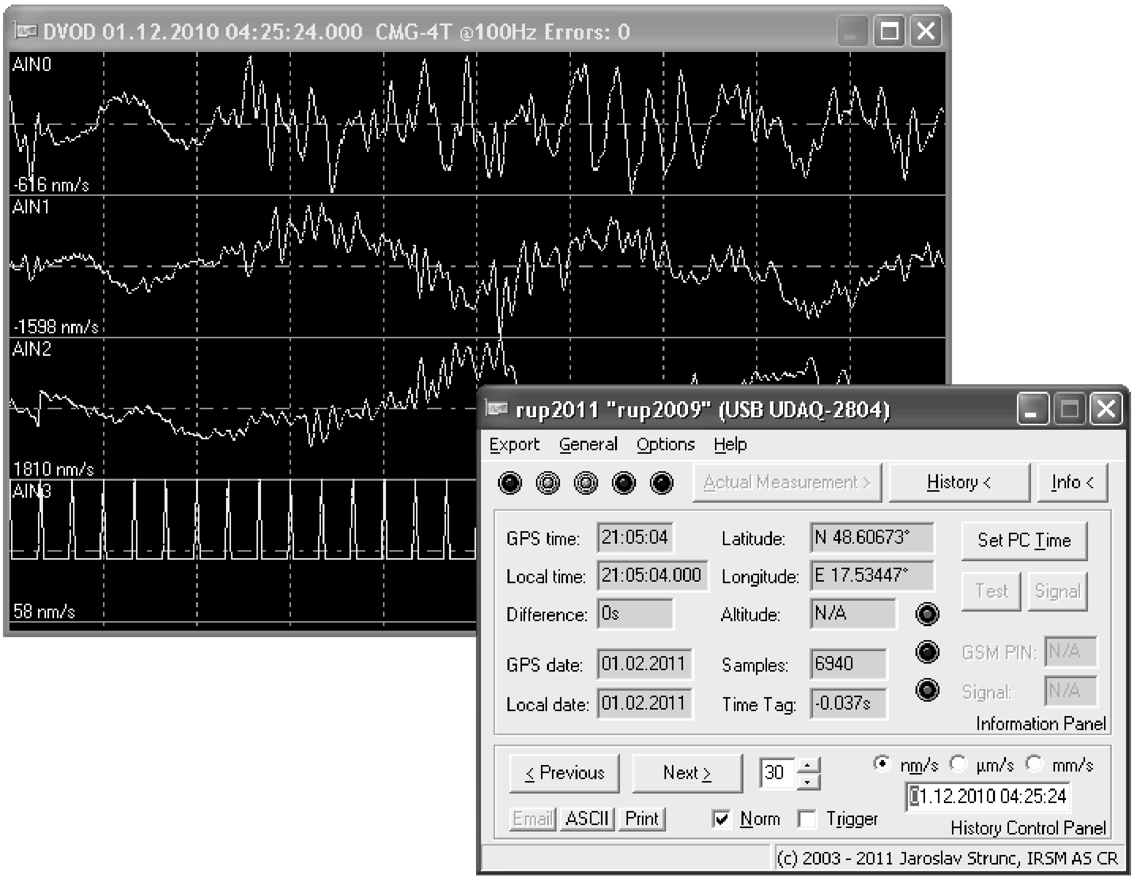

Fig. 4 RUP2011: Information panel, front, and history window, behind (showing an oncoming Lubin Event).

this suite is RUP2011, released in autumn of 2010. The apparatus works most often in continuous mode but the trigger mode can be switched on simultaneously. Data can be stored in GSE, mSEED or plain ASCII format and can be transferred via standard protocols like FTP, SFTP. Small amounts of trigger data can also be sent via SMS. The station may be configured and checked using Remote Desktop Protocol. A standard seed-link protocol is going to be implemented and deployed during the first quarter of 2011.

The main process provides functions for simple event evaluation and its export or print. All data processing and statistically important information, e.g. Earth position, time correction, trigger occurrence, and GSM signal intensity, are recorded and stored in a log-file.

The number of channels can be increased simply by plugging more ADC modules into the microcomputer. Not only the same modules can be combined to work together but any combination of modules listed above is possible.

Figure 4 shows the graphic user interface (GUI) of RUP system. There is the main window with basic information as GPS and local time, gathered number of measuring samples etc. The second window is a waveform window that can be shared between actual measurement and view of data measured recently and stored locally. There is plot begin of Lubin event from December 1st 2010 at 4:24:34, $M_L = 3.1$ in Figure 4 measured in Dobrá Voda using UDAQ-2804 module and Guralp CMG-4T (10s) sensor. Components are from top Z, N, E and GPS time.

4. SINGLE STATION DEPLOYMENT

The scientific version of the apparatus uses a 21-bit or 28-bit ADC module with 4 analog input channels. These instruments are used for all IRSM's scientific projects within the Czech Republic and by our partners in Slovakia for high sensitive seismic measurements around important industrial buildings, e.g. nuclear power plants. This variant is expected to operate together with a high gain short-period or broad-band sensor such as the LE-3D, CMG-4T, or STS-2. The whole network in Czech Republic presently comprises stations operating at depth at Jáchymov (500 m below surface level) and Jesenice (150 m below surface level), the next is seismic array at Nový Kostel in Western Bohemia, then a very-

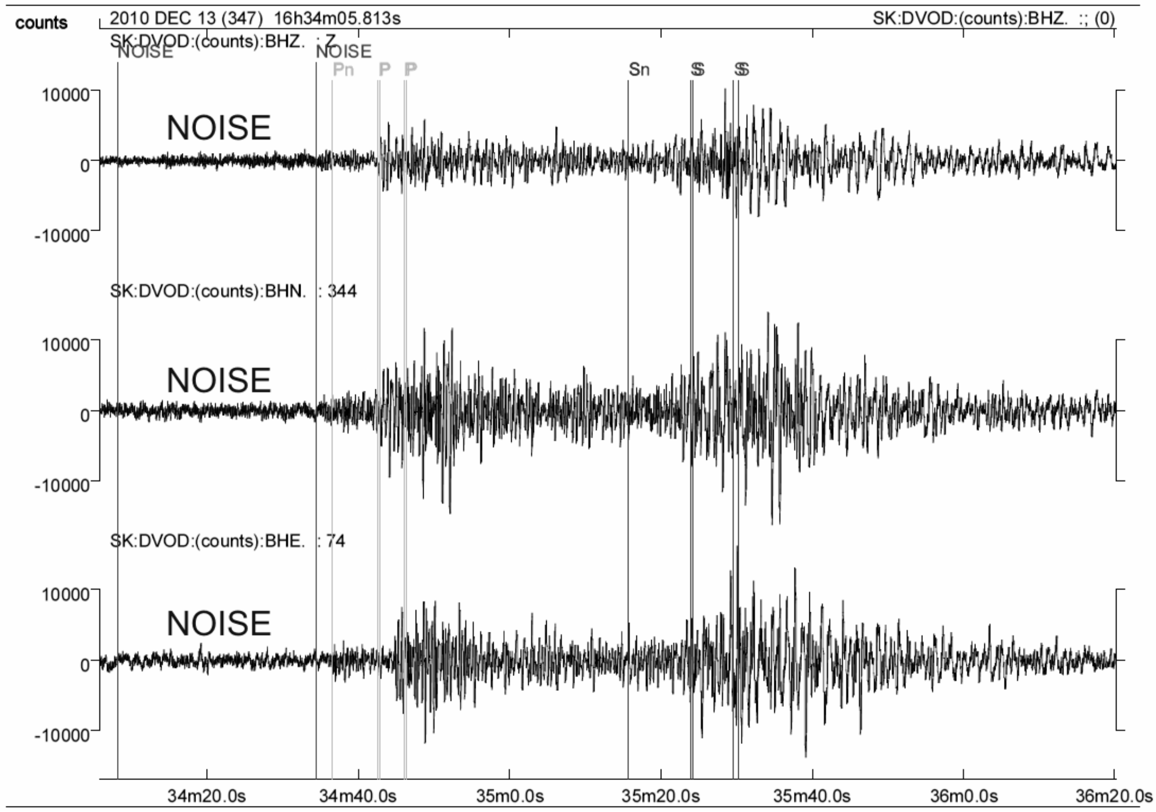

Fig. 5 An event from Lubin in Poland recorded at Dobra Voda in Slovakia by the RUP2011.

broad-band station at Chvaleč in Eastern Bohemia, and network of stations at Prague Castle. Very important is also a local network around the underground gas storage facility at Háje near Příbram.

Figure 5 shows an example of a seismogram from Dobrá Voda in Slovakia. It is an event from Lubin in Poland on December 13th 2010 at 16:33:46, $M_L = 3.0$ with epicentral distance about 350 km. It was recorded by the RUP2011 with an UDAQ-2804 module and Guralp CMG-40T (10s). The visible window is high-pass filtered with corner at 1 Hz. The part marked 'noise' shows the background seismic noise that has peak-peak amplitude about 100 nm/s which means 1700 count – it is almost 12-bit resolution (1 count = 0.058 nm/s). This effect of high resolution of seismic noise is possible only using an analog-to-digital module with a high dynamic range, i.e. 28-bit.

5. ARRAY MEASUREMENT

Multi-channel apparatus, especially with detached ADC modules, were developed for measurements spread within a relatively small area such as a circle of up to 200 m in diameter. The UDAQ-2812 offers four such modules and, if necessary, this can be increased with a certain number of additional modules. Several in-situ tests have been undertaken and three small-aperture arrays are currently being deployed in the Czech Republic: arrays have been upgraded at Ostaš and Nový Kostel and newly installed at Lazy. In addition, there is also a new installation at Dobrá Voda in Slovakia.

The shape of the arrays used at all the mentioned sites is similar; three satellite sensors in the apexes of a triangle and with one near the geometrical centre. The current equipment consists of four local, almost independent, stations with 21-bit digitisers. For this reason, all the data are strongly dependent on time synchronisation by GPS using hardware sync-line. The necessity of such synchronisation will be eliminated using UDAQ-2812. Furthermore, events without an exact GPS time (if, for example, due to a malfunction) will still be useful and usable for event localisation.

Figure 6 shows an example of data gathered during a shallow seismic field experiment using an array apparatus with UDAQ-2812. It was performed by a drop hammer in Nečtiny. All four 3-component sensors were very close together so the signal coherency is evident. In the figure are consequently plot components Z, N and E of all sensors. The last channel is accurate time signal from a GPS receiver. The highest peak value of velocity of each time series is noted on the left side.

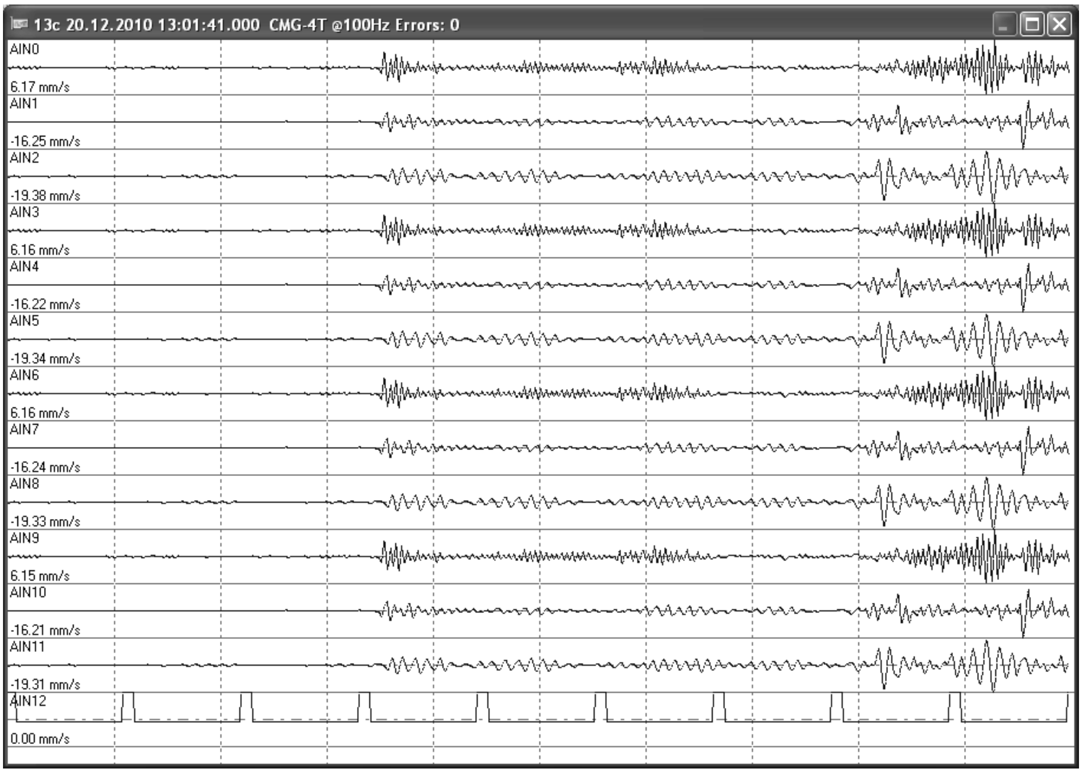

Fig. 6 Data gathered during a shallow seismic experiment using the RUP2011/2812 and 4 Lennartz LE-3D sensors.

6. CONCLUSIONS

New instruments developed by authors during 2010 provide cutting-edge technology in modern seismology. They are able to store a high dynamic range signal without additional functions such as gain-ranging. New ADC modules with an output 28-bit resolution can maintain the fidelity of a wide range of signals, from small seismic noise, below 1 nm/s, to an event with a velocity of more than 70 mm/s.

All measurements are provided by our data-logging system, RUP2011. A hardware/software suite such as this can be used for the monitoring of activity within fault zone areas, so-called macro-seismic regionalisation. This approach is fundamental for planning important civil engineering projects according to assumed local historical seismicity.

The small-aperture seismic array, specific spatial distribution of seismic sensors, and very small event detection are the main focus for the new 28-bit ADC modules. Weak event detection becomes very important for the protection of historical buildings and monuments such as Prague Castle. It is necessary to monitor several sites simultaneously, often without the possibility of using GPS time synchronisation. In such cases, the synchronous processing of all the measured inputs becomes highly significant.

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REFERENCES

Brož, M. and Štrunc, J.: 2009, Response of historical buildings on induced signal with exactly defined frequency spectrum, EGU General Assembly 2009, Vienna, Austria.

Brož, M., Štrunc, J. and Svatoš, J.: 2008, Monitoring of seismic impact on historical buildings and their damage during building the tunnel Blanka – especially influence on the stability of historical buildings in the Prague Castle area. 2nd. Traditional International Colloquium Geomechanics and Geophysics, Ostravice, May 22 – 23, 2008, Ostrava.

Input/Output Inc., 1999: Sensor Nederland, SM-6 Geophone, Online: http://www.iongeo.com/content/includes/docManager/121026.pdf (as of January, 2011)

Málek, J., Brož, M., Stejskal, V. and Štrunc, J.: 2008, Local seismicity and the Hronov–Poříčí Fault. Acta Geodyn.Geomater., 5, No. 2 (150), 97–104.

Štrunc, J.: 2005, RUP2004 – Seismic Apparatus, Complete User Manual, Rev. 1.2, internal document, published on web-site, IRSM ASCR, Prague, Czech Republic, (in Czech), Online: http://www.irsm.cas.cz/RUP2004/RUP2004.pdf (as of June, 2010).

Štrunc, J. and Brož, M.: 2004, 21-bite A/D converter with USB port for seismic measurement, Rozvoj seismologie, inženýrské geofyziky a geotechniky, Sborník 13. regionální konference s mezinárodní účastí, ÚGN, Ostrava, 63–64, (in Czech).

Štrunc, J. and Brož, M.: 2006, RUP2004 – high definition apparatus for standalone, network and micro-array applications in seimics, Transactions of the VSB - Technical University of Ostrava, Civil Engineering Series, 6, no. 2, VŠB-TU, Ostrava.

Štrunc, J. and Brož, M.: 2007, Seismological instruments for local monitoring and monitoring networks. Trhací technika a pyrotechnika 2007, září 2007 v Brně, Český svaz vědeckotechnických společností, Společnost pro trhací techniku a pyrotechniku, Prague, (in Czech).

Štrunc, J. and Brož, M.: 2011, Weak earthquakes detection using micro-array at West-Bohemian swarm area, Acta Geodyn. Geomater., submitted.

Texas Instruments: 2009, ADS1282, High-resolution analog-to-digital converter, datasheet, pdf-form, www.ti.com.