

# Universal Multifunctional IBM PC I/O Board for Clinical Examinations and Experimental Research in Neuroscience

YU. KAMINSKY, I. KREKULE

*Institute of Physiology, Academy of Sciences of the Czech Republic, Prague, Czech Republic*

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## Summary

The PC is and will remain a basic instrument in the laboratory arsenal in the next few years. The key role of the IBM PC and its clones prompted us to develop a universal multifunctional I/O board (UNIMUL) for this computer. The board will make it possible to use the IBM PC for a wide range of tasks from a simple interface for laboratory processing of data to complex IBM PC-based instruments, e.g. a stimulator, signal analyzer, chart recorder. The present article summarizes the experience gathered during the design and application of the described I/O board in more than 10 different IBM PC-based laboratory and clinical systems listed in the Appendix. An example of the application of the I/O board is presented in the conclusion of this report together with the discussion of the future role of new Application-Specific Integration Circuits (ASICs) and single chip processors in this domain.

## Key words

I/O board – IBM PC – Experimental data processing

## Introduction

The analysis of requirements on I/O boards of PC based systems applied to the control and evaluation of experiments in laboratory research or clinical tests shows that following three types of functions should be always implemented by such board: i) signal amplification, isolation, normalization, multiplexing, A–D [Analog to Digital] and D–A conversions, ii) signal shaping and board synchronization and iii) I/O interfacing with the PC bus.

i) An A–D converter (ADC) can usually handle input signals, the amplitude, frequency and internal impedance ranges of which do not correspond to the biosignals encountered in the experiment. Therefore, a multichannel amplifier with software controlled gain and frequency response is almost always necessary at the input of the multiplexer of the ADC on the I/O board. Moreover, clinical safety rules dealing with protection of the patient against electrical shock hazards are usually implemented by an isolation unit between the PC and the biosignal source.

ii) Signal shaping and board synchronization serve as auxiliary functions. Signal shaping is usually implemented by comparators, Schmitt triggers and one-shot multivibrators which generate signals capable of controlling other parts of the I/O board or marking

important events [e.g. time instants when a signal is crossing the zero level]. The synchronization of the I/O board is usually accomplished through a fixed rate [crystal controlled] clock and software programmable counters, both binary and decimal.

iii) I/O interfacing with the PC bus differs according to the path width of the I/O data transfer [1 bit, 1 Byte or 1 word width] and by transfer control (programme [flag] control, interrupt driven control and DMA [Direct Memory Access] I/O control). The 1 bit data width applicable to slow data transfer rate can exploit the standard serial communication channels [protocols] of the PC, e.g. RS 232 or RS 422. This results in considerable economy because no custom-made interface with the IBM PC bus is necessary in this case.

A parallel interface with 1 or 2 B width of the data path, i.e. the so-called parallel discrete I/O board, e.g. [Refs 1, 2], represents a simple, commercially available board, albeit without any signal shaping and amplifying circuits. The described system exploits an 8 bit data path width, so that it can be applied to all types of IBM PCs including the early ones based on Intel 8088 as the CPU (Central Processing Unit, i.e. control and arithmetic units) chip.

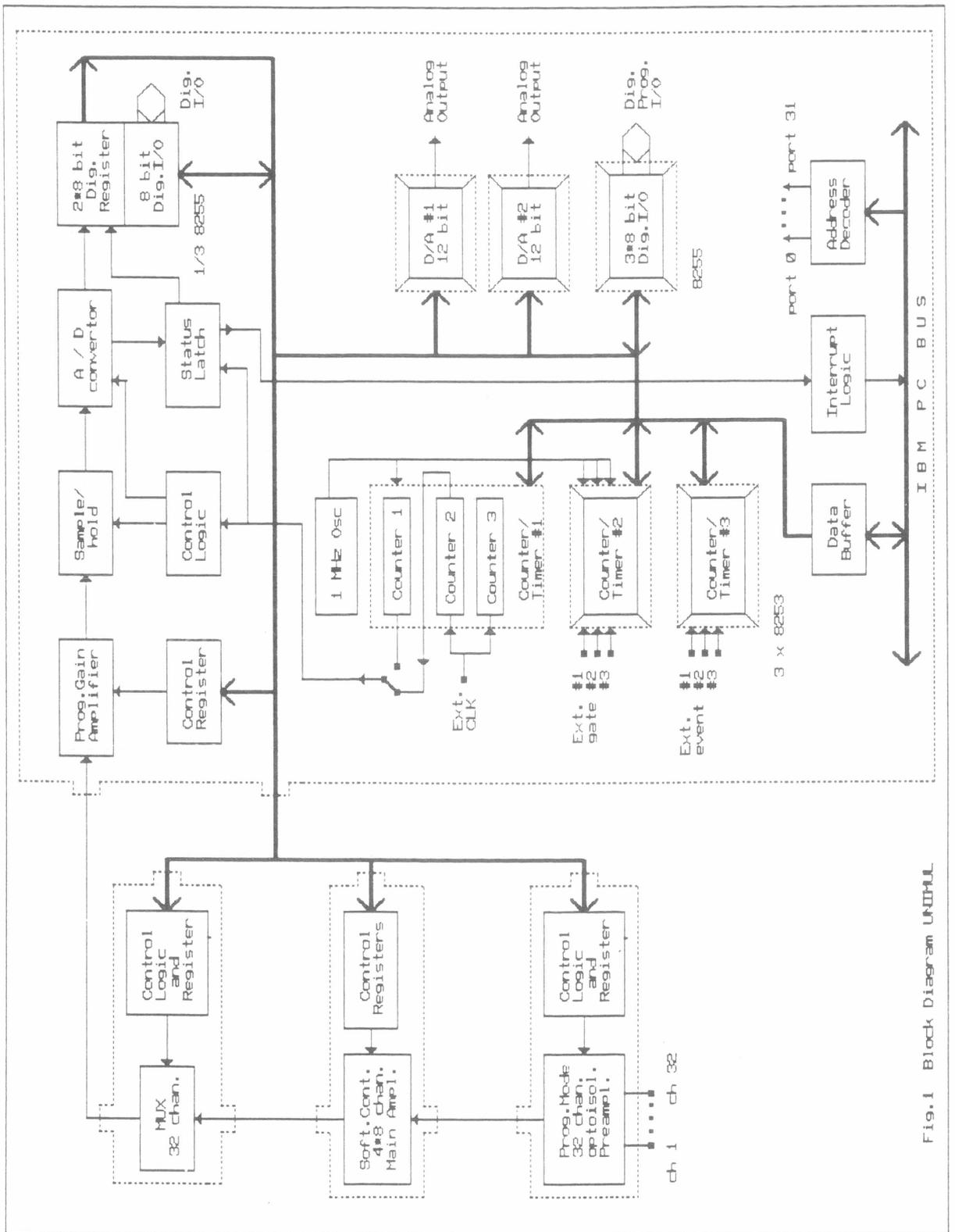


Fig. 1 Block Diagram UMIOUL

Fig. 1

Block diagram of the universal multifunctional I/O board of an IBM PC based system (the double-framed blocks – full and dotted lines represent socketed ICs; the full path of the chipenable signals, i.e. ports 0–31, is not shown for the sake of simplicity, external circuits are framed in broken lines, e.g. preamplifier).

## General Design Considerations

The philosophy of the universal multifunctional I/O board (UNIMUL) design reflects the trade-off between the redundancy of the hardware and the set of functions which can be implemented. To improve the cost efficiency of the I/O board, two measures were put into effect: i) expensive Integrated Circuits (ICs) are connected with the board through sockets and ii) the signal amplification, synchronization and shaping parts of the board can be extended by additional modules. The socketing of expensive ICs, moreover, improves the maintenance of the board. The extending modules can be arranged either as piggy-back modules with standard edge connectors, as separate modules on the mother board or even as a separate box. The extension modules compensate for the lack of the space available on the board, which is limited by the size of standard IBM PC boards. The UNIMUL was conceived to achieve functions of any of the already developed, custom made IBM PC boards of systems listed in the Appendix. The main technical specifications of the UNIMUL are as follows:

- $8 \cdot N$  channel amplifier, [ $N = 1, 2, \dots, 16$ ;  $A = 200 - 200\,000$ ; (DC)  $0 \text{ Hz} - 5 \text{ kHz}$ ];
- provision for measuring time intervals between events;
- provision for triggering external devices;
- 10 bit ADC with  $16 \cdot M$  channel multiplexer [ $M = 1, 2, \dots, 8$ ];
- 32 bit discrete I/O;
- 12 bit, 2 channel DAC [slew rate up to  $500 \text{ kHz}$ ];
- 8 bit width of the I/O bus data path.

## Detailed description of the UNIMUL

### i) Signal amplification and isolation

Main amplifiers always belong to the standard hardware of the UNIMUL although they are arranged either as a piggy-back board, as a separate board or even as a separate box. A battery of 8 amplifiers can be situated on a separate plug-in board of the IBM PC motherboard which provides the power supply (e.g. as in the polygraph implementation described in the following paragraph), while a separate box can house up to  $8 \cdot N$  ( $N = 1, 2, \dots, 16$ ) amplifiers of the same type. A system containing more than 8 amplifiers can be assembled from several amplifier boards. Each of the amplifiers consists of several operational amplifiers and has programme-controlled gain: 1–1000 (1, 10, 100, 1000); frequency band: (3 dB/oct), DC–5 kHz; which can be controlled by programmable analog filters: LF cut-off: DC, 0.01, 0.02, 0.1, 0.2, 1.0, 10, 100 Hz; HF cut-off: 20, 50, 100, 200, 500 Hz, 1 kHz, 2 kHz, 5 kHz.

Optoisolation is applied to the input of each channel of the main amplifier. Between the output of the main amplifier and the input of the amplifier attached to the input of the ADC is a programme-controlled multiplexer (see Fig. 1).

Signals from living tissues are connected to the above amplifiers through a preamplifier situated close to the recording electrodes. This preamplifier also serves as an impedance transformer. Technical parameters of the preamplifier are: gain = 10 or 100; input impedance (monopolar) = 100 M $\Omega$ ; frequency band = DC – 10 kHz; input noise (short circuited input) < 1  $\mu\text{V}$  ptp; common mode rejection = > 100 dB. The preamplifier can operate in one of the following modes under software control: a) data recording; b) autocalibration using internal square waveform with programmable amplitude and repetition rate; c) calibration using an external trigger signal; d) measurement of the tissue-electrode junction impedance.

### ii) Signal shaping and board synchronization

These circuits are limited in the standard UNIMUL set-up to timing and counting circuits. The board has three socketed universal programmable counter/timers (Intel 8253), each of them is  $3 \cdot 16$  bits long. Timing is supported by an internal, fixed frequency (1 MHz) clock. Inputs and outputs of the above counters are connected *via* jumpers to different ports (flag) and they can be coupled together to realize a counter longer than 16 bits.

### iii) IBM PC bus interface

The UNIMUL interface to the IBM PC bus allows for programme or interrupt controlled data transfer on a 8 bit wide data path. Standard user reserved addresses are used, i.e. 300H–31FH as well as the normally unused interrupt requests IRQ3 – [COM2] or IRQ5 – [Printer 2]. The address part of the IBM PC bus is interfaced directly, i.e. bits A0–A9 are decoded and ANDed with the bus signal called AEN which marks the I/O transfer. The resulting signals are connected with the "Chip Select" pins of the particular part of the universal I/O port (Intel 8255) which handles the I/O of the IBM PC bus data part (Low Byte). The data path is bidirectional and bimodal (analog and discrete). The analog input is converted by the 10 bit ADC (TDC 1013) with the maximum rate of conversion  $\leq 10^6$  samples/s. The ADC is triggered by one of the above mentioned programmable timers. The discrete part of the data path is accomplished through the above mentioned universal I/O port (Intel 8255). The discrete output is protected against short circuiting by applying serial resistors. The discrete input is protected by diodes against voltage surges. The analog

output is supported by a pair of DACs (AD 7574) connected directly to the bus. The ADC and one of the I/O port ICs are socketed.

### An example of UNIMUL application

As an example of the application of the multifunctional Analog and Digital I/O Board a paperless, 8-channel chart recorder will be briefly described. It was designed for the study of spreading depression in the brain of rats, i.e. for observation of slow brain potentials and EEG up to 30 Hz.

A separate box with 8 preamplifiers as well as the array of 8 main amplifiers housed on a separate board were used, so that the computer I/O board (see Fig. 2) contains:

- 2 discrete I/O ports (Intel 8255);
- 3 universal counters (Intel 8253)
- 1 ADC, 10 bit,  $10^6$  samples/s
- 2 DACs, 12 bit,  $2 \mu\text{s}/\text{conversion}$ .

The polygraph provides a maximum sampling rate of 256 samples/s on each of the eight channels

simultaneously, allowing for a maximum continuous time interval of data recording on the hard disk of 4 min for each 1 MB of RAM buffer available, since 2 B are required to store each sample.

The display of the polygraph presenting up to eight waveforms continuously, page after page, is equipped with an interactively controlled cursor (see Fig. 3), to enable precise reading of the time and for comparison of a time-sequence of specific features of recorded waveforms. Moreover, a name (up to 10 characters long) can be assigned as label to every waveform. All or selected waveforms can be stored on the hard disk of the computer in a continuous manner or as interactively selected episodes only. The software of the polygraph can be extended to exploit the polygraph for averaging or waveform enhancement *via* off-line digital filtering of records.

The software of the example was written in professional Basic (Microsoft Quick Basic) which is easy to develop in an interactive regime and then to be compiled for the application. More details of the described system can be obtained by contacting the authors.

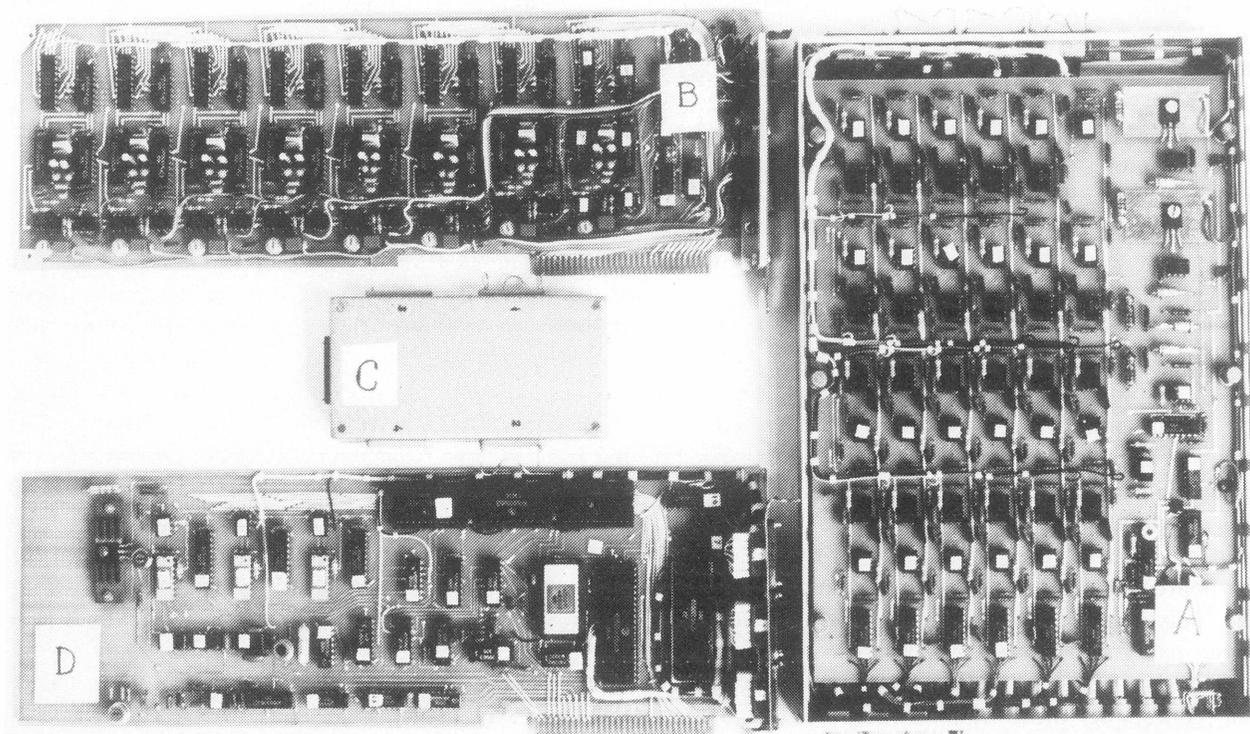


Fig. 2

Picture of the universal I/O board implementing an 8-channel polygraph for physiological data: a) 32-channel preamplifier; b) 8-channel main amplifier; c) multiplexer; d) universal I/O board: UNIMUL.

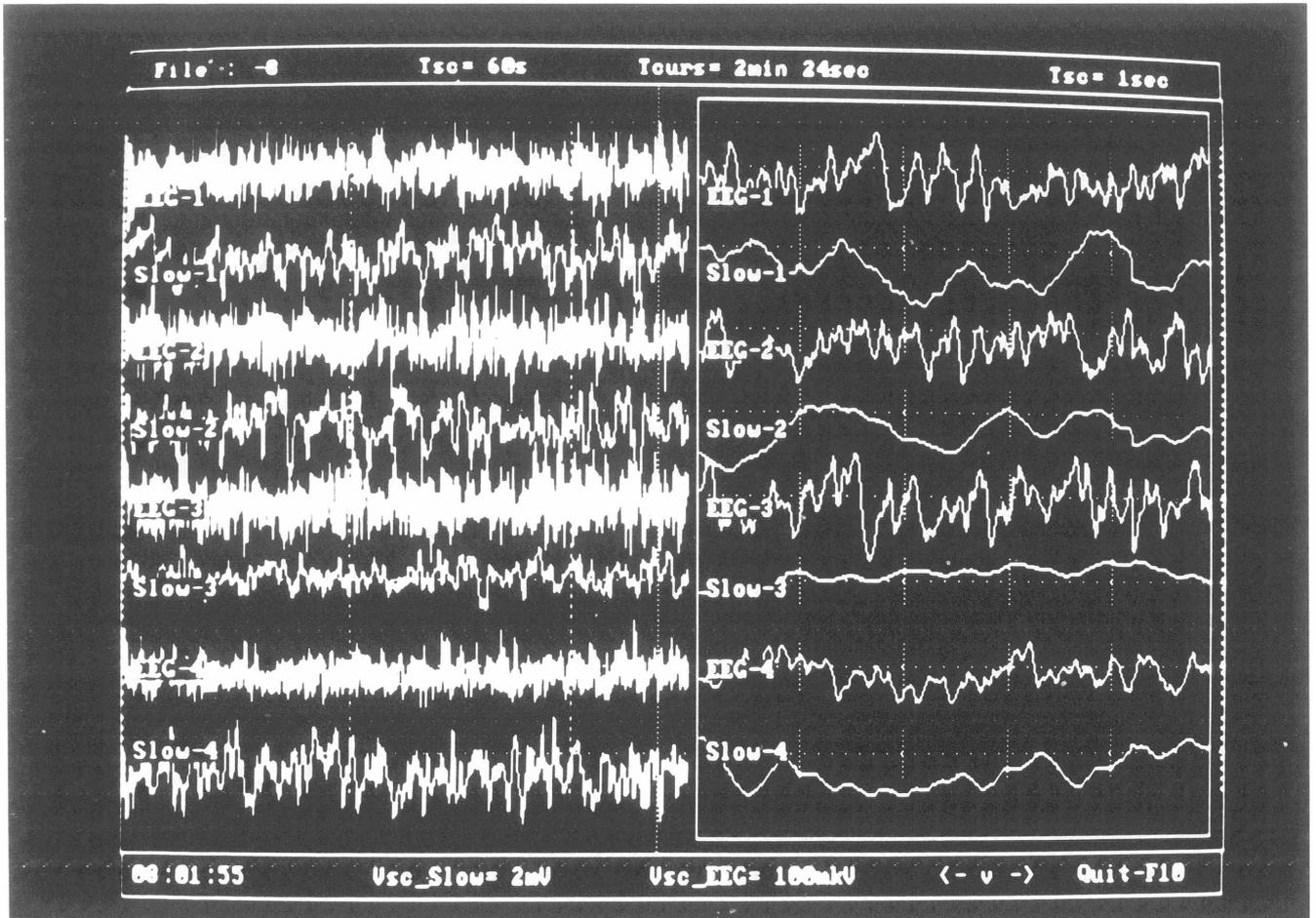


Fig. 3

Picture of the screen of the VGA display presenting 8 labelled channels of physiological low-speed data recording and resembling 4 pairs of EEG and slow potentials each pair being recorded from one electrode. There are two windows of comments (*cw*). The upper *cw* presents the name of the file, time scale and the time corresponding to the cursor position (since the beginning of recording). The *cw* at the bottom indicates the time of the start of recording, amplitude scales and the help instruction explaining how to quit the programme (F10). Notice time markers, i.e. small vertical lines, 1 min apart, i.e.  $T_{sc} = 60\text{ s}$  (5 min of record per screen width) and the interactive cursor represented by the dotted line shown in the middle of the screen. The position of the cursor is controlled by arrow keys of the key board. The 5 s of the record following the cursor position can be inspected in more detail with a time zoom by using the window which can be called by the programme into the right half of the screen. The time marks inside of the window are 1 s apart ( $T_{sc} = 1\text{ s}$ ) and also depict the amplitude scale (different for EEG and slow potentials) by the peak to peak distance and its corresponding value described in the *cw* at the bottom (2 mV for slow potentials, 100  $\mu\text{V}$  for EEG).

## Discussion

Development of ICs tends to higher integration, so that single chip processors and micro-controllers containing I/O devices such as ADC and DAC are available (e.g. the INTEL 80C196 KB represents such a single chip 16 bit computer/controller) [Ref. 3]. They also enable the application of specific ICs (ASICs) implementing complex functions like microprocessor bus interfacing

(IBM PC Bus), including both data and address handling, A-D conversion, multiplexing input analog data according to a stored programme loop and I/O data buffering. As an example of such an ASIC, the LM 12458 - 12 bit + sign Data Acquisition IC should be mentioned [Ref. 4]. It makes it possible to process 13 bit samples with a sampling frequency of up to 87 ksamples/s. The industrial applications of the latter mentioned circuits will soon appear and it will result in significant saving of space of I/O boards and increased

reliability. The application of a single chip computer as a part of an I/O board will increase the versatility of these I/O devices, since their functions will be determined by down-loaded application software transferred *via* a standard serial asynchronous channel. The same serial communication channel can also be used for other control purposes during run-time. The only problem currently facing the application of single chip controllers is the low performance of their analog I/O part. This is so because designers of these controllers are often forced to exploit serial operations and data transfers instead of parallel interconnections to save chip space. The maximum sampling frequency of these ADCs does not usually exceed 10 ksamples/s. However, it should be pointed out that with the progress of semiconductor manufacturing technology their I/O capabilities will improve and single chip controllers will play an important role as parts of universal I/O devices in the near future.

## Conclusions

The advantages of contemporary computerization of laboratory instrumentations are evident. Computers are opening up new application opportunities even for classical laboratory instrumentation such as chart recorders, stimulators, operant boxes, etc. Thanks to computers, these instruments are more accurate due to self-calibration functions and auto-compensation to changes of the environment (e.g. temperature, power supply, etc). Computerized instruments are also more reliable due to embedded self-diagnostics which significantly improves their maintenance and servicing. These instruments are less prone to user errors because any potentially harmful setting of operation is automatically signalled and eventually inhibited. The design of more complex automatic instrumentation is stimulated by computerization of these instruments because their input and output signals can be linked and interconnected.

In general, we are presently witnessing two approaches to the application of computers to laboratory instrumentation [Refs 5, 6]. In the former, the computer becomes an integral part of the instrument which remains similar to the pre-computer era device including its control elements. The later approach is characteristic for the new computerized generation of instruments in which the form of the computer prevails and the functions typical for the given instrument are implemented by a board inside the computer or located in a box standing beside the computer. The former approach is better suited to older classical users. It is usual in instruments of the highest performance class. However, this solution also tends to be more expensive when compared with the latter, computer-like approach. The latter approach is attractive because the current computer to user

interface is used and because it offers additional functions provided by the computer as text editing, spreadsheet computing, etc. This approach is becoming more price-effective because of the fast, price/performance oriented development of computers into which enormous resources are being invested. The described universal multifunctional I/O board of an IBM PC computer paves the way to the second mentioned approach. Moreover, its application possibilities are not exhausted by the list of already available systems based on similar hardware and software.

The design of any universal I/O computer board must always be a compromise between the flexibility of its application and the cost including maintenance. The more universal I/O board is usually more costly due to the larger number of ICs required, despite a larger production series which can better dilute the cost of the board development. Rich application software and the simplicity of maintenance enabled by a number of measuring points which are accessible through the software represent other advantages of more universal boards. The described I/O board UNIMUL contains a number of ICs which can be used for maintenance purposes when not required by the functions to be implemented. We believe that the presented universal multifunctional I/O board UNIMUL will find a number of practical applications in experimental neuroscience laboratories despite its relatively large number of ICs. It is clear that, in the future, the ratio between the exploited and idle circuits of an I/O board will tend to decrease concomitantly with decreasing prices of ICs.

## Acknowledgement

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## APPENDIX

The list below enumerates the IBM PC based systems which were designed by using custom-made specialized boards based on the described standard hard and software building blocks and which are currently in use (1992):

- 1) System for recording and analysis of EEG
- 2) System for recording and analysis of ECG
- 3) System for tracking locomotion of freely moving animals (Morris water tank experiments)
- 4) System for investigation of visual perception of humans
- 5) System for recording and analysis of spirogram
- 6) System for evaluation of physical fitness of human operator
- 7) Combined system for psychophysiological examination in man

- 8) System for research in electrophysiology (recording and processing of: EEG, ECG, REMG, PG [respiration], SGP [skin galvanic potential])
- 9) System for visual evoked potential stimulation and averaging [Ref. 7]
- 10) Pharmacological monitoring systems (recording and on-line processing: summary neurone unit activity, ECoG, brain slow potentials, steady potentials, heart rate, REMG, respiration frequency, pO<sub>2</sub>, body temperature, occurrence of events)
- 11) System for experimental investigation of the electrophysiological correlates of behaviour
- 12) System for automation of operant animal experiments
- 13) System for investigation of slow evoked potentials in biologically active points

## References

- [1] DATA ACQUISITION AND CONTROL, Keithley Metrabyte/Asyst/Dac, Vol. 24, 1991.
- [2] AMPLICON LIVELINE, issue 4/Jan. 1992.
- [3] 16 BIT EMBEDDED CONTROLLER HANDBOOK, Intel, USA, 1989.
- [4] LM 12458, NATIONAL SEMICONDUCTOR, 1991, Data sheet.
- [5] THOMPSON B.G., KUCKES A.F.: *IBM-PC in the Laboratory*. Cambridge Univ. Pres, Cambridge, U.K., 1989.
- [6] WILLIS J., TOMPKINS C., WEBSTER J.G.: *Interfacing Sensors to the IBM PC*. Prentice Hall, N. Jersey, Englewood Cliffs, USA, 1988.
- [7] KAMINSKY Yu, BUREŠ J., KITTLEROVÁ P., KREKULE I.: IBM PC based visual evoked potential stimulator and averager. *Physiol. Res.* 42: 41–44, 1993.

## Reprint Requests

Yu. L. Kaminsky, Institute of Physiology, Academy of Sciences of the Czech Republic, 142 20 Prague 4, Vídeňská 1083, Czech Republic.