Concept and Development Status of the Digital Upgrade of the Mini Multi-channel Analyser (DMCA)

J. Brutscher[a], A. Birnbaum[a], J. Keubler[a], S. Jung[b], B. Richter[d], P. Schwalbach[c], A. von Zweidorf[c], M. Koestlbauer[b]

[a]GBS Elektronik GmbH, Radeberg, Germany
[b]International Atomic Energy Agency, Vienna International Centre, PO Box 100, 1400 Vienna, Austria
[c]European Commission, DG Energy, Directorate Nuclear Safeguards, L-2920 Luxembourg, Luxembourg
[d]Forschungszentrum Jülich, D-52425 Jülich, Germany

Contact to author: brutscher@gbs-elektronik.de

Abstract. The Mini Multi Channel Analyser (MMCA) is a portable electronics module used for neutron and gamma ray Non-Destructive Assay (NDA) of nuclear material. The MMCA is widely used in nuclear safeguards to perform certain classes of verification activities on nuclear material. For more than a decade, an important but non-exclusive area of application has been low- and medium-resolution gamma spectroscopy and attribute testing.
To make use of advances in digital technology, communication protocols and standardisation, display technology, and user interaction paradigms, while preserving the main functionality and compatibility with the existing MMCA, a digital upgrade of the MMCA (DMCA) is being developed in the frame of the German Support Programme to the International Atomic Energy Agency (IAEA) with cooperation of the European Commission. The DMCA is dubbed MCA-527. At the same time, a data acquisition and analysis software interface optimized for in-field use is being developed ("MCAtouch").
In this paper, development status and performance parameters of the digital MCA-527 as well as the software interface MCAtouch are discussed in the context of safeguards requirements for typical in-field applications.

1 General concept and requirements

The MMCA, because of its customized software, is a widely used instrument in a lot of safeguards applications [1-3]. However, as the development of this device took place more than 15 years ago, a new design has become necessary. Electronic components such as processors, ADCs and data storage devices with much higher capabilities and capacities but with the same or lower power consumption are now available, whereas with the old design obsolescence issues are becoming increasingly problematic.
The goal of the new development has been the creation of a hardware platform which can replace the existing MMCA in all its applications with as little effort as possible, but also to expand the capabilities of the DMCA to the limits which are possible with state-of-the art components and the given restrictions in size and power consumption.

1.1 New hardware

The following development goals have been agreed upon:
-The new DMCA should support, as far as possible, all existing safeguards applications.
-It should not consume more power than the existing MMCA, and its operational time on battery should be the same or longer.
-Its size and weight should be comparable to the MMCA.
-Its versatility and capabilities should be extended to widen its range of application.
-Numerous improvements in detail, as suggested by users, may be integrated.
-Design with new components where problems with obsolescence are expected to be low.
-A processor from a widely used processor family from a big manufacturer is chosen; in case of obsolescence or an available upgrade the firmware can easily be ported.

1.2.Software improvement

For verification of nuclear material in the field, inspectors need robust devices and applications optimized for usability with just the right functionality for the measurement task at hand. To make best use of the upgraded

MCA hardware, a new software user interface for the typical in-field use cases of nuclear inspections, named MCAtouch, is being developed. A mock-up has been provided by IAEA (M. Koestlbauer). To achieve the essential design priniciple of usability
- touchscreen operation will be supported
- the interface will be clearly diplayed also on small screens
- the number of features will be minimized
- the number of mouse clicks per task will be minimized

2 Hardware realization

With signal processors and high sample rate ADCs becoming available, also with low power consumption, the decision was made to design a digital MCA providing also greatest versatility. As a good compromise between performance, processor load, and power consumption it was chosen to sample the input signal with a 14 bit ADC and 10MS/s. The following analogue components are preceding the ADC:
-Low pass filter with a bandwidth of around 3 MHz. This is reasonable for a 10MS/s sample rate.
-Input range offset DAC, to correct small preamplifier offsets and optimize the ADC input range for positive or negative preamlifier signals.
-Coarse amplifier in steps of 2-5-10-20-50-100, corresponding to a full amplitude signal range from 10V down to 200mV. The coarse amplifier steps are a legacy from the MMCA, but good enough to fit the ADC to different preamplifier signal ranges. The amplification steps are chosen such that they yield the same results as the MMCA with the same settings. Actually, only amplification settings >10 are really amplifications, settings <10 are attenuations. Amplifications >100 are futile as they only decrease the signal acceptance range, but in no way improve the resolution. Therefore, amplifications >100 as well as the fine gain are entirely achieved by the digital filtering.
The fine gain range, which is 0.5 ... 1.5 in the MMCA, is now extended to 0.5 ... 6.5.
Everything else in signal processing, which is realised in the MMCA by analogue circuitry, is now enabled by the signal processor and had to be implemented in the firmware.

Fig 1: Old MCA 166 with palmtop (left), new MCA527 (right).

2.1 Pulse shaping

The main task of a pulse shaping amplifier within a conventional MCA is to convert a voltage step from the preamplifier signal to a Gaussian shaped pulse the height of which is measured. The time constants which are used for this Gaussian pulse are relevant for spectral resolution and throughput. The MMCA offers here selectable 1µs and 2µs.
With digital filtering by the MCA-527, the output is a trapezoidal signal with a rise time and a flat top time. The flat top should correspond to the rise time of the preamplifier signal and can be adjusted from 0µs to 5µs. The rise time corresponds roughly to twice the shaping time of a conventional shaping amplifier; so, a shaping

time of 1µs corresponds to a rise time of 2µs. For legacy reasons, the adjustment of the MCA-527 is performed in terms of the shaping time and can be varied between 0.1µs and 25.5µs.

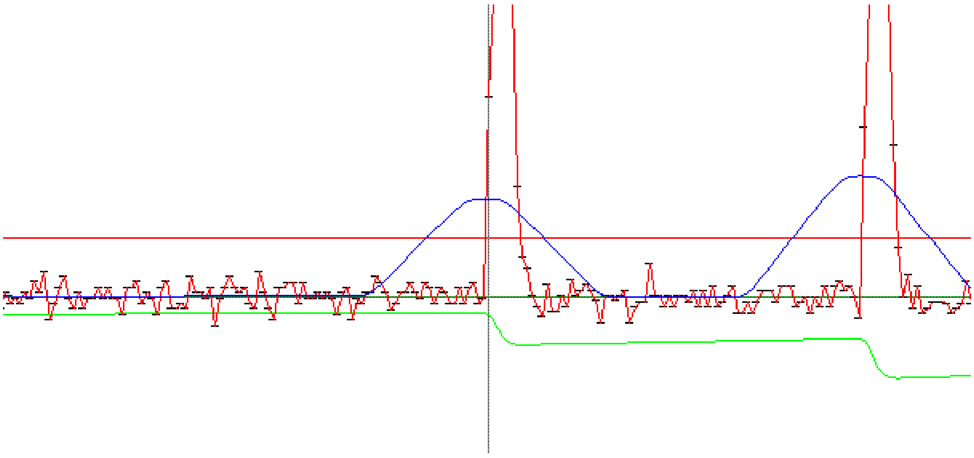

Fig. 2: Signal (lower green curve); trigger filter (red, noisy line) and main filter (blue) values evaluated by MCA-527.

2.2 Triggering

The MMCA splits the input signal into two channels: a fast channel for triggering and pile-up rejection and a slow channel for spectroscopy. The MCA-527 signal processing is quite similar: A short trigger filter is continously applied to the incoming signal and checks for events. If a valid event is found, the longer and more time consuming main filter is applied to evaluate the pulse height.

Different trigger filters are selectable. So, the "1-21" double differentiating trigger filter is adequate for higher counting rates, as it provides highest pulse pair resolution, whereas the "–101" single differentiating filter is more sensitive and provides the widest dynamic range.

2.3 Pole zero cancellation

The pole zero setting accounts for the decay time of the preamplifier signal. A correct pole zero setting is especially important at higher counting rates, to make sure that a signal starting from the preamplifier baseline is evaluated with the same amplitude as a signal starting on top of another one. In the MMCA, pole zero cancellation is achieved by adding a defined amount of DC from the input to the output. In the MCA-527, the same is done numerically in the digital filter.

2.4 Timing jitter

A problem inherently present in digital systems is timing jitter. As the preamplifier signal is sampled with 10 MS/s, and as the events are asynchronous, a timing / trigger error of 100ns is to be expected. A timing error of 100ns together with a signal decay time of 50µs can cause an additional amplitude error of 0.2%, which is unacceptably high. So, digital filters have been designed to cancel jitter and pole zero at the same time.

2.5 Gated baseline restorer

Gated baseline restorers (GBLR) were introduced to keep the zero energy value always at channel no. zero and to prevent spectral deterioration due to preamplifier offset and low frequency noise. The MMCA contains two GBLR with different time constants. The same holds true for the MCA-527 which has a very slow analogue GBLR for re-adjusting the input offset, and a fast digital GBLR, the reaction time of which can be adjusted.

2.6 Differential nonlinearity

Differential nonlinearity is a general problem with analogue MCAs working with a SAR ADC (Successive Approximation Analogue-to-Digital Converter). SAR ADCs have a typical differential nonlinearity of 50%, whereas for gamma spectroscopy a nonlinearity of 1% is required. With a digital MCA, the resulting amplitude is calculated from a multitude of ADC measurements, and, therefore, differential nonlinearity effects are cancelled out. Only with some extreme settings without practical value (e.g., 16k channels, shaping time 0.1µs, and fine gain 6.5) such effects can be seen.

2.7 Additional features

- A gate input, which was only available as an option for the MMCA, is now implemented as standard, and it is found as a LEMO 00 socket on the front panel.
- For the body now used is a tight metal housing with connectors on both front and rear side.
- HV module and batteries are now much easier to exchange.
- High voltage is available up to 3600V
- There are two additional LEDs; one is indicating charging, and the other one indicates HV polarity, and if HV is switched on or off. A window allows to see HV module inserted.
- In addition to RS232 communication and USB communication, which were already implemented in the MCA166-USB, Ethernet communication via a local area network is possible.
- A temperature sensor is integrated logging the actual MCA operating temperature; temperature information is stored together with the spectra.
- Pin 3 of the D9 preamplifier supply connector is configured as auxiliary low speed 10 bit ADC input.
- An additional extension port consists of a UART interface, +5V supply, two digital outputs, two digital inputs where one is configurable as counter. This is intended for, e.g., connecting a GPS receiver or additional neutron or gamma counters to the MCA-527.
- For detectors working in an extremely noisy environment, the digital MCA offers a low frequency reject triple differentiation main filter. This 3rd order high pass is capable of filtering low frequency signal components to such an extent that pole zero setting is omitted.

3 Achieved parameters and results

3.1 Spectral resolution

The spectral resolution achieved with a good planar HPGe detector in the low energy range is within 10% comparable to the result of the MMCA. For the high energy range the MCA-527 is definitively superior due to its increased channel depth and lower noise level. But also for low resolution detectors improvements have been obtained. With a CZT and settings optimized to 0.8µs shaping time and 0.6µs flat top resolution could be improved by 10%. Even with a NaI and settings to 0.2µs shaping time and 1.6µs flat top some improvement was noted.

3.2 Throughput

Throughput depends very much on filter settings and will be thoroughly investigated later. For one test, a throughput close to 100 kcps has been achieved with a 0.5µs shaping time constant. Even higher throughputs may be achievable, but this may be at the expense of resolution.

3.3 Dynamic range

With the MMCA, the standard dynamic range is 2% – 97%, as below 2% there are some non-linearities, and the channels above 97% are used for sliding scale average. Neglecting the low energy non-linearity, the dynamic range may be at best 0.5% – 97%.
With the MCA-527, the dynamic range depends on the chosen trigger filter and fine gain and may be as large as 0.2% – 100%. The upper limit is always 100%, as there is no sliding scale linearization.

3.4 Pulse pair resolution.

The pulse pair resolution describes the ability to distinguish between subsequent events, and, therefore, is a good measure for the ability to prevent pile up and give exact counting rates. With the double differentiating trigger filter the pulse pair resolution is around 0.4µs and, therefore, better than for the MMCA. The single differentiating trigger filter yields a pulse pair resolution of about 1µs which is worse than for the MMCA, but it provides for an extended dynamic range.

3.5 Weight and power consumption in comparison with the MMCA

	MMCA	MMCAUSB	MCA-527
Weight	672g	664g	829g
Power consumption idle, without detector	0.93W	0.95W	0.62W
Power consumption with HPGe (GL1020R)	2.2W	2.3W	2.2W

In measuring mode with a detector, all three MCAs have, within 5%, the same power consumption, whereas in idle mode the MCA-527 consumes only 2/3 of the power of the previous instruments.

4 Software MCATouch

The MMCA was designed to be used with the HP200LX palmtop computer. But almost 10 years ago, the HP200LX became obsolete, but numerous applications still rely on this palmtop. So, there is an urgent need to replace the classical combination of HP200LX palmtop with MMCA.

The Panasonic toughbook with touchscreen has been selected as reference for implementation in combination with the new DMCA.

The IAEA (M. Koestlbauer) developed a mock-up of the software demonstrating the basic functionalities. This has been adopted by GBS and made functional.As the obsolescence of computer or palmtop hardware is a principal problem occurring in cycles of 2 years, the software was realised using Microsoft Visual Studio and designed to run on Windows 7 or XP as well as on Windows Mobile.

The functionality of the software is determined by setup files selectable from a menu.

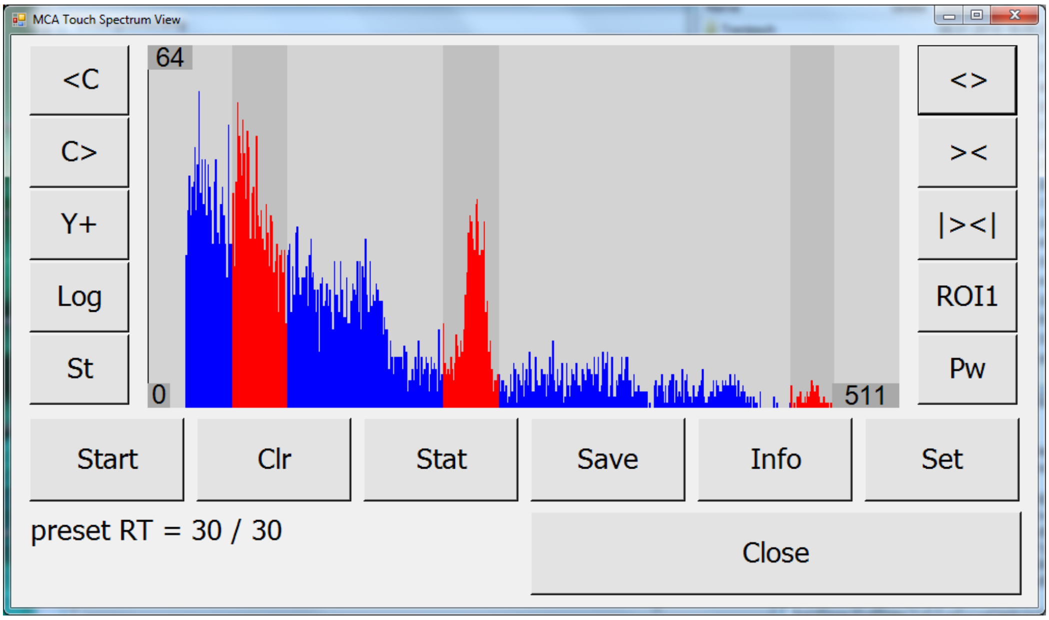

Fig. 3: Main window of MCATouch.

In contrast to the majority of existing MCA software the evaluation process in the MCA-527 runs continuously and in parallel to the measuring process. So, information about the significance of a peak in a ROI is permanently updated. For RS232 communication, the spectrum updating cycle is slightly longer. The functions first to be integrated are:

- Simple attribute testing, i.e., basically a gamma-spectroscopic measurement with a fixed region-of-interest (ROI) and the task to identify a peak, if it exists.
- Uranium enrichment measurement, using an algorithm similar to the classical enrichment meter algorithm as used in U-235 and UF6 software.

There will be an interface for 3rd party evaluation software and additional functionality. The following is planned:

- Integration of NaIGEM

- MCS, CANDU Bundle Verifier for Baskets (CBVB)
- TREND95.

Acknowledgements
The work is sponsored under task A1791 of the German Support Programme to the IAEA.

[1] F. Gabriel, A. Wolf, D. Proehl, R. Jainsch, K.W. Leege, R. Arlt, P. Schwalbach, B.Richter, “MiniMCA – Evaluation, Field Test and Commercialization“, Proceedings of the 19th ESARDA Annual Symbosium, Montpellier, France 13-15 May, 1997

[2] M. Aparo, R. Arlt, F. Gabriel, R. Jainsch, K.W. Leege, A. Birnbaum, U. Filges, “Development of software for the MiniMCA – design principles and Implementation”, ESARDA Symposium on Safeguards and Nuclear Material Management, Sevilla, Spain, 4-6 May 1999

[3] Duc T. Vo, “Extended Evaluations of the Commercial Spectrometer Systems for Safeguards Applications”, Los Alamos National Laboratory report, LA-13604-MS, 1999