A Low-cost Multi-channel Analogue Signal Generator

F. Müller[a], K. Schmitt[a], W. Shen[a], R. Stamen[a]

[a] Kirchhoff Institute for Physics, University of Heidelberg, Germany

fmueller@kip.uni-heidelberg.de

Abstract

A scalable multi-channel analogue signal generator is presented. It uses a commercial low-cost graphics card with multiple outputs in a standard PC as signal source. Each color signal serves as independent channel to generate an analogue signal. A custom-built external PCB was developed to adjust the graphics card output voltage levels for a specific task, which needed differential signals. The system furthermore comprises a software package to program the signal shape.

The implementation of the signal generator is presented as well as an application where it was successfully utilized.

I. Introduction

The presented signal generator provides up to 12 independent analogue signals on a low-cost basis. It consists of a standard PC hosting a commercial multi-monitor graphics card that acts as source for the analogue signals. The graphics card is controlled by a dedicated software package running on the same machine. An external device was developed as part of the signal generator, being an example of how to condition the signal.

A possible application, the emulation of analogue signals of the ATLAS calorimeter trigger inputs for the Level-1 PreProcessor test rig, is described in section VI..

II. Concept

The signal generator consists of three building blocks. In a first step, the signal is programmed either from basic pulse shapes or from pulses recorded with an oscilloscope. These signals are mapped to a 8-bit digital signal, as shown in figure 1 (left). At this point, the signal is strictly positive, featuring an artificial, non-zero baseline. The generation of negative signals, i.e. the application of an offset, is performed at a later step.

The analogue signal is generated in a second step, using a commercial graphics card as signal source. The basic idea is to use the DAC of the graphics card and the already existing periphery of the card (bus, memory, control unit) to generate analogue signals. Each color channel of the graphics card thereby serves as an independent signal source, with the native properties from the graphics card specification, as given below. These can be considered sufficient for many applications, like e.g. analogue components of the LHC experiments at CERN. The signal is unipolar, as illustrated in figure 1 (middle).

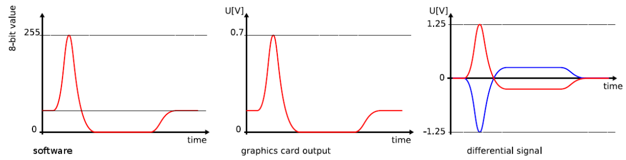

Figure 1: The desired pulse shape is created and mapped to the 8-bit output of the graphics card (left), which generates a single-ended unipolar signal (middle). To condition the signal for a specific task, gain and offset are adjusted, including the conversion to e.g. differential signals (right) [2].

Finally, the signal is conditioned to a specific application by a third building block, which is a dedicated external device. This device has to perform a calibration of the graphics card signal. In addition, the artificially introduced baseline is taken into account by shifting the signals with a global offset. This offset is applied using a dedicated channel of the graphics card. The last operation is to adjust the voltage levels to the desired range of the application.

Only this last operation is patricular for the specific application. In the following, the case of a differential output and an additional fan-out of the signal is presented, which corresponds to the application given in section VI.. Figure 1 (right) shows the signal after conditioning.

III. Graphics Card as Signal Source

Each color channel of the graphics card serves as an independent signal source. It is an unipolar signal with an 8-bit resolution of the output voltage and a time resolution ("pixel clock") of up to 5 ns. This can be considered sufficient to represent an analogue signal for systems operated at a lower speed, like e.g. many 40 MHz systems at the LHC. The signal is represented by a fixed image consisting of three signals at a time (red, green, blue). The longest possible continuous signal that can be encoded into the image is in the order of 10μs, which corresponds to one line on the screen. This restriction is due to the need for horizontal synchronisation of analogue CRT monitors and emerges as a blanking space at the end of each line and each screen, where the electrical output is zero. This typically takes 20% of the total time. The total signal length nevertheless is up to 10 ms, the minimal frequency about 100 Hz ("monitor frequency").

In order to maximize the number of channels, graphics cards with multiple monitor outputs were tested. The Matrox QID Pro [1] was chosen as the model with the best electrical properties.

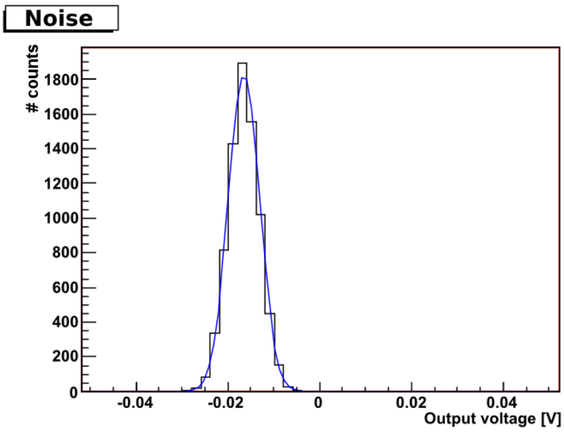

Figure 2: Noise measurement of the Matrox Millenium G400 with DAC set to zero. All outputs feature a constant, non-zero offset within ±20 mV [2].

Figure 2 shows the measurements of the noise of the Matrox Millenium G400, which has very similar properties as the used model. The noise was determined by measuring the output with DAC set to zero, i.e. by displaying a black image, resulting in a gaussian noise with a RMS of 3.4 mV. The linearity was also measured and found to be within a 1% deviation over the output voltage range. Furthermore, figure 2 shows a deviation of the signal from zero in spite of the DAC set to zero. This offset was found on all color channels of the graphics card to be constant within 20 mV, which has to be corrected on the subsequent calibration stage of the external conditioning device.

IV. Software Package

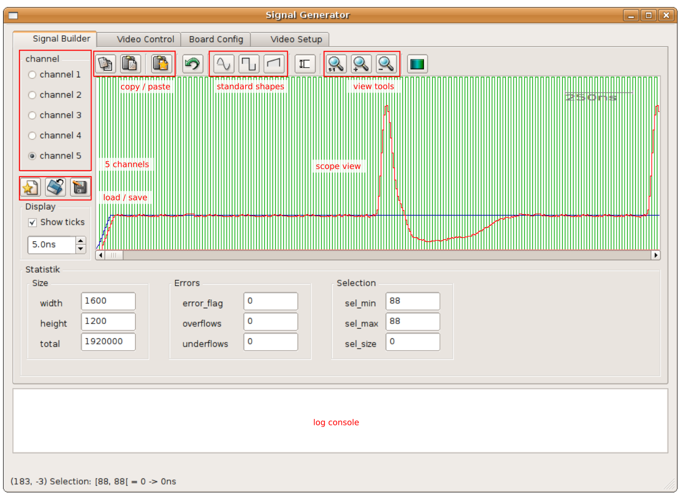

Figure 3: Graphical user interface of the software package to create, modify and save signal shapes. The main view shows a 40 MHz clock (green), a constant signal (blue) and a typical pulses for the ATLAS LAr type calorimeters (red). These signals were used in the application described in section VI. [2].

A software package was developed to program and create the signals. It consists of two parts. The first is a graphical tool that offers basic pulse shapes, modification tools and the possibility to import external data. The prepared pulse shapes are stored in a generic file format. Three of the signals are merged into a fixed image which correspond to the desired signal shape at the output of the graphics card. The second tool is a console application for linux that connects to a dedicated X window server running on the pc that hosts the graphics card. Thus it drives the graphics card by displaying the saved signals as fixed images at full screen, resulting in a repeating signal as long as the application is running.

V. Signal Conditioning

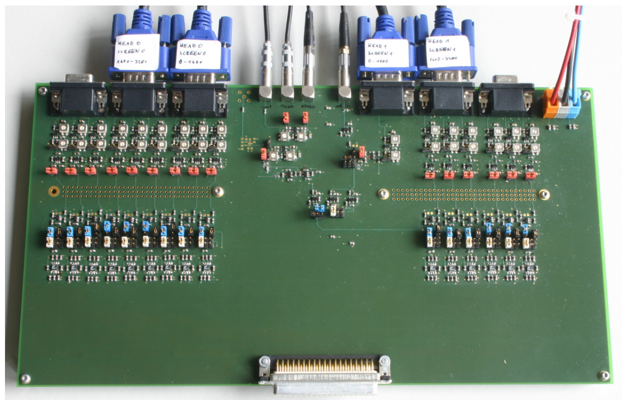

Figure 4: The Fan-out and Application Board (FAB) performs calibration, fan-out and conditioning of the signals [2].

An external device was developed to condition the output signal to the voltage levels for a specific task. It is a PCB that consists of several buffer stages to calibrate for gain and offset. Up to six monitor outputs can serve as inputs. One channel is explicitly used to apply a global offset on all other signals in order generate negative, as well as positive, signals. The output are 16 differential signals, which can be configured by an upstream fan-out stage.

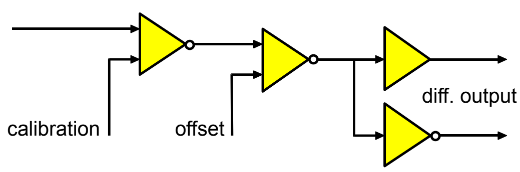

Figure 5: Scheme of the signal conditioning: Calibration for gain and baseline, application of a global offset and preparing of the output signal (in this case: differential signal).

Figure 5 shows a scheme of the signal conditioning for one channel. At the first stage, baseline and gain of the input signal from the graphics card are calibrated. This calibration is

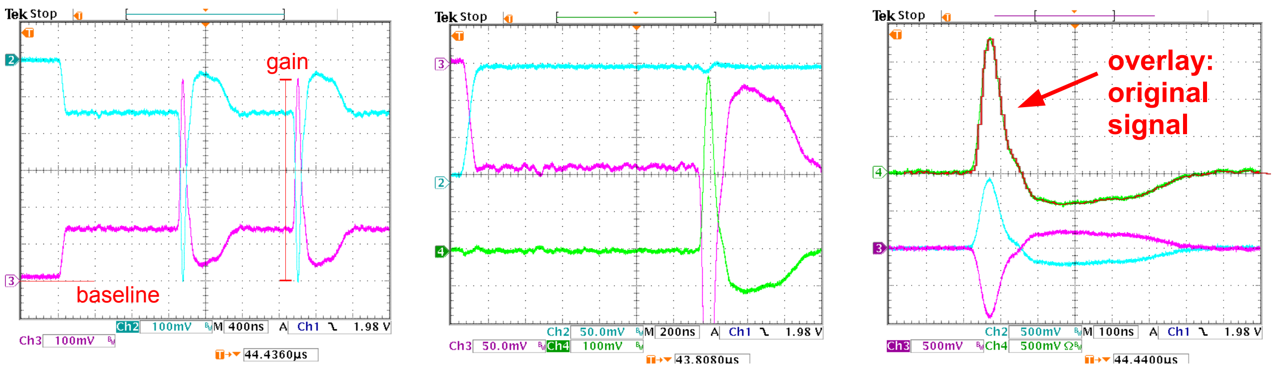

Figure 6: Signal chain on the Fan-out and Amplification Board for a typical pulse of a the ATLAS LAr type calorimeter. Left picture: First, the original signal (red) is calibrated for gain and baseline (blue). Middle picture: Then a global offset (blue) is applied, resulting in a continuous baseline (green). Right picture: Finally the single-ended signal is converted to a differential signal (green). Also shown are the two branches of the differential signal (blue, red) and the original signal (red overlay) [2].

implemented by variable resistors of an operational amplifier in inverted circuit and has to be performed once. At the second stage, a global, negative offset is applied on all channels in order to make negative signals possible, using a dedicated, inverted channel of the graphics card. Hence, the offset is programmable by software, taking into account the artificially introduced baseline at the creation of the signal, as described in section II.. The presented version of the device for the signal conditioning was developed for a task that required multiple differential signals. Therefore, the signals are then fanned out and converted from single ended signals to differential ones at the last stage. This last stage, of course, varies for the specific task.
Figure 6 shows the development of the signals after the several stages of the signal conditioning.

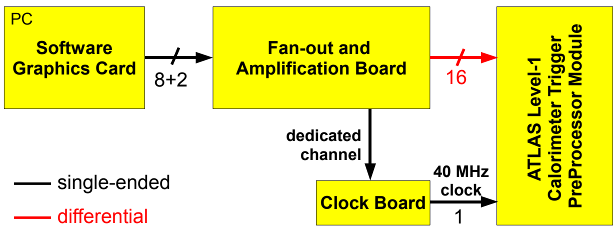

Figure 7: The setup of the PreProcessor test bed consists of the signal generator, which delivers 16 differential channels. Furthermore, an external device (*clock board*) uses a dedicated channel to provide a 40 MHz clock.

VI. Application

The signal generator was successfully applied in a test bed for the PreProcessor Module (PPM) of the ATLAS Level-1 Calorimeter Trigger. One of the main tasks of the PreProcessor is the digitisation of the analogue pulses from the ATLAS calorimeters at a rate of 40 MHz. These pulses are transmitted differentially with a voltage amplitude of up to 2.5 Volts. The key characteristics are a rise time of 50 ns and an undershoot of up to -0.5 Volts for signals from calorimeters based on Liquid Argon technonolgy. The typical shape can be seen in the figure 1. Considering the sampling rate of 200 MHz, the presented signal generator can be considered highly sufficient to emulate the analogue ATLAS calorimeter pulses.

A. *Test Bed for the PreProcessor Module*

The test bed for the analogue parts of the ATLAS Level-1 Calorimeter Trigger Pre-Processor is shown in figure 7. Since the connectivity of the PPM is 4 connectors with 16 channels each, the signal generator was set up with 8 independent signals of the graphics card that are fanned out and converted to 16 differential signals.

In order to achieve a synchronous sampling of the pulses on the PPM with respect to the signal generator, the test setup also has to provide the bunch crossing frequency of 40 MHz to the PPM. This requires an additional device, since the signal generator suffers from the blanking space that prevents the generation of such continuous signals.

B. *Clock Synchronisation Board*

The Clock Synchronisation Board uses another dedicated channel of the graphics card to provide a clock synchronous to the 16 signal channels. The device features a CPLD for basic logic function and routing, and a voltage controlled oscillator in a phase-locked loop (PLL). An incoming 40 MHz signal from the graphics card serves as reference clock, while the inhibit function of the PLL is used to bridge the intrinsic blanking space of the graphics card signal. Therefore, the reference clock is analysed to detect the beginning of the blanking space. This is achieved by a monoflop that is charged by the reference signal. Once the reference clock stops, the monoflop turns to zero. This activates the inhibit of the voltage controlled oscillator, whereby it sustains the 40 MHz clock. After the blanking space, the PLL ensures that the voltage controlled oscillator synchronises with the reference clock again. See figure 8 for illustration.

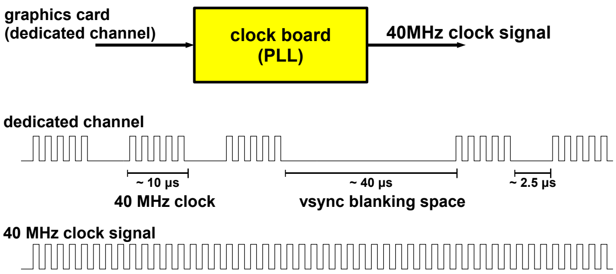

Figure 8: Scheme of the 40 MHz clock, provided by a dedicated channel for reference. A PLL with a voltage controlled oscillator is used to both synchronise and bridge the intrinsic blanking space, using the inhibit function of the phase detector of the PLL.

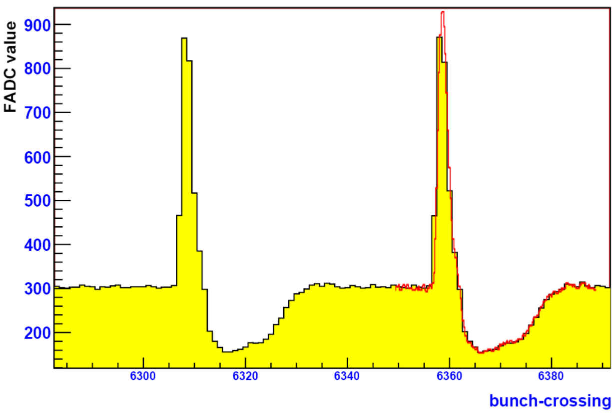

Figure 9: Digitised signal (yellow) and original signal (red overlay) [2].

C. Measurement

For the measurement, the signal generator was providing pulses from a test beam pulse library [3] as well as the reference clock. The PPM was configured to digitise the analogue signals without further processing. The result is shown in figure 9, with the digitised signal in black, and the original signal as an overlay in red. Both are in very good agreement. The similar digitisation levels of two consecutive pulses furthermore demonstrate the synchronisation of the generated signals and the PPM sampling frequency, provided by the Clock Synchronisation Board.

VII. Summary

The presented signal generator is applicable in all fields with need for multiple analogue signals where a blanking space is no drawback, or can be compensated as described. The advantages are multiple, easily programmable signals with acceptable quality at very low expense.

References

[1] Matrox Graphics Inc., User Guide matrox QID Series, 10876-301-0221, 2008.01.11

[2] F. Müller, Rate Metering for the ATLAS Experiment, HD-KIP 08-22, 2008

[3] H. Stenzel, Trigger Tower Analogue Signal Library, November 2001.