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Nucleo based oscilloscope – ADC and time sampling

[1]*Jozef BOŠKO,* [2]*Tibor VINCE,* [3]*Oleksii KRAVETS*

[1,2] Department of Theoretical and Industrial Electrical Engineering , FEI TU of Košice, Slovak Republic
[3] Kremenchuk Mykhailo Ostrohradskyi National University, Ukraine

[1]jozef.bosko@student.tuke.sk, [2]tibor.vince@tuke.sk, [3] mikhalych.83@gmail.com

***Abstract* — In this paper Nucleo usage as an oscilloscope controller is analyzed. First oscilloscope and DSP are described. Focus to ADC is paid and time sampling is described. Then Nucleo platform is introduced. Principle of Nucelo activity and its advantages and disadvantages are described. Later Nucleo and Arduino are compared.**

***Keywords* — ADC, DSP, Nucleo, oscilloscope, sampling**

I. Introduction

Measuring electricity is an important thing, but ordinary devices cannot measure high frequency electrical signals. For such measurements, devices called oscilloscopes are used. Their disadvantage is complex construction and high price. In order to construct a sufficiently precise oscilloscope, several principles must be followed. Depending on the measured electrical signal we need to adjust the sampling rate. At the same time, an analogue signal is measured at the oscilloscopes, so an accurate signal conversion to the digital signal must be sufficiently accurate. These parameters subsequently increase the cost of the resulting device.

II. DSP

A digital signal processor, the DSP (Digital Signal Processor), is a dedicated processor (CPU) for signal processing.

For this purpose, it is used to be equipped with one or more analogue-to-digital converters (A / D converters), digital-to-analogue converters (D / A converters) and an optimized (fast) Arithmetic-logic unit (ALU) usually with a higher number of parallel processed bits than a "classical" processor. Because it is assumed to process input signals and to generate actions for the actuators, it usually has more inputs and outputs, which are multiplexed.

Digital signal processors are widely used. We find them almost in every modern electronic musical instrument, we find them in measuring instruments, control units, In general, their deployment is warranted if another processor is not suitable for price or performance. [1]

III. Oscilloscope

It is a device that faithfully displays the waveform of an electrical signal, mostly a voltage. The oscilloscope is the most commonly used measuring instrument in electronics. When properly used, it provides an insight into the operation of the diagnosed device. However, in the case of misuse, the image it provides can significantly distort the reality. The input signal is, therefore, in the case of conventional Real-time oscilloscope voltage, but otherwise it may be another signal. For example, current from a current probe. Modular oscilloscopes also have an optical module and an input is an optical signal. In any case, oscilloscopes are primarily designed to measure fast signals. Speed is one of the key parameters of an oscilloscope to be able to display the shape of a fast signal. This means that the oscilloscope can achieve a higher sampling frequency, so it can measure more accurately fast changing electrical signals. [2]

IV. Analog to Digital Converter

Electrical voltage is an analogue value, devices that work on a digital principle cannot evaluate the value of the measured value without the auxiliary circuit. To measure and subsequently evaluate the values of the measured analog electrical signals, we must use an analogue to digital converter. This converter provide the conversion of the analog value into the binary code that responds. The binary value can be easily processed using by a computer, microcomputer, microcontroller, or other device. [3][4]

A. Parallet Analog to Digital Converter

The fastest kind of a Analog to Digital converter is a parallel Analog to Digital converter. This is because the entire transfer takes place simultaneously at the same time. The input signal is converted using comparators. They compare it with a reference voltage that is graded according to the resolution of the Analog to Digital converter. For resolution of n bits, the converter need 2^n-1 comparators. With the arrival of the clock pulse, the comparator status is written to the flip-flops circuits. Subsequently, the decoder converts the status of the flip-flops circuits to the resulting numerical value. [3]

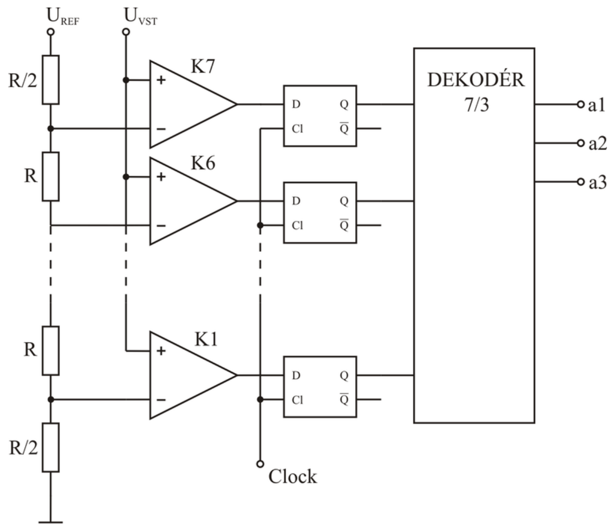

Fig. 1 Paralel A/D Converter

B. Analog to Digital Converter with Gradual Approximation

As the name suggests, this converter converts the Analog value to digital gradually bit to bit. For the example, suppose we have an eight bit converter. At the start of the transfer, the MSB is set to logical 1, and the remaining bits are set at logic 0. The register has a value of 1000 0000, this value corresponds to the reference voltage value. In the comparator, the reference voltage is then compared with the input voltage. If the input voltage is higher than the reference value, Uvst> UREF, the MSB value is left to the logic value 1, otherwise the MSB value is set to logical 0. In the next step, it continues to a lower bit which is again set to logic value 1. The approximate register is now stored at 1100 0000 or 0100 0000. Then, the reference voltage is again compared to the input voltage. This goes on after the LSB. After complete conversion, we have the resulting binary value that matches the size of the input signal. The disadvantage of this converter is that the input signal cannot be changed during the transmission. If this happens, the transfer will not take place correctly. [3][4]

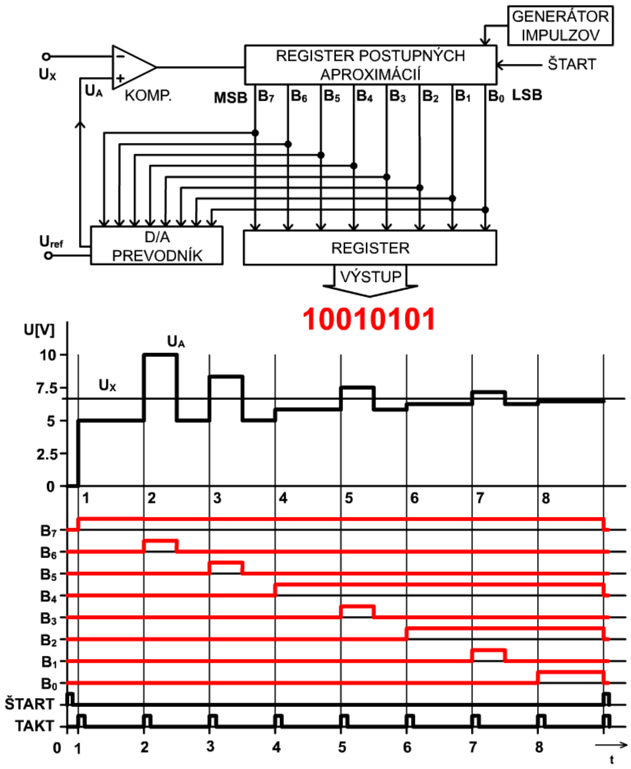

Fig. 2 A/D Converter with Gradual Approximation

C. Integration Analog to Digital Converter

The Integrated Analog to Digital converter works on the principle of charging and discharging the capacitor. At the beginning of the transfer, the reader is reset, the switch is switched to position 1. After switching the switch, capacitor C is charged and the counter is started to count. This step is illustrated in the following figure (0; T1). After charging the capacitor, the counter is reset and the switch is switched to position 2. The capacitor is connected to a reference voltage but it has the opposite polarity as the input voltage, so the capacitor starts to discharge, and the counter is started to count again. The counter stops when the comparator evaluates that in capacitor C is zero voltage. This corresponds to time t = T2. The total time period is determined by a certain number of impulses of the pulse generator.[4]

$$T_2 - T_1 = \frac{N_x}{f_0} \tag{1}$$

N_x - counts counted impulses
f_0 - represents the constant pulse frequency

At time T_1, the n-bit binary counter counts 2^n of pulses

$$T_1 = \frac{2^n}{f_0} \tag{2}$$

The number of these pulses is the final value of the Analog to Digital converter.

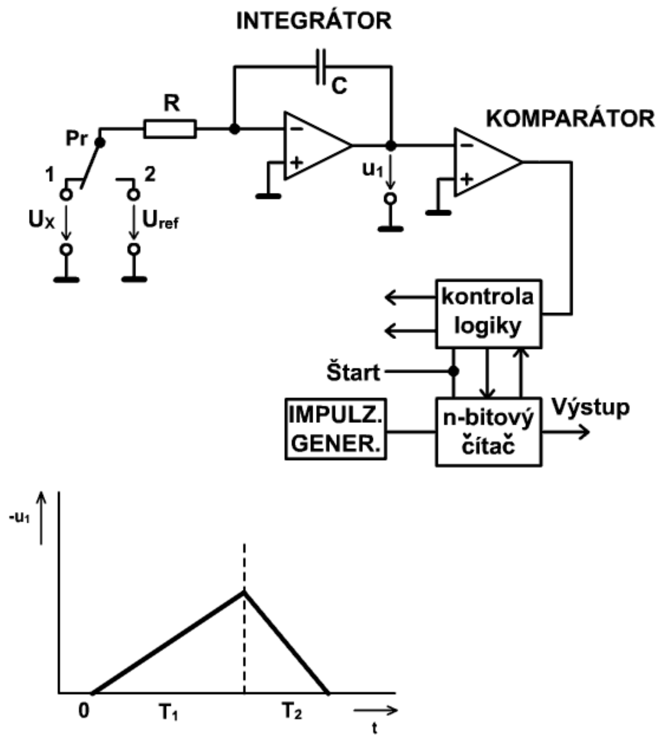

Fig. 3 Integration A/D Converter

D. Analog to Digital Converter in Arduino Due

The SAM3X / A architecture is specially designed for use in high-speed applications. Therefore includes multilayered field bus matrix and a number of SRAM, PDC and DMA channels that are able to process parallel running tasks with maximum data throughput.

This microcontroller is used on the Arduino Due platform and is based on the 32-bit ARM® Cortex®-M3 processor. Its maximum clocking rate is 84MHz, it has 512KB flash memory and 96KB SRAM memory. Integrated multiplexer Offers 16 independent analog inputs.

SMARTSAM3X / A contains a 12-bit Analog to Digital Converter (ADC) that is controlled by an ADC controller. The conversion is carried out in the range of 0V to ADV_{REF}. Analog values in this range at thr analog inputs are converted linearly. The entire reference voltage range is generated internally from one external reference voltage node that can be equal to the analog power supply voltage. No For noise filtering is required an external capacity separation.

The ADC supports two modes of operation, 10 and 12 bit modes. Conversions of active analogue channels are triggered by a software or hardware trigger. The software trigger is realized by writing the START bit on 1 in the control register. The hardware trigger can be an external signal to the ADC input (ADTRG). The minimum time between two consecutive trigger events must be greater than the duration of the longest conversion sequence. If a hardware trigger is selected, the conversion starts after a delay beginning at the leading edge of the selected signal. ADC hardware logic automatically performs conversions on active channels and then waits for a new request.

The tracking phase begins during the transfer of the previous channel. If the tracking time is longer than conversion time, the tracking phase is prolonged and begins after the previous conversion. After completion of the conversion, the resulting 10 or 12-bit digital value is stored in the current data channel register and in the last converted data register [5].

V. Time Sampling

A. Real-time sampling

PAM (Pulse-Amplitude Modulation) samples are taken from the input signal for the duration of its one period. These samples are remembered and then how they remember they are reproduced. This sampling is based on the Schenon-Kottelnik (Nyquist) theorem, which states that the sampling signal frequency must be twice greater than the signal frequency. For the practical use of this theorem in digital oscilloscopes, the sampling signal frequency must be at least 4 times greater than the sample signal frequency to maintain the amplitude, phase and frequency with minimal error. For illustration figure Fig. 1b, shows that when using two samples, the dashed sine wave has a longer period, i.e. a lower frequency, and smaller amplitude than the unchecked sine wave. With four samples per minute during the sine wave signal tracking, the error is small, but when monitoring the recurrence waveform signal, it is displayed as a sinusoidal signal. This occurs if we monitor signals with a frequency close to the upper limit frequency of an oscilloscope (as well as an analog oscilloscope).

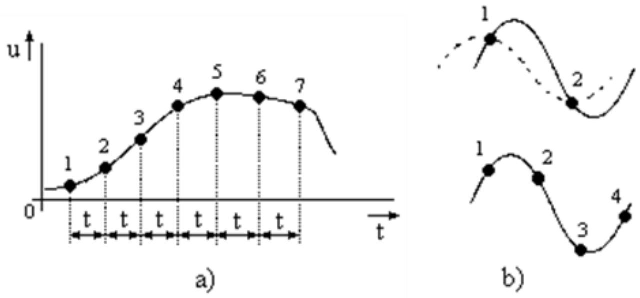

Fig. 1 Real-time sampling

B. Repeated Sampling - Random

In this sampling, the sampling signal has a precisely defined frequency, and PAM sampling takes place over several input signal periods. For each sample PAM, the time span from the trigger point is recorded. This is different for different samples. Upon reconstruction of the signal, the sample data is sorted according to increasing time offsets to the appropriate order. Random sampling also takes place before the trigger point ("negative time"). This is shown in figure Fig. 2b.

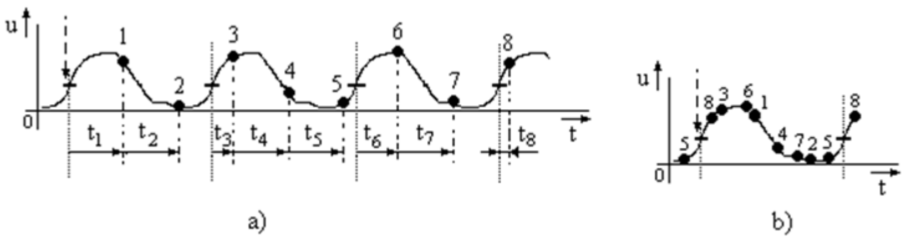

Fig. 2 Repeated Sampling - Random

C. Repeated Sampling - Sequential

Here, only one PAM sample is obtained from one input signal period. In each subsequent period, PAM sampling is delayed by the same time Dt. After removing a certain number of samples, they are memorized and re-plotted according to the increasing time span from the trigger point to the appropriate order. For clarity, the process is illustrated in figure Fig. 3b.

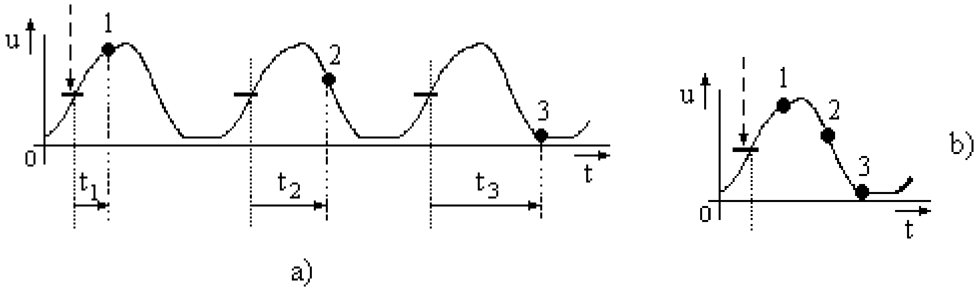

Fig. 3 Repeated Sampling - Sequential

Unlike random sampling, we can´t get the run-in before the trigger point ("negative time"). This sampling allows for a very accurate reconstruction of the input signal and allows for relatively slow A/D converters with better resolution. [8]

VI. MBED

The mbed development platform is the fastest way to create products based on ARM microcontrollers. The project is being developed by ARM, its Partners and the contributions of the global mbed Developer Community. In practice Mbed is online compiler tool. This means that for use it is necessary have a Internet connection. Applications for the mbed platform can be developed using the mbed online IDE, a free online code editor and compiler. Only a web browser needs to be installed on the local PC. The mbed IDE provides private workspaces with ability to import, export, and share code with distributed Mercurial version control, and it can be used also for code documentation generation. Applications can be developed also with other development environments such as Keil µVision, IAR Embedded Workbench, and Eclipse with GCC ARM Embedded tools.

The mbed software development kit (SDK) provides the mbed C/C++ software platform and tools for creating microcontroller firmware that runs on smart devices. It consists of the core libraries that provide the microcontroller peripheral drivers, networking, RTOS and runtime environment, build tools and test and debug scripts.

A components database provides driver libraries for components and services that can be connected to the microcontrollers to build a final product. [12]

VII. STM32 NUCLEO

STMicroelectronics STM32 Nucleo Development Boards provide an affordable and flexible way for users to try out new ideas and build prototypes with any STM32 microcontroller line, choosing from the various combinations of performance, power consumption, and features.

The Arduino connectivity support and ST Morpho headers make it easy to expand the functionality of the STM32 Nucleo open development platform with a wide choice of specialized shields.

The STM32 Nucleo board does not require any separate probe as it integrates the ST-LINK/V2-1 debugger/programmer. It comes with the STM32 comprehensive software HAL library together with various packaged software examples and direct access to mbed online resources.[10]

A. Features

- Two types of extension resources
  - Arduino Uno Revision 3 connectivity
  - STMicroelectronics Morpho extension pin headers for full access to all STM32 I/Os
- On-board ST-LINK/V2-1 debugger/programmer with SWD connector
  - Selection-mode switch to use the kit as a standalone ST-LINK/V2-1
- Flexible board power supply
  - USB VBUS or external source (3.3 V, 5 V, 7 - 12 V)
  - Power management access point
- User LED (LD2)
- Two push buttons: USER and RESET
- USB re-enumeration capability: three different interfaces supported on USB
  - Virtual Com port
  - Mass storage (USB Disk drive) for drag'n'drop programming
  - Debug port

B. Nucleo F446RE features

- STM32F446RET6 in LQFP64 package
- ARM®32-bit Cortex®-M4 CPU with FPU
- Adaptive real-time accelerator (ART Accelerator™) allowing 0-wait state execution from Flash memory
- 180 MHz max CPU frequency
- VDD from 1.7 V to 3.6 V
- 512 KB Flash
- 128 KB SRAM System
- 4 KB SRAM Backup
- Timers General Purpose (10)
- Timers Advanced-Control (2)

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- Timers Basic (2)
- SPI (4)
- I2S (2)
- USART (4)
- UART (2)
- USB OTG Full Speed and High Speed
- CAN (2)
- SAI (2)
- SPDIF-Rx (1)
- HDMI-CEC (1)
- Quad SPI (1)
- Camera Interface
- GPIO (50) with external interrupt capability
- 12-bit ADC (3) with 16 channels
- 12-bit DAC with 2 channels

Picture of Nucleo F446RE for illustration purpose is shown in Fig. 4. Nucleo F446RE pinout is shown in Fig. 5.

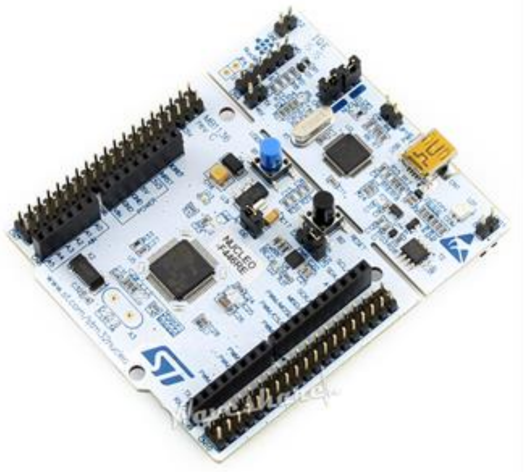

Fig. 4 Nucleo F446RE

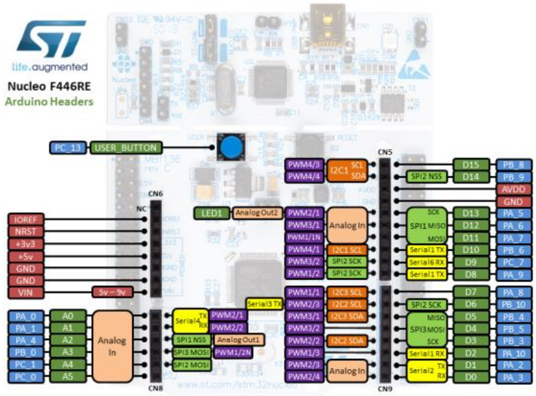

Fig. 5 Nucleo F446RE pinout

VIII. NUCLEO VS ARDUINO

As the best competitor for Nucleo we can choose Arduino Due. Arduino now has a wider spread and a very active community, but also the NUCLEO series looks so promising. NUCLEO board hasn't an external EEPROM memory and even the micro STM32 hasn't an internal EEPROM memory to store permanent variables in case of board reboot, while Arduino can count on Atmel microcontroller EEPROM. In addition, NUCLEO lacks of an external power connector in case we want to use shields requesting a power voltage above 5V or an external power supply. The comparison between NUCLEO board and Arduino DUE is harsher because they mount the same family of microcontrollers (ARM

Cortex-M), but the NUCLEO has a Cortex-M4 despite of the Cortex-M3 on Arduino DUE and has the floating-point unit too.

So in case you wish to use algorithms that use floating-point heavily, the C code will be written in the same way on both boards but the compiler for Cortex-M4 will generate far fewer instructions which will be executed quicker and also with significant performance increase in term of low memory footprint. Arduino DUE has a larger number of I/O modules, but those pins can't bear (if configured as input) voltages above 3.3 V, limiting the use of Arduino shields that request 5 V.

Both microcontrollers have the same internal flash memory size as 512 KB. With memory, Sram has the advantage of Nucleo, which has more than a quarter of its memory over Arduin Sram. 128 KB (+ 4 KB) versus 96 KB. Processor speed has a higher Nucleo, 180 MHz versus 84 MHz. Both use the 12-bit Analog-Digital Converter and 12-bit Digital-Analogue Converter, with the difference that Nucleo has 3 Analog-Digital Converters.

IX. CONCLUSION

In this paper topics of ADC and time sampling are described. These are key problems of oscilloscope. The main goal of the project is to build an custom oscilloscope based on DSP net expensive microcontroller like Nucelo or Adruino Due. To achieve maximal efficiency, problems of ADC and time sampling need to be discussed. Nucleo is described and explained its benefits, and so pointed out why the Nucleo is chosen as the main part of the project. In the next continuation of the work it is necessary to address the measurement itself and the problems that are associated with it. For example, this project will probably have a problem with the amount of measured data. Because the oscilloscope should be as fast and accurate as possible, the amount of data will be high. This places requirements on the size of the internal memory and its use. After designing the software solution, it is also necessary to focus on the hardware part. It is necessary to construct auxiliary circuits that will allow the Nucleus to measure the input signals through the internal Analogue-to-Digital Converter of the Nucleo.

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