Analogue Coprocessor

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Abstract

The goal of the project was to construct and test an analogue coprocessor for control systems. The concept was to try to execute on it some of the mathematical operations, which are difficult to perform on a digital device. During the project module intended to perform integration was designed, built and tested. Schmitt inverter based oscillator and a DAC from Boufallo Labs BL702 SoC were used as the input signal sources. Output was observed with the use of laboratory oscilloscope and virtual oscilloscope built with Arduino Nano ADC. Due to failing in implementing proper circuit, concepts of solving ODE and building a programming interface to a device were considered theoretically.

Intermediate Project
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1 Description of a project

The goal of the project was to construct and test an analogue coprocessor for control systems. The concept was to try to execute on such machine some of the mathematical operations, which are difficult to perform on a digital device. An example of such operation is integration, which needs a large amount of iterations, when performed using numeric algorithms. On the other hand, analogue integrating circuit can be easily built. Moreover, processing of the input signal comes with no latency. Also the power consumption of such circuit should be lower then any digital implementation. This features are especially important for robotic applications. During the project module intended to perform such operation was designed, built and tested.

2 Integrating module

Integration is an operation, which can be easily implemented with the use of analogue circuitry. Moreover, integrating circuits can be connected in a way which allows to solve ordinary differential equations, what is an important problem in a field of robotics and control engineering. With the use of Autodesk Eagle software module performing such operation was designed. Moreover, it is not an ordinary integrating circuit, but a modification, which allows to put several inputs, which will be added before an integration. As the circuit inverts the polarity of a input signal, it is followed by a inverting amplifier. Gain of an output is controlled with two variable resistors. Schematic of the integrating-adding circuit along with the inverting amplifier was presented on a figure 1. Input and outputs connections can be seen at figure 2. Designed printed circuit board is at figure 3.

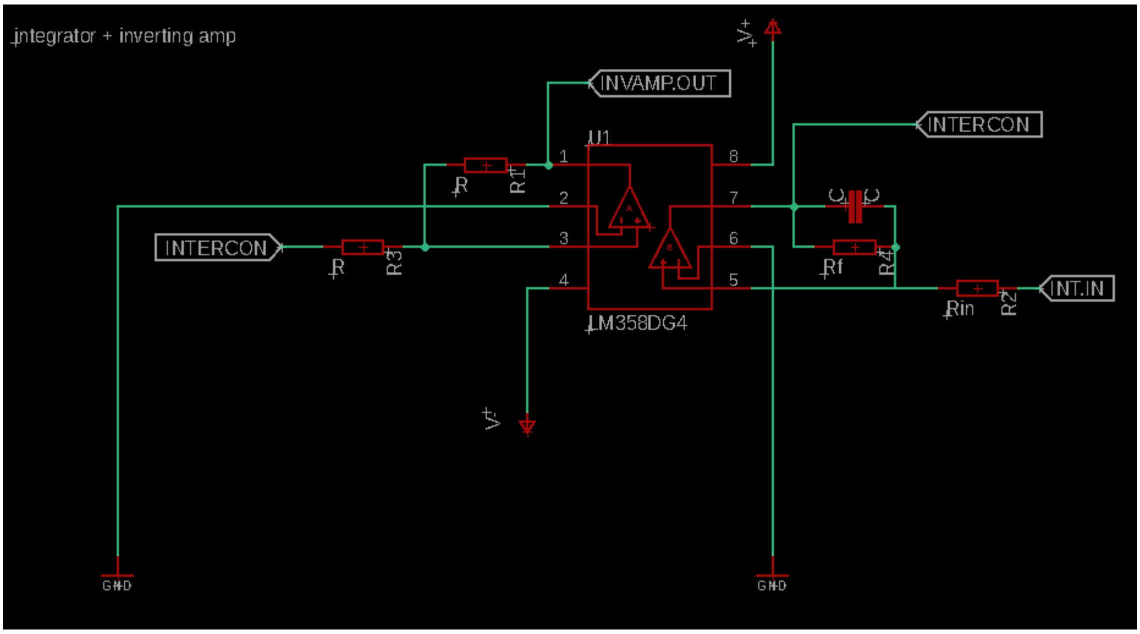

Figure 1: Schematic – integrating-adding circiut and inverting amplifier

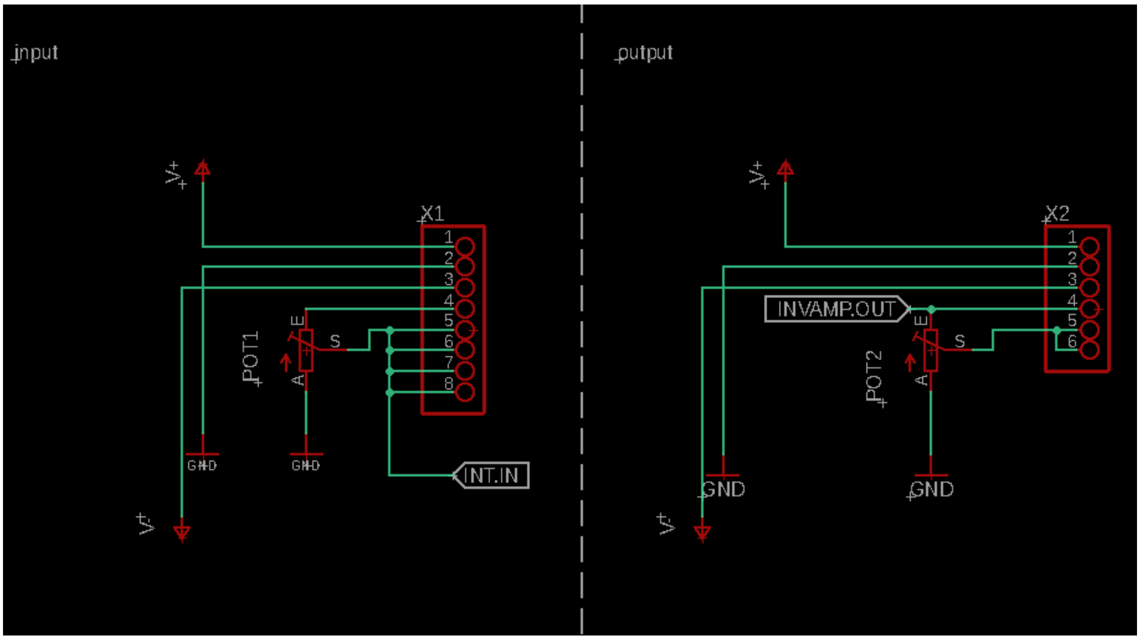

Figure 2: Schematic – input and output connections

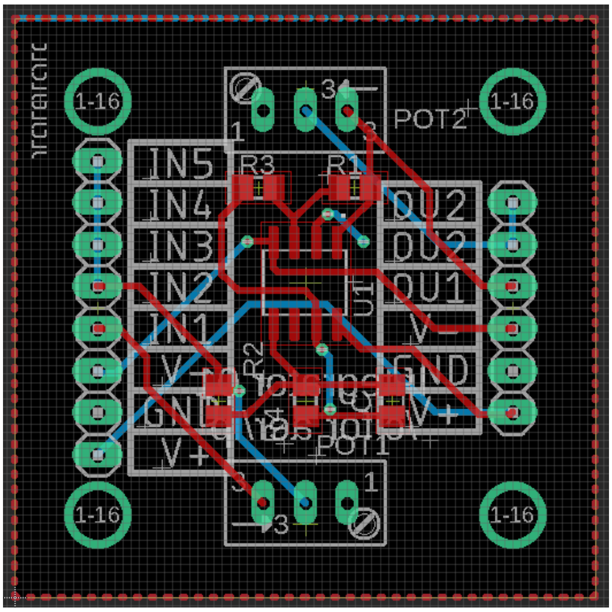

Figure 3: PCB design

Before ordering the board in a manufacture simulations were run with the use of Paul Falstadt circuit simulator (2). As one can see on a figure 4, output signal indeed is a integral of an input (lowest plot is an input, the one above it – an output). Although that simulation could lack some real life physical effects (noise, non-ideal amplifiers), it could give some intuition that the circuit should work as expected. After the design and simulation stage, PCB was ordered and later soldered. Ready board was presented on a figure 5.

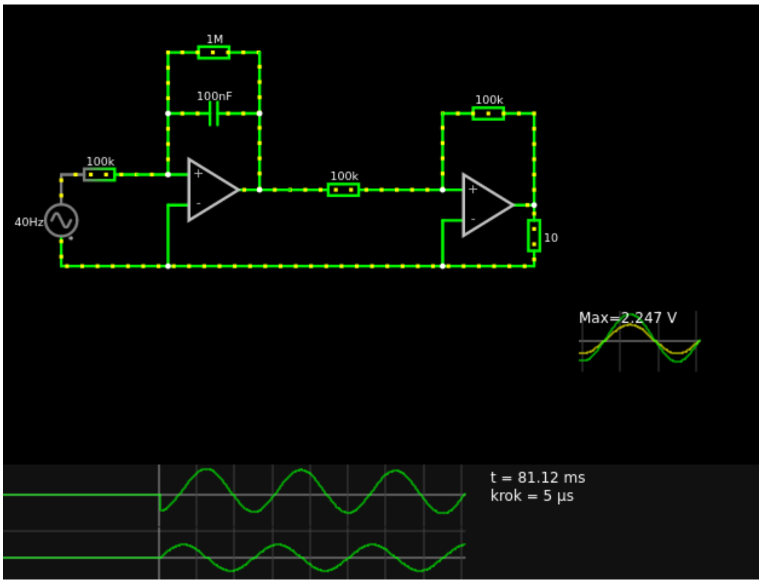

Figure 4: Simulation results

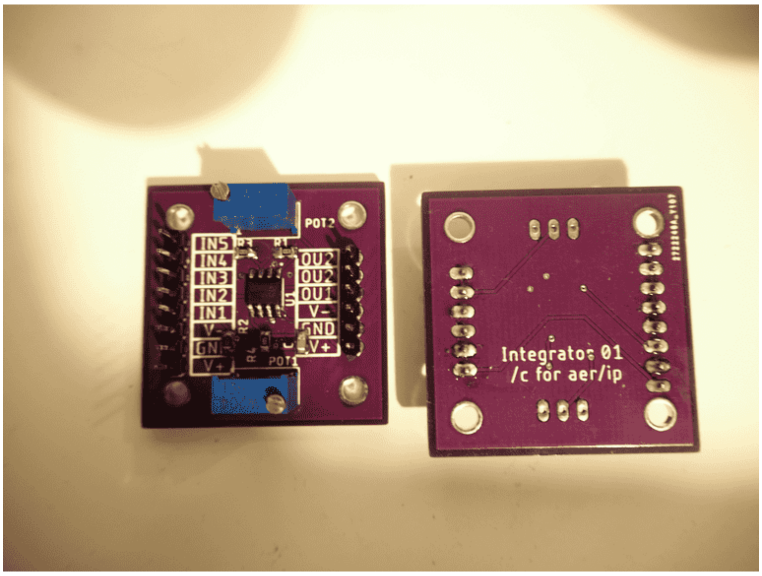

Figure 5: Soldered PCBs

3 Testing the module

3.1 Testing set

As the module is designed as a coprocessor for embedded circuits, it should be able to take an input signal from a microcontroller or some external source (for example from a set of sensors) and write output to the microcontroller. As the module operates on analogue signals, they need to be properly prepared. For an input, digital-analogue converter was used, and output was converted from analogue to digital. XT-ZB1 develompent board was used as the source of an input signal. It is based on a BL702 SoC from Boufallo Labs (1). It was especially interesting, as the chip is not very popular outside China, despite of being build with a RISC-V architecture and having wide range of peripherals. The software was prepared with the use of a software development kit given by a manufacturer. Another tested input signal generators were schmitt inverter oscillator circuit and a photodiode. Output signal was connected to a analogue port in an Arduino Nano and then converted to digital signal, which was send through an UART to a linux personal computer. At the linux machine, there was running a program which draws samples from `/dev/ttyUSBx` in a oscilloscope-like manner, so that signal could be analyzed by a tester. To do that, Simple Device Model framework was used.

3.2 Results of the tests

First tests includes connecting test input signal sources directly to the ADC of an Arduino Nano and observing how the peripheral would perform. At high frequencies sampling rate is too low and the software is not able to recreate the proper shape of a signal. For the lower frequencies it works with acceptable accuracy. Photos of the working virtual oscilloscope were included at figures 6 and 7. Both input signal sources and virtual oscilloscope (thus the ADC) proved to have been working correctly, although in a more advanced application (for example in a control system, that need to update the output signal with high frequency) there will be need to choose accurate enough DAC and ADC, possibly with the use of external modules.

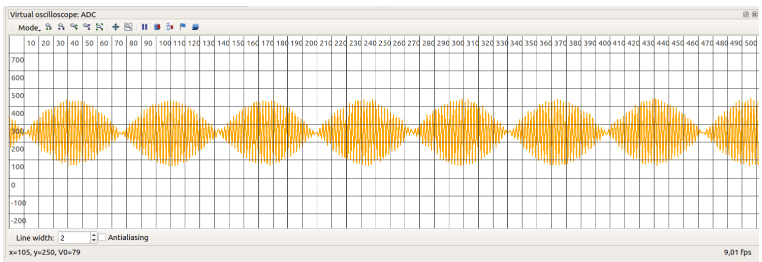

Figure 6: Virtual oscilloscope – signal from a BL702 DAC peripheral

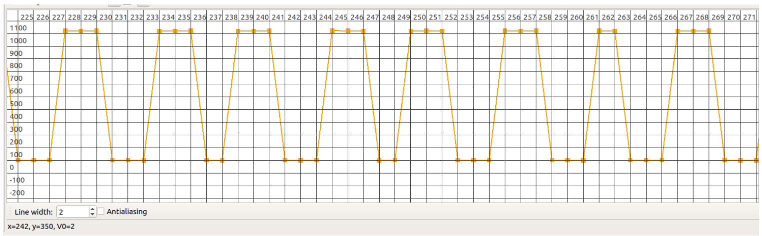

Figure 7: Virtual oscilloscope – square signal from a schmitt inverter based oscillator

After initial tests, integration module was connected after the input signal generator. On a virtual oscilloscope the output appeared to look noisy and it was not easy to recognize the shape of an outcome wave. Thus the laboratory oscilloscope was connected to the output of the module. Results was not as expected. Instead of integration, output signal had shape of the differentiated input. Photos of the oscilloscope were included below. On figure 8 one can see square signal from a schmitt inverter based oscillator and the output response of the module. Spikes which are going to the negative and positive limit voltage can be observed. On a figure 9 slightly different input signal and the corresponding output was presented.

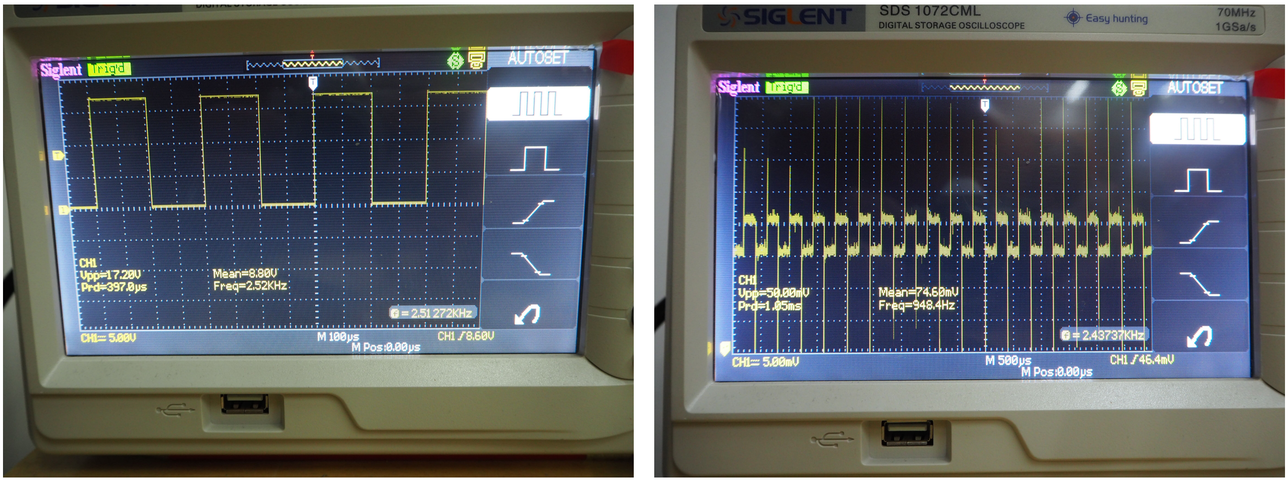

Figure 8: Input square signal and the corresponding output of the module

Despite of the different operation that is performed by the module, current measurements were performed. They should not vary much in case when the amplifier would be integrating, as it was intended to be – the gain of the module has not been changed. As the source was symmetrical, power was added from negative and positive power supply wires measurements.

$$8.71\ \text{V} * 1.162\ \text{mA} = 10.12\ \text{mW},$$
$$8.53\ \text{V} * 1.088\ \text{mA} = 9.28\ \text{mW},$$
$$10.12\ \text{mW} + 9.28\ \text{mW} = 19.4\ \text{mW}.$$

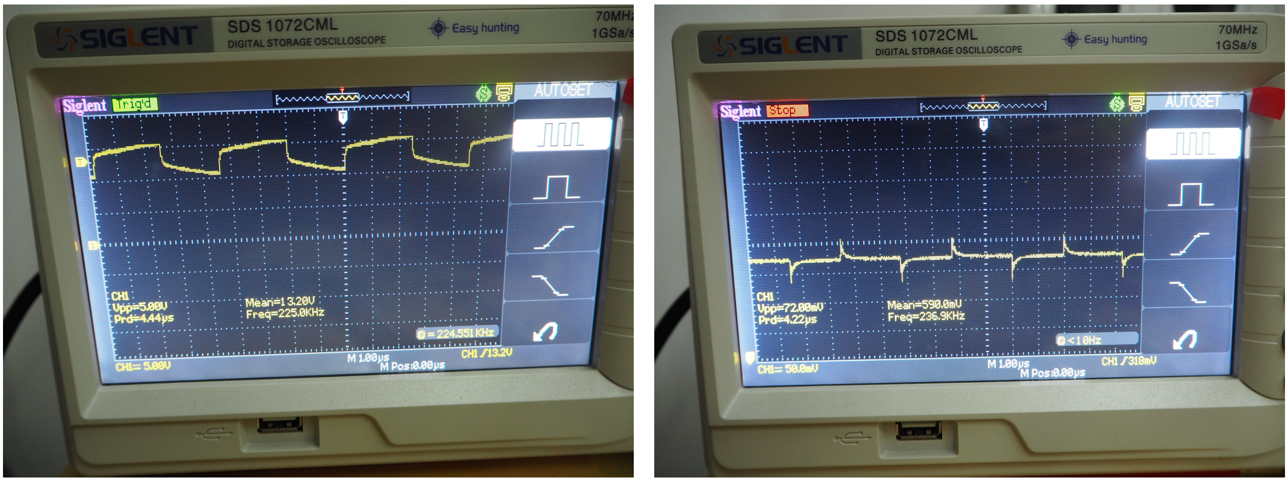

Figure 9: Second input signal and the corresponding output of the module

4 Conclusion

The power consumption of the module proved to be very low – only about 20 mW. It proves that the idea of using it as a coprocessor for embedded or low-power applications is reasonable. The other thing is that as the circuit is analogue, the resolution of an output is unbounded. The quality of measurements depends only on an ADC and a DAC parameters. The best results would be accomplished for purely analogue systems. For example: control system, that would take some signal from the analogue sensor as a reference signal and convert it (by solving a differential equation) into the output, which would directly control an actuator. Such system could have high accuracy and be low-power, which would allow to supply it from the solar panels or other renewable energy source and to work fully autonomously for a long period of time, even if it would be constantly working. Moreover, such control system could be small and cheap in production, as it would consist only of basic components as capacitors, resistors and operational amplifiers.

5 Towards the general-purpose analogue computer with programmable interface

Constructed circuits was designed to be capable of integrating, but they were also designed in a way, that they could be connected in a chain, which would allow to integrate a signal more then once. As they have a mechanism of summing each input (up to 5 can be connected), they have everything needed to solve the ordinary differential equations. Let us analyze an equation

$$u = a\,\dddot{y} + b\ddot{y} + c\dot{y} + dy,$$

$$\dddot{y} = -\frac{1}{a}(b\ddot{y} + c\dot{y} + dy - u).$$

From that, the following diagram can be build:

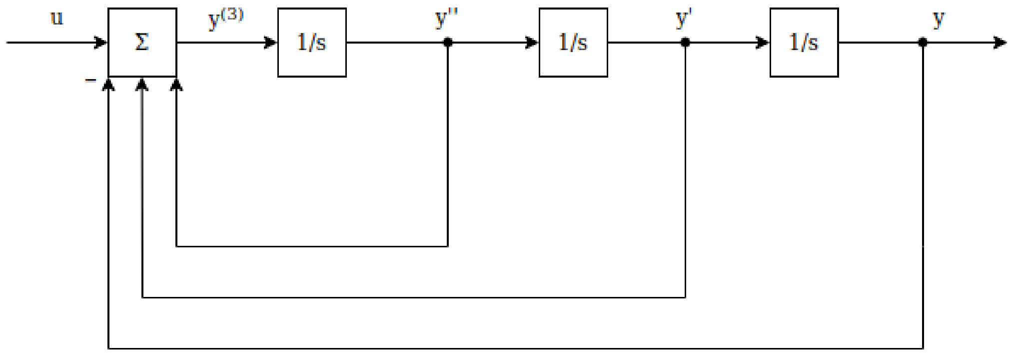

Figure 10: ODE solver scheme

From figure 10 it can be concluded that equations of such type can be solved using proposed modules. However, for different types of equations, structure of connected modules would be different. Setting it up by hand and connecting modules with wires is inconvenient. Another problem is that constants (a, b, c, d ...) are being set through adjusting variable resistors. Perfect solution would be to have an interface to setting both constants and interconnections from a microcontroller. It was not fully developed during the project, but it is planned to do so. Instead of variable resistors, digital potentiometers would be used. For configuration of the interconnections, analog switch array would be used – in fact, first tests already have been made, with mt8816 chip. Such interface would assure flexibility in a coprocessor design.

References

[1] BL702 overview. `https://www.bouffalolab.com/bl70X`.

[2] Paul Falstad electronic circuit simulator. `https://falstad.com/circuit/`.

[3] Resources of the Analog Museum. `http://analogmuseum.org/english/library.html`.

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[5] G. Cowan. A VLSI Analog Computer / Math Co-processor for a Digital Computer.

[6] J. Baranowski, Z. Nosal. Układy Elektroniczne.

[7] S. Ulmann. Handbook of Analogue Computing.