Open Hardware Analog Computer for Education – Design and Application

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***Abstract*—Nowadays, most technical study courses in universities and similar institutions focus on digital computation and signal processing. Accordingly, graduates have some kind of tunnel vision because they have been trained to think of digital computation as a panacea for all problems encountered in real life.**

As digital computing is nearing basic physical boundaries with respect to integration densities and energy consumption it is important to extend the curriculum in computer science to include unconventional computing approaches such as analog computing.[1] Therefore it is necessary to give students and hobbyists as well the opportunity to get some hands-on-experience with analog computers. Since classic analog computers have become museum pieces, there is a need for a modern cheap and small analog computer, which can be used not only for teaching analog computer programming but can also be used in mathematics education to give students an intuitive grasp of dynamic systems and differential equations. Other fields of application are the engineering sciences, life sciences and basically all fields of technology where differential equations play a crucial role.

This paper describes such an analog computer, called *THE ANALOG THING*, which has been developed to satisfy the above requirements. This analog computer is cheap (about 300 EUR) and versatile. Several of these computers can be coupled together to form a larger machine, and can also be used as part of a hybrid computer setup. The key design decisions are outlined and several problems suitable for class room use are described.

***Index Terms*—analog computer, education, open hardware**

I. Introduction

Currently, there is a significant lack of expertise regarding analog electronics in general, and analog computing in particular in our school and university curricula. Due to the basic limitations of digital computers regarding integration densities, power consumption, and parallel scalability unconventional computing approaches such as quantum computing and analog computers will play crucial roles as co-processors for traditional stored program digital computers.

Accordingly it is of vital importance to incorporate these computing paradigms into todays university curricula. A cheap, versatile, and powerful open hardware platform for analog computing is therefore required. This platform, which is described here is called *THE ANALOG THING*, *THAT* for short, and shown in figure 1.

[1] A thorough introduction to analog computing can be found in [1].

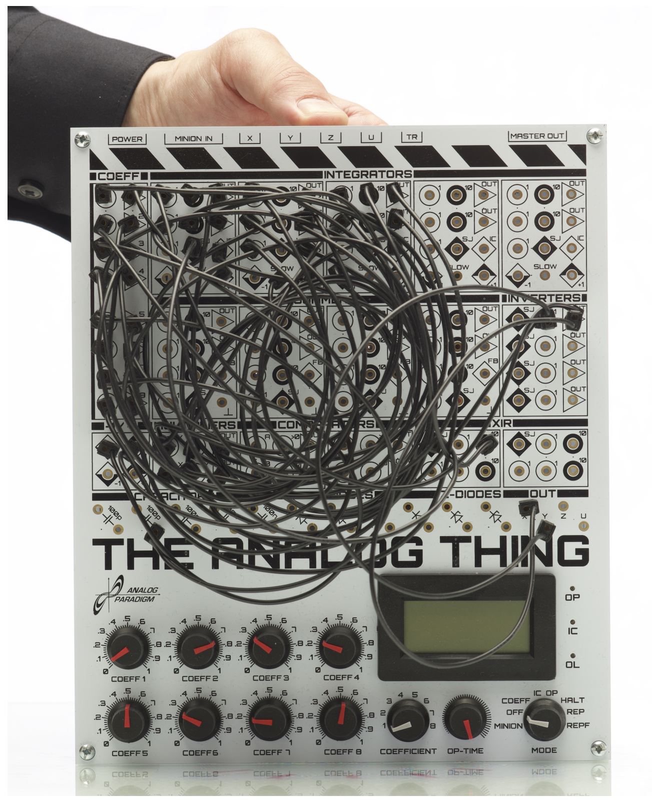

Fig. 1. *THE ANALOG THING*, a small, versatile, and cheap analog computer

II. Characterstics

THE ANALOG THING contains enough computing elements so that moderately complex programs can be implemented. The computer has

- five integrators with three inputs weighted with 1 and three inputs with weight 10 and two selectable time constants $k_0 = 10$ and $k_0 = 10^3$,
- four summers, also with three 1-inputs and three 10-inputs,
- four dedicated inverters,
- two comparators,
- two four-quadrant multipliers,
- eight manual coefficient potentiometers,

- two free resistor networks and
- several free diodes and capacitors.

In addition to this, the computer also has a digital readout for setting coefficients, reading variables etc. and supports not only manual control but also iterative operation. This makes it possible to solve differential equations in rapid succession, resulting in a stable picture on an oscilloscope of the behavior of a problem as parameters are changed.

III. Construction

The computer itself is built from two printed circuit boards, PCBs: One is the *FRONT* panel which not only contains the jacks for the patch cables but also most of the passive computing elements such as the precision resistor input networks for summers and integrators. The jacks are plated through-holes suitable for 2 mm banana plugs.

The second PCB is called *BASE* and contains the electronics for the computing elements and the manual control and readout. Mounted between FRONT and BASE is a sheet of acrylic glass which acts as a physical stop for the plugs, to guarantee that the plugs contact the through-hole plating at their thickest diameter. This significantly helps to reduce the cost of the overall system as individual 2 mm jacks aren't required. FRONT and BASE are connected by two 50 pin connectors.

The system is powered by an external 5 V USB power supply and needs a maximum of about 350 mA. All internal voltages (± 12 V for the analog circuits, ± 10 V as reference voltages, and 5 V for the digital control logic) are derived from this power source by means of a DC/DC-converter.

Although we expect that most *THAT* systems will be bought as fully assembled device, the open hardware concept (all schematics, layout data etc. are publicly available) allows hobbyists and other interested groups to build their own analog computers. The system is built mainly from SMD components with some through-hole components, such as the manual coefficient potentiometers and the mode and selector switches. Most of the passive components have 0805 form factor and the integrated circuits are all in SOIC packages.

IV. External connections

Interfacing an analog computer to external devices is quite straightforward due to its voltage representation of values. To simplify things further, *THAT* features five RCA phono sockets on the rear, four of which are connected by means of $1:10$ voltage dividers to jacks at the patch field while the fifth connector provides a signal which can be used to trigger an oscilloscope or a data logger at the start of a simulation run.

The voltage dividers ensure that typical output values are roughly between ± 1 V and can thus safely be connected to a sound card, enabling any computer with sound input to be used as a cheap alternative to an oscilloscope.

In addition to these signals the computer also features a dedicated connector labelled *HYBRID* which makes it possible to control the analog computer's operation with an external digital computer such as an *Arduino* or a *Raspberry Pi* board. The four output signals available at the Cinch connectors are also fed to this connector and are level-shifted to a voltage range of $0 \dots 3.3$ V so that they can be connected directly to typical modern analog inputs of boards like those mentioned above.

If one *THAT* is not sufficient for a certain problem, several of them can be daisy-chained into a larger system by using the dedicated *Master* and *Minion* connections.

V. Applications

THE ANALOG THING can be used for a wide variety of applications, such as:

- the introduction to differential equations and systems thereof with examples ranging from simple such as the simulation of radioactive decay up to more complex problems such as Mathieu's equation or a van der Pol oscillator,
- the simulation of dynamic systems (eg. reaction kinetics in (bio-)chemistry),
- the implementation of chaotic systems such as Lorenz or Rössler attractors,
- game-like applications such as a bouncing ball in a box or variants of "Tennis for Two",
- the simulation of eco-systems,
- the simulation of the spread of diseases,
- the simulation of engineering systems,
- the study of control systems,
- physical problems such as the one-dimensional Schrödinger equation and many more.

VI. Resources

Detailed information about this small analog computer can be found at https://the-analog-thing.org and a dedicated Wiki at https://the-analog-thing.org/wiki/. News about the system are disseminated by means of newsletters which can be found at https://the-analog-thing.org/newsletter/.

Since *THE ANALOG THING* is an open hardware project we encourage and welcome everyone and every institution interested in unconventional computing in general, and in analog computing in particular, to actively participate in further developments and applications of this machine. We hope to establish a healthy and growing community with many ties to other, already well established communities such as the Arduino world, the Maker scene and many more. Happy analog computing, everyone!

References

[1] Bernd Ulmann, *Analog and Hybrid Computer Programming*, De-Gryuter, 2020

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