# Model-1.1

## User manual[1]

Prof. Dr. BERND ULMANN, 07.10.2019, Version 1.1-1

# 1

# Introduction

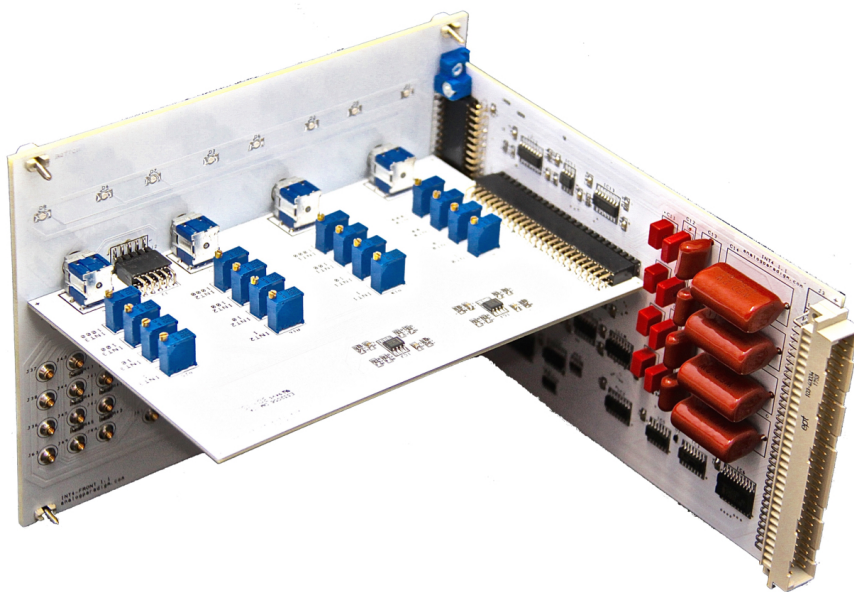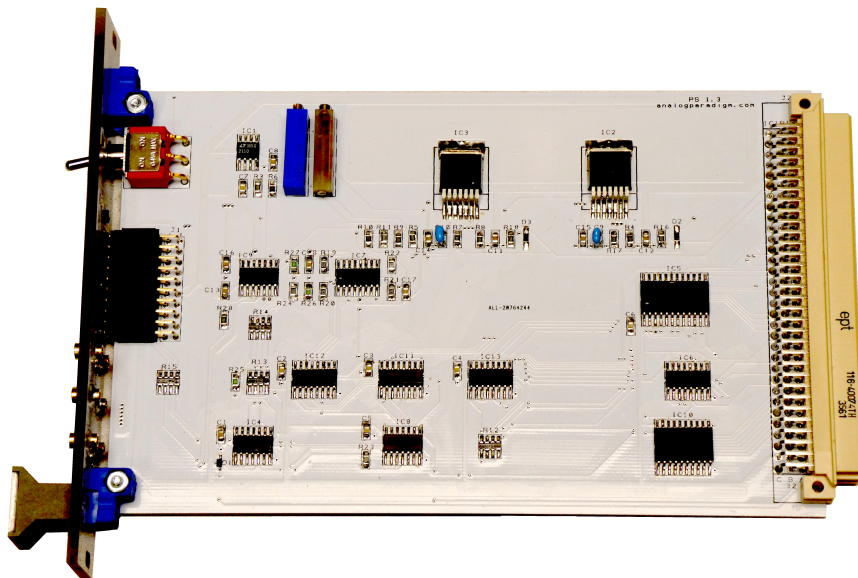The Analog Paradigm "Model-1.1" analog computer is a modern modular analog computer. It is ideally suited for universities and research labs. This system was developed from 2015 to mid 2019 and makes extensive use of modern integrated circuits which results in low power consumption and small size. Figure 1.1 shows two typical modules as an example of the technology employed: On the top the precision voltage reference (PS) can be seen, while the bottom picture shows the quad-integrator module INT4.

All modules are based on "Euro standard cards" $(100 \times 160 \text{ mm}^2)$ and plug into standard 19-inch chassis which are equipped with an Analog Paradigm backplane. The interconnection between the various computing modules is done using patch cables equipped with standard 2 mm banana-plugs.

A detailed description of the principles of operation of the various computing elements shown in the following can be found in chapter 2 of [ULMANN, 2017].[1] [ULMANN, 2013] gives a comprehensive account of the history and basics of analog computing. Other useful resources are [CARLSON et al. 1967] and [GILLILAND 1967].

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[1]A copy of this book will be shipped with every Analog Paradigm analog computer.

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Figure 1.1: Typical computing modules

# 2

# Modules

The Model-1.1 analog computer is a modular system which can be expanded from a basic entry-level system consisting of two chassis to larger systems containing four and even more chassis. Each group of up to four chassis holding computing elements requires a dedicated power supply and precision voltage reference. The first group also requires one control unit CU. Table 2.1 lists the module complement of a minimum system.

Summers, integrators, and the voltage reference unit PS can generate overload conditions which will be displayed on the front of the affected module by a red LED. In addition to this the control unit can be set into a mode where an overload condition will halt the current computer run. Such an overload condition is typically the result of erroneous patching and/or scaling of the analog computer program. It does not harm the computer, it only impacts the validity of the solution generated.

## 2.1  Power section

The power section consists of two units: An external laptop-type 24 V power supply which connects to a jack on the back of the upper chassis and the PS module which not only contains the power switch but also yields the precision reference voltages of $\pm 10$ V. Up to four chassis holding computing elements can be powered by a single external power supply and a PS module.[1]

Figure 2.1 shows the front panel of the PS module. The two groups of three 2 mm jacks each allow access to ground (GND) and the $\pm 10$ V machine units. An overload will be displayed by means

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[1]The small configuration of the Model-1.1 analog computer as described here consists of two chassis. It can extended later to include more chassis and computing elements if required.

| Name | Description | Remarks |
|------|-------------|---------|
| NT | External 24 V power supply | One per system |
| PS | Precision voltage reference | One per system |
| CMP4 | Four comparators with electronic switches | |
| PT8 | Eight buffered coefficient potentiometers | |
| CU | Control Unit | One per system |
| MDS2 | Dual multiply/divide/square root | |
| XIR | Free resistor networks | |
| XID | Free Diodes | Optional |
| XIBNC | BNC-Adapter | Optional |
| MLT8 | Eight multipliers | MDS2 as an option |
| SUM8 | Eight summers | Four can be used as open amplifiers |
| INT4 | Four integrators with four time constants each | Two can be controlled individually |

Table 2.1: Module complement of a typical small system

of two associated LEDs on the front panel if any of these outputs is overloaded by a short to ground or a short between the machine unit outputs which should generally be avoided.

## 2.2  Control unit

The control unit (CU), shown in figure 2.2, is the heart of the analog computer as it controls the overall operation of the system's integrators as these are the only computing elements which are time dependent. An integrator can be in one of the three following states at any time:

**Initial condition:** Here, the integrator's output is set to the negative of the value present at its initial condition input, *IC*. The following integration operation starts with this value.

**Operate:** During this mode, *OP*, the integrators will integrate over the weighted sum of their respective inputs (with implicit change of sign).

**Halt:** The integration operation is (temporarily) halted and the integrators' outputs keep their last value. Due to unavoidable drift effects, the output value will change slowly. Accordingly, this state (*HLT*) should not be active for prolonged periods of time (several seconds).

The CU allows the following modes of operation of the analog computer:

**Manual control:** This is the simplest mode of operation: The states IC, OP, HLT are controlled by pushing the buttons labelled INITIAL and OP/HALT, respectively.

**Single run:** Here, the CU will automatically enter the states IC, OP, and HLT for predetermined time intervals. The IC-interval can be selected to be either long or short, depending on the lowest time scale factor selected at the integrators of a computer setup. If all integrators are set to a time scale factor $k_0 \geq 10^2$, the IC-interval can be set to short by pressing the button labelled ICTIME. The OP-time is controlled by means of the three-digit push-button precision potentiometer at the top of the CU front panel. The OP-interval can be set in $10$ ms steps. After one IC- and OP-phase, the computer will be set to HLT-mode. This mode is especially useful when a plotter is connected to the computer.

**Repetitive operation:** This mode of operation is quite similar to single run with the exception that the computer cycles through IC-OP-IC-OP... until HALT or INITIAL is manually selected. This mode is ideally suited for computer setups with large time scale factors in conjunction with an oscilloscope as the output device.

At the bottom of the control unit are several input/output jacks:

**TRIG+/TRIG-:** Here, a trigger impulse is available, which can be used in conjunction with external devices such as an oscilloscope.

**TIME:** On this jack, a voltage proportional to the selected OP-time is available.

**EXTHALT:** A high-signal at this input will interrupt an ongoing OP-cycle and switch the computer into HLT-mode. This is often useful if some simulation is to be run until certain conditions are met which can be detected by a comparator.

## 2.3   Hybrid Controller

A hybrid controller, HC, can be used instead of the manual control unit CU described above.[2] This allows coupling the analog computer with a digital computer by means of a USB interface actually forming a *hybrid computer*. The digital computer has complete control of the analog computer in a setup like this.

The hybrid controller features eight digital potentiometers with a resolution of 10 bits each, eight digital input lines which can connect to the outputs of comparators, and eight digital output lines which can be used to control the electronic switches of CMP4 modules or to individually control integrators with respect to their mode of operation. In addition to that it allows to readout individual computing elements under program control. It also has an input for an external hold signal as well as a trigger output for external equipment such as oscilloscopes.

To facilitate programming, a Perl module `IO::HyCon` is available at `https://metacpan.org/pod/IO::HyCon`. Since the hybrid controller expects simple commands sent over a serial interface

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[2]A system may contain either a CU or a HC but not both modules at the same time!

it can also be controlled without this library by sending appropriate commands and receiving and parsing the return codes sent by the HC.[3]

## 2.4 Summers

The SUM8 module contains eight summers of which four can be used as open amplifiers by patching a special connection.[4] Figure 2.4 shows the front panel of this module.

The front panel is divided into two rows, each containing the jacks associated with four summers. Each summer has five inputs, three of which with weight 1, and two with weight 10. In addition to this, each summer also features a jack labelled SJ directly connected to the summing junction of the underlying operational amplifier.[5] The summers also have four/three output jacks which are paralleled for each summer.

The four summers in the top row can also be configured as open amplifiers by patching a connection between the two jacks labelled $\perp$ and FB.

## 2.5 Integrators

The INT4 module contains four independent integrators, each with a manually selectable time scale factor of $k_0 \in \{1, 10, 100, 1000\}$. Figure 2.5 shows the front panel of this module: Each integrator has three inputs with weight 1, three inputs with weight 10, and one input jack SJ connected to the summing junction of the operational amplifier. Using the input labelled IC, the initial value (condition) for an integration operation can be supplied.[6]

Typically, all integrators are under control of the control unit CU. In some cases, it is desirable to have some integrators controlled independently from the control unit (e. g. by means of electronic comparators or the like). The two rightmost integrators of the INT4 module offer the possibility of individual control by means of two input jacks labelled ModeIC and ModeOP.

## 2.6 Potentiometers

The PT8 module, shown in figure 2.6, contains eight buffered coefficient potentiometers. The first seven potentiometers feature one input and two paralleled output jacks each, while the eighth po-

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[3]Customers have successfully controlled the HC module directly from Python and other languages.

[4]An open amplifier is an amplifier without internal feedback path. Such devices are typically used to implement implicit functions such as division, square roots etc.

[5]These inputs are typically used to implement limits, additional resistive/capacitive feedback paths, or connect additional input resistor networks.

[6]Since initial conditions of $\pm 1$ are quite common, there are jacks connected to the machine units located on the front panel of the INT4 module, too.

tentiometer can be used as a free potentiometer with two input jacks. If this potentiometer is to be used as a simple coefficient potentiometer, its jacks labelled Inb and $\perp$ have to be patched together.

**Due to the output buffers of these potentiometers, their outputs may never be connected directly with an SJ input of a summer or integrator!**
This is in contrast to some classic analog computer programs where unbuffered coefficient potentiometers are sometimes used as variable input weights for such computing elements.

## 2.7   Multiplier

Basically, there are two different modules available which offer multiplication capabilities: MLT8 and MDS2. Of these, MLT8 is shipped with an Analog Paradigm Model-1.1 analog computer while MDS2 can be ordered as an option. Their respective front panels are shown in figures 2.7 and 2.8.
While the MLT8 module features eight multipliers, the MDS2 module contains just two computing elements which can be configured by means of a rotary switch to perform multiplication, division, or square rooting.[7]

## 2.8   Comparators

The CMP4 module, shown in figure 2.9, contains four electronic comparators, each of which has an associated electronic SPDT switch (single pole double throw). The inputs to the comparators are labelled A and B. The jack labelled $A + B > 0$ yields the logic output signal of the comparator which can be used to control electronic switches by connecting it to the jack labelled $>$ of an electronic switch. If no such connection is patched, each comparator controls its associated electronic switch.
Each electronic switch has two input jacks denoted by a circle, and two paralleled output jacks denoted by a triangle. **Since the electronic switches are buffered, input and output jacks may not be interchanged!**

## 2.9   XID, XIR, XIBNC

There are three passive modules which can be used with an Analog Paradigm Model-1.1 analog computer. These are shown in figure 2.10:

**XID:** This module contains six free diodes and two 10 V Zener-diodes which can be used to implement limiters, absolute value functions etc.

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[7]Division and square rooting can also be implemented by MLT8 multipliers in conjunction with an open amplifier.

**XIR:** The XIR module contains two free precision resistor arrays which can be used to extend the input capabilities of any summer or integrator by connecting the jack labelled SJ of the XIR module with the SJ input of the computing element to be extended. Each of these two arrays implements inputs weighted by $0.1, 1, 1, 10, 10, 10, 100, 100$.

**XIBNC:** This module contains four BNC jacks which can be used to connect the analog computer to external equipment such as oscilloscopes, signal generators etc. Since this module is isolated, it is necessary to connect the jack labelled $\perp$ with the GND jack of the PS module to assure a proper ground reference.

Figure 2.1: Precision voltage reference
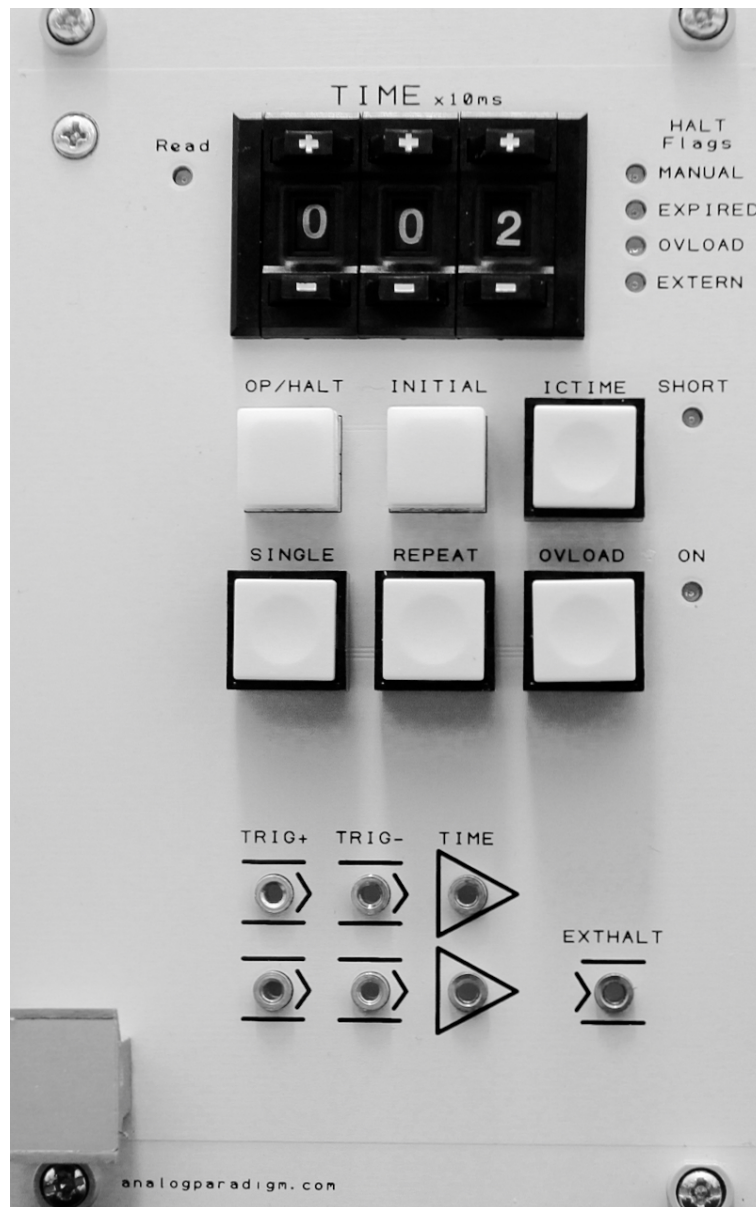
Figure 2.2: CU front panel
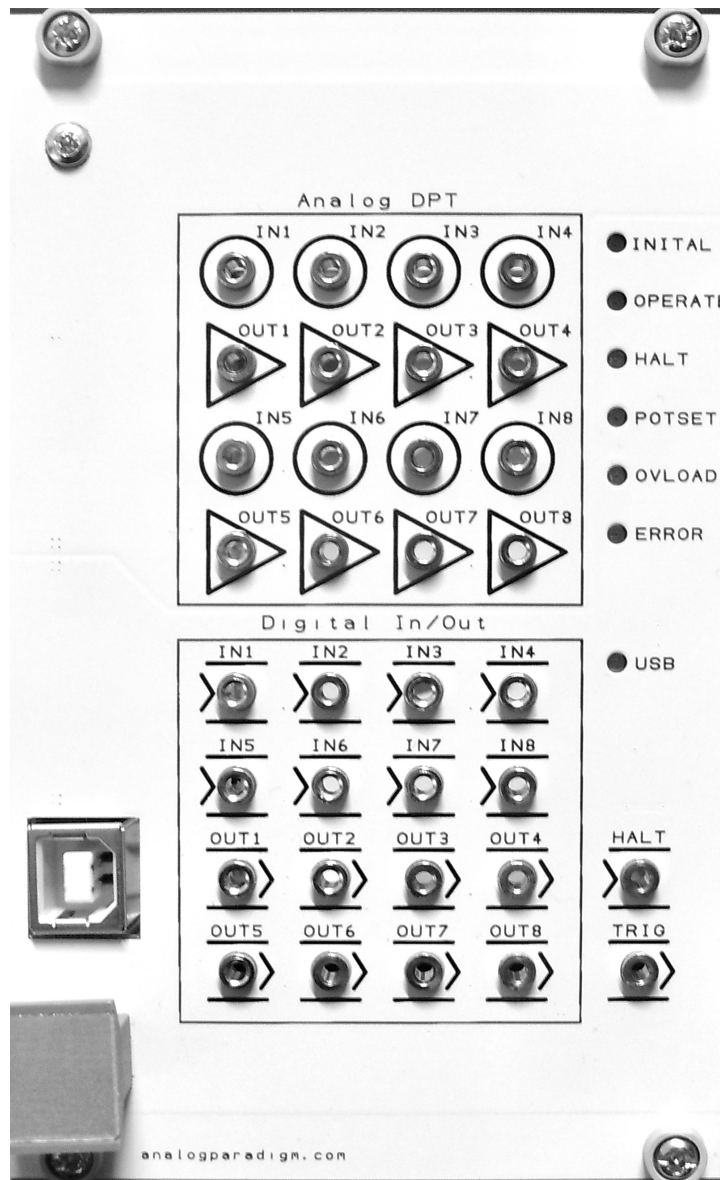
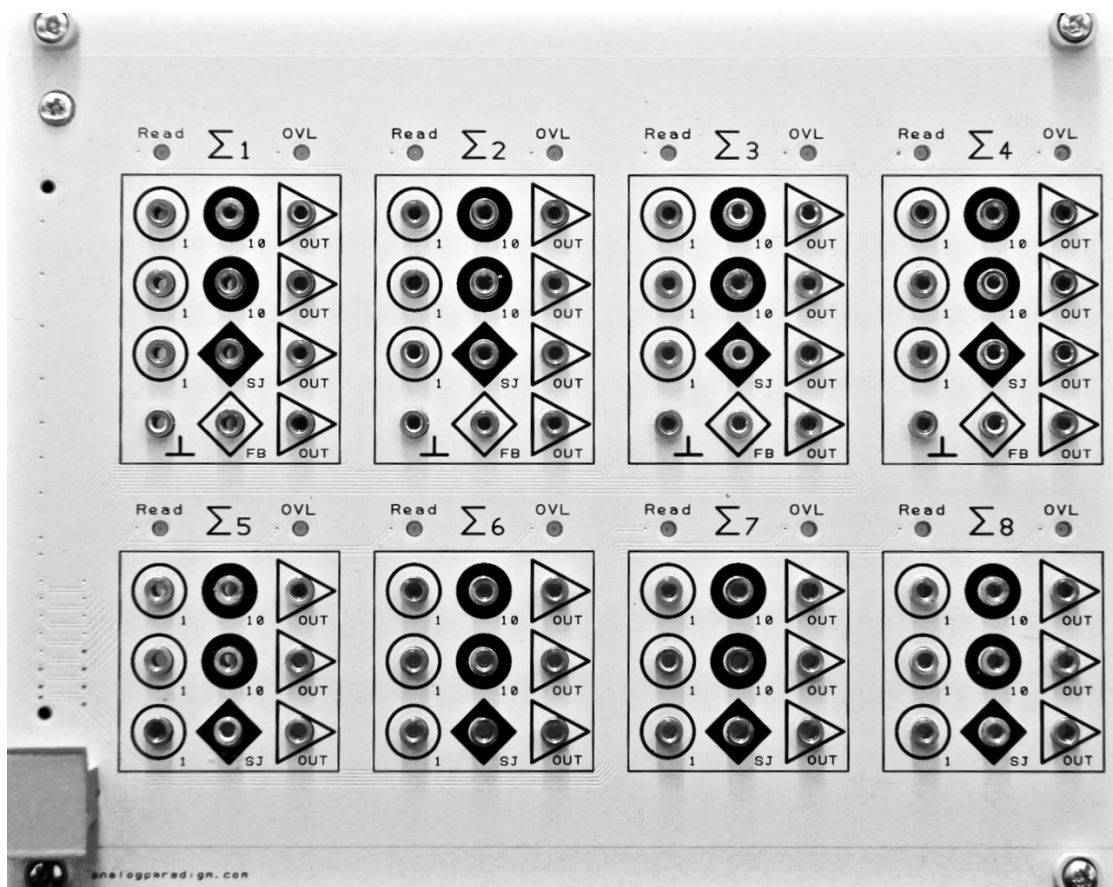Figure 2.3: Hybrid controller front panel
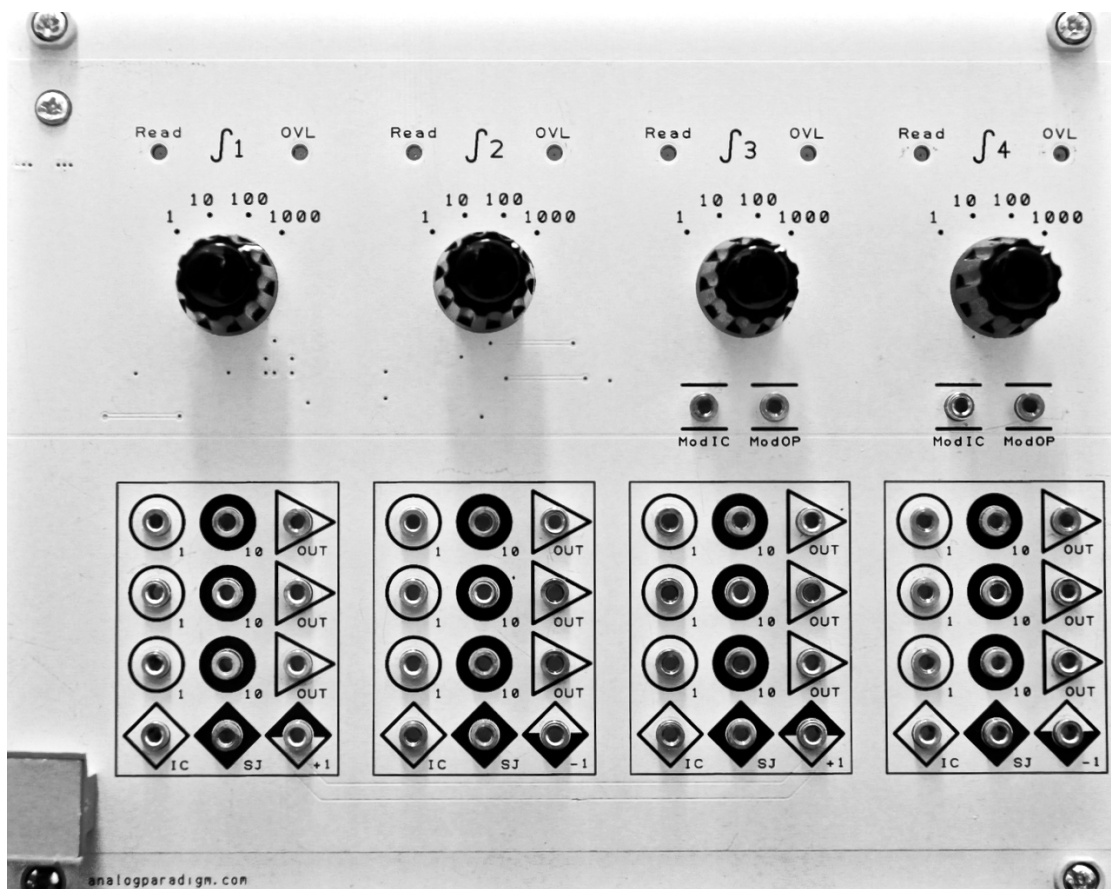
Figure 2.4: SUM8 module
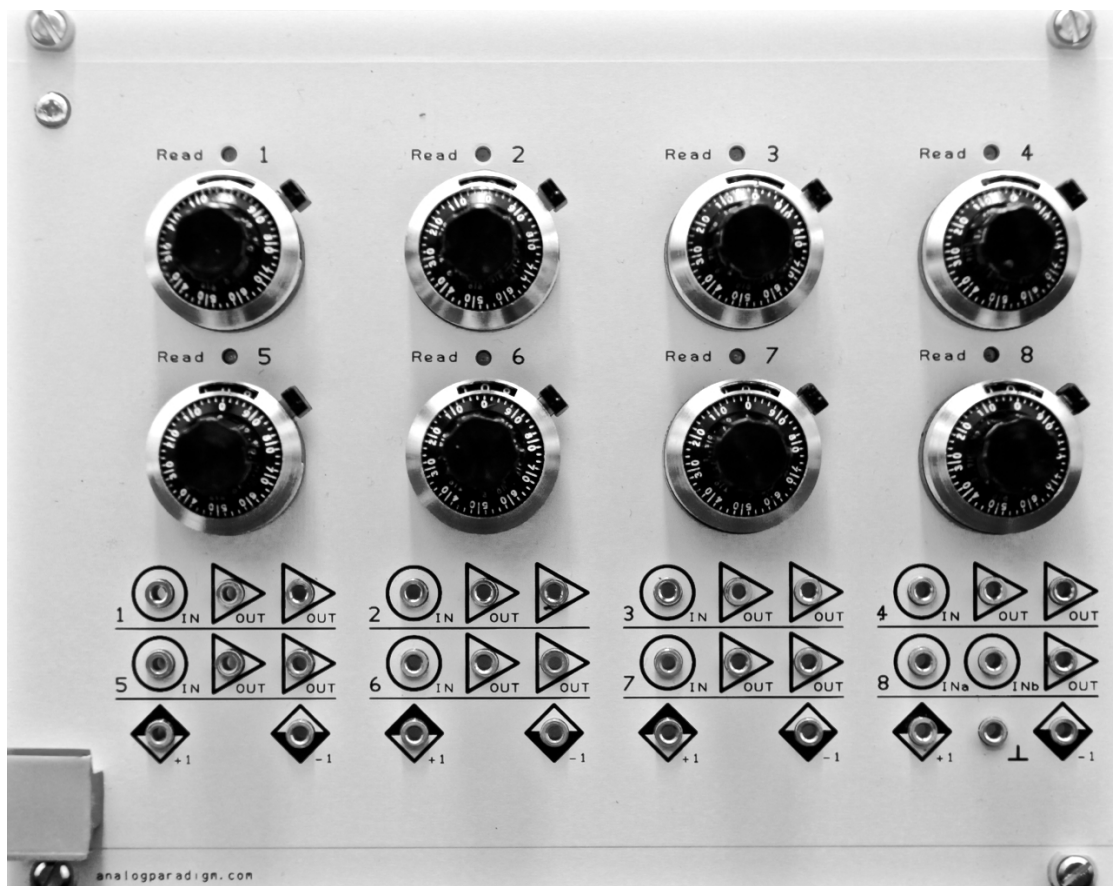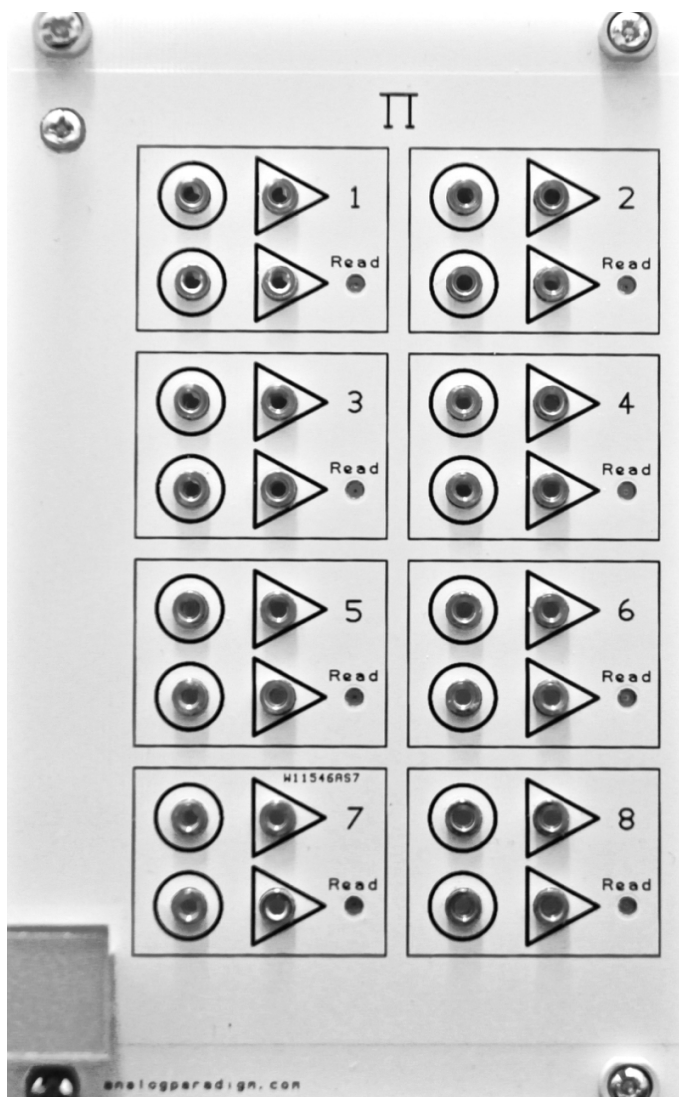
Figure 2.5: INT4 module

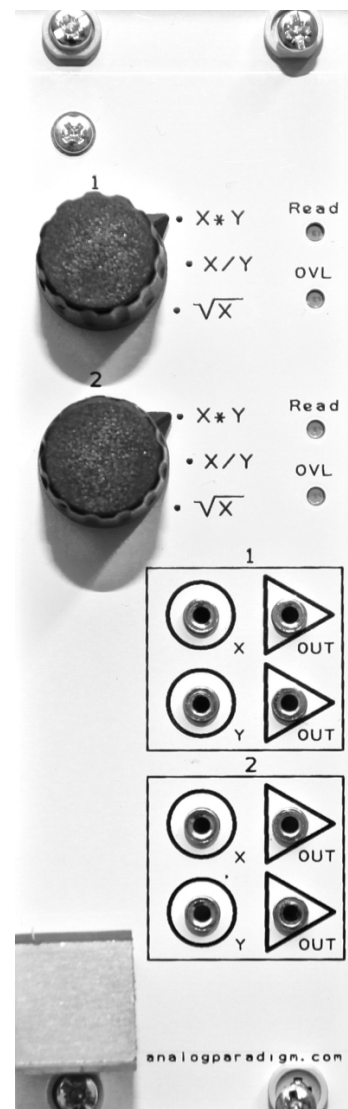Figure 2.6: PT8 front panel
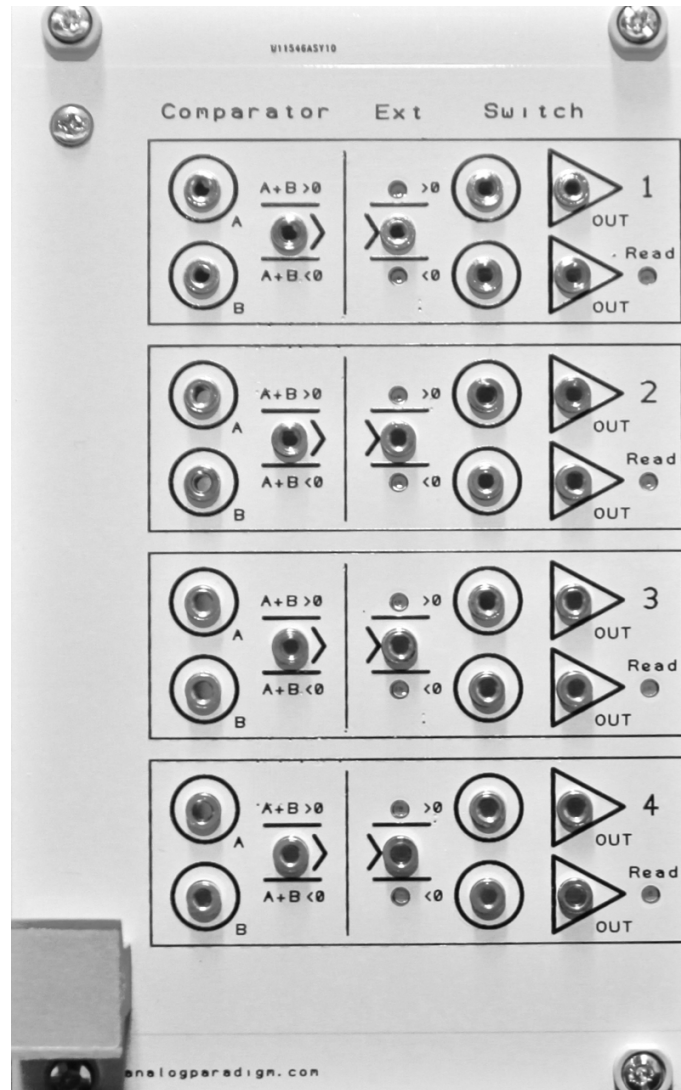
Figure 2.7: MLT8 module
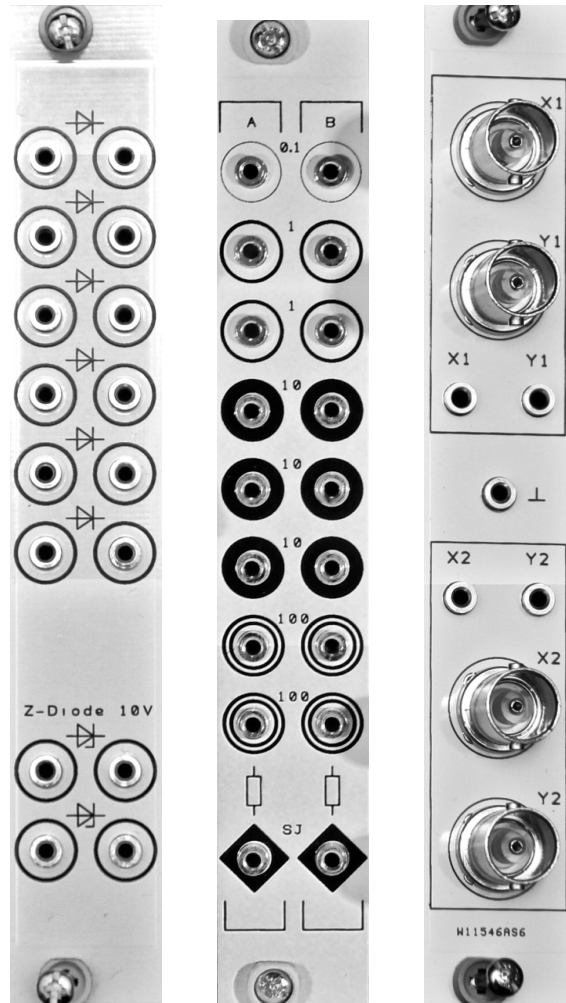


Figure 2.8: MDS2 module

Figure 2.9: CMP4 module

Figure 2.10: XID, XIR, XIBNC

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# First steps

The computer is powered by an external 24 V laptop-style power supply that plugs into a socket on the back of the upper chassis. The power switch is located on the front-panel of the PS-module on the far left of the upper chassis. After plugging in the external power supply, connecting it to the analog computer and switching the system on, the green Power-OK LED should light and, provided that there are no patching errors, no overload LED should be lit.

After switching the computer on, the key labelled IC on the control unit should be depressed once to make sure the system is in IC mode (the button will be lit yellow). Patching can be done in any mode but is typically performed in IC mode.

## 3.1 Modes of operation

The various modes of operation can be controlled as follows:

**Manual mode:** In manual mode, only the push-buttons INITIAL and OP/HALT are required. Depressing IC will force all integrators not under individual control to take on their initial conditions. Depressing OP/HALT will then switch the computer into OP mode. Depressing OP/HALT repeatedly again will toggle between HLT and OP.

**Single run:** If none of the integrators of the computer setup is set to a time scale factor less than 100, the IC-time should be set to short by pressing the button ICTIME once. If lower time scale factors are required, the IC-time should be set to long, otherwise the initial values can not be set correctly. In the next step the desired OP-time is set by the push-button precision

potentiometer on the top of the CU in 10 ms increments. Pressing the button labelled SINGLE will then start one cycle consisting of OP, followed by HLT.

**Repetitive operation:** This mode works like single run with respect to setting the IC- and OP-time. Depressing the push-button labelled REPEAT will then cause the computer to cycle through IC-OP-... until either INITIAL or OP/HALT is pressed.

## 3.2   Do's and don'ts

- The output of a PT8 coefficient potentiometer should never be patched to a SJ-input of a computing element. (This is in contrast to classic analog computers which typically had no buffered potentiometers.)

- It is good practice to plug in a patch cable into the input jack first and then into the output jack of the preceding computing element. This avoids accidental shorts caused by dangling cables during patching.

- Electrostatic discharges to the computing elements should be avoided.

[ULMANN, 2017] contains a wealth of practical examples which have been implemented on Analog Paradigm analog computers. Many of these examples are suitable even for the smallest Model-1.1 computer.

# Bibliography

[CARLSON et al. 1967] ALAN CARLSON, GEORGE HANNAUER, THOMAS CAREY, PETER J. HOLSBERG (eds.), *Handbook of Analog Computation*, 2$^{nd}$ edition, Electronic Associates, Inc., Princeton, New Jersey, 1967, available from `http://www.analogmuseum.org/library/eai_handbook.pdf`

[GILLILAND 1967] MAXWELL C. GILLILAND, *Handbook of Analog Computation (Including Application of Digital Control Logic)*, SYSTRON-DONNER CORP., 1967, available from `http://www.analogmuseum.org/library/handbook_of_analog_computation.pdf`

[ULMANN, 2013] BERND ULMANN, *Analog Computing*, Oldenbourg Verlag, 2013

[ULMANN, 2017] BERND ULMANN, *Analog and Hybrid Computer Programming*, Walter De Gryuter GmbH, Berlin/Boston, ISBN 978-3-11-066207-8

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