Affordable Flexible Analog Computer RG14-Mini

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1. Introduction

As classical analog computers are no longer produced, there is a lack of affordable new ones, with the exception of [The Analog Thing](). The latter, however, sticks to the classical model with all its inconveniences.

My new design is close to the classcial design, with some small, but for my opinion significant changes:

1. The computing elements are plugged into the connection board, thus it is possible to archive calculations.
2. As the computing elements are pluggable, the configuration can be adapted; there is no other limit for the computing elements than the number of slols.
3. Computing elements have a current input as primary input, thus avoiding a lack of input menans.
4. Potentiometeres deliver a current, not a voltage; thus can be calibrated in advance.
5. Digitally set potentimeters allow quick and precise setup.
6. The modules can be configured with jumpers for various functions.
7. Integrators have a very quick initialisation circuit and can thus be used as track-and-hold
8. Initial conditions for integrators can be set with potentiometers on the module, but also via a current input.
9. The adder has options to function as (inverting) adder, precision rectifier or comparator; no free wiring of components is required.
10. Potentiometers have a (digital) switch than can disable the output; so more than one signal can be switched directly, and no switches are necessary on calculating modules.
11. Power supply is only (precise) 30V DC. Calculations use ±10V.
12. A module is small: 100mm x 14mm and can be made on perfboard with 2.54mm spacing.
13. Connections use a common and affordable prototype plugboard.
14. Repetitive operation not yet provided

This project was designed to verify the design of the modules; an advanced version without plugboard, but with digitally controllable options and connection is under test.

More information could be found at https://rclab.de/en/analogrechner/inhalt.

2. Construction

The following picture shows a plugboard with 10 places, using 7 modules to generate triangle curves:
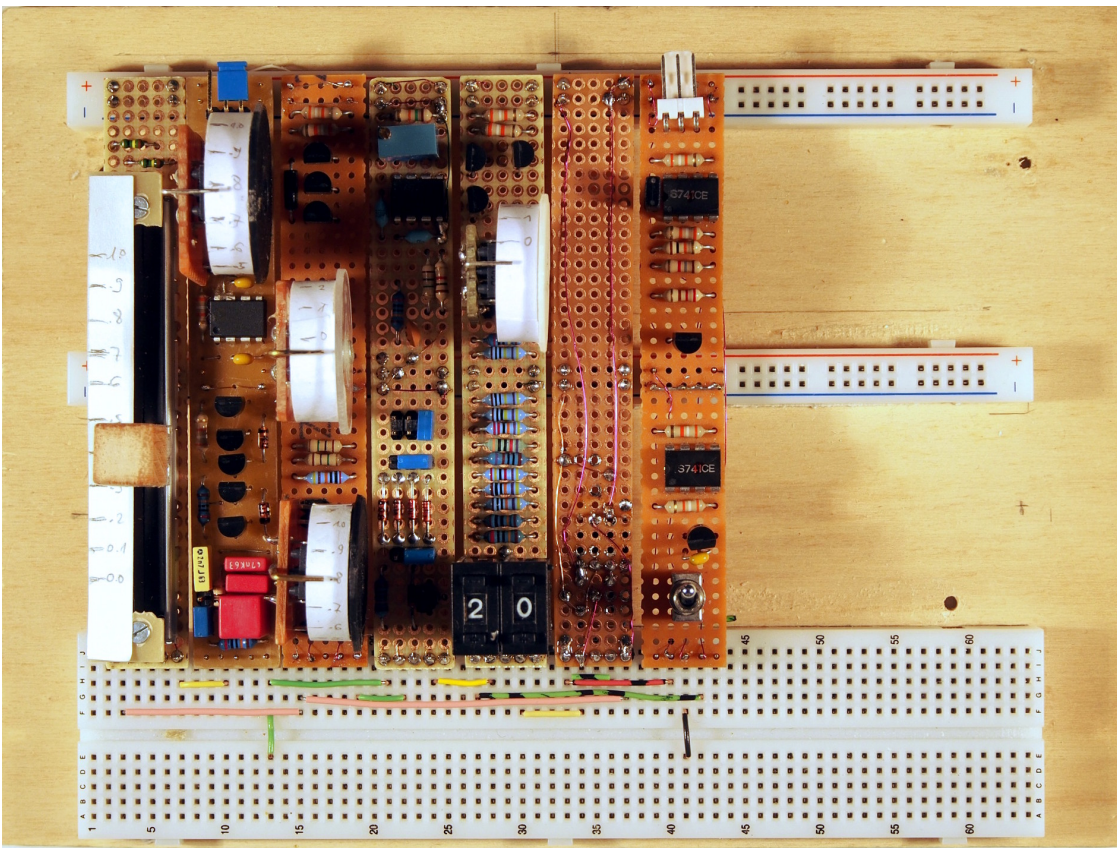
Each module is 100mm x 14mm; the raster, as defined by the plugboard, is 600mil = 15.24mm.

This kind of plugboard can be sepearated in the middle connection part and two power busses. On the top is a double power bus bar (+15V upper, red; -15V lower, blue); in the middle the ground line (blue, lower) and the signal to set initial conditions (red upper).

The modules are, from left to right:

- Potentiometer KL as linear potentiomenter (special)
- Integrator with intial value 0.8
- Potentiometer KG with two for coarse / fine, output switch unused
- Adder configured as commparator
- Potentiometer KS; digitally settable from 0.00 to 9.90 digitally and additonally a fine setting upto 0.10
- Adder
- Power adapter with switch for initial / run mode

The common term *Potentiometer* was used for the settable voltage-to-current converter; it will be called *factor connector* or *factor* hereafter. The active calculating elements are called *functor* as they realise a function like addition, integration etc.

The symbols used in the following schematics are variations of the normally used ones:
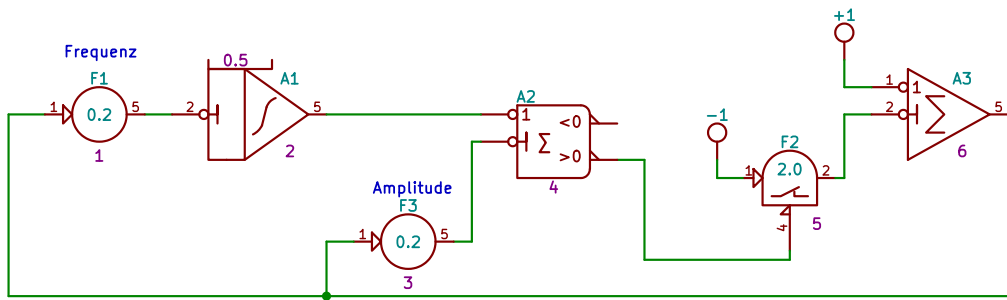
A circle denotes a factor with voltage input and current output. There is an inversion bullet at the input, followed by a ground symbol to denote that the functor has a virtual ground at the input. The numbers below are the slot numbers, and the numbers near the in- and outputs are the pin numbers of the 5-pin connector. If a switch is used, the half circle on a box is used as for F2 in slot 5.

Due to the current input, more factor connectors are required than normally. Although more expensive than a potentiometer, the overall gain in useablity and the fact that there are never to few inputs justifies this expense.

While normally of no concern, it might be good to know that the output voltage range is ±10V and the input current range is ±50µa for the numbers ±1.

2.1. Functors (calculating elements)

The active calculation elements called *functors* provide an output voltage as a function of the input current (including time).

The five pins on the plugboard are used as follows:

1. Voltage input for the factor 1 (i.e. 200kΩ)
2. Primary current input (±50µA)
3. Defined per module
4. Defined per module
5. Voltage output

Pins 3 and 4 may be analog in- or outputs, or digital signals; the latter sinking 1mA to ground (from positive supply) if true.

Pin 1 is always a factor 1 voltage input to save factor modules if the factor is 1 as is often the case.
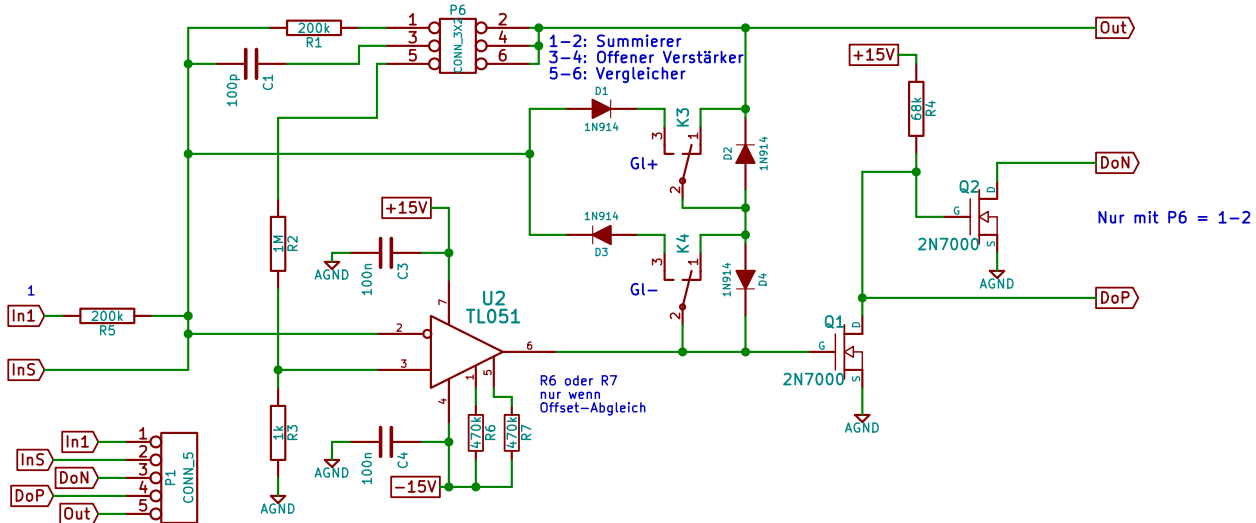
2.1.1. Adder

By jumper on the board, the adder can be configured as:

- plain adder

- limiter (rectifier) positive
- limiter (rectifier) negative
- comparator
- zeroing amplifier (open amplifier)

The circuit:

The 5 pins are used as follows:

1. Voltage input factor 1
2. Current input
3. Digital output if < 0 when configured as comparator
4. Digital output if > 0 when configured as comparator
5. Voltage output.

The limiters are precision rectifiers that limit the output to positive or negative values (after inverted) with factor 1, i.e. a current of +25µA gives -5V for the negative and 0V for the positive version As they are normal adders otherwise, an extra input current can be used to shift the input discriminating value; the output is always either positive or negative (including zero).

If configured as a comparator, pins 3 and 4 are digital outputs if the input current is less or greater zero, i.e. the output has maximum positive or negative voltage. They might be used to switch factors on or off. The comparator has a small hysteresis of 1‰ to avoid oscillations. Pins 3 and 4 should not be used otherwise.

The zeroing (open) amplifer has already a small capacitor in the feedback path.

2.1.2. Integrator

The integrator can be configured for 1/sec or 100/sec only:
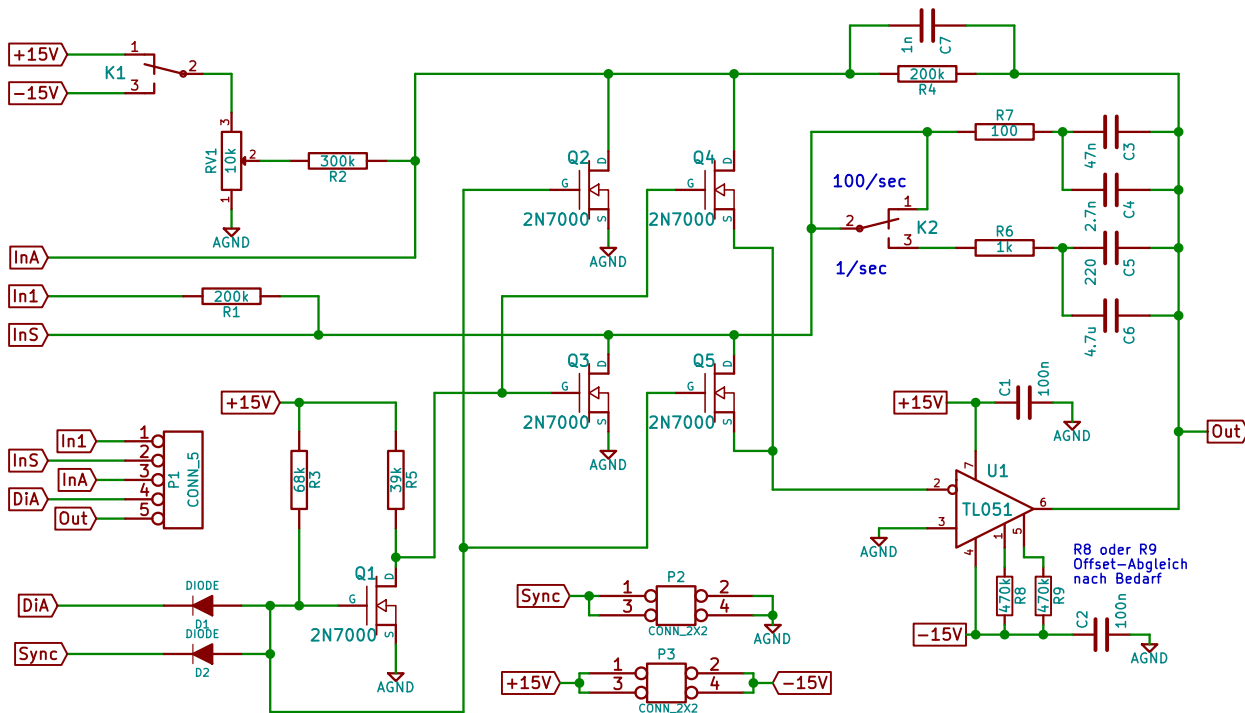
The 5 pins are used as follows:

1. Voltage input factor 1
2. Current input
3. Current input for external initial value
4. Digital input for use as track-and-store
5. Voltage output.

The initial value can be set by a (vertical) potentiometer with 5% accuracy. The polarity is selected by a jumper. Additionally, a current at input 3 can be used for the initial value. Then, the potentiometer should be set to zero. If the polarity would be included in the potentiometer, a switch would be necessary to deactivate it, and the accuray halved.

Setting the intial value uses a — not so common — quick scheme, where the capacitor is charged from the op amp output to ground, thus the charge time is defined by the output impedance of the op amp. It requires two additional switches, but allows the circuit to be used as a track-and-store device. (An example has not yet been found). Initialisation time is less than 10ms for the 1/sec range.

The integration capacitor is composed of two capacitors that may be selected to achieve 1% accuracy.

The proposed op-amp TL051 has a low offset voltage of at most 1.5mV, which is small enough for most applications. The drift is less than 1.5% in 100sec in the 1/sec range with one connector connected and zero input. The better available AD820 has 0.8mV offset and thus half the drift. Using the AD820 for the integrators and the TL051 elsewhere is a good compromise that avoids soldering calibration resistors.

If a TL071 or TL081 is used, the offset voltage is less than 15mV, and the offset should be corrected during manufacturing by soldering extra resistors.

2.1.3. Multiplier

The Gilbert-cell based AD633 is used for the multiplication of two numbers.

Pin usage is special:

1. Factor 1 voltage input for pin 2
2. Current input for multiplicand or divisor
3. Current input for multiplicator or dividend
4. Factor 1 voltage input for pin 3
5. Output

May be configured for multiplication, division, squaring and square root. The sign of one operand and thus of the output may be inverted by configuration.

Circuit:
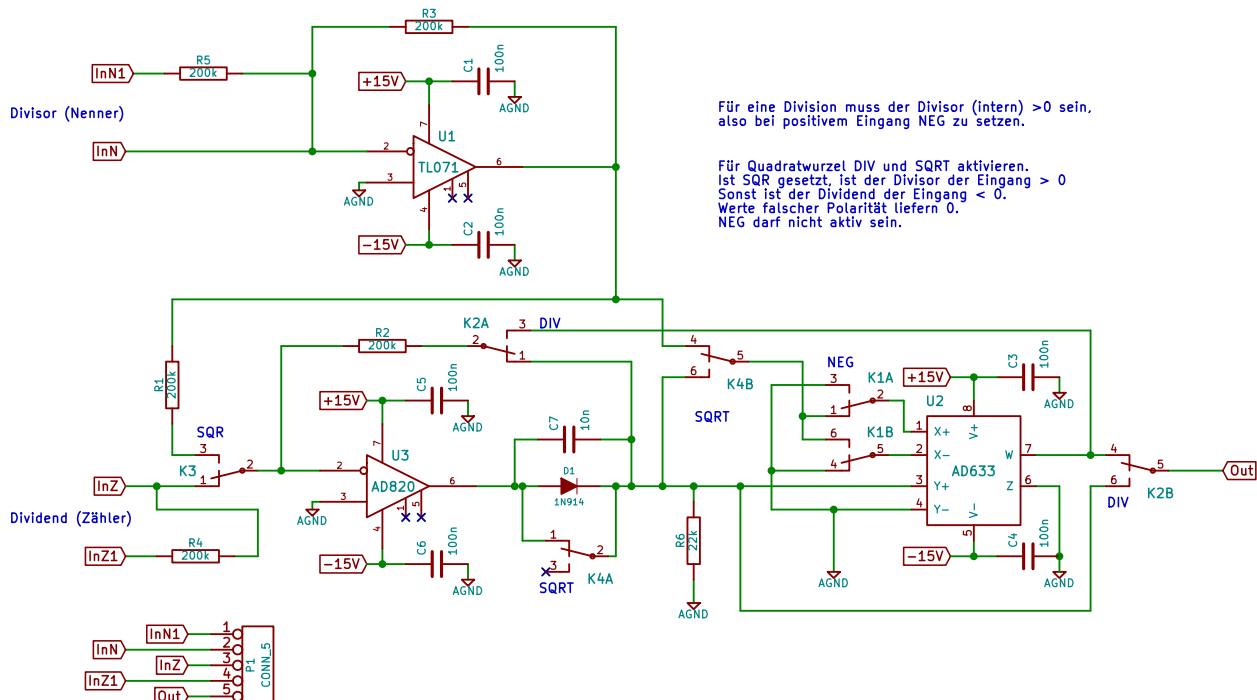
2.2. Factor connectors

A factor connector converts a voltage to a current to (virtual) ground with a setable factor.

The simplest version uses a potentiometer (e.g. 10kΩ) with a resistor (200&kΩ) from the tap to the output. The largest linearity error by this resistor is 0.75% for a factor of 0.67 (see http://rclab.de/analogrechner/potentiometerbelastung).

Because the output is always connected to a virtual ground, the factor is independent of the number of connected connectors, thus it is not necessary to adjust the potentiometer depending on the circuit used; a fixed scale can be used. This means that it is no longer possible to determine the actual setting by probing the output with a voltmeter.

2.2.1. Standard factor connector KS

The standard version of a factor connector not only allows factors larger than 1 (upto 10.0), The upper digits are set digitally (from 0.1 upto 9.9), plus a potentiometer for the lower digits (from 0.00 to 0.10). As the latter has 5% accuracy, but only a weight of a tenth, the overall accuracy is still better than 1%.

The circuit used is:
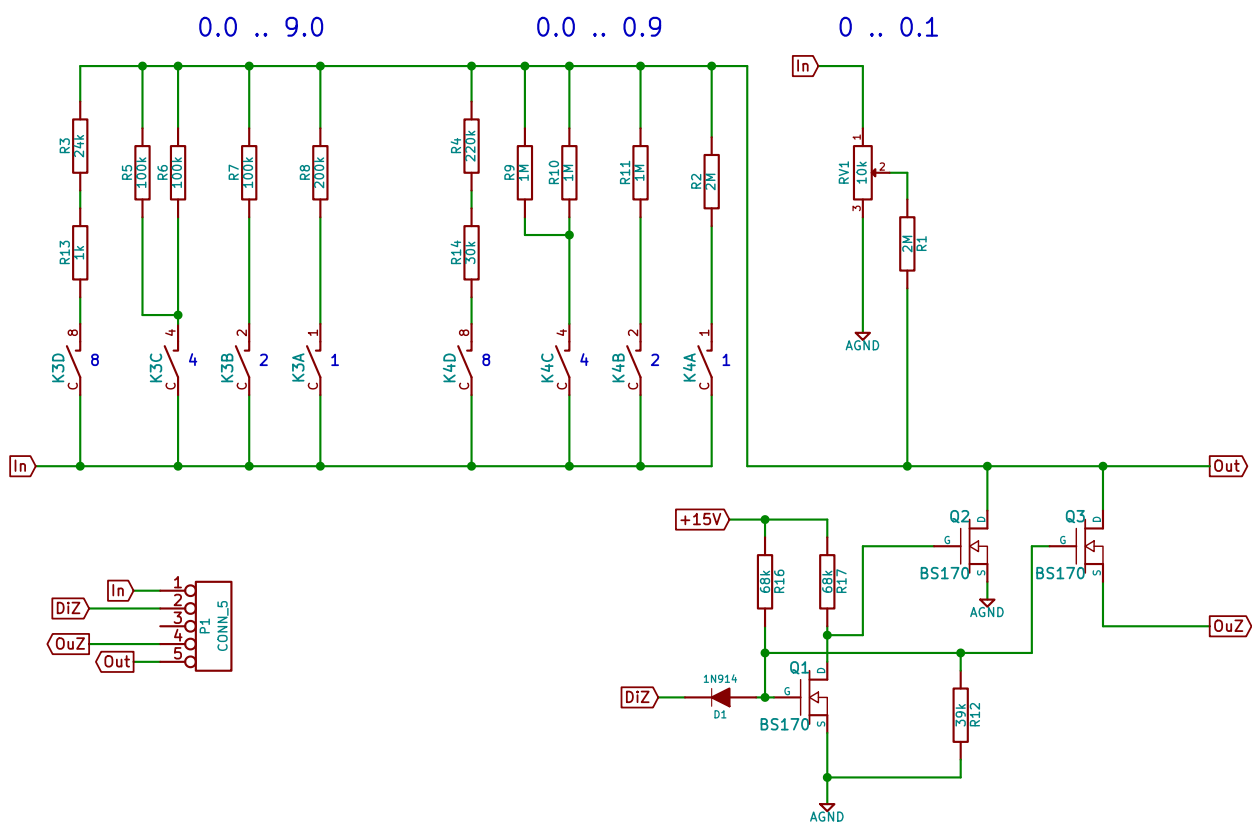
This connector has an analog switch to switch the output on or off, controlled by a digital input, e.g. from a comparator.

Pin usage:

1. Voltage input
2. Digital input to switch off (if active low)
3. Not used
4. Current output from the switch
5. Current output unswitched

Pin 5 must be left open if pin 4 is used, as otherwise the current node would be shorted.

The preferred BCD switches for manual change without tool are fairly expensive; thus, BCD switches for screw driver operation can be used alternatively.

2.2.2. Double factor: KD

The double factor has two (not switchable) factor connector in one module to save slot space:
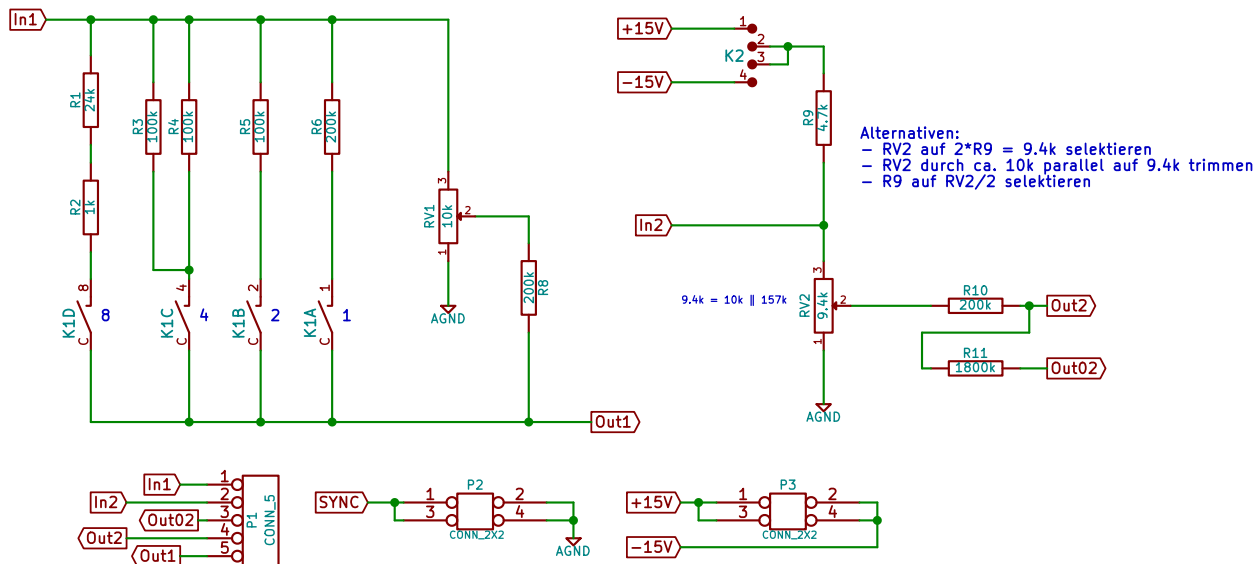
The fist factor connector has one digital switch for 0.0 to 9.0, and one potentiometer for 0.0 to 1.0, thus the accuracy is about 5%. A variant uses the switched factor 0.0 to 0.9 and the analog part from 0.0 to 0.1, thus has 0.5% accuracy.

The second factor is just a potentiometer upto 1.0 with 5% accuracy, and can be supplied with the constant 1.0 from the power supply. It has also a second output with factor 0.1, thus from 0.0 to 0.1.
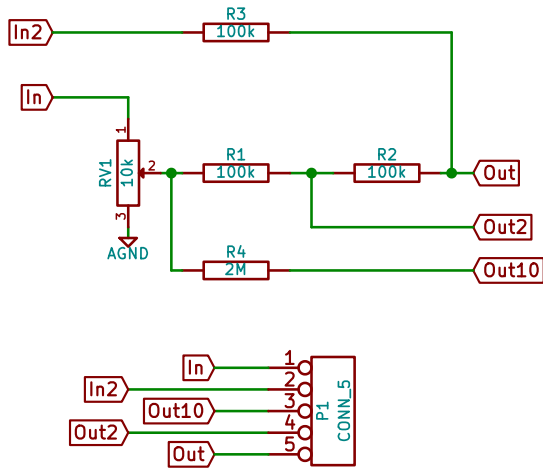
Pin usage:

1. Voltage input first factor
2. Voltage input second factor
3. Current output second factor upto 0.1
4. Current output second factor upto 1.0
5. Current output first factor.

Pin 2 must be left open, if the constand 1.0 is supplied; and pin 3 must be left open, if pin 4 is used.

2.2.3. Linear variant KL

Instead of a common potentiometer, a linear potentiometer is used:

Pin assignment:

1. Voltage input
2. Input for ±1
3. Current output upto 0.1
4. Current output in conjunction with pin 2
5. Current output except

Normally, pin 1 and pin 5 provide a common potentiometer, with an extra output on pin 3 for small factors; could be used together with pin 5.

If pin 1 is connected to +1 and pin 2 to -1, pin 4 supplies a constant between -1 und +1.

2.2.4. Coarse-fine connector KG

Another connector with a switch adss the values of two potentiomenters, one in the range 0.0 to 1.0 and the other one in the range 0.0 to 0.1:
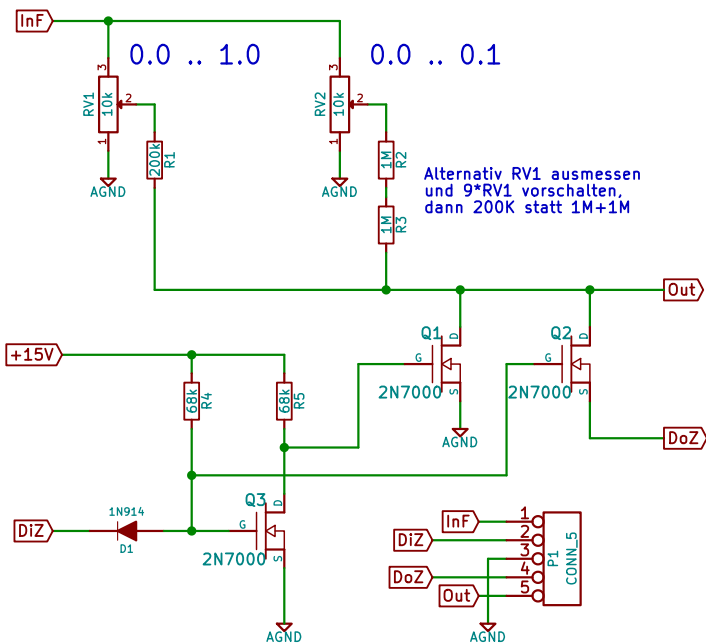
In general, both potentiometers should be used alternatively, i.e. the other one set to zero. Adding a small value to a large one is, however, less useful than originally assumed, as the accuracy of the first one is 5% and thus half of the value to be addend with the second one.

This module has more historical than actual value.

2.3. Power connector

A module is always used as a power supply.

It is normally provided with 30V DC , and internally generates a ground line for ±15V as well as precise ±1 voltages (10V):
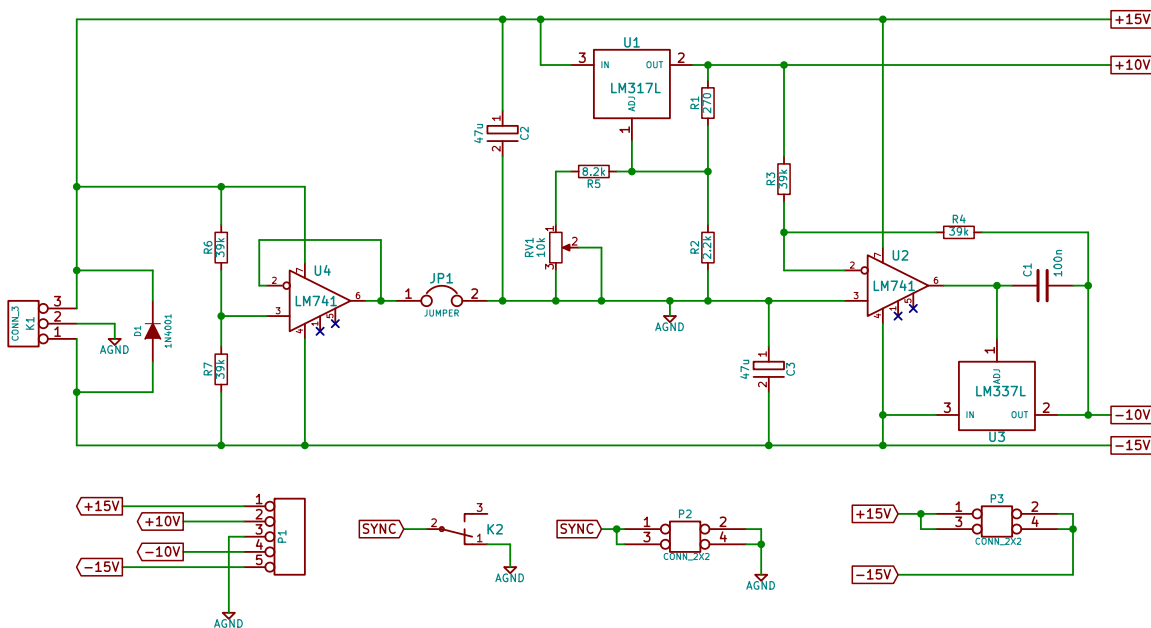
At the 5-pin connector, it supplies:

1. +15V
2. +10V calibrated
3. GND
4. -10V calibrated 5: -15V

The integrators derive the initial value from ±15V, as well as some factor connectors. These are thus dependent on the accuracy of the supply; but are anyhow not precise.

3. Construction

There are several ways to make a module, with different levels of required skills and base material.

Perfboard

It is perfectly possible to use perfboard ([https://en.wikipedia.org/wiki/Perfboard]) with 0.1" dot raster. The first modules were made this way, and also special modules made only once.

Best is to use double sided (not necessay with plated holes) perfboard as this allows to solder on the opposite side of the components.

This important for the connectors to the plugboard, so that the pins can be solderd at least on the top side, to avoid stress when drawn.

If the copper is on the bottom, this is fine for THT devices, in particular for jumpers. But soldering the connectors on the bottom side is a bit tricky and requires much experience in soldering. Copper on top is good if there are no jumpers to solder.

Single-sided PCB

Until today, all modules were made on home-etched PCB, as the effort to route the connections with wire is not so low, and as I had the circuits drawn in KiCad anyhow, making a PCB was little extra effort that payed off already with the second one.

See the preceeding section on the selection of top or bottom copper.

Nearly all existing ones used copper on bottom in order to hold THT components on the top. Note that the connector soldering pads were squares (instead of circles) to allow more copper to solder and hold.

Lately, a factor connector with copper at top was made, with resistors, switch transistors and BCD coded switches for all three digits on top.

Double-sidede PCB

Using double sided PCB with should be used whenever affordable, in particular with plated-through holes.

Such PCBs are currently under construction.

Potentiometers

Standard carbon potentiomenters can be used if equipped with a scale that is individually calibrated.

Because the boards are only 14mm wide, thumbwheel potentiometers with a scale around the circumfence are a good choice.

While many variantes were probed, currently the APLS RK09K111 provides the best options, because the axis of the horizontal operation cylinder is 6.5 mm distance from the PCB, allowing to use a 3D-printed thumbwheel of 12mm diameter, thus 40mm circumfence and 30mm usable scale, allowing 3mm distance for 10% variation and thus 5% accuracy (if the scale is calibrated manually).
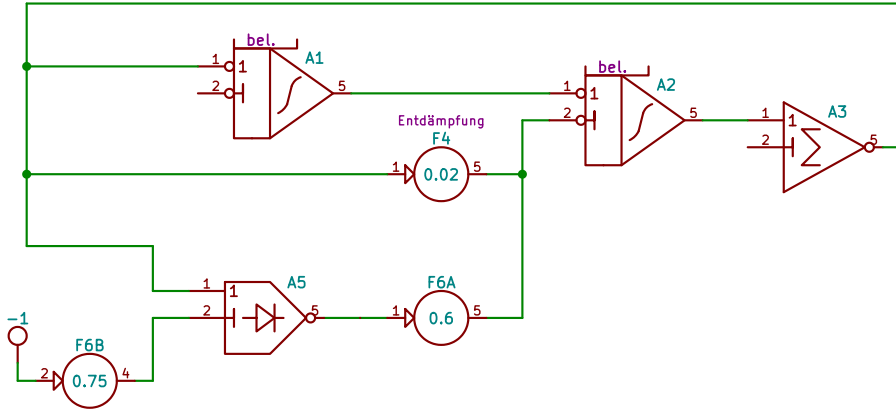
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4. Examples

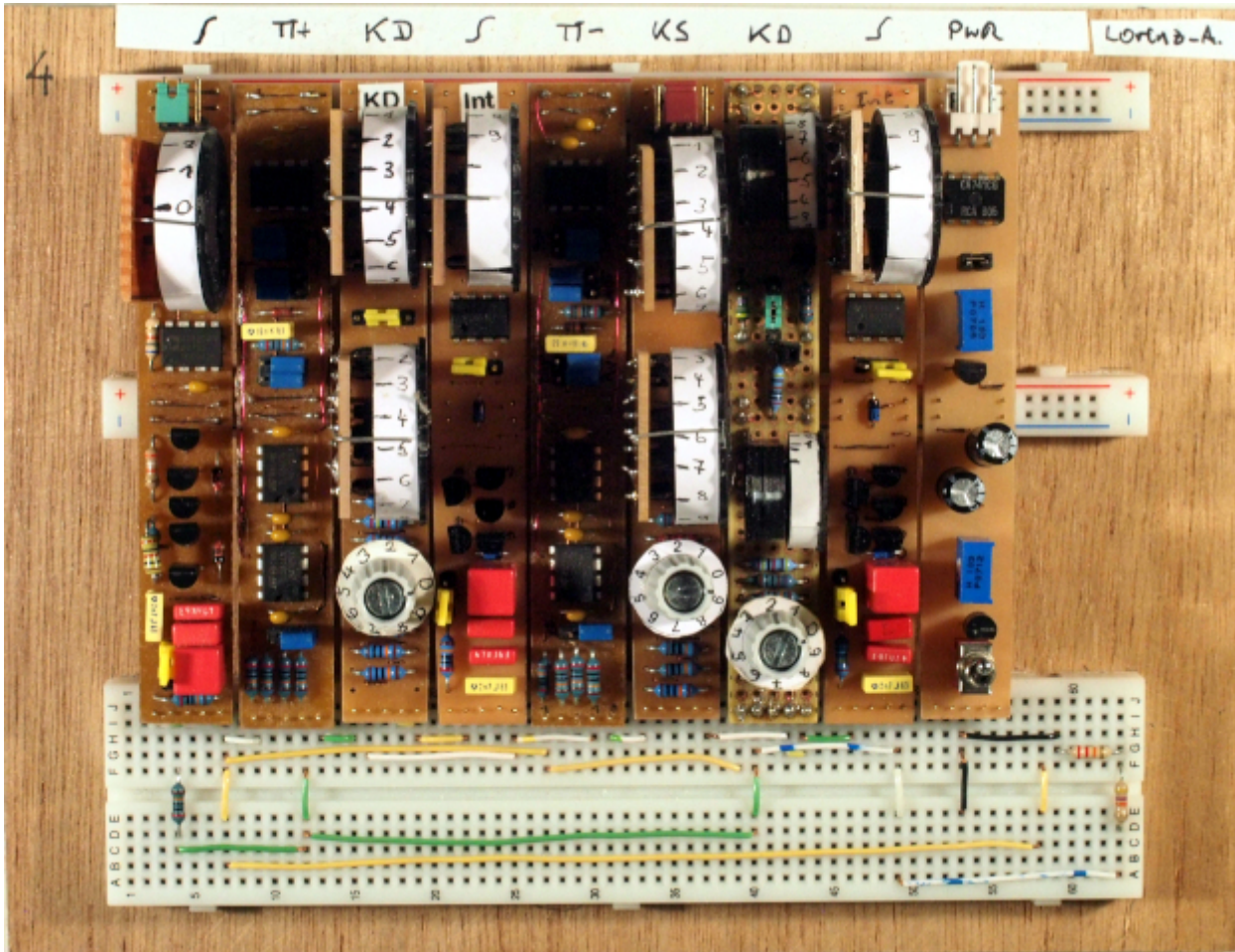For some examples, a picture and schematics are shown.
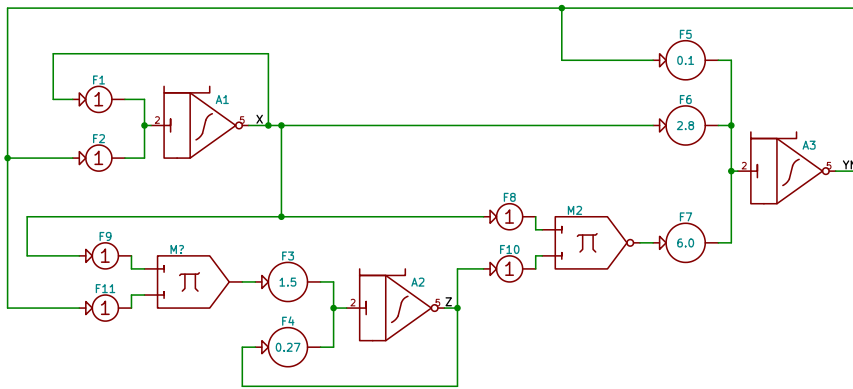
4.1. Triangle generator
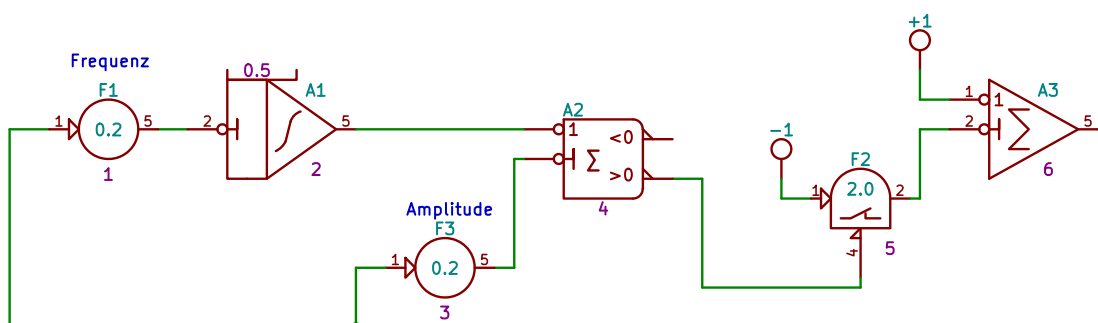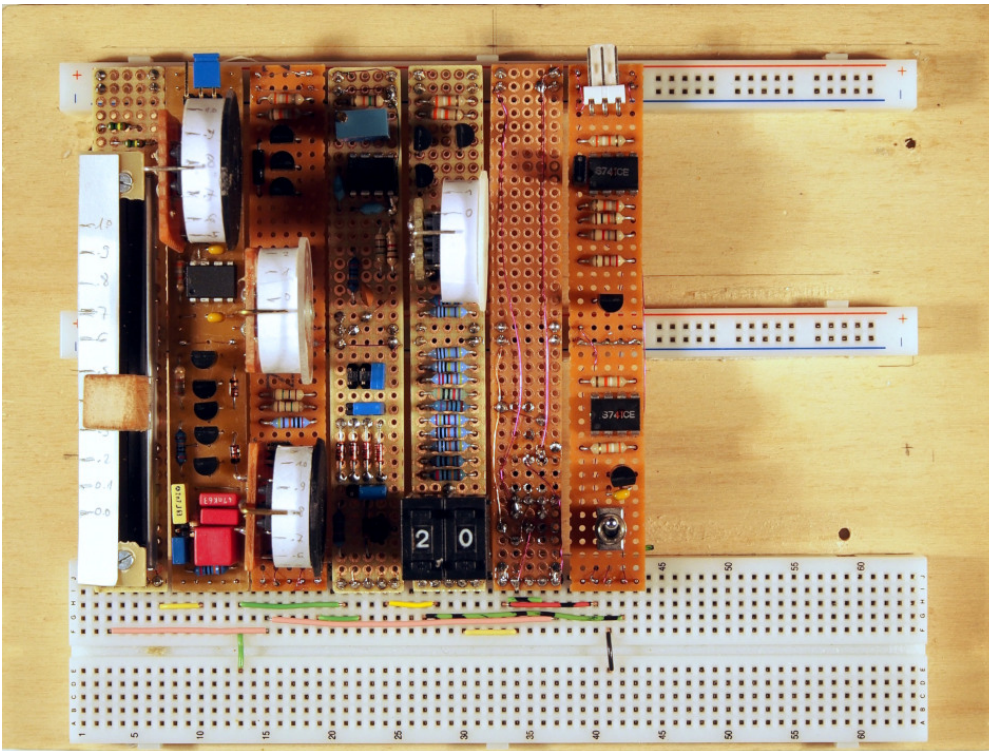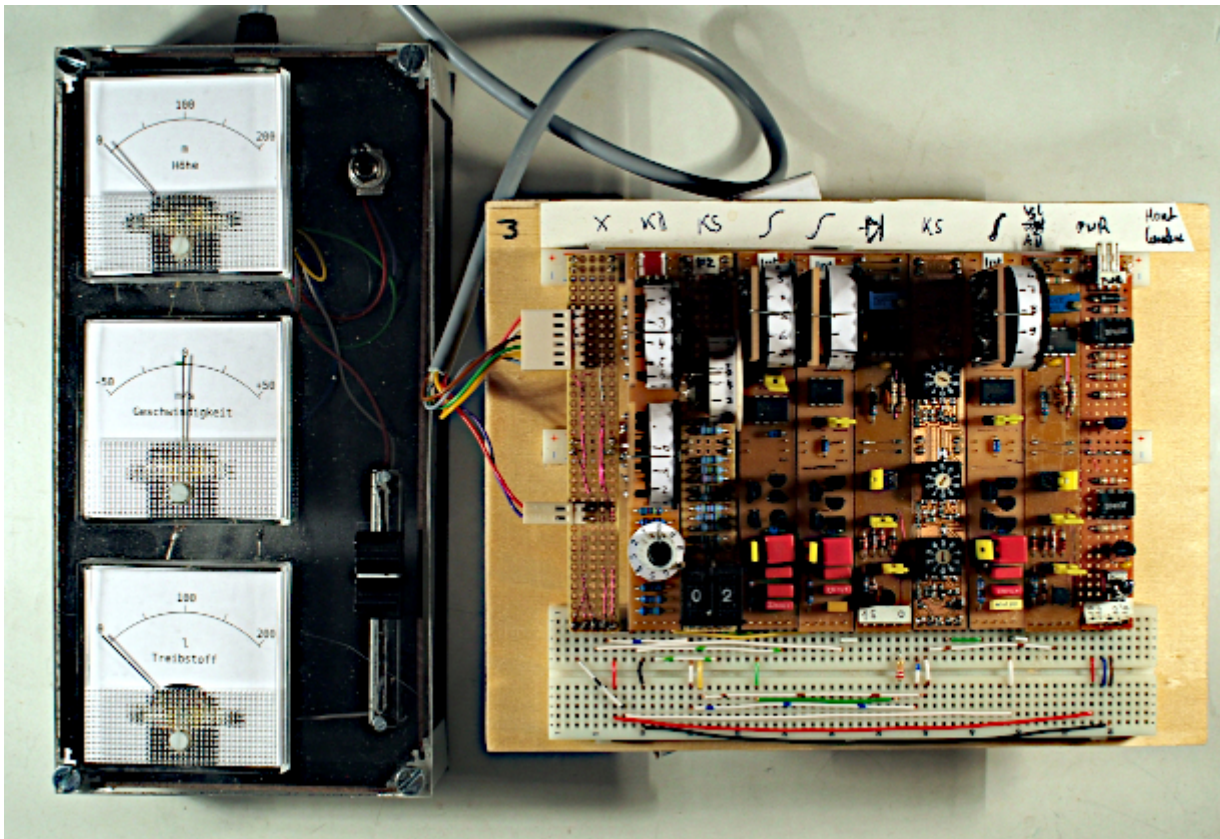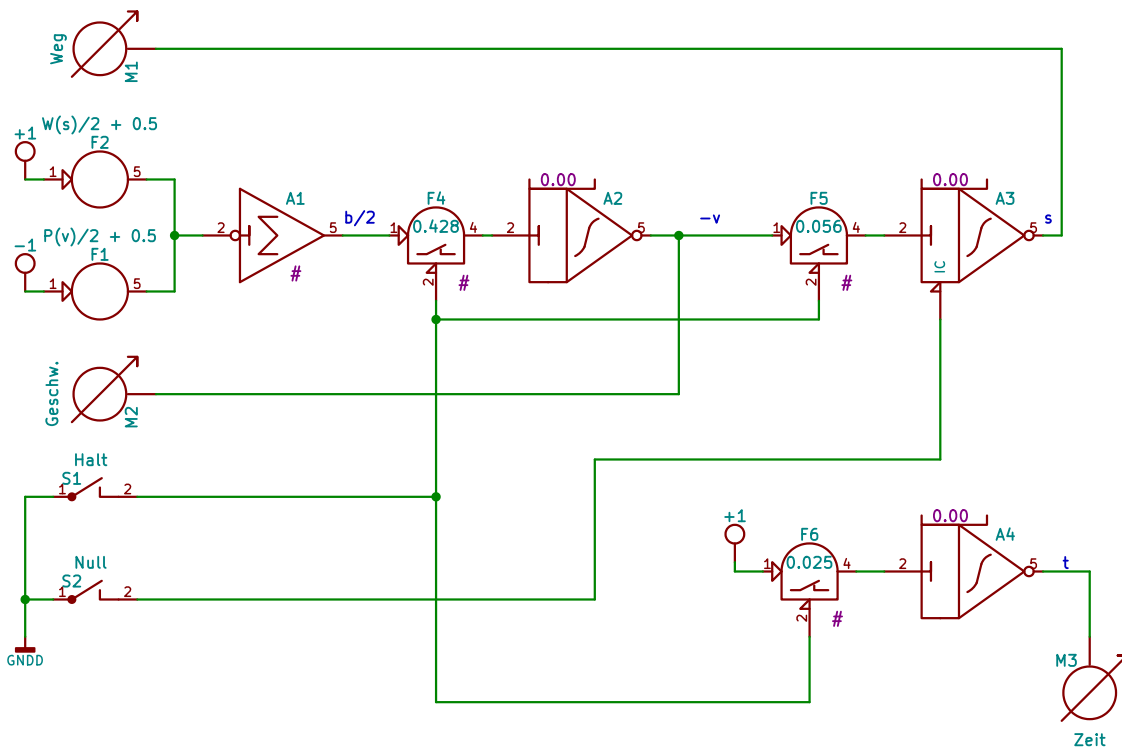
4.2. Sine generator

4.3. Lorenz-Attractor

Lorenz—Attraktor (RG14—B)

3 Integrierer   5 Faktor—Koppler
2 Multiplizierer   6 Faktor—Verbinder
—————————   ————————————
5 Funktoren   11 Koppler

4.4. Moon lander

4.5. Fahrdiagraph (Train simulator)

5. Literature

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