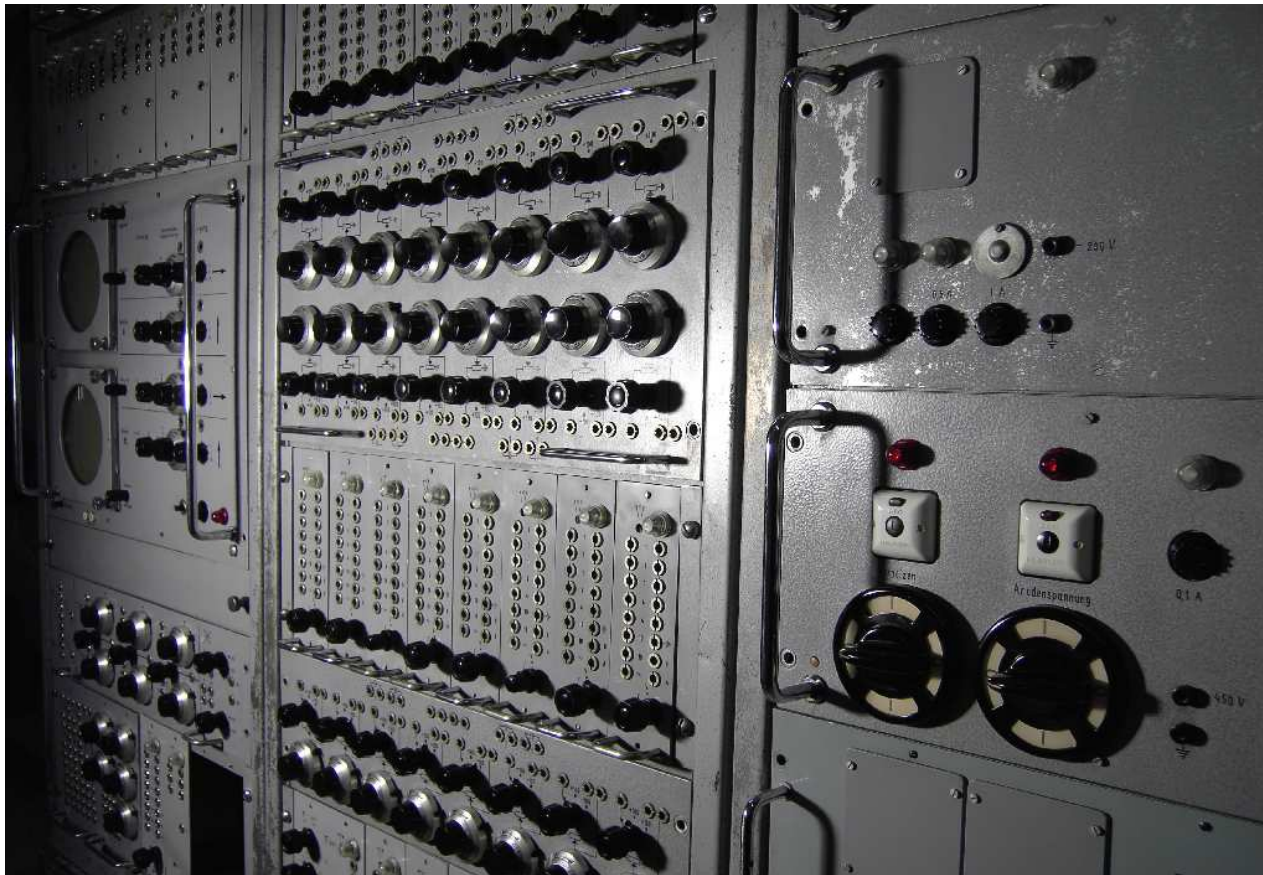# Telefunken Analog and Hybrid Computers

Bernd Ulmann

09-APR-2006

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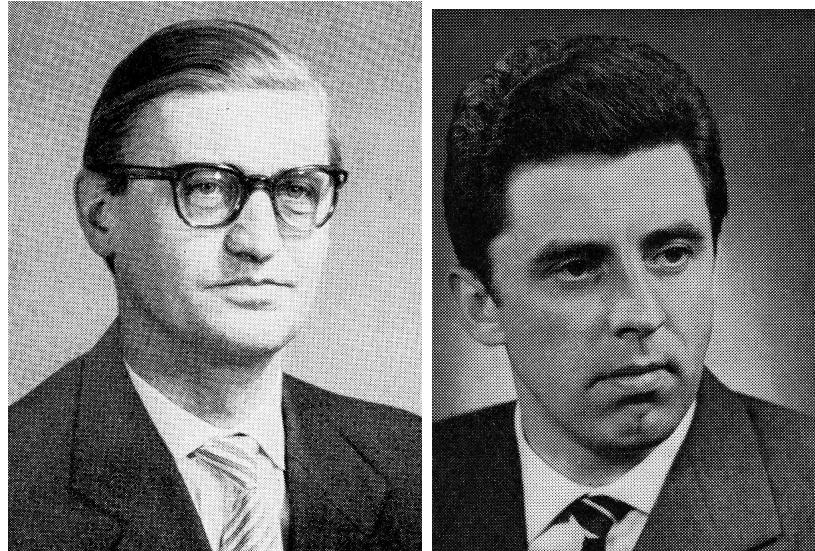
The prototype

It all began in 1955 with the very first analog computer ever built by Telefunken:

Dr. Kettel and Dr. Kley

The father of this machine was Dr. Kettel (on the left – cf. [9][p. 378]). Telefunken as an "engineers company" always supported new ideas and thus Dr. Kettel was able to start the development of a tube based analog computer.

On the right is Dr. Kley (cf. [4]), one of Dr. Kettel's co-workers. Another important person was Dr. W. Schneider who developed the parabola multipliers used in the prototype.

The Prototype

The following picture shows the three racks of the prototype in its current state of preservation:

The Prototype

The prototype has several remarkable features which will be covered in more detail in the following:

- It is tube based – even the diodes in the function generators are valves.

- It does not feature a central patch panel – instead it consists of a plethora of small modules which have their inputs and outputs routed to the front panel.

- There is not a central readout system as in the later production version and all following machines.

- It does not use chopper stabilized amplifiers resulting in a maximum calculation time of about 100 seconds only! So this is a truly repetitive analog computer, not a long term computer as its successors.

- The computer features inverters, combined summers/integrators, multipliers, function generators, coefficient potentiometers and a dual oscilloscope.

The power supply system

The rightmost rack of the system contains the power supply system consisting of

- the main control panel containing the mains switches and some readout electronics to monitor critical voltages,

- a voltage constanter (made by Wandel and Goltermann!),

- the power supplies generating +/-200 Volts (stabilized) as needed by the amplifiers,

- and a precision power supply for the machine units of +/- 100V.

Power supply control

The following picture shows the main power control panel with its prominent power switches (heaters and anode voltage) as well as the jacks for measuring supply voltages with an external instrument:

Precision power supply

The most critical supply voltage is the machine unit of +/- 100 Volts. It is generated by a sophisticated double rail regulator featuring only one control potentiometer for both voltages:

Computing elements

The leftmost and middle racks contain all computing elements of the machine which are shown in more detail in the following:

- A typical coefficient potentiometer drawer,

- inverters (used to change the sign of an input signal),

- integrators/summers,

- the time base,

- the function generators,

- the multipliers,

- some special functions and, finally,

- the dual oscilloscope.

Potentiometers

The following picture shows one of the coefficient potentiometer panels. Note that each potentiometer has a rotary switch allowing its use as an initial value potentiometer by connecting it to one of the machine units or using it as a normal voltage divider in a computer setup:
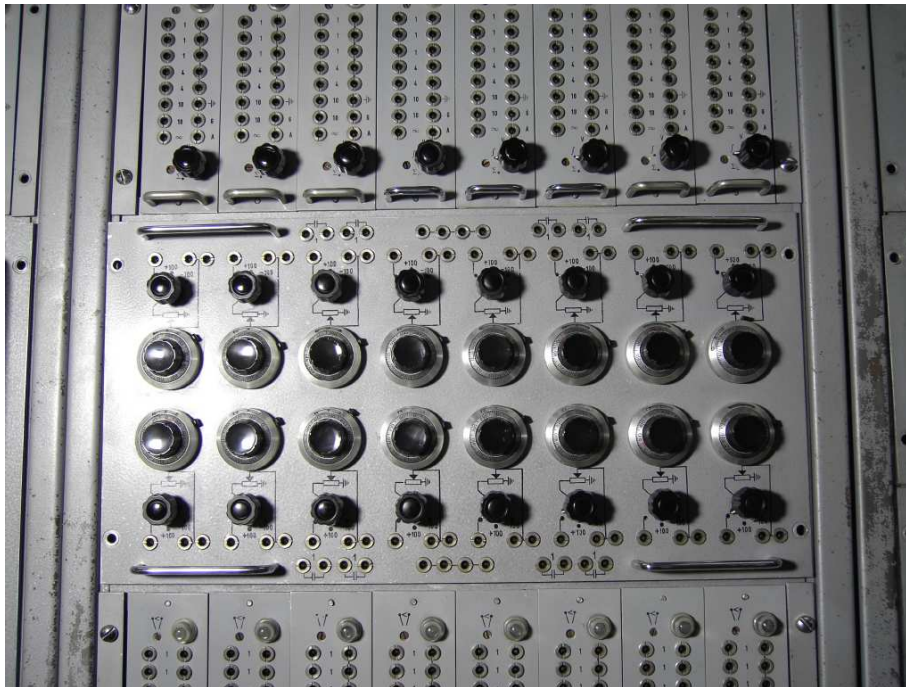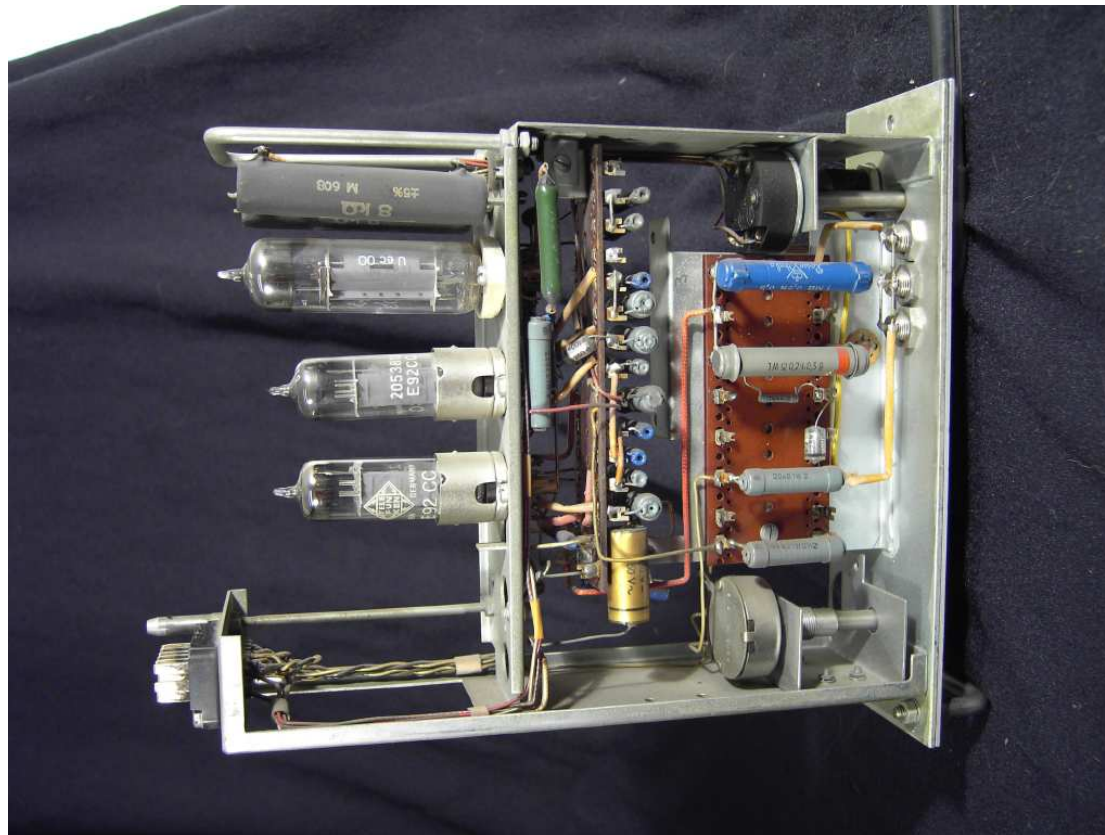
Inverters and Multipliers

The picture below shows a drawer containing four multipliers and a drawer containing eight inverting amplifiers:
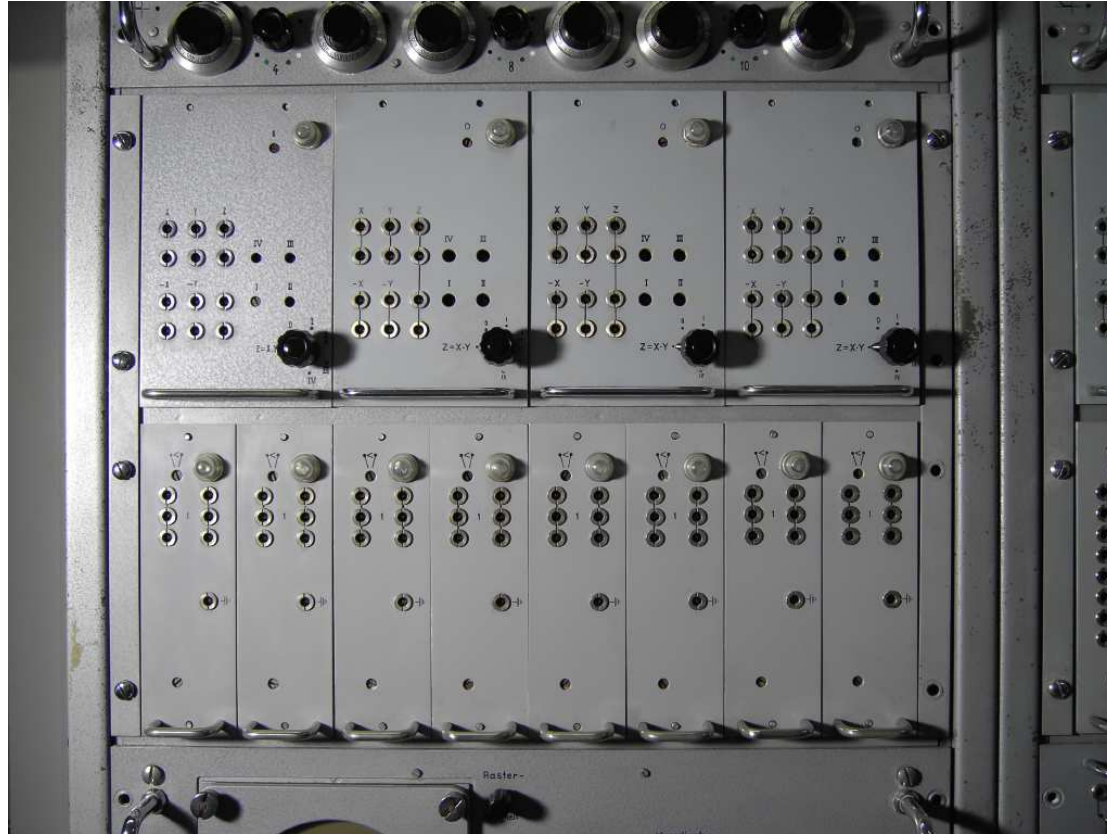
The inverter

In the following the interior of such an inverter is shown. It consists of two differential stages using two E92CC tubes and an EL803 as the output stage:

Drift compensation

The inverter amplifiers have no drift compensation at all – only the summers/integrators feature a drift compensating circuit.

Normally drift compensation is done by using two different amplifiers:

1. A DC coupled main amplifier which is subject to drift and

2. an AC coupled auto zero amplifier which samples the voltage at the summing junction of the main amplifier and generates a correction signal to be fed back into the main amplifier.

Dr. Kettel and Dr. Kley established a much simpler scheme which allowed to use only one amplifier while still having some drift compensation. The idea behind this was to sample the drift voltage at the summing junction with a capacitor and using the voltage between its plates as a corrective signal while perfoming calculations.

The repetitive integrator/summer

The following drawing shows the implementation of this scheme ([8][p. 140]) – C_0 is the drift compensation capacitor while C is the integration capacitor. Such an integrator had only two states: Initial condition and run mode.
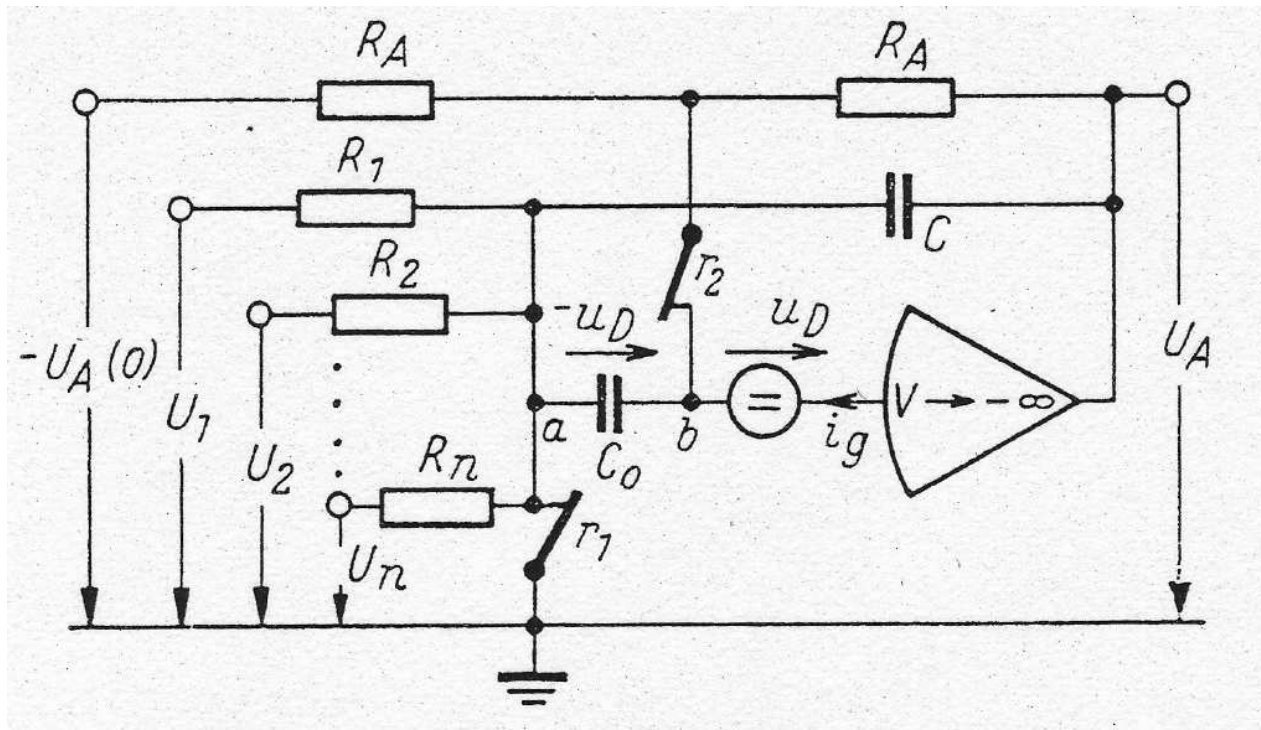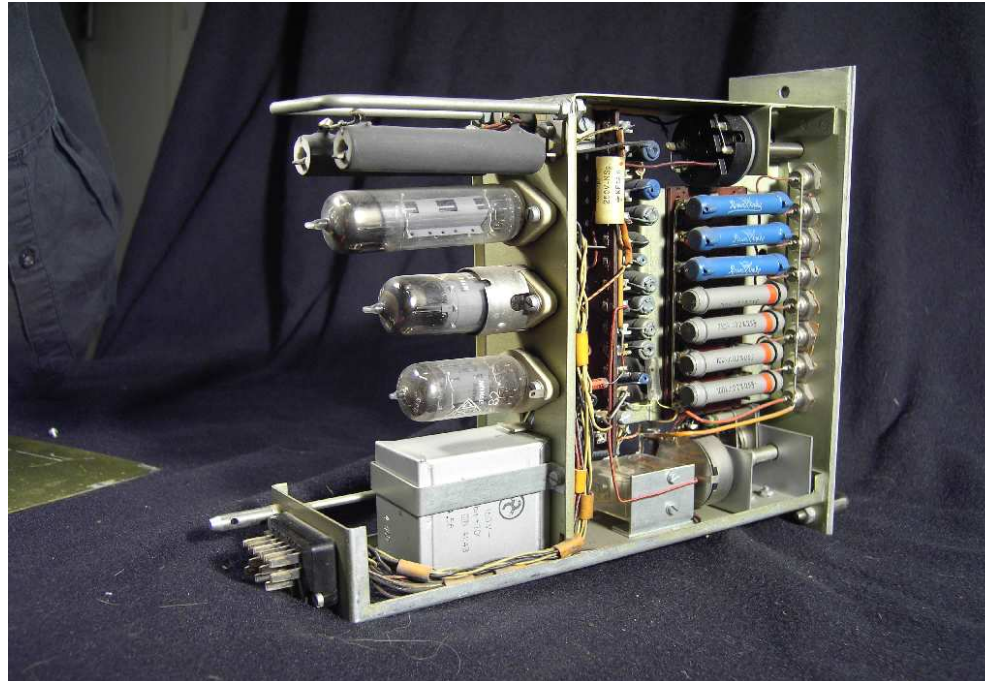
The repetitive integrator/summer

The following picture shows the front plate of such a summer/integrator:
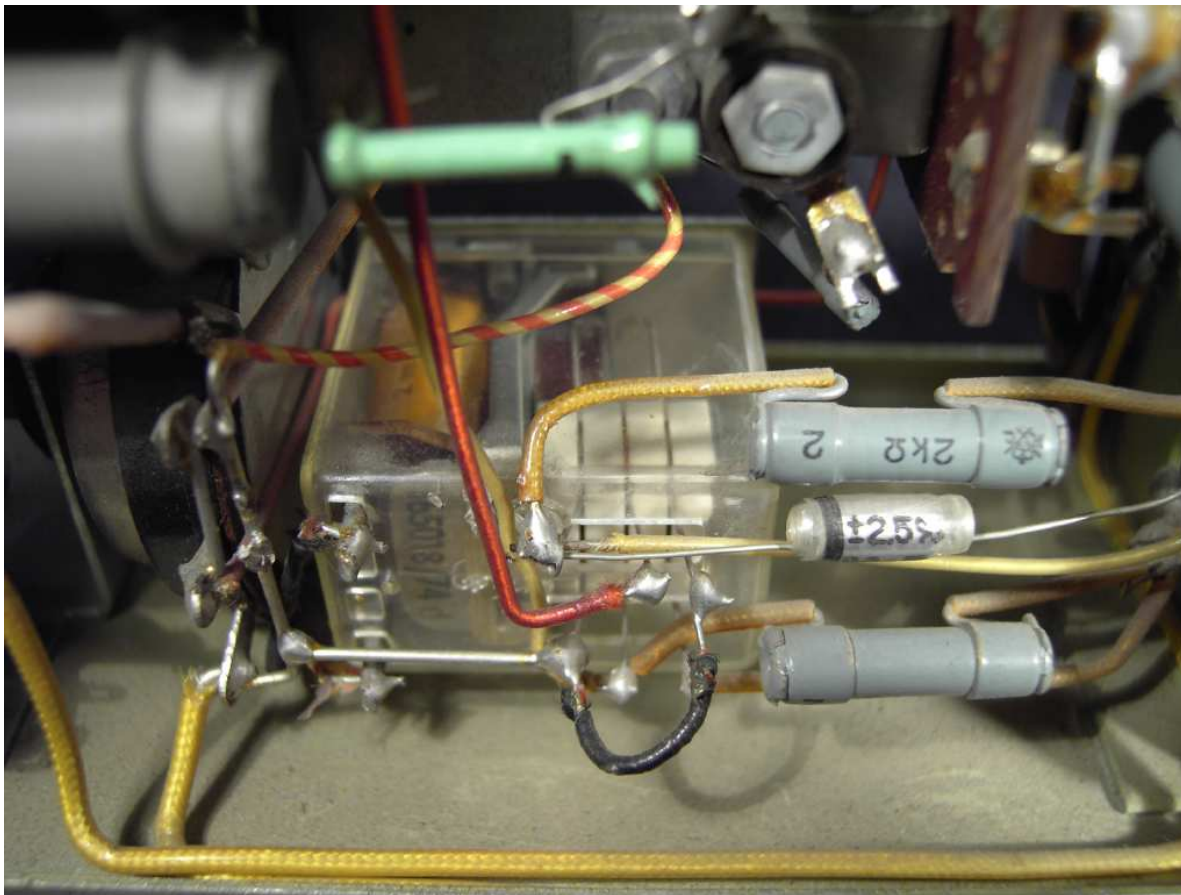
The repetitive integrator/summer

Its interior looks like shown below. Note that the amplifier part is identical to that of a simple inverter. The large capacitor on the back of the unit is the drift compensation capacitor.

The repetitive integrator/summer

Telefunken used a high speed relay to reset this amplifier circuit:

Time control

A special integrator is the time base unit of the system. It is used to control the time span of the run mode phase of a calculation. Essentially it generates a ramp ranging from -100 V to +100 V which is used to control the x-deflection of the oscilloscope, too.

The function generator

The picture below shows one of the two variable function generators. It is based on a polygon approximation of the desired function and features 10 support points:

The function generator

Each part of the polygon can be based on one out of eight possible curve shapes which are selected by the rotary switches (picture on the left). The picture on the right shows the input jacks (note that x and $-x$ are needed!) and the switch used to control the maximum slope of the polygon:

The multiplier

The multipliers of the prototype are of the parabola type, i.e. they rely on the fact that $4xy = (x+y)^2 - (x-y)^2$. The square functions are generated by using diode based polygon function generators as shown below (see [8][p. 143]):
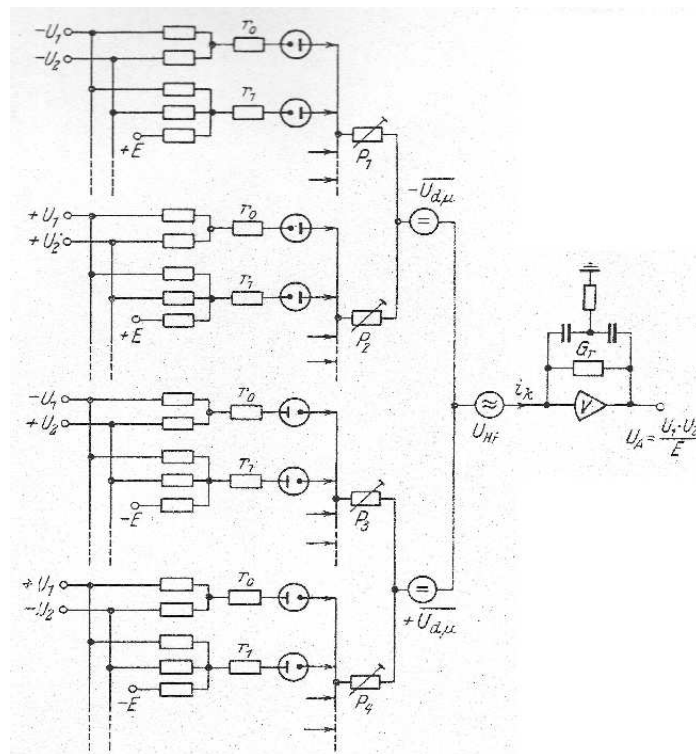
The multiplier

The front plate of such a multiplier is shown in the following – please note that both input variables x and y have to be supplied with positive and negative sign simultaneously:
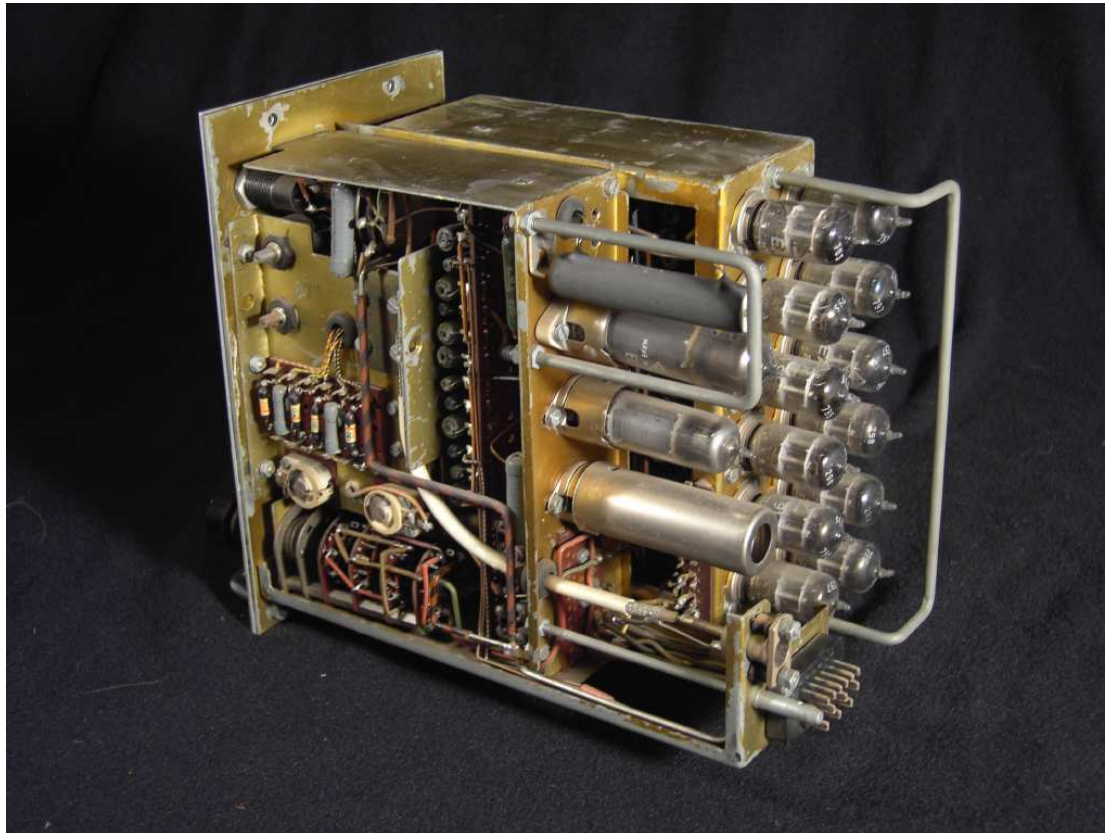
The multiplier

The following picture shows the right hand side of such a multiplier (showing the output amplifier):

The multiplier

The rear of the unit looks like this:

The multiplier

The heart of a parabola multiplier are the resistor networks defining the support points and the slopes of the polygons:

The multiplier

The function generators for the squaring functions need lots of diodes – selected and matched EAA91 tubes:

Special functions

Apart from these conventional units the prototype had some drawers implementing special functions as shown below (backlash, comparator relays and five additional coefficient potentiometers):

The oscilloscope

The main output device of this (repetitive) analog computer was a special dual oscilloscope which relied on the time base of the computer to generate the necessary x-deflection:

State of preservation of the prototype

While it is fortunate that the prototype survived the last 51 years and has not been lost or scrapped, its current state of preservation is rather poor:

- There is no documentation at all.

- The (very special) patch cords have been lost.

- It has been cannibalized for several tens of years, so dozens of tubes are missing, passive components like power resistors and capacitors have been removed, etc.

- Without the drawings it is not even clear which tubes and parts are actually missing. In the oscilloscope alone are about 25 empty tube sockets.

- The racks are in need of massive rework and painting.

If you know of any drawings, documentation, etc. or are willing to volunteer, please send me a note to `ulmann@vaxman.de` – every help, every hint is welcome!

Solving van der Pol's DEQ

The first application example published in [8][p. 135] was the solution of van der Pol's differential equation[a] $\ddot{y} - \mu \left(1 - y^2\right) \dot{y} + y = 0.$

The setup of the prototype to solve this DEQ was as shown below:

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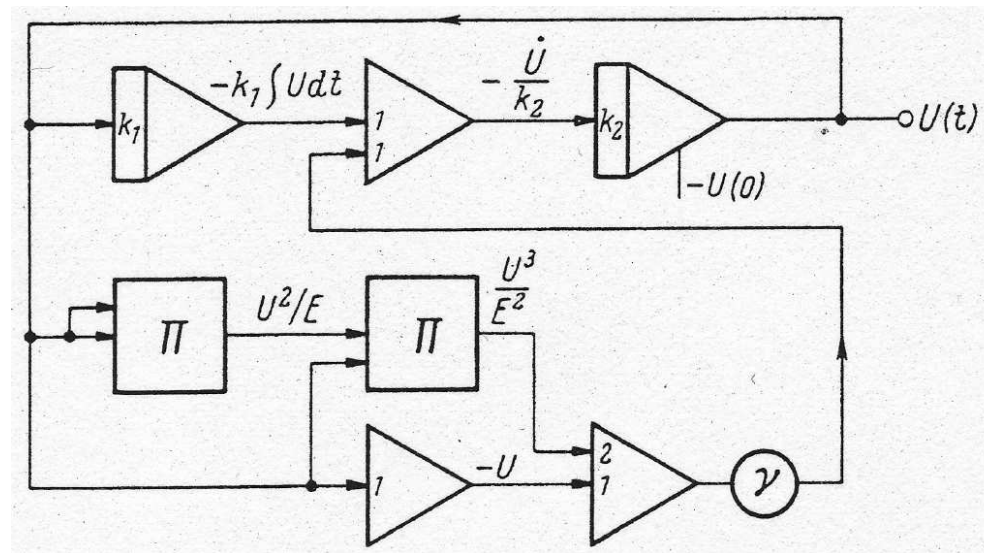
[a]This may have been chosen as an example since this DEQ is quite important in oscillator design – a genuine Telefunken area of interest.

Solving van der Pol's DEQ

The picture below shows some particular solutions of this equation as calculated on the protoype – quite remarkable for 1955/1956 (the upper row shows amplitude plots while the lower row shows the corresponding phase plots – see [8][p. 135]):
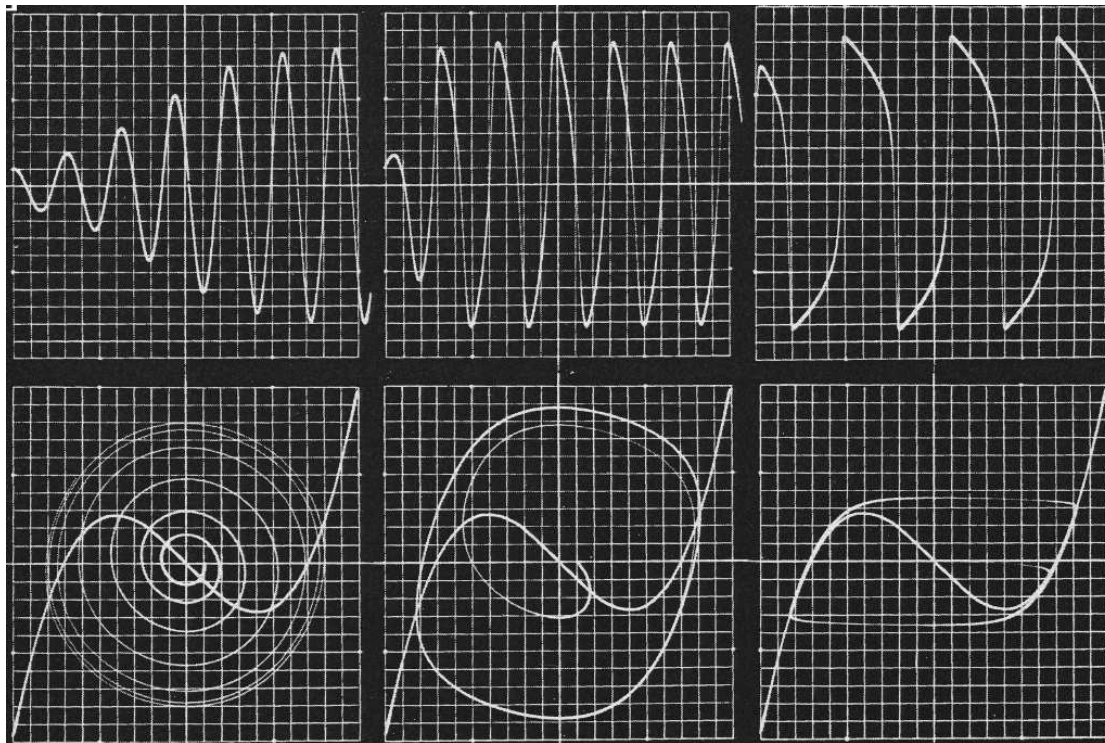
The first production model

The following picture shows the resulting production model, the RA463/2 (one surviving machine can be seen in the Munich museum of technology, another one has been scrapped in mid April 2006 in Hamburg! What a tragic loss! If you ever hear of a machine which needs to be saved from scrap, let me know – `ulmann@vaxman.de`). This picture has been taken from the sales brochure [5]:
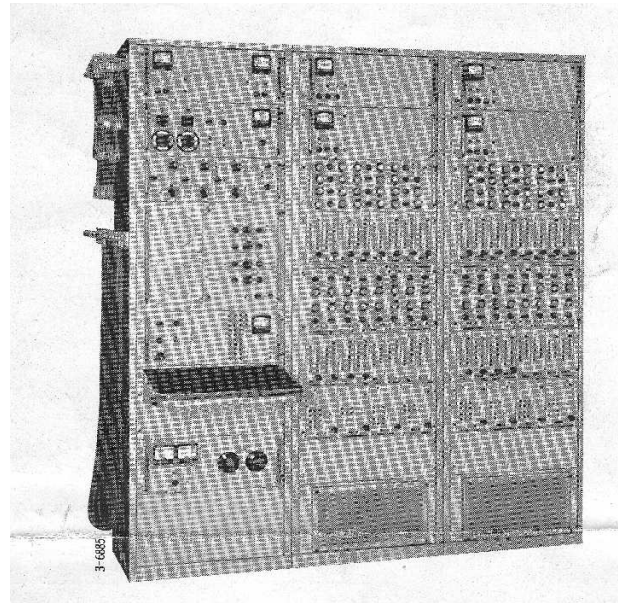
The first production model

The picture below (cf. [5]) shows the module placement of this production model which is quite different to that of the prototype:
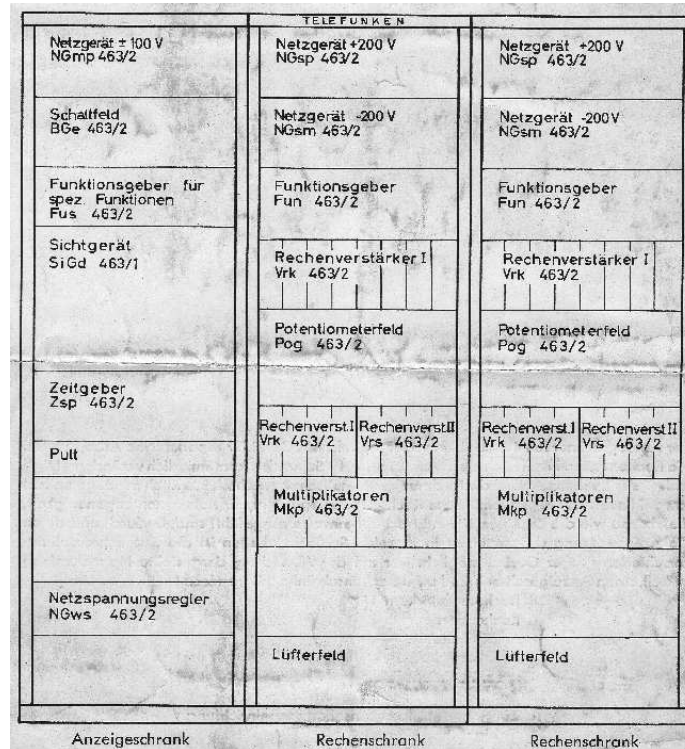
Towards a transistorized analog computer

This prototype and its production form, the RA463/2, were the only tube based analog computers ever built by Telefunken.

In the second half of the 1950s, Dr. Kley developed a more sophisticated, chopper stabilized amplifier which was intended to be used in later tube based computers (cf. [8][p. 140]):
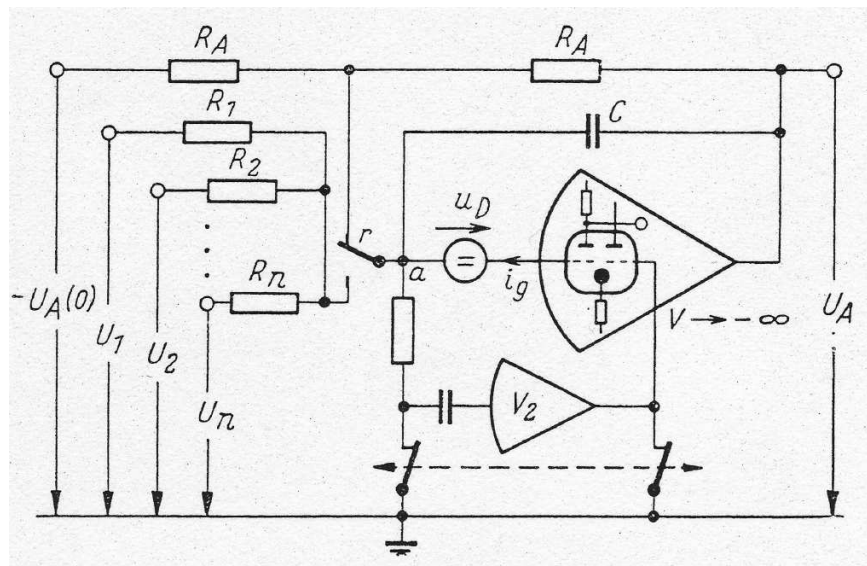
Towards a transistorized analog computer

This chopper stabilized operational amplifier had a DC coupled main amplifier and a drift free AC coupled amplifier V_2 which sampled the error voltage at the summing point a of the main amplifier.

The output of V_2 was then rectified and fed into the non-inverting input of the main amplifier thus cancelling out the initial drift of this amplifier.

Dr. Kley's tube based amplifier never made it out of the laboratory since Dr. Meyer-Broetz, who had come to Telefunken in the mean time, decided to use a new device, the transistor, to build a better amplifier for the next generation of Telefunken analog computers.

The schematics of this first transistorized high precision operational amplifier which still makes modern high integrated circuits look like toys when it comes to the technical data looked like this:
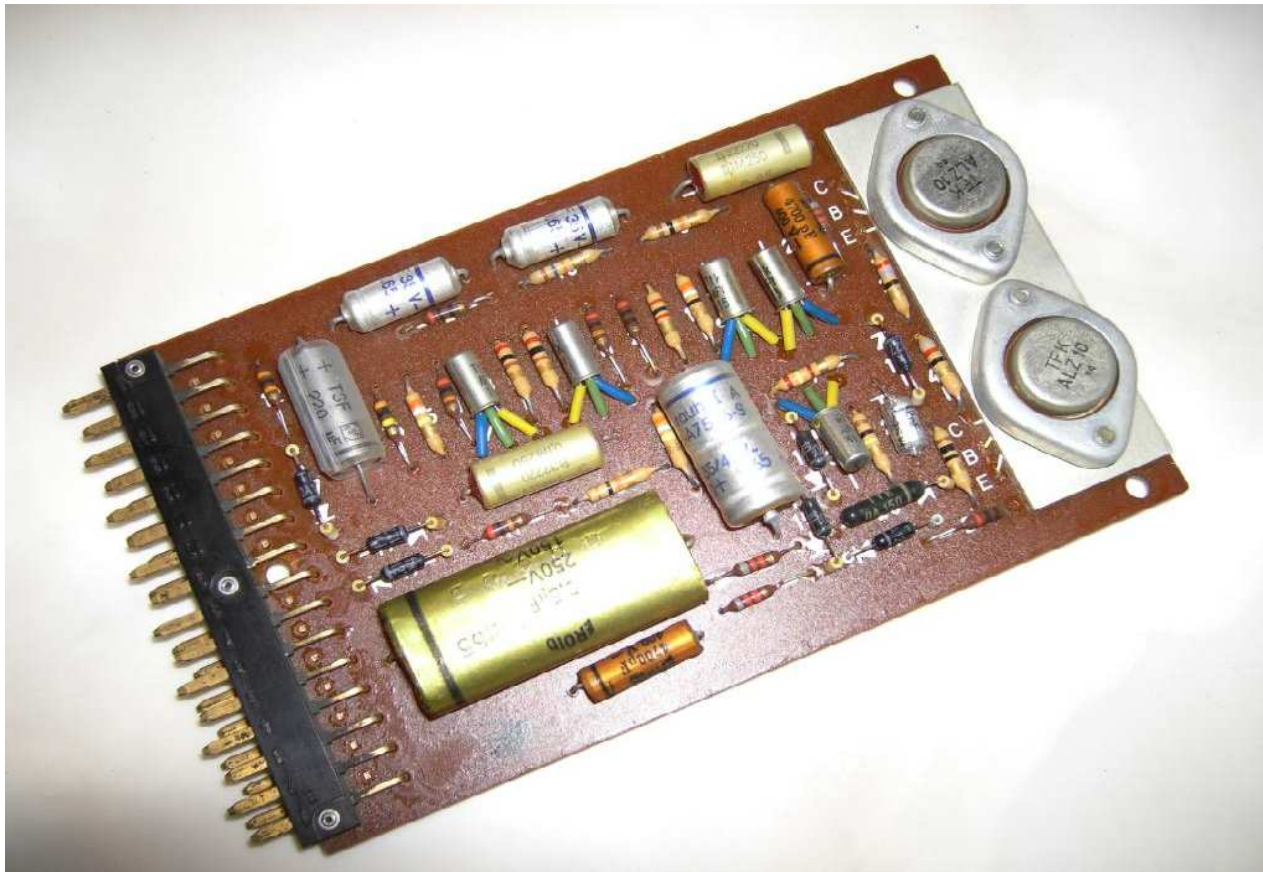
The first transistorized operational amplifier

This amplifier had in essence the same setup as the one proposed by Dr. Kley – a main amplifier (note the recovery diodes at the summing junction) and an AC coupled auto zero amplifier. The AC conversion of the DC drift voltage was done by mechanical chopper relays fed with a 400 Hz voltage while the rectification was done using Ge-diodes in a synchronous demodulator. The output of the auto zero amplifier was also used to detect an overload of the main amplifier (cf. [6][p. 19]):
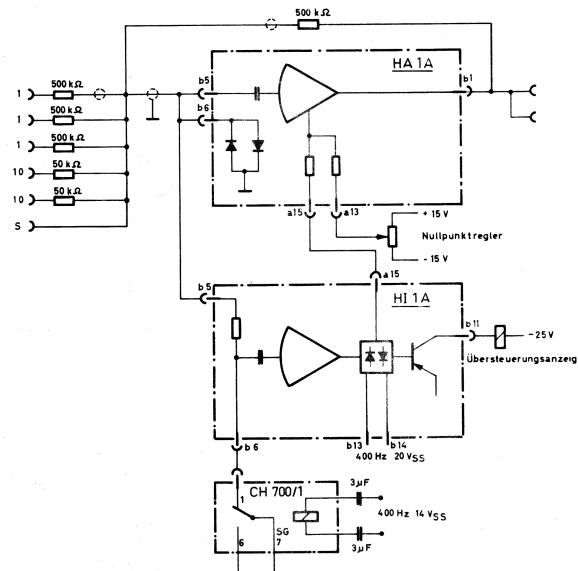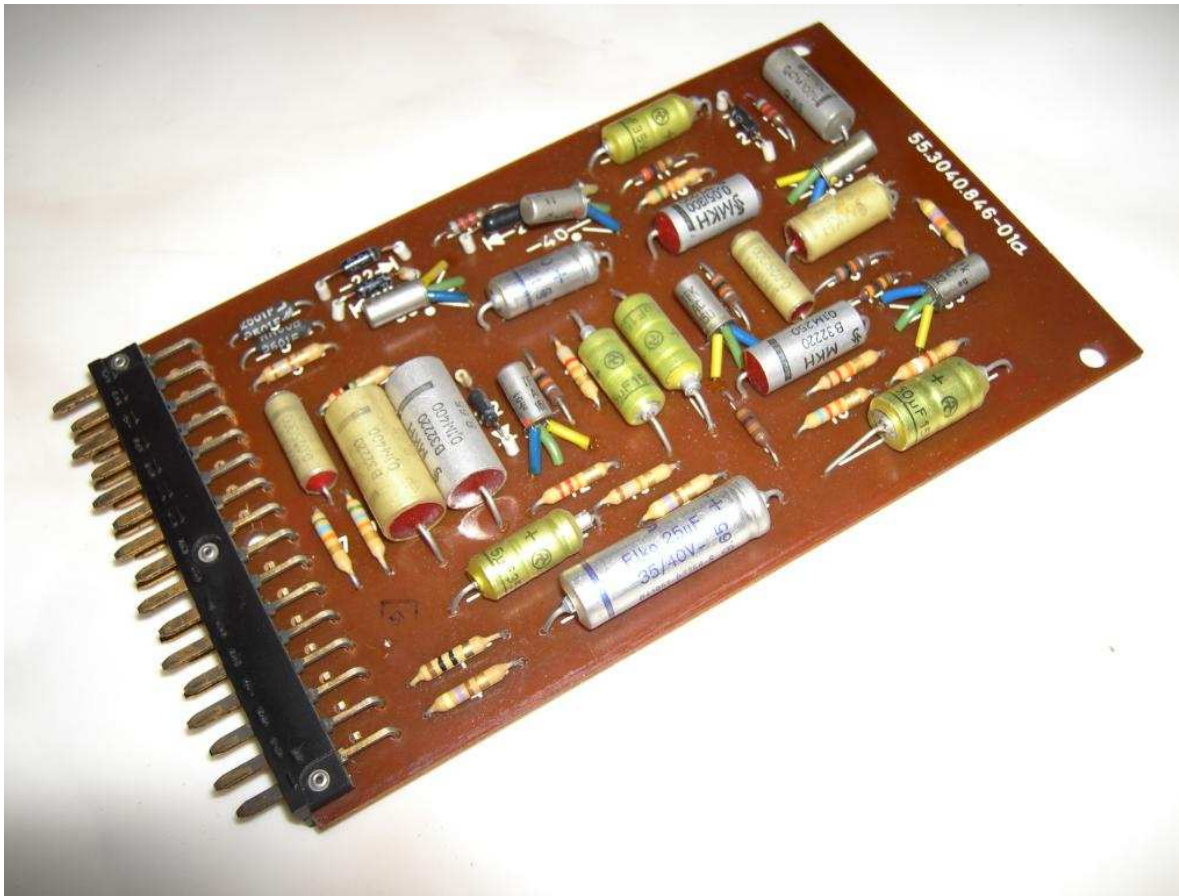
The first transistorized operational amplifier

The following picture shows the main amplifier of such an amplifier pair:

The first transistorized amplifier

The support amplifier generating the drift correction signal looks like this:

The RA800

The first transistorized large scale precision analog computer based on this incredible amplifier (having a DC-gain of about 10^9!) was the famous RA800 shown below (cf. [2][p. 133]):
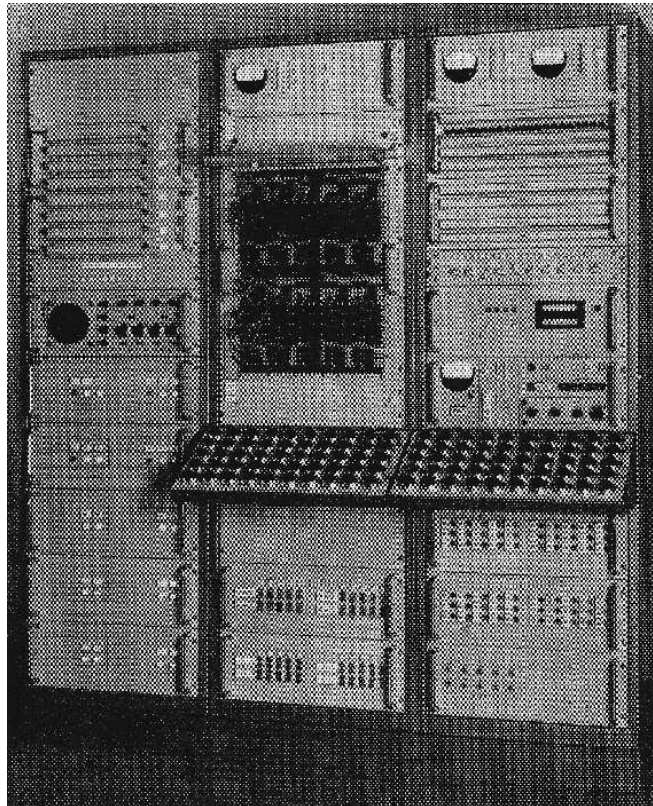
The RAT700 – the first table top analog computer

The RA800 had a smaller cousin, the RAT700 – the first transistorized table top analog computer built by Telefunken (in fact it was ready some weeks before the RA800):

RA800 and RAT700

The RA800 and the RA700 had a lot of things in common – most notably they used the same drawers containing 15 operational amplifiers and they had the same power supplies (the only difference being that the RA800 had more power supplies than the small RAT700).

While the RAT700 was a quite inexpensive system without a removable patch board, using unshielded patch cables and 0.1 percent components, the RA800 was an expensive high precision analog computer:

- It had a removable patch board,

- used special shielded patch cables,

- made use of 0.01 percent components and

- housed the integrator capacitors in a temperature controlled oven thus minimizing environmental effects.

Amplifiers and power supplies

The following picture shows the combined amplifier/power supply drawer of an RAT700 system. The power supplies are housed in the right half of the drawer while the 15 operational amplifiers occupy the left half:
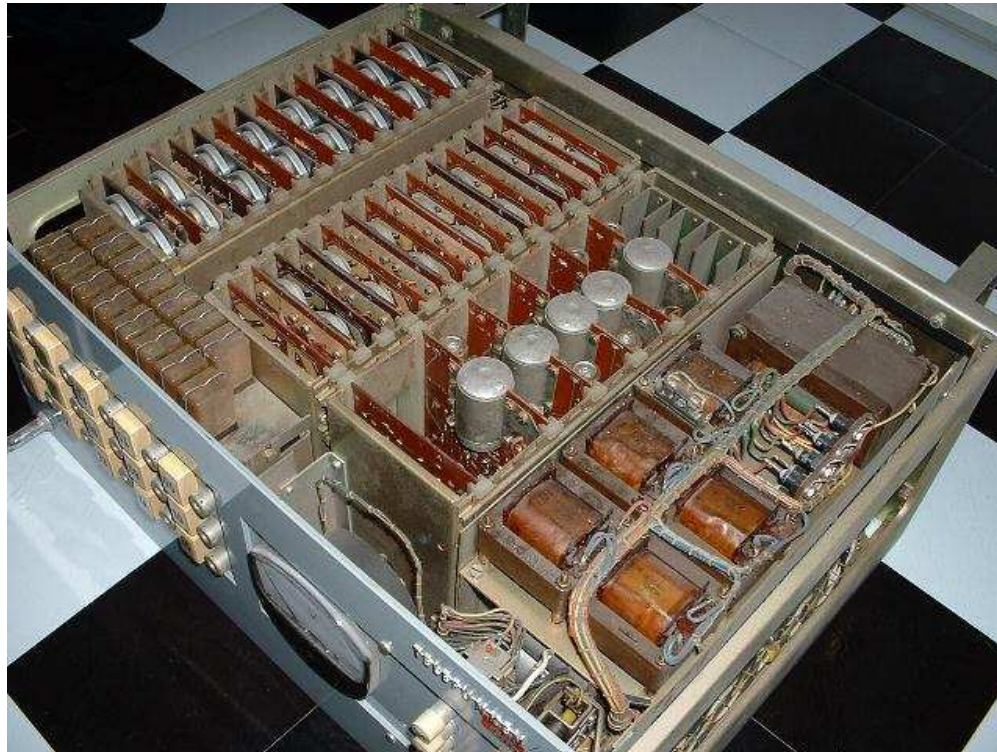
The patch panel

The picture below shows the lower drawer of an RAT700 containing the central
patch panel (using cheap 4 mm banana plugs) and the timing and control panel of
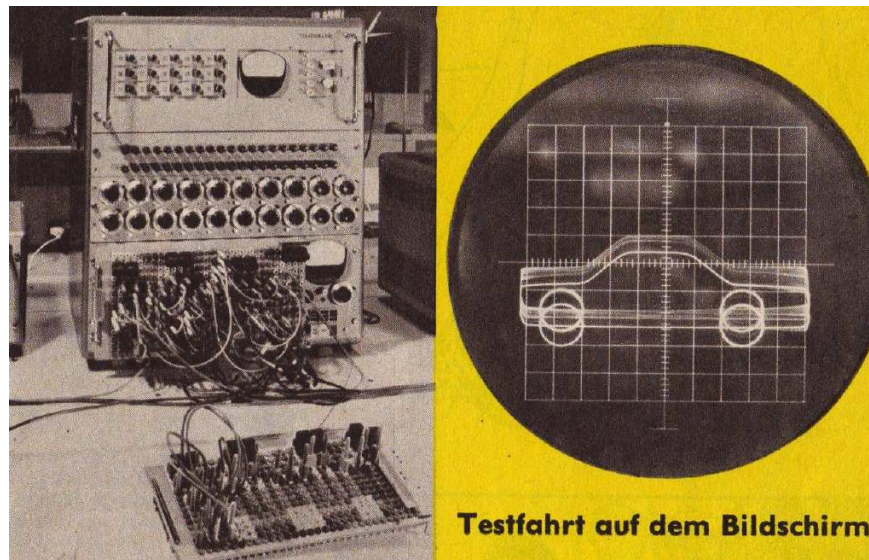the computer:
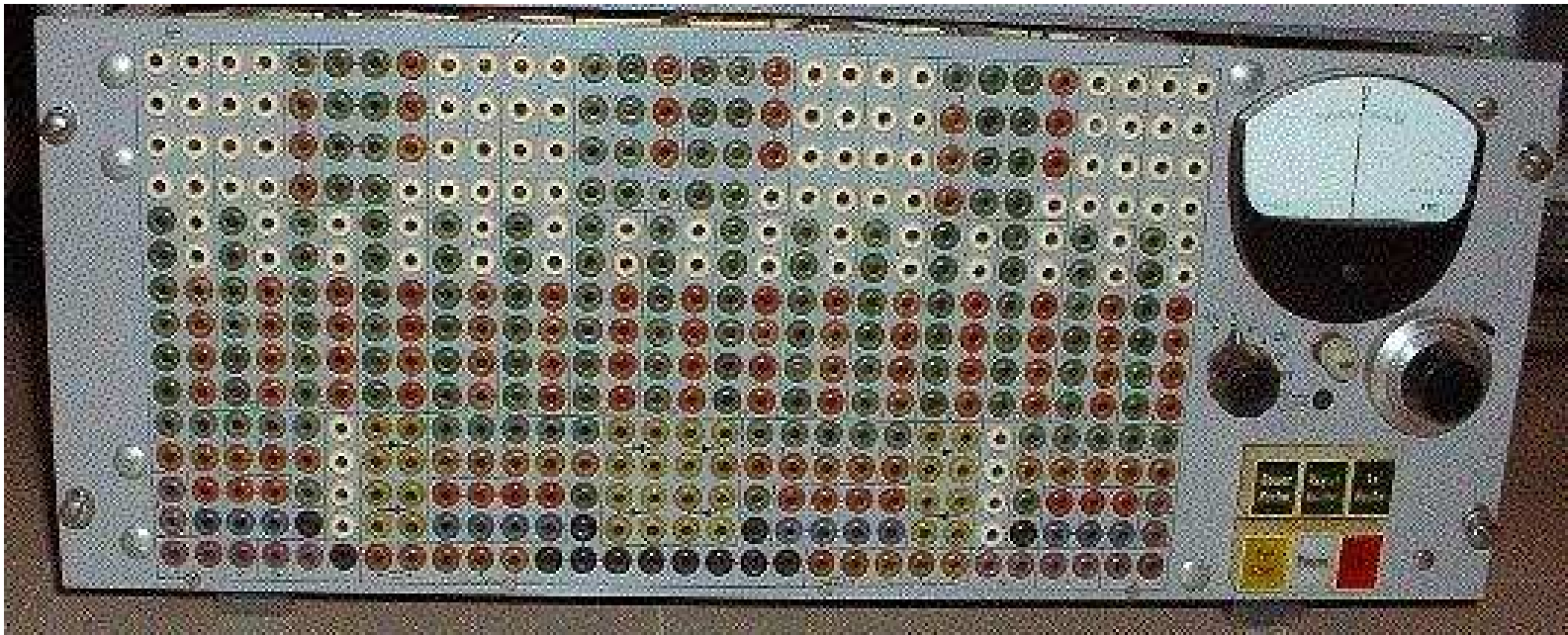
Towards removable patch panels

Later versions of this computer featured a removable patch panel which was available as an add-on using special spring contacts plugged into the main panel which made contact with the plugs of the removable panel mounted in front of the original panel. The picture below shows these contacts on an RA741 computer:
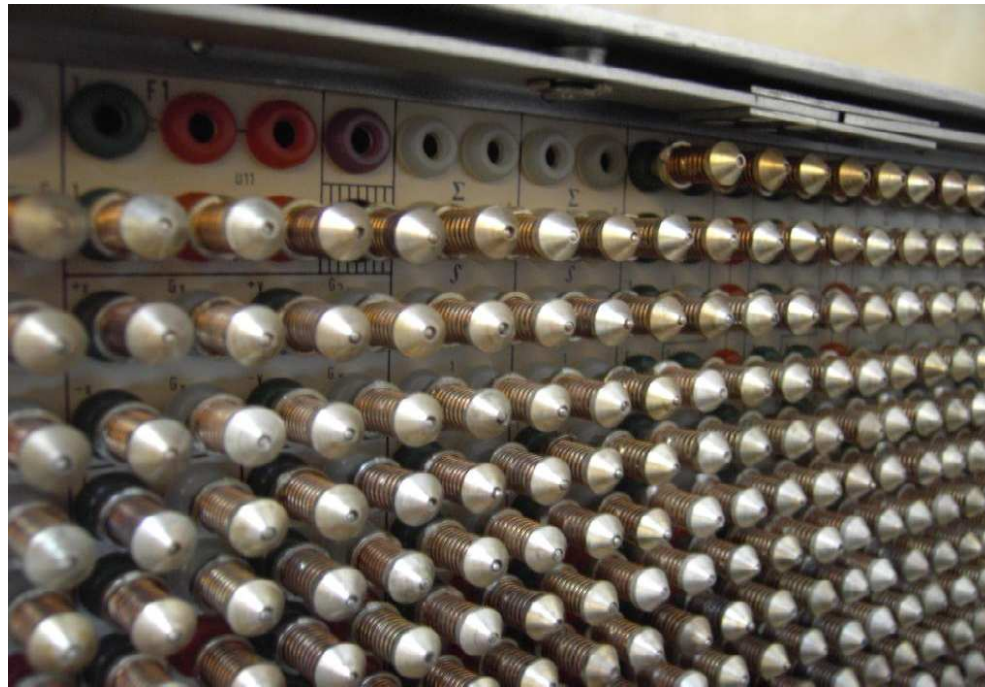
A demonstration of the RAT700

Telefunken had some very impressive demonstrations run at the Hannover fairs, etc. One example is shown below (it needed all computing elements of the RAT700 as well as a special (hidden) circuit to generate the car silhoutte since there were not enough function generators available in the basic machine). This masterpiece had been programmed by Dr. Giloi: [3]

Testfahrt auf dem Bildschirm

Telefunken's table top analog computers

The family of table top analog computers (note that a typical system like the RAT700 weighs more than 100 kg – finding a table supporting this is not that easy) was well received throughout universities and the industry.

Beginning with the RAT700 introduced in 1960, Telefunken continued to build successor systems well into the 1970s (at least until 1972).

Follow on systems were the RAT740 (which had a higher precision than the cheap RAT700), the RA741 and the RA742 – both shown on the following pages.

The RA741 normally came with a removable patch panel and had a much more sophisticated timing and control unit than the RAT700. The RA742 followed this line replacing the relays controlling the integrators by electronic switches and offering a new patch board system.

The RA741
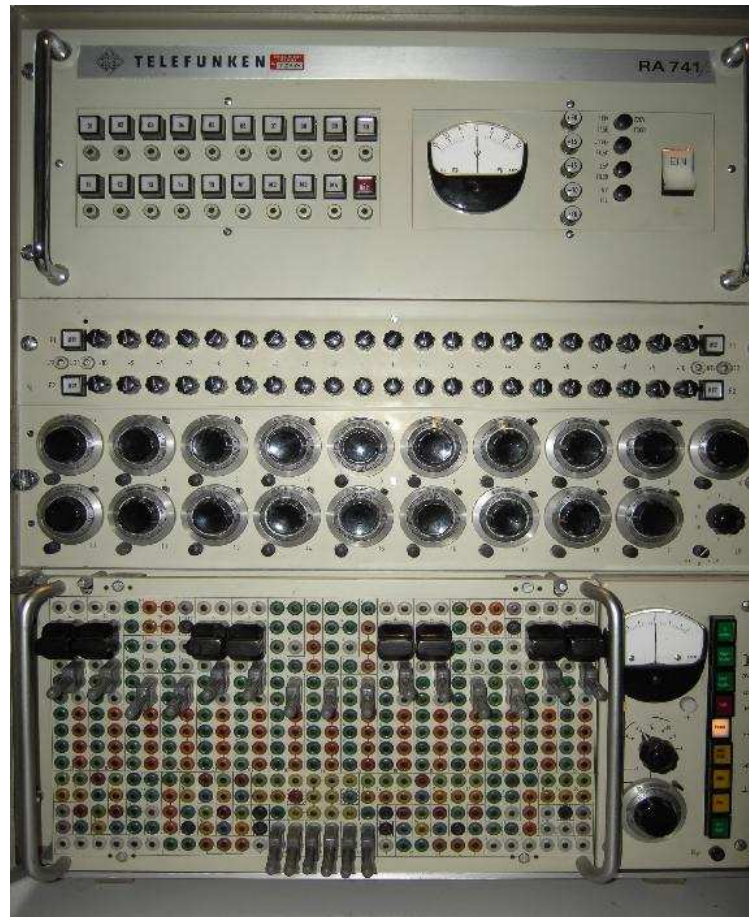
The RA742

Towards hybrid computing

Many problems can not be solved using an analog computer alone – these problems require a hybrid system, consisting ideally of an analog and a digital computer coupled together by some AD/DA-converters.

A first step towards such a system was made by Telefunken with the introduction of the DEX ("Digitalzusatz") which looked like an analog computer but contained digital elements like and/or-gates, monoflops and flip flops.

This system could be used to control an analog computer like the RA742 or its predecessors. Lacking any AD/DA-converters, both systems communicated by means of comparators controlled by the analog part and relays controlled by the DEX.

The following picture shows a complete setup consisting of an RA742 on the right and a DEX102 on the left with an OMS811 oscilloscope on top.

Towards hybrid computing

The RA800H – the first hybrid computer

The first large scale hybrid computer consisting of a precision analog computer and a versatile digital subsystem (the DEX802) was Telefunken's famous RA800H, shown below (cf. [1][p. 273]):
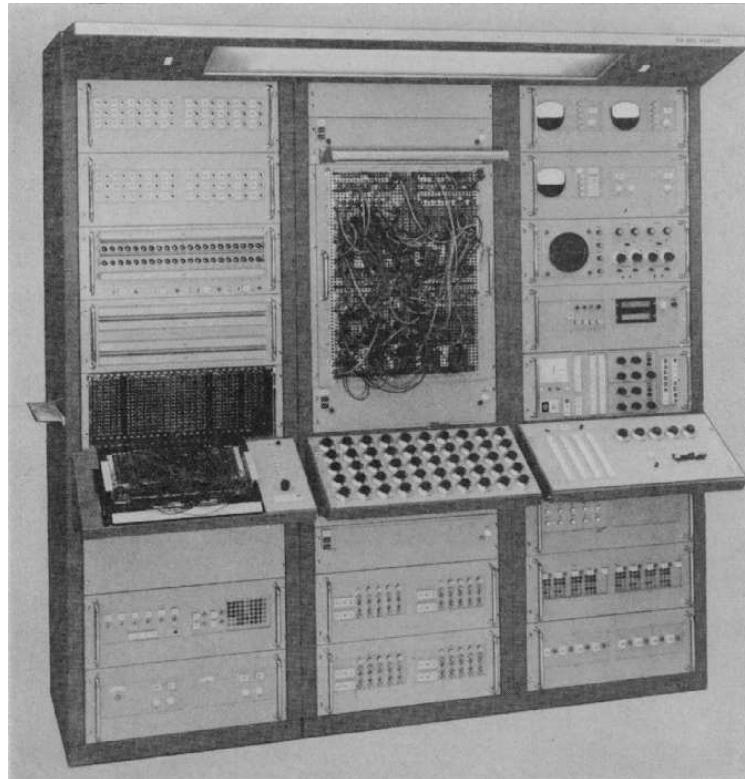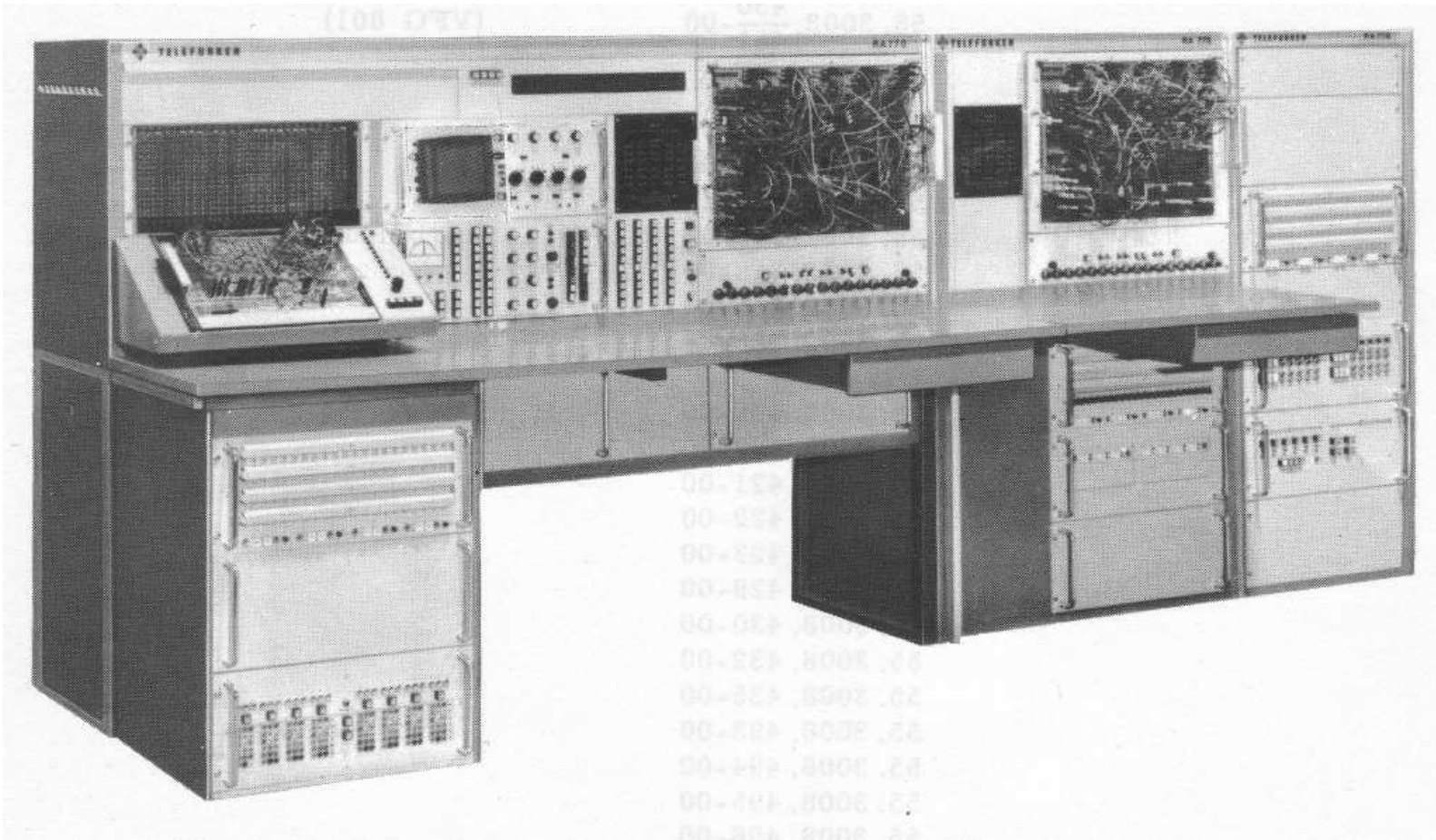
The RA770

Obviously the RA800H was based on the highly successful RA800 analog computer introduced in 1960. It was the first analog computer to make use of the newly introduced Si-transistors and used electronic choppers instead of the mechanical ones used in its predecessor system.

Another system designed in the same time frame was the RA770 – the brain child of Dr. Giloi. This machine was the first (and only) being built into a table facilitating easy access to all elements and making use of the most sophisticated circuits and a very dense packaging technology.

This system is shown in its maximum configuration in the following picture (cf. [7][p. 1-0]). The RA770 is on the left, followed by an RA775 expansion computer and the HKW900 ("hybrides Koppelwerk") on the far right (this contained various AD/DA-converters, etc.).

The RA770 + RA775 + HKW

The end of an era

These two systems, the RA800H and the RA770, both introduced in 1966, marked the end of an era.

Sales were dwindling and the most gifted developers either left Telefunken at all (Dr. Giloi went to the university Berlin) or moved on to new interesting projects (Dr. Kley started research on automatical correctness proofs for digital computer programs), etc.

The last system being introduced to the market was the RA742 which was just a minor improvement on well known technology. The RA770 was sold until the late 1970s and then the analog computer business collapsed.

Help

As you may have noticed, analog computing is my passion! Therefore I would like to ask you for help:

- I am trying to save analog computers from scrap where ever I can. If you happen to know about a system looking for a good home, please let me know. (I am not afraid of large systems and I would really love to get an RA770 or an RA800(H), for example! I will pay for all expenses to save the machine from scrap and I will arrange shipping, etc.)

- I am interested in trivia, documentation, computer setups, sales brochures, etc.

- Please spread the word and help to save these machines from getting lost and forgotten.

You can reach me always at `ulmann@vaxman.de` or by mobile phone at 0177/5633531 (in Germany) in case of an emergency. Thank you very much!

References

[1] Helmut Adler, "Elektronische Analogrechner", VEB Deutscher Verlag der Wissenschaften, Berlin, 1968.

[2] Helmar Frank (Hrsg.), "Kybernetische Maschinen", S. Fischer Verlag, 1964.

[3] "Hobby", Heft 6, 1965.

[4] Adolf Kley, "Elektronische Hybridrechner – Eine Einfuehrung in Wirkungsweise, Aufbau und Anwendung", Frankh'sche Verlagshandlung, 1969.

[5] "Elektronischer Analogrechner RA 463/2", Telefunken, AH 5.2 Apr. 58.

[6] "Transistorisierter Tisch-Analogrechner RAT700 – Beschreibung und Bedienungsanleitung", Telefunken.

[7] "Hybride Praezisionsanalogrechenanlage RA 770 D – Technisches Handbuch (Teil 2)", Telefunken.

[8] "Telefunken Zeitung", Jg. 30 (Juni 1957) Heft 116.

[9] "Telefunken Zeitung", Heft 4 (1967).