The Telefunken RA 770 Analog Computer

On November 18th, 2007, a dream dack from days of childhood came true, when I became the very, very happy and proud owner of a wonderful Telefunken RA 770 analog computer which can be seen after restoring and repair in the photo above. The RA 770 is, by my opinion, the finest analog computer ever made by any manufacturer, it is a high precision analog computer (10^-6) in the very best tradition of Telefunken which can be seen in every detail of the system.

I would like to thank Mr. Flankamp from the Forschungsinstitut Mlich who saved this wonderful machine from scrap and gave me a phone call asking if I were interested in the system. Without his invaluable support the system would have been scrapped. Also I would like to thank Mr. Fine from the Bundesfernmeldetechnisches Sc hulz with some formal aspects.

On November 19th, 2007, my beloved wife Erika and I were on our way with a truck to Jülich to get the machine. Mr. Flankamp and his coworkers did a great job in loading the rather heavy system which was partially dismantled into the truck and transporting it to Berlin.

Restoring and repairing the machine:

The picture on the left shows the nearly empty main frame of the RA 770 after it arrived at home (without the lady of the house, of course). The frame is made of extruded aluminum and weighs roughly 40 kg. Very heavy and very strong. Erika and I were very lucky that we could get the frame into the house.

Prior to transporting the system we removed all drawers as well as all printed circuit cards and cabling as far as possible to get the weight of the frame down and to minimize the risk of damaging something during the transport.

On the right, the subframe GBC 770 can be seen - normally it is located on the lower left of the main frame and contains the power supply, the operational amplifiers, the function generators, the main servomotors and the fdcs. This frame has been removed, too, to facilitate the transport of the system.

It was obvious that some cross wires have been living in the system when we looked at the GBC 770 in more detail. Some of the cables were cut and some were just pushed aside. Cleaning the system was a major task. I had to unscrew the main wire to clean every single part of the system thoroughly and then unpack it for damage due to its inhabitants.

The result of the first cleaning efforts can be seen on the left - we were afraid that this might only be the beginning of a rather disgusting work dealing with incredible amounts of mice droppings and the dirt and rw were right.

The picture on the right shows the first impression we had after removing the top panels from the machine. Nearly everything was covered with mice droppings and felt sticky and smelled rather bad to say the least.

The rear amount of the problem became obvious at the control relais frame which is located in the middle of the machine and contains a variety of control relais for the overall operation of the system.

It turned out that the mice droppings were not easily removed since they were quite sticky and left a disgusting residue everything they were placed on. Only I began to pick them one after the other with work pieces out of the circuitry. After this I would clean the area with detergent.

Unfortunately the mice had found that the insulation of the wiring of the machine tasted good and started to chew through some wires which can be seen in the picture on the right.

Fortunately all of the wires which were cut through were easily replaced since the mice were kind enough to let some traces of both ends of the wires intact so with a lot of guessing and the occasional help of the fantastic circuit schematics from Telefunken it was just a matter of time to fix the damages done by the mice.

One of the most time consuming (and most disgusting) problems is shown in the picture on the left. There are the card racks which hold the function generator cards. Since the cards were in the rack for quite a long time (10 years) they completely dismantled since it proved next to impossible to clean the slides without removing them from the card rage.

During dismantling the card racks I became clear that the mice excrements found their way to the board mounted to the card rages causing corrosion on contacts and flashing its way into the printed potentiometer housings of the parabolic function generators of the multipliers.

The picture on the right shows the cleaned function generator with the left of the protective potentiometer housings removed. Cleaning these the settings of the potentiometers are critical for the operation of the multipliers the process of cleaning them was very delicate and time consuming.

The two pictures above show the process of extracting the GBC 770 expansion frame is the main frame of the RA 770 analog computer. Attaching the three interconnect cables to the main frame required some detective work since these seemed to be the only cables which had not primarily intended. Fortunately their wiring matched with only one exceptable on the main frame, such.

The picture on the left shows the six additional interconnect cables which carry signals between the main frame and the three drawers to be installed in the GBC 770 expansion frame.

The picture on the right shows the completed frame of the machine after cleaning, repairing the broken wires and conducting the expansion frame GBC 770.

All of this cleaning and repair work was very interesting not only for me but for Steirlichen, the cat, as well. He did his very best to be of assistance but could not find any surviving mice. I am sure he would have saved the machine from their revenge if he had been there in time.

Subassemblies:

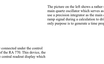
The following section shows the various subassemblies which are part of the RA 770 analog computer.

The picture on the left shows one of the two power supplies - this one contains the power distributors for the fans voltage, the temp control, the mains fuses and delivers -15 V for processing relays and 5 V, 12 V and 15 V for the logic lights. Only the -15 V supply is stabilized - the power transformers are mounted on the large cooling fin on the rear.

The two pictures above show the top and bottom view of the second power supply, the STV 771. This power supply delivers the following voltages:

Voltage Usage
+115 V for input stages of the amplifiers,
+115 V for output stages of the amplifiers
+115 V for the function generator cards
-18 V For servos amplifiers
+1.18 V Very high precision reference voltages

The top view of the power supply shows the two main transformers on the top of the picture as well as the vast amount of coils to smooth the voltages prior to feeding the regulators. The relays visible on the bottom of the picture detect overcurrent conditions and process the signal which is displayed on the error condition on a control display field.



The two pictures above show the top and bottom view of the power distribution system of the RA 770 - although the contents of the various computing elements are very small (only several inch cubed) the power distribution bars are of a large dimension to avoid overcurrent. Voltage drops. Of course there is a control ground point in the machine since ground loops would be fatal for the overall accuracy of the system. The various different ground lines (relay ground, chassis ground, high precision ground etc.) are connected only at this common ground point.

The fans for the cooling of the machine are located in the rear of the machine (Ventilatoren Berlin/gmbh) can be seen. It is divided into three parts (from left to right):

- The central selection system which can be used to select any active computing element in the computer system and connect it to the oscilloscope for monitoring the signal.
- The time control which is based on a common, even stabilized quartz generator. The output of this generator is fed into a chain of decimal dividers. The outputs of these divider stages can then be selected and connected to the main clock.
- On the far right the control control section can be seen - its switches control the operation of the overall machine.

The picture above shows the top and bottom view of the precision digital voltmeter DVM 781. Obviously it is not too popularized which is due to the fact that Telefunken once decided to stop building its own precision digital voltmeter and instead started using the Fluke 8000A series oscilloscopes. Instead it was decided to use an off the shelf high precision digital voltmeter from another vendor and surround this with the necessary circuitry to interface the same external interface as the rest of the system.

The picture on the left shows a rather unusual feature for an analog computer. This card contains the even stabilized quartz quartz oscillator which serves as the basis for all clock signals derived from its output. Most analog computers just use a precision integrator as the main clock, but for the RA 770 there is an often occasion to have a time proportional output available which is used for the function generator cards. Instead of a digital divider chain a precision integrator for the only purpose is to generate a time proportional deflection voltage.

The system incorporates a control high precision digital voltmeter which can be connected under the control of the control and DBG 771 to the output of any active computing component of the RA 770. This device, the DVM 781, is capable of measuring voltages with a resolution of 0.01 mV. Unfortunately, this device is a rather bulky which can be seen quite good in the very first picture of this page.

The adjustment screw in the middle of the front plate controls the voltage regulator which supplies the incandescent display lights.

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This OEM digital voltmeter (made by KNICK) DVM 1 can be seen in the picture above. It is based on the technique of dual slope integration and has a precision of 0.01 percent.

Around 1970 Telefunken decided to abandon its own line of specialized dual trace oscilloscopes specially developed for the analog computer business (Type 1015 and 1017) and instead started using off the shelf oscilloscopes from Tektronix made for 307 This device was then named DBG 771 and used in conjunction with the RA 770 analog computer. Its front plate can be seen on the left - since the standard Telefunken drawer is a bit larger than the 19 inch stand rolling it looks a little bit strange but it was a very convenient way to mount the DBG 771 in the system.

Unfortunately, my DBG 771 has a serious problem in its high voltage power supply which I until now was unable to fix (due to the lack of schematics, mainly). Therefore I decided to mount one of my two 1502A oscilloscopes which were used in the machine, too.

The next part of the system covered here are the servo potentiometers which are used in the RA 770. The basic idea is to have a central keyboard on which coefficient values can be entered with a precision of four decimal digits. This value is then set by a servo loop consisting of a small motor coupled to a precision potentiometer and some servo electronics.

This keyboard can be seen in the overall picture of the machine on the top of this page between the DBG 771 and the analog patch field. The two pictures above show the interior of this coefficient setting unit. It consists of some 20 precision voltage dividers which are connected to four sets of ten keys each generating an output voltage between 0.0000 and 0.1999 machine units (10 V). Please note that the precision resistors on the bottom left of are missing.

The picture on the right shows one of seven servo potentiometer units used in the RA 770. These units consist of 15 or 5 depending on the model potentiometers with their associated motors, a small gear and a clutch.

The two pictures above show the left and right side view of such a servo potentiometer unit with the shielding removed.

On the left a detailed view of the innards of such a servo potentiometer drawer can be seen. The potentiometers are mounted on a special mounting plate which allows easy exchange in case of a failure. The connection of the servo potentiometers to a simple slip clutch to avoid damage to the potentiometers in case of a faulty servo loop.

The pictures above show some of the servo potentiometer drawers installed in the computer.

Visible on the right is the panel holding the potentiometers for the zero adjustment of the operational amplifiers of the main frame. The panel is located behind the central overload indicator panel (see the first picture of this page, next to the analog patch panel).

On the left the digital expansion drawer is shown. Nearly every large scale analog computer built after about 1967 contains some digital circuitry to overcome the problems of analog computing such as drift, temperature dependency and aging of analog computational computations etc. This was also used in optimization problems and the like where decisions had to be made based on analog computed values.

Three digital expansion groups are normally programmed like their analog counterparts by patching the desired connections between the logic elements needed for a computation. Thus digital patch field can be seen on the bottom of the DZ 771. On top is the card rage holding some logic circuit boards.

The two pictures above show the top and bottom of the DZ 772 logic expansion group during the cleaning phase.

The rest of the DZ 772 is shown on the right. Since it is one of the central control elements of the RA 770 analog computer (apart from the DBG 771) it has a lot of connections going to nearly every part of the system.

The expansion frame GBC 771 allows the installation of additional drawers like the SNV 771 containing non linear networks. Part of its front plate can be seen in the picture on the left. The drawer may contain up to eight function generators with a total of 24 additional operational amplifiers which may be used as stand alone inverters or as summing amplifiers. The function generators are fed from the main frame via a special connector. The drawer with number Telefunken analog computer systems, too, its front plate contains eight small analog patch fields.

The two photos above show the top and bottom view of the SNV 771 drawer. In the middle are two card rages holding 12 operational amplifiers each with some control circuitry. The two outer cages can be populated with function generator cards. This particular SNV 771 unit contained the 24 operational amplifiers which were used as inverters on the main analog patch field.

Thanks to Mr. Klitzsch from Frankfurt/Main who donated some remains of an RA 770 analog computer he was working with during the 1970s and 1980s I had some spare function generator cards in stock, so I could populate the SNV 771 drawer which was the same as the left picture some time early half of the data acquired - the function cards I could send into data cards, so the SNV 771 this electro drawer is on its maximum.

The picture on the top right shows such a pair of function generator cards. This pair, called SIN 1A and SIN 1B, implements the function sin(pi/2 * x) for x varying between +1 machine unit (10 V).

On the right the front plate of the next expansion drawer, the quad variable function generator VFG 801, can be seen. It contains four dynamic function generators.

The top view of the VFG 801 can be seen on the left. On the bottom the 12 potentiometers of one of the four function generators can be seen. The function generators are based on operational amplifiers with diode function networks in the necessary operational amplifiers (see per function generator making a total of eight amplifiers per drawer).

Located behind the analog patch field is the central computing element magazine holding up to 60 high precision operational amplifiers (operational amplifiers with a very low temperature dependency, very high precision resistors and capacitors as well as lots of control relays). The picture on the right shows the empty magazine.

Located under analog patch field are two blocks holding the high precision integrator capacitors for 60 integrators in two drawers, one of which is shown above.

The two pictures above show the central shielded analog patch field of the RA 770 analog computer. The patch panel is easily removable thus allowing rapid change of programs on the machine. In contrast to other machines made by Telefunken (e.g. the RA 1000) the patch panel contains only the most necessary connections. The main connections are made via the patch field on the front of the machine. This patch field has a single round connector which allows the fast and the storage coordinate the machine has experienced. This is a sharp contrast to the patch field of the Telefunken RA 1000 which contained a lot of connections.

Located under the patch field are sixteen hand set coefficient potentiometers and eight hand set resistors. A very special feature of these potentiometers is the fact that four of them can be coupled together by turning a knob thus forming two precision doubly potentiometers. This is a unique and very useful feature I have never seen on any other analog computer and makes the rapid setup of manually controlled servo generators and the like easy.

The two pictures above show the setting knobs for analog patch field controlling it with the central computing element magazine and the various other components of the RA 770.

On the left the cabling behind the central computing element magazine which is located behind the analog patch field can be seen.

The RA 770 uses chopper stabilized amplifiers in every place where extreme high precision and low drift is of prime importance (integrators, etc.). Some places with lower overall precision the function generators and the like the cheaper non chopper stabilized amplifiers are used. Chopper stabilized amplifiers are used in the RA 770 is called SV 3 and contains a single amplifier without choppers stabilization and without overload detection. This type of amplifier is, for example, used in the SNV 771 drawer.

The picture on the left shows one of the four operational amplifiers ever made for an analog computer. This is the so called OPV from Telefunken (designed by Prof. Dr. Meyer-Brötz who developed the first transistorized operational amplifier for the Siemens and Halske analog computer in the late 1950s).

On the right, under the central shielded patch field, the semiconductor choppers and demodulation circuits are located. Below this sheet the two power output transistors can be seen. The left half of the card contains the (heavily) implemented input stages of the operational amplifier. The right half of the card contains the (heavily) implemented output stage which is used for the chopper driven drift compensation. This is the place where the overload detection takes place, too.

On the right, a SK22 board is shown. This board contains the high precision resistors and control relays to implement two summers in the RA 770.

To more complex counterparts, the SK41, can be seen on the left. This board contains the control logic, precision resistors and capacitors as Zener-less (with Zener) precision integrator/summers in comparison with two OPA operational amplifier cards. The extreme number of relays used on this board is due to the fact that all integrators in the RA 770 are equipped with overload relays which adds quite complexity. The integrator control is, of course, purely electronic and does not involve any relays.

Documentation:

The documentation for this great machine is just overwhelming - its quality and quantity are really outstanding. Up to now only a few bits of documentation have been scanned and are available here:

- Kurzvorlesung Bedienungsanleitung Ü des Telefunken Analogrechners RA 770 in ®, Pap (about 2.5 MB)
- Kurzbeschreibung Elektro-Fotoprotokollgerätes RA 770 - a Telefunken publication (color, about 65 MB)
- Operators Manual chapter two (about 1 MB)
- Operators Manual chapter two (about 0 MB)

Conclusion:

This completes this short page about the newly built wonderful Telefunken RA 770 analog computer. I will in the future post more information about the system when I have gained more experience and have completed some more difficult computations on the system as by now.

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