The Philips GM5655

A simplistic cathode ray vacuum tube oscilloscope

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The Philips GM5655 [1] is a compact, and back then affordable, cathode ray tube (CRT) oscilloscope used by many of the faculties of the university. It was introduced in 1946 and was still in production in the early sixties. During this quarter of the century, both the internal construction and circuit changed, whilst the exterior remained unaltered. The study collection owns all different versions, as well as a special exploited view-version, where the modules are separated. The intended purpose of the device was to measure low frequency signals or signal tracing in radio circuits using an optional probe, the GM4575. The probe uses a non-linear tube for detecting radio signals and will not be further discussed in this article. Owing its simplicity, the GM5655 is good specimen to study the basic structure of an CRT based oscilloscope. When introduced in 1946, comparable scopes were heavy and bulky pieces of equipment. The GM5655 is exactly the opposite: it is small, even compared with modern digital storage scopes!

The cathode ray tube (CRT)

The most important components in a CRT are the glass envelope, the source (electron gun), the deflection plates and a phosphor coated screen. Almost all CRTs have the typical Erlenmeyer-flask (conical) shape. The device is evacuated to allow electrons to travel freely without interacting with oxygen or other particles.

Figure 1. The GM5655 in use

The electron source relies on the thermionic effect to free electrons into the vacuum. These free electrons are produced by a so called emitting surface, the cathode, coated with specially selected materials such as barium to lower the work voltage. The cathode is heated by a filament, or heater, to drive the electrons out of the coated surface. A cloud of free electrons is formed surrounding the cathode. Part of the electrons are extracted from this cloud by an anode having a high positive voltage (several 100V).

The anode consist of a metal plate, having a very tiny hole. Electrons accelerate towards the anode, and a part of the electrons hit the plate and form a so called plate current. The other part passes through the hole forming an electron beam or ray, hence the name cathode ray tube. Typically a CRT has multiple anode plates cascading each other, focusing the beam whilst passing through them.

Using two pairs of deflector plates, arranged in X and Y direction, and an electrostatic field, the beam can be deflected. After the deflection plates, the electron beam propagates further through the vacuum and hits the screen. The screen is uniformly coated with a layer of phosphor. By luminescence, the phosphorus layer is emitting light when impacted by the electron beam.
The deflection plates need to be supplied with large amplitude signals because electrons pass through them at very high speed. This is also why early CRTs always are quite long compared to the display diameter: a lower control signal can be used. Further development showed the possible use of magnetic deflection, enabling CRT tubes to become shorter whilst obtaining larger screen diameters.

The GM5655 uses the DG7-3 CRT tube (L4)[3], with a screen diameter of 7 cm: half the typical smart phone screen. The tube uses a relatively low supply voltage of 600V DC. Typical beam currents are in the order of several hundred microamperes. The DG7-3 has a grid in be-

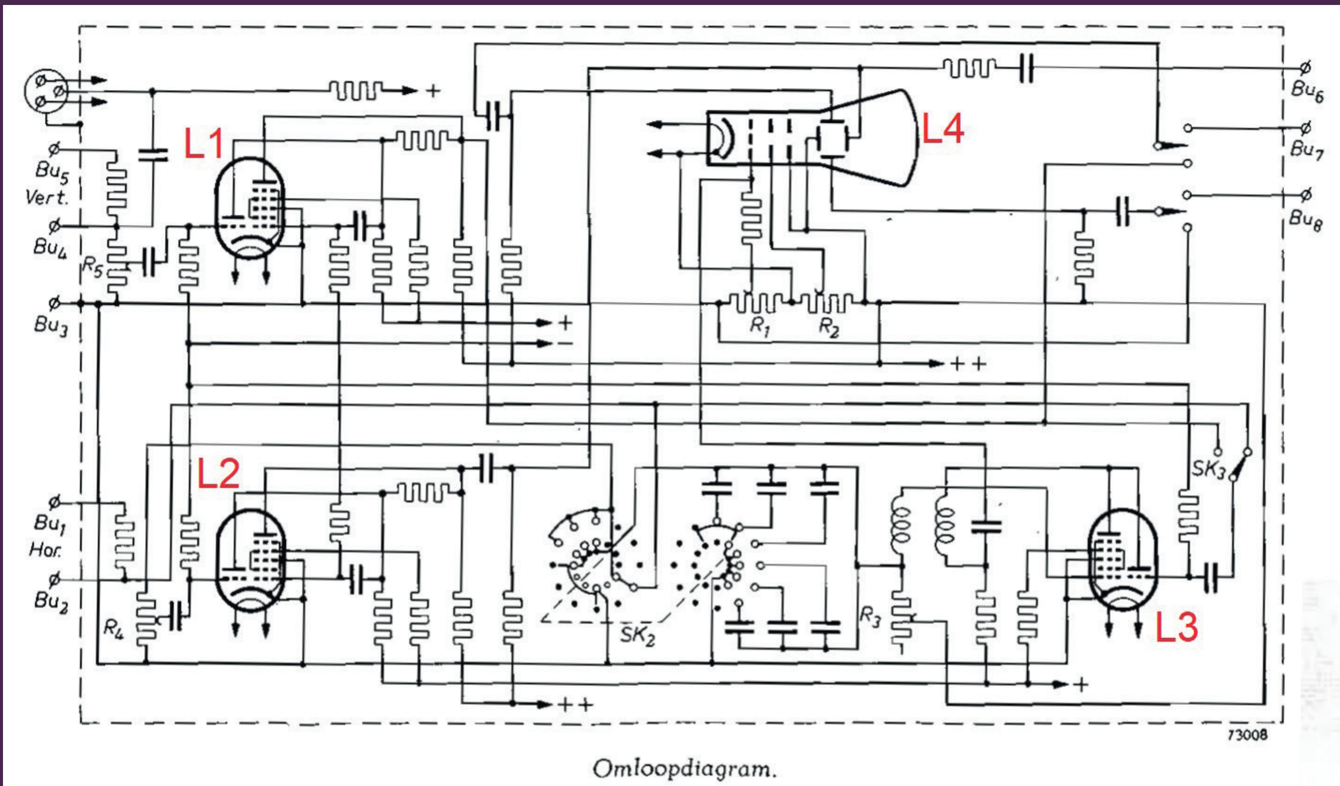

Figure 2. The circuit schematic

tween cathode and its anodes. With this grid, the beam current can be controlled (using a low negative potential), altering the intensity of the visible light.

The simplified circuit of the GM5655, obtained from the original user manual is shown in figure 'GM5655 circuit'. It consists of 2 linear amplifiers, an oscillator, a synchronization stage and the CRT. All these units receive power from a power-supply consisting of four different voltage levels. For simplicity, the power supply circuit is omitted in this drawing.

In the GM5655 three ECH21 [4] tubes, two EZ2 tubes and a DG7-2 tube are used (figure ECH21, EZ2, DG7-3). Two of these tubes form the linear amplifiers for driving the X and Y deflection plates of the CRT tube. The linear amplifier comprises a two stage design around L1 and L2, were the first stage is a high gain common cathode triode amplifier followed by another high gain common cathode pentode stage. The heptode section of the ECH21 can be used as a high gain pentode, by connecting the grids in a specific manner, as shown in the circuit diagram. To work around the fact that the cathodes of the heptode and triode section are interconnected, the cathode is grounded and the grids obtain the right bias potentials via a negative supply line.

The third ECH21 tube forms an oscillator and a synchronization stage . The heptode is generating a ramp-shaped wave for the horizontal sweep, whilst the triode is used for synchronizing the ramp signal to the input signal.

The power supply needs to provide 4 different potentials: 300V DC, 600V DC, -5V DC and 6.3V AC. The 300V and -5V are needed for the linear amplifiers, oscillator and synchronization stage. For the CRT screen the highest potential is needed (600V DC). All tubes use the 6.3V AC winding for heating their filaments.
The high voltage supplies are realized using two identical stacked 300V supplies consisting of two EZ2 [5] full-wave rectifier tubes, a gapped filter inductor and some electrolytic capacitors. The inductor has a gapped core to increase its capability of supplying DC current without saturating.

The ECH21: a combined heptode-triode tube

The GM5655 makes use of three pentode-heptode tubes of the type ECH21. This was a very popular vacuum tube in the late 1940s. Vacuum tube engineers at Philips developed a new vacuum tube for use in radio receiving sets. Tree important design requirements were set:

1. The tube needed to be very compact
2. The construction must allow a fully automated manufacture process
3. It should have low device capacitances to allow high frequency use

Shortly before and during WW2, Philips put a lot of effort in developing tubes having an all-glass construction. Advantages of this new construction were the ability to fully automate production and very low device capacitances. The latter was very important in the development of VHF and UHF RADAR. After the war, the new all-glass construction quickly became the standard, and was adopted to almost all vacuum tubes. All the tubes in this oscilloscope use the all-glass construction.

The ECH21 tube contained two systems: a triode and a heptode, reducing the tube count in a typical radio set. The tube was useful in many applications. The main application was found in super-heterodyne radio sets, popular back than for AM reception. The triode would act as local oscillator and the heptode as mixer/multiplier. The GM4655 uses three ECH21 tubes. Tube L1 and L2 are used as x and y deflector amplifiers. The triode section is used as input stage, with the heptode section, wired as pentode, as final stage. From the third ECH21, L3, the heptode is used as saw tooth oscillator and the triode to synchronize the signal under test with this saw tooth signal.

Construction

A typical electronic device made in the 1940s uses the so called 'hard-wired' construction. No carriers (PCBs) for the components are used, resulting in messy internals. The components are placed and soldered in the right place, using their lead wires for support. The GM5655 in contrary uses circuit boards, without a printed circuit, figures 'boven' 'rechts' and 'links' show the internals. In the boards, soldering turrets are mounted. The interconnection of the turrets is done using wires, located at the backside of the boards. All components have their designated location, and can be easily reached for service. This is a really unique and ahead of its time feature of this vintage oscilloscope.

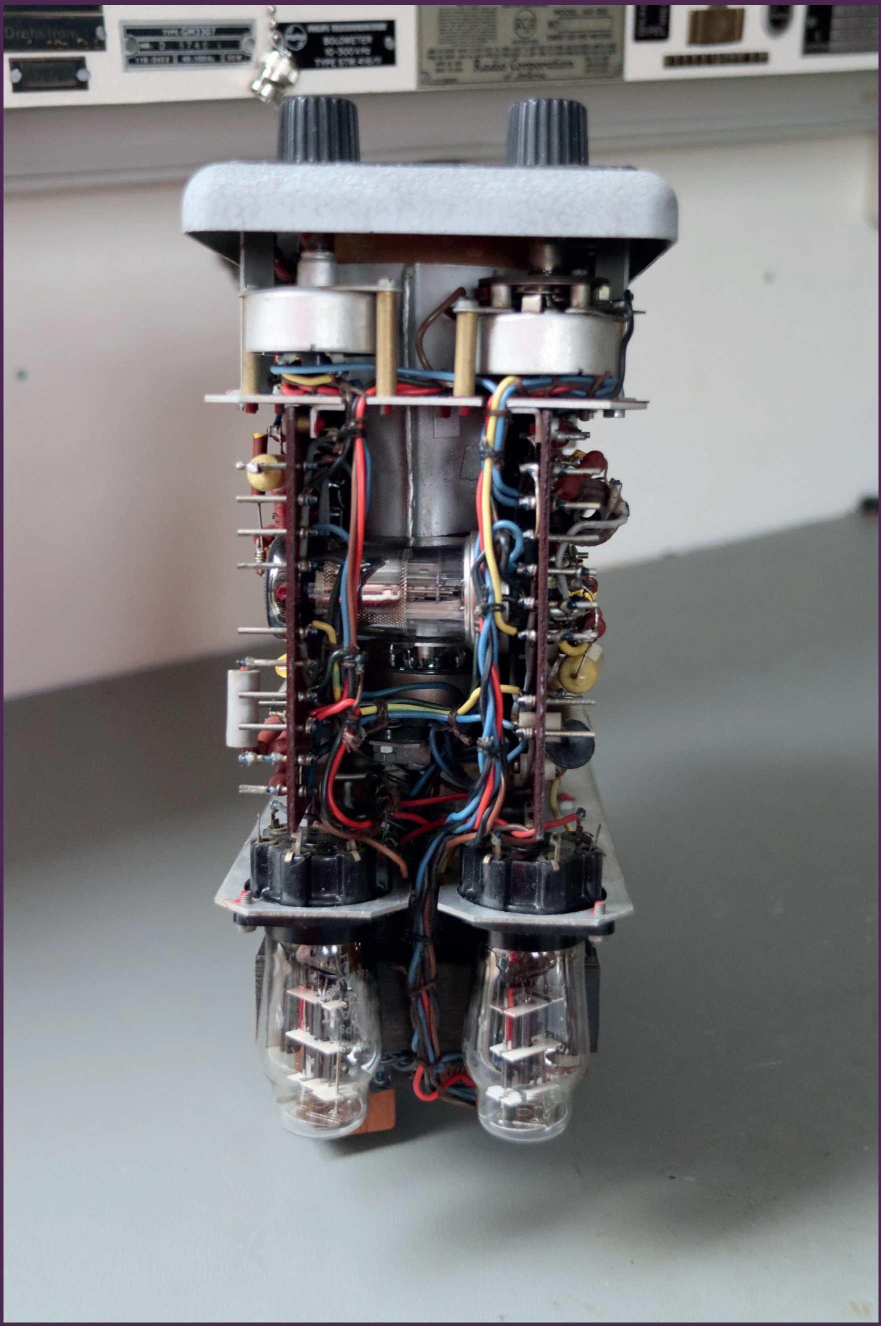

Figure 3. The osciloscoop without casing

Bringing her back to life

Waking up an old unknown electronic appliance is always a challenge. Capacitors dry out over time, insulators become brittle and tubes may lose their vacuum due to flaws in the glass envelope or glass-to-metal seals. On top of that is the unknown factor of repairs and modification carried out by previous owners. Especially equipment contained in the study collection have a high likelihood of tempered internals, since engineers and scientists do not throw away stuff without attempting repairs.

By slowly powering the scope with a variac, it came to life, barely. During the heating of the tubes, the beam became shortly visible, but it quickly got deflected outside the screen area. Consulting the schematic, two possible culprits were found: the two tar-sealed capacitors coupling the X and Y amplifiers to the deflector plates of the CRT. After replacing these components, the beam was centered in the middle of the screen. A sine wave was fed into the scope to verify the operation of the X and Y amplifiers. The wave showed on the screen but was badly distorted. Using a multimeter and the voltages indicated in the schematic the problem was quickly found: the negative supply rail which is used for biasing was at zero instead of -1.5V. The negative supply uses an selenium-cell as rectifier, an early semiconductor. These are pronoun to fail, as even the manual from 1952

Figure 4. The tubes used to create this machine

already states a typical repair method using an OA50 GE diode. The faulty rectifier was replaced by a conventional silicon diode with a resistor in series, to roughly match the internal impedance of the old device. After some additional preventive repairs the scope was fully working as intended.

Measuring or indicating waves

The X and Y amplifiers in the scope do not use any form of feedback. Therefore the transfer of the linear amplifiers is highly dependent on device parameters. As vacuum tubes have a large spread in parameters (up to +/-20% is assumed to be normal) the gain is not constant during operation. In general, a new tube has well over 2 times the typical transconductance stated in the datasheet. During its operational lifetime it will decrease until it has reached about 80% of the datasheet value, where it is said to be at the end of its life. To make things worse, the input level of the X and Y amplifiers is continuously variable using a carbon-film potentiometer, which have a +/- 20% non-linearity.

The screen does not have a grid. Combined with the above mentioned problems in the linear amplifiers, it becomes clear that the GM5655 is not very useful for doing absolute measurements. Therefore it was common practice to have a GM6005 voltmeter (also in the collection) in parallel with the input of the GM5655.

Conclusion

The GM5655 gives a wonderful insight in the technology involved in a CRT based oscilloscope, as well as an insight in the state of electronics in the mid-20th century.
For further information regarding oscilloscopes, measurement equipment in general and / or vacuum tubes, please feel free to visit the study collection down in the basement below DEMO. You're welcome on Mondays after 10 AM.

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[1] https://www.pa3esy.nl/Philips/meetinstrumenten/html/gm5655/pdf/GM5655_3.pdf
[2] "Saga of the Vacuum Tube", Gerald F.J. Tyne 1977, page 37, (available in the library of the study collection)
[3] https://frank.pocnet.net/sheets/030/d/DB7-3.pdf
[4] https://frank.pocnet.net/sheets/033/e/ECH21.pdf
[5] https://frank.pocnet.net/sheets/102/e/EZ2.pdf