Enigma G-111

A rare version of Zählwerk Enigma G31

by Paul Reuvers and Marc Simons

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1. Introduction

1.1 Preface

In May 2009, German auction house Hermann Historica [2] acquired an Enigma machine with serial number G-111 that would be up for auction in October 2009. Mr. Thomas Rief of the auction house, contacted Enigma historian David Hamer in the USA [5] for information about this type of Enigma. Mr. Hamer subsequently contacted a number of other Enigma researchers to get additional information. On 1 July 2009, Paul Reuvers and Marcus Simons [1] were given the opportunity to have a closer look at the machine when they visited Hermann Historica in Munich. The results of their investigation is presented in this paper.

The G-111 is an Enigma of the *Zählwerk* type model G31. This model is sometimes referred to as the *Enigma G*, as later versions had serial numbers starting with the letter 'G'. The machine is also known as the *Abwehr Enigma*, as it was sometimes used by the German Secret Service, the *Abwehr*, during WWII. Both these names are incorrect and should be used with care. According to historical documents [10] issued by the manufacturer, the official name of this model was:

Glühlampen-Chiffriermaschinen „ENIGMA" mit Zählwerk
und zwangläufiger Kupplung der Chiffrierwalzen.

Throughout this paper, we will therefore identify the machine as *Zählwerk Enigma*, model G31. As will become clear, the manufacturer, Chiffriermaschinen AG (later: Heimsoeth und Rinke), used different internal designators for each model and version. The internal designator used for the G-111 is Ch. 15b.

This paper describes the machine in general technical terms. The overall conclusion is that, although the machine is in bad condition, it is nevertheless a very rare item and as such a beautiful witness of time. A future owner will certainly appreciate this machine. We highly recommend to have this machine professionally serviced, preserved and/or restored in order to avoid further deterioration.

We are indebted to Mr. Thomas Rief and his colleagues at auction house Hermann Historica for granting access to the G-111 and for allowing us to take a series of detailed photographs of the machine, measure some never-before-seen features and recover the wiring of the wheels. We should also like to thank Frode Weierud [3] in Switzerland, for the historical backgrounds to this particular machine and for his help with the internal machine type designators. His research in the German archives has proved invaluable on many occasions.

Eindhoven, August 2009,
Paul Reuvers & Marc Simons

1.2 Global History

The history of the Enigma machine starts around 1918, when the first patents for its design were filed [2]. In 1923, the first machines appeared under the Enigma brand. The early models (A and B) printed directly to paper and were therefore called *Schreibende Enigma* (printing Enigma). These machines were bulky and above all very expensive. In 1924, a low-cost Enigma (C) was introduced that produced its output on a panel with 26 (sometimes 28) lamps rather than on paper. This was called the *Glühlampenmaschine* (lamp machine). It was powered by a battery, but needed the energy only for lighting one lamp at a time. The wheels were moved by applying pressure on one of the keys on the keyboard. It is *this* design of the lamp machine that most of the current Enigma machines are based on.

On the next page is a simplified family tree of the various Enigma models. From the top, the tree has two branches. The left branch shows the printing Enigma machines. In this paper we will concentrate in the rightmost branch, that shows the development of the lamp machine, of which Enigma C was the first. Enigma C also was the first Enigma machine to use a reflector (*Umkehrwalze*, UKW).

Several models and variants were developed from Enigma-C, such as *Funkschlussel C* used by the Kriegsmarine, and a special version for Sweden, that contained some of the additional Swedish letters. Both these variants had 28 letters rather than the more common 26. All Enigma C machines had a fixed UKW that could, however, be mounted in a number of different positions.

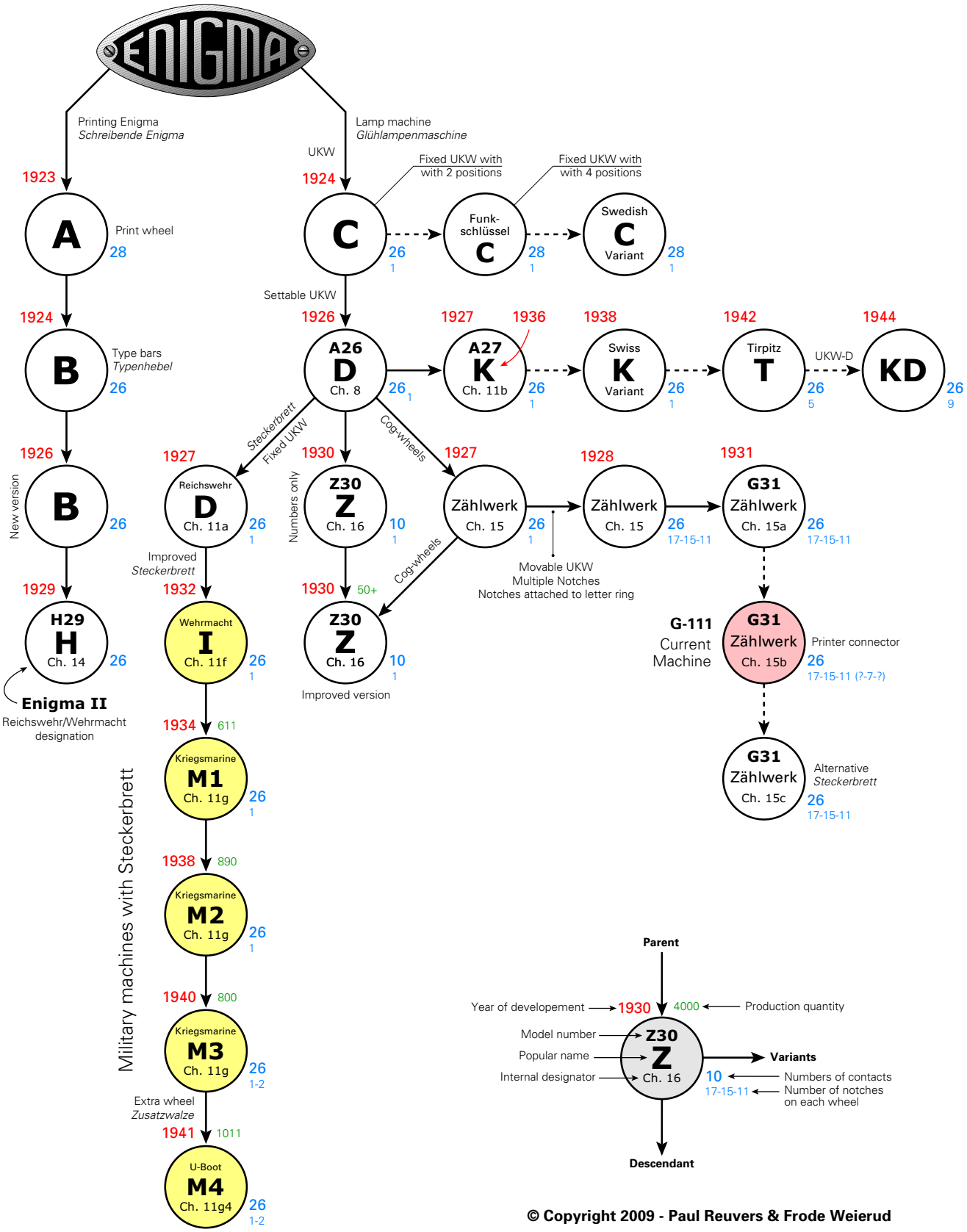
The Enigma C eventually led to the development of the Enigma D in 1926. Enigma D had a settable UKW, which means that it could be set to any of its 26 positions at the start of a message. The UKW did not move during encipherment. Enigma D was given the internal designator Ch.8. It was sold commercially to a number of international customers, such as banks, oil companies, governments and large enterprises.

The German *Reichswehr* (the predecessor of the *Wehrmacht*) adopted the Enigma in 1926 and the first machines, based on the Enigma D, were delivered in 1928. These machines were internally identified as Ch.11a. The *Reichswehr* improved the cryptographic strength of the machine by adding a so-called *Steckerbrett* (plug board) to it. They also introduced the new name for this machine: Enigma I (Roman number 1), so that it could be discriminated from the large printing Enigma H, which they called Enigma II. The Enigma I machines were also built by Chiffriermaschinen AG (later: Heimsoeth unde Rinke) and had the internal designator Ch.11f. All machines used by the German *Wehrmacht* and *Lufwaffe* during WWII, are of the type Enigma I. The variants that were later used by the *Kriegsmarine* (M1, M2, M3 and M4) were all derived from the Enigma I. These are the only machines with a *Steckerbrett*. In the tree, they are marked yellow. The majority of Enigma machines found in recent years, is of the type Enigma I.

Around the same time as the Enigma I was developed, Chiffriermaschinen AG also developed an improved version of the Enigma D, which was called *Glühlampenchiffriermaschine „ENIGMA" mit Zählwerk und zwangläufiger Kupplung der Chiffrierwalzen*. For the rest of this paper we will use the name *Zählwerk Enigma*. It was identified internally as Ch.15 and at least three different version of this machine are known to exist (Ch.15 a, b and c). The first machines of this type were sold in 1926 or 1927. The *Zählwerk Enigma* was cryptographically stronger than the Enigma D and was much better built. Cog-wheels were used for the wheel-turnover mechanism rather than pawls and levers as in the other models. Because of the cog-wheels, the machine had the ability to be 'stepped back' allowing for mistakes to be corrected, a feature that was not present on the other models. A counter (*Zählwerk*) was present to count the number of enciphered letters. Furthermore, the *Zählwerk Enigma* had a movable UKW, which means that the UKW is stepped during encipherment.

In those days, potential customers probably had the option to buy the cheaper Enigma D or the improved *Zählwerk Enigma*, depending on their budget. Surviving records [10] show that the price for a *Zählwerk Enigma* was 1000 Reichsmark in 1929. In the early days, all machines had, confusingly, serial numbers starting with the letter 'A' and there is no way to discriminate the model from just the serial number. Up to that moment, all Enigma machines used coding wheels with a diameter of approx. 10 cm. The wheels of the *Zählwerk Enigma* where slightly different, as they had to support the cog-wheel driven wheel-turnover mechanism and had multiple turnover notches, but their diameter was the same.

In or around 1931 a smaller version of the *Zählwerk Enigma* was introduced. It was called model G31. It is identical in operation to the earlier Ch.15 but is a bit smaller, has no battery compartment and has wheels with a smaller diameter. The machine described in *this* paper (G-111) is of the type Ch.15b which means that it has a connector for an external printer.



Machines like the G-111 are often called *Enigma G*, as the later versions had serial numbers starting with the letter 'G', but this is not the case for all machines that belong to this family. The machine is also known by the name *Abwehr Enigma*, as it was sometimes used by the German secret service, the *Abwehr*, during WWII. But it wasn't the only machine that was used by the *Abwehr*, and the *Abwehr* wasn't the only user of the machine. The only correct name is *Zählwerk Enigma Model 31*. Machines of this type were also sold to other countries, such as The Netherlands (Navy) and Hungary.

Compared with the more common Enigma I, the *Zählwerk Enigma* (Ch.15) has a number of characteristic differences:

- Complex cog-wheel driven wheel-turnover mechanism (German: *Zwangläufiger Kupplung der Chiffrierwalzen*)
- Ability to reverse the stepping mechanism (for correcting mistakes)
- Multiple wheel-turnover notches (based on relative prime numbers)
- No Steckerbrett (the Steckerbrett was reserved for the Army)

A few examples of *Zählwerk Enigma machines* (Ch.15) are given below. The leftmost one (A351) was probably made in 1926 or 1927. It clearly shows the cog-wheel driven turnover mechanism and has a counter in front of the rightmost wheel. To the right of the counter is a small axle that could take a crank, allowing errors to be corrected by turning the mechanism back one or more steps. The machine is housed in a oak wood case that is roughly of the same size as the Enigma D.

The image on the right shows a slightly later version (A865) that was found in The Netherlands in 2007. This machine is described in patent DE534947 [7]. In this machine, the counter has been moved to the left and a crank can be inserted in a cog-wheel close to the rightmost wheel. Apart from that, the machine is functionally identical to the previous one. This machine is also shown in the first picture on the next page. The wooden case roughly has the same size as that of the Enigma D. Note that for this machine a slightly more expensive type of wood was used (probably mahogany) suggesting that this machine was probably intended for the wealthier customer.

In addition, the later G31 model (Ch.15 a, b and c) had the following differences:

- Smaller body
- The lamp panel is inclined (on other models it is aligned horizontally)
- The coding wheels have a diameter of 85 mm (rather than 100 mm as on the other models)
- Optional connection for an external printer (Ch.15b only)

The images on the next page, show an early *Zählwerk Enigma* (Ch.15) and the later G31 model (Ch.15a) side by side. The rightmost one is the *Zählwerk Enigma* model G31 (Ch.15b). The machine can easily be recognised by the inclined lamp panel and the prominent lever at the top. Why this machine is so different from the other models is unknown. Perhaps it was just an attempt to create a smaller, more portable, machine. The wheels are smaller and therefore take less space, and it doesn't have a battery compartment.

Early Zählwerk Enigma A351
Courtesy of FRA Museum, Sweden

Early Zählwerk Enigma A865
Found in The Netherlands in 2007

Zählwerk Enigma A865

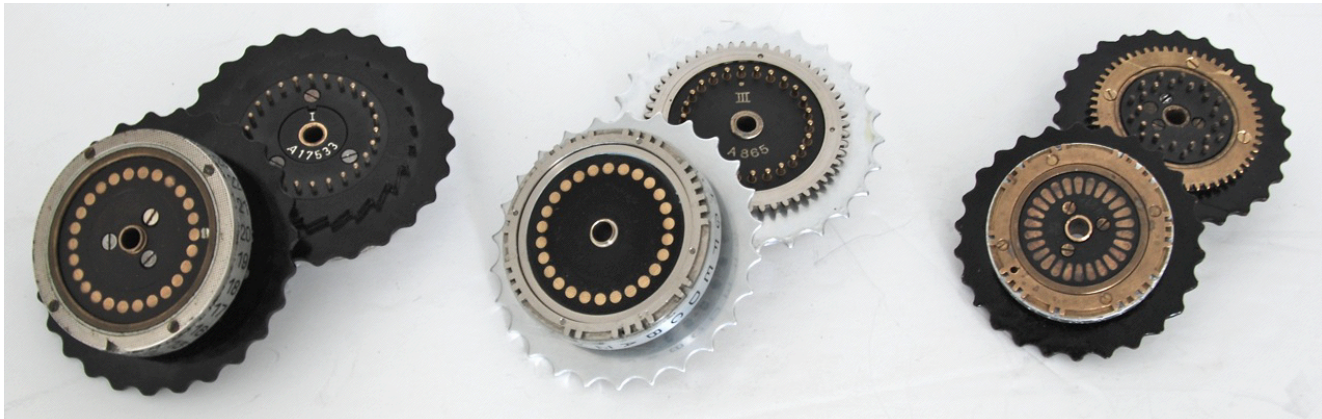
The Enigma G-312 at Bletchley Park

The rightmost image above shows a nice example of a *Zählwerk Enigma* model G31. It is the G-312 that is on public display at Bletchley Park in the UK [4]. It was described in detail by David Hamer in January 2000 [5]. The G-111 belongs to the latter category (model G31), but has a slightly different designator (Ch.15b) as it has the additional printer connection.

The image below shows three different sets of wheels. The leftmost set shows both sides of the wheels of a standard Enigma I. The largest diameter (the thumbwheel) is approx. 100 mm and the diameter of the cylinder holding the numbers is approx. 75 mm. The wheel is transported by pawls engaging the triangular gaps on the right hand side of the wheel.

The wheels in the middle are from a *Zählwerk Enigma* (Ch.15). They have the same outer dimensions as the leftmost ones but features a cogwheel on the right and a more complex wheel with a varying number of teeth on the left, supporting the complex wheel-turnover mechanism.

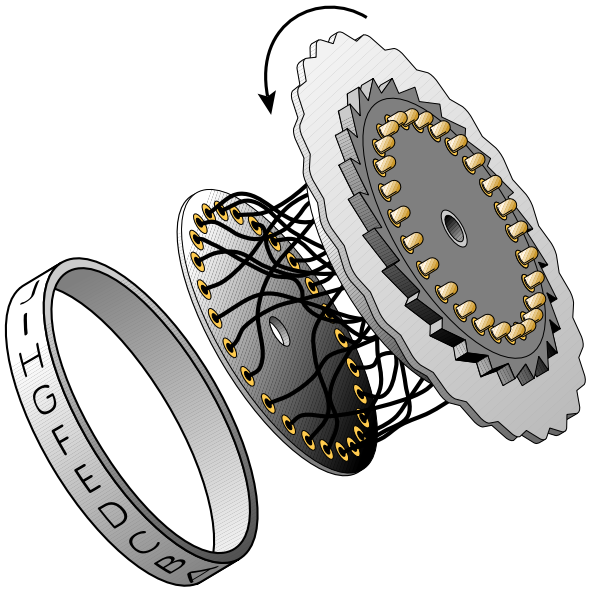
The wheels on the right are from a *Zählwerk Enigma* model G31 (Ch.15a). They are similar in design to the ones in the middle, but the largest diameter is just approx. 85 mm. The diameter of the letter disc is approx. 62 mm. Furthermore, the spring-loaded contacts on the right are arranged in a zig-zag pattern and the contact pads on the left are oval-shaped. Wheels of the latter kind are used in the G-111.



From left to right: the wheels of an Enigma I (Ch.11f), a Zählwerk Enigma (Ch.15) and a model G31 (Ch.15a)

1.3 Working principle of the Wehrmacht Enigma

Although it is beyond the scope of this paper, a brief explanation of the working principle of the Enigma machine might be useful when trying to understand the differences between the standard Enigma I (used by the *Wehrmacht*) and the *Zählwerk Enigma*. Below is a simplified circuit diagram of the Enigma I, which features a *Steckerbrett* (plug board) that is not present on other machines. The entire principle is based on a closed electrical circuit. In other words: if a key is pressed, a lamp will be lit. Which lamp is turned on, depends on a series of permutations such as the coding wheels.

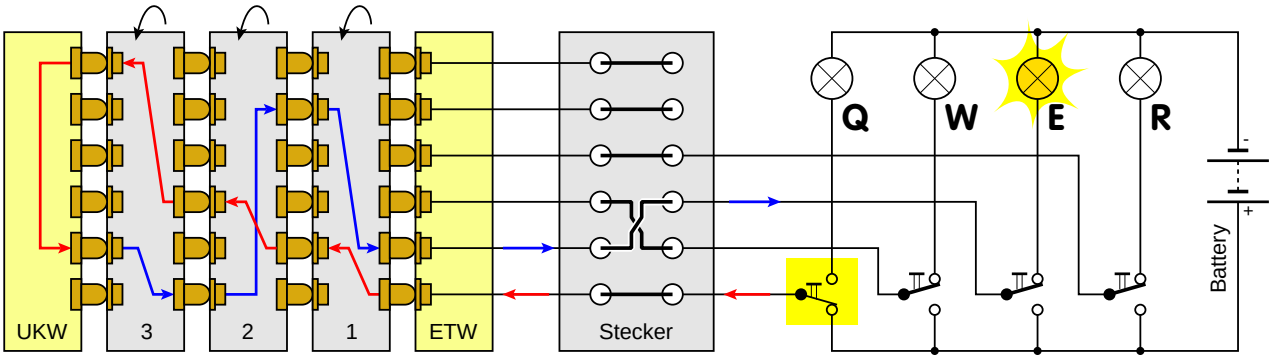


The keyboard of the Enigma (input) only has 26 letters (A-Z). Likewise, the lamp panel (output) also has 26 letters. Spaces, numbers and punctuation marks were either left out, or were spelled in full.

When typing on the keyboard, each letter is 'scrambled' by a series of coding wheels. Each wheel has 26 contacts on either side and a ring with the letters A-Z or the numbers 01-26 around its perimeter. At the right, each wheel has 26 spring-loaded contacts. At the left are 26 circular contact pads.

Inside each wheel is a series of 26 'scrambled' wires that each connect one of the spring-loaded contacts on the right to a contact pad on the left. These wires 'translate' a letter into another letter. Furthermore, on each key press, the rightmost wheel makes a single step, which effectively changes the wiring for each new letter. After the rightmost wheel has completed a full revolution, it will cause the next wheel to step, and so on, similar to the odometer in a car. This is called regular stepping. Under certain circumstances, the middle wheel can make an extra step on two successive key-presses. This anomaly has been described in a paper by David Hamer in 1997 [11].

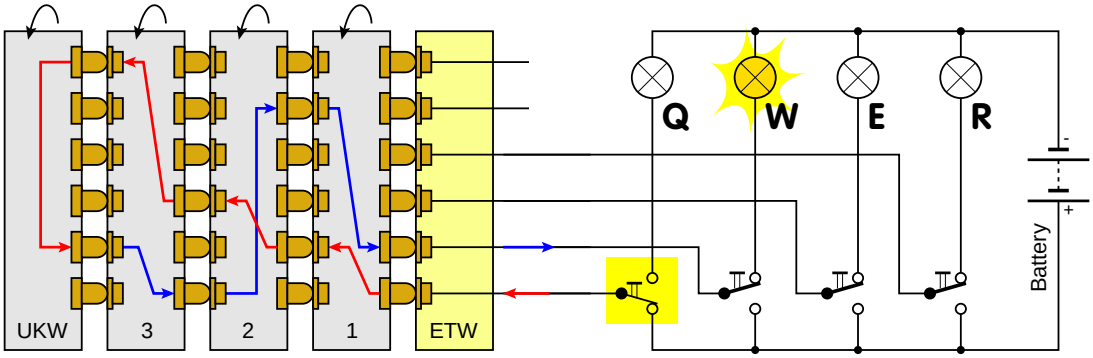
In the example below, the letter 'Q' is pressed. Follow the red arrow. The current will first pass the *Steckerbrett* (straight through) and then via a static disc (the *entry wheel*, or *Eintrittswalze*, or *ETW*) onto the first coding wheel (1). The coding wheel 'translates' the letter into some other letter and passes that onto the next wheel. This continues until the current leaves wheel (3) on the left. At the far left is a (static) reflector (*Umkehrwalze*, or *UKW*) that sends the current back into wheel (3). Now follow the blue arrow. This time the current passes the three wheels from left to right until it hits the ETW again. From the ETW it is passed through the *Steckerbrett* again, where it is swapped with another letter. Finally, the current leaves the *Steckerbrett* and the lamp for the letter 'E' is lit.



From the above it is clear that this whole operation is reversible. In other words: if – in the above situation – the letter 'E' was pressed, the lamp 'Q' would be lit. The current just flows in the reverse direction. This effect is caused by the UKW and allows the sender and the recipient of a message to setup their Enigma machines identically. A nasty side-effect of this principle is that a letter can never be translated into itself. In other words: if the letter 'A' is pressed, it may be translated into any other letter, except for the letter 'A'. This was one of the weaknesses that helped the code breakers at Bletchley Park to break the Enigma during WWII. Another weakness of the Wehrmacht Enigma is the regular stepping of the wheels. On the other hand, the addition of the *Steckerbrett* made this machine more difficult to break that any other model.

1.4 Working principle of the Zählwerk Enigma

The basic principle of the *Zählwerk Enigma* is similar to that of the *Enigma I* described on the previous page. It has a keyboard, coding wheels and a lamp panel. But that's about where the similarity ends. The *Zählwerk Enigma* does not have a *Steckerbrett* which made the *Enigma I* more difficult to break. On the other hand, it has a far more complex wheel-turnover mechanism that causes each wheel to step more frequently in a less predictable manner. This is called irregular stepping. Furthermore, the UKW can be set to any starting position and is moved by the wheel-turnover mechanism. As such, the UKW plays an active part in the ciphering process. This is not the case with the Enigma I, where the UKW is static.

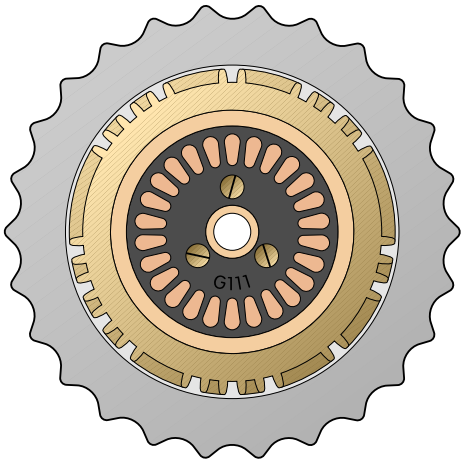


The simplified circuit diagram above, explains how the *Zählwerk Enigma* works. From an electrical point of view, it is identical to an Enigma I without the *Steckerbrett*. As such it is simpler than an Enigma I. From a mechanical point of view however, the *Zählwerk Enigma* is much more complex. First of all, the UKW (reflector) can be moved by wheel 3, which increases the maximum number of permutations.

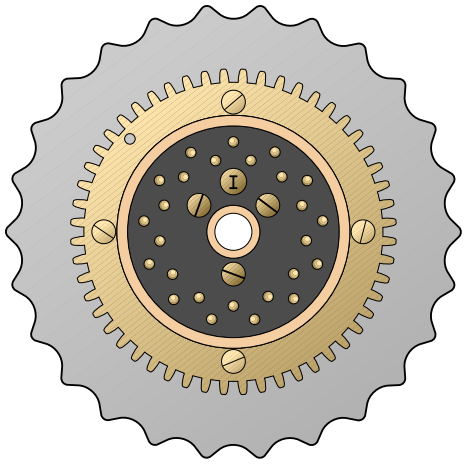
Secondly, each wheel has multiple turnover notches, causing the wheel on its left to step more frequently. As the number of notches is a relative prime of 26, the total (cryptographic) period of the entire system is increased enormously. All known *Zählwerk Enigma* machines, have 17, 15 and 11 notches on wheels I, II and III respectively.

Another mechanical difference between the *Zählwerk Enigma* and the Enigma I, is the way in which the wheels are moved. In the Enigma I, a mechanism with pawls, levers and notches drives a saw-tooth-shaped ring on the right side of the wheel. As a result, a wheel can only step forward. The stepping mechanism of the *Zählwerk Enigma* is driven by cog-wheels so that the entire stepping mechanism can work in both directions, allowing for (typing) mistakes to be corrected. Because of the cog-wheels, even the most complex wheel-turnover scheme can be reversed. Furthermore, the stepping mechanism of the *Zählwerk Enigma* does not suffer from the double stepping anomaly of the Enigma I, as described on the previous page [11].

Due to differences in operation as described above, the *Zählwerk Enigma* is not compatible with the Enigma I. In other words: it is impossible to exchange messages between these two Enigma variants.



Left side of an Enigma-G wheel



Right side of an Enigma-G wheel

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2. The G-111

2.1 History

Only a limited number of *Zählwerk Enigma* machines have survived (approx. 10 to 20) and only 3 of them are known to be on public display. They are all of the type Ch.15a. These machines are considered very rare. The G-111 has a special feature that has not been seen on similar machines before: it has a socket for a large connector at its left side. The presence of this connector makes the machine even rarer, perhaps even one-of-a-kind. The G-111 should therefore be considered extremely rare. The internal designator for this machine was Ch.15b. The connector and its use are described in chapter 3.

Records [3] have shown that this machine was from the first batch of this model (G31) ever manufactured. It was part of a series of 24 machines (serial numbers G-101 to G-124) that were delivered to Hungary. It is likely that the sale took place in or around 1931. It is unknown at this time who the customer was but, knowing the close relationship between the German and Hungarian intelligence services, it is very likely that it was the Hungarian Army, or perhaps the Hungarian intelligence service.

According to the previous owner, he bought the G-111 about 30 years ago on a flea-market in Berchtesgaden. It is unknown how the machine ended up there, as it was originally sold to the Hungarians. One possibility is that it was recovered by the Germans during WWII, but it is entirely possible that it ended up there for some other reason, including 'by chance'.

2.2 Physical condition

2.2.1 Wooden box

The wooden box has suffered quite a bit. In some way this is good, as it has protected the machine for worse. Much of the veneer on the top lid has gone and the wood is very dry. Unfortunately, the lid-supporting brackets on both sides have been lost and appear to have been broken out of the lower part of the case. As a result, the lid can't be left open without the support of, say, a wall. The leather carrying strap is original and complete. It is dried out, has cracks and should never be used. This is normal for a leather strap of that age. The manufacturer plate and the logo are missing (have been removed).

The crank – used to wind back the wheel mechanism in case of typing mistakes – is present and is stored inside the lid of the wooden case. It might not the original crank, but one that was made sometime during its lifetime, when the original one was lost. Please refer to chapter 2.3.3 for more information about the crank.

The wooden box with the top lid up

The leather carrying strap

Advice: If a future owner wishes to restore the case, we suggest to repair the parts that are broken out of the bottom part and replace the supporting brackets by replicas. This would allow the lid to remain open without any further support and would be suitable for display purposes. We suggest to leave the rest of the case in the current state as a witness of time, and only treat the wood appropriately to avoid further deterioration of the wood. The leather strap should also be preserved to avoid further deterioration.

2.2.2 Exterior

The exterior of the machine is in bad condition. The outer metal shell shows serious signs of rust and the text on the indicating plate above the power switch has become unreadable. The lamp film has cracks at the letter 'V' (the fifth letter on the bottom row) but the remaining letters are OK. On the keyboard, the glass on four of the key-tops has been broken. It is up to a future owner to determine whether to leave the machine in this condition, or to have it restored to its original state.

Top view of the machine

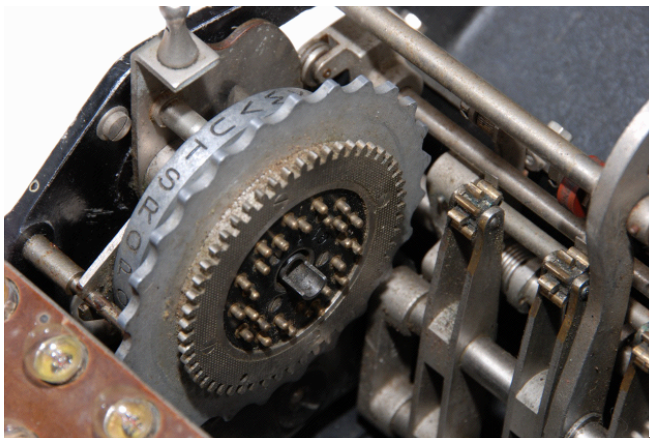
Close-up of the keyboard and the lamp panel

The bottom of the machine is in surprisingly good condition. It is bolted to the bottom of the wooden box with four M5 bolts. For our research, these bolts had been removed temporarily, prior to our visit. The original bolts are present with the machine. The serial number of the machine (111) is stamped in white ink at the bottom. The 4 rubber feed, bolted to the bottom of the base plate, are still in good condition.

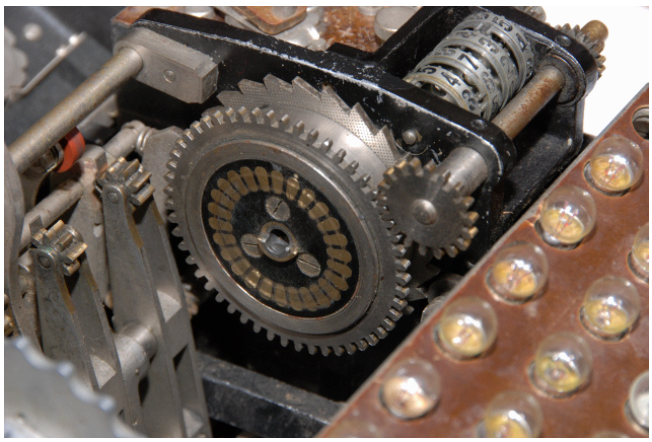
2.2.3 Interior

The interior of the G-111 is in bad condition. That doesn't mean however that it is beyond repair. It is complete and can be brought to life when this is considered necessary by a future owner. The machine shows significant signs of heavy use. After the war, it has probably been stored in dusty damp place. The mechanism and the wheels are very dry and dirty, but can be cleaned and maintained. The contacts of all switches inside the machine are corroded but can be preserved.

Currently, the wheel-turnover mechanism isn't working. This might be caused by a missing or broken spring, but it might also be the effect of an engaged key-locking mechanism, a feature described in chapter 3. Some of the red rubber rollers (located behind the wheels) are broken or missing.



The Umkehrwalze (reflector)



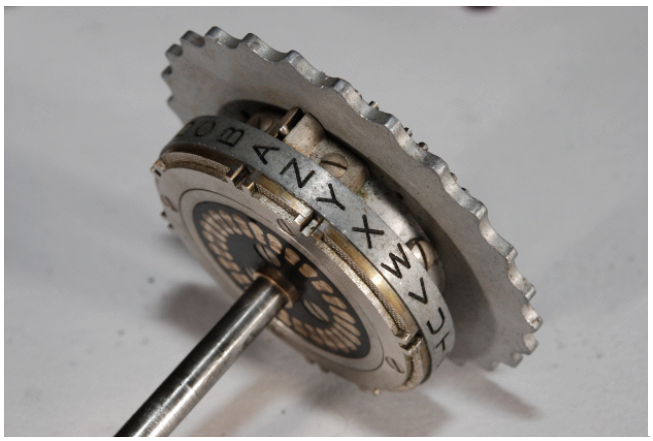
The Eintrittswalze (entry wheel)

Advice: The interior of the G-111 urgently needs maintenance. All contacts are corroded seriously and it is our advice to have them cleaned and preserved, whilst this is still possible. Cleaning the interior requires most of the machine to be disassembled. Once properly serviced, there is no reason why this machine shouldn't work again.

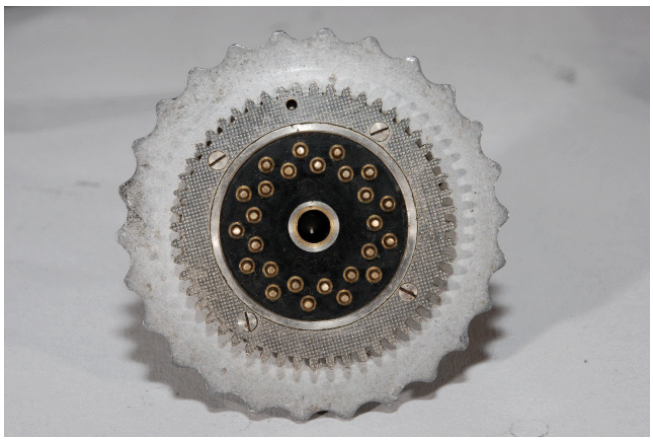
2.2.4 Wheels

The wheels all have matching serial numbers (G-111) and are functional. The machine has clearly been used heavily, as the contact pads on the left side of each wheel show wear and the heads of some of the spring-loaded contact on the other side have been flattened somewhat. For our research we've cleaned the contact pads slightly with a non-invasive technique. All contacts and wires inside the wheels are alright and no short circuits has been found. The wiring of the wheels has been recovered and the results are presented in chapter 2.3.3.

The leftmost image below shows the left hand side of one of the wheels, showing the oval-shaped contact pads. Also clearly visible in this picture is the small pin used for the *Ringstellung* (ring setting), currently at the letter 'A'. The rightmost image shows the right hand side of the wheel, featuring the spring-loaded contacts arranged in a zig-zag pattern. The latter was probably necessary because of the smaller diameter of the wheel. The top of each of the spring-loaded contacts normally is rounded, but the image shows that some contacts have been flattened somewhat due to wear.



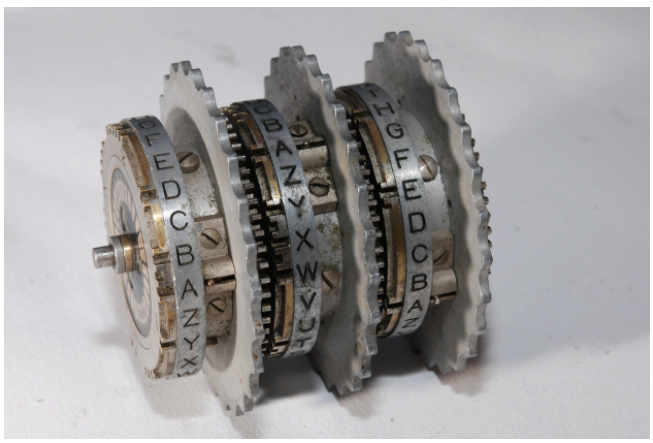
The left side of a wheel and the Ringstellung



The right side of one of the wheels

The leftmost image below shows the complete drum of the machine. The disc on the right is the entry disc *(Entrittswalze, or ETW)* and the one of the left is the reflector *(Umkehrwalze, or UKW)*. In between the ETW and the UKW is a spindle with the coding wheels. In this machine, three wheels are present on the spindle. The right most image below shows the three wheels on the spindle.

The drum inside the machine



Three wheels on a spindle

It is often thought that this machine is a true 4-rotor machine, but that is more a matter of interpretation. If the UKW is ignored for a moment, there are just three coding wheels. The UKW on the left is, however, also part of the coding mechanism so, if that is counted in, it *is* a 4-rotor machine. On the other hand, every Enigma has an UKW and could therefore be called a 4-rotor machine. The only difference is that in a standard Enigma I, the UKW is fixed, whilst in a commercial machine (e.g. D or K) it can be set to any of 26 positions (settable UKW) and in the *Zählwerk Enigma* it is moved by the wheel-turnover mechanism as well (movable UKW). The expression '4-rotor machine' is often used for the Enigma M-4 (Ch.11g4): a machine with 4 coding wheels and an UKW. It was used by the Kriegsmarine during WWII exclusively for the U-Boot section.

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2.3 Machine description

2.3.1 Patent shield

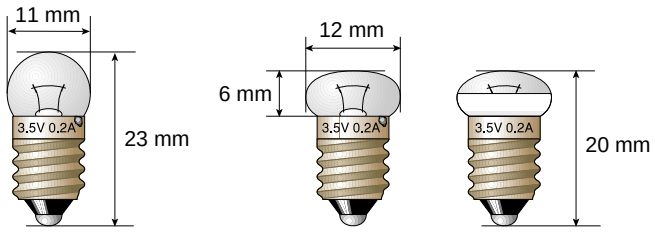
The G-111 holds a patent shield at the rear side, that can only been seen when the machine is removed from the wooden box. It is fitted permanently to the case and is located just below the rear hinge. A series of patent numbers in various countries is listed. The abbreviation 'D.R.P.' stands for *Deutsches Reichspatent* (German Patent). The abbreviation 'D.R.P. ang.' stands for *Deutsches Reichspatent angemelded* (Patent Pending). The line at the bottom reads: *Weitere Patenten in allen Kulturstaaten* (More patents in all cultural states).

Position of the patent number label

Close-up of the patent numbers

2.3.2 Lamps

The lamps that are currently present inside the G-111 are definitely not the original ones. They are of the standard spherical type rather than the special 'flattened' models used in those days. Furthermore, the lamps show no sign of age and are specified at 6 V rather than 3.5 V. The drawing below shows the difference between ordinary (spherical) light bulbs and the special flattened types used in the Enigma. Two different types are known: a fully clear one, and a half-opaque one.



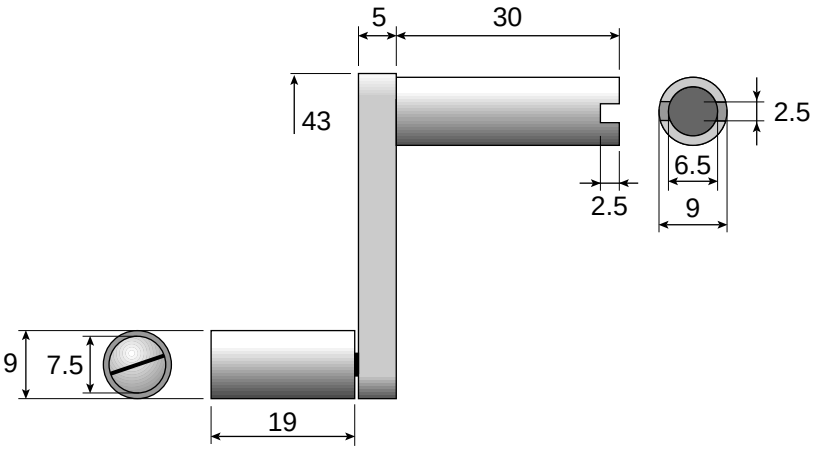
Standard E10 lamp **Flat-faced lamps**

The diameter of the flat-faced lamps is slightly larger (12 mm) and, more importantly, they are somewhat lower than the standard ones. Using standard lamps may cause damage to the letters of the lamp panel itself. The letter film is made of celluloid that is easily burned when it is touched by a burning lamp. Furthermore, a standard lamp may cause physical damage as it tries to 'push' itself through the film.

> *Advice: It is recommended that these lamps are either removed by the future owner or (better) that they are replaced by either original lamps or suitable replicas of 3.5 V / 200 mA. The cracks that are currently visible on the lamp panel (see chapter 2.2.2) are most likely caused by the use of improper light bulbs. It is up to a future owner of the G-111 to have the lamp film replaced, repaired or to leave it in the present state.*

2.3.3 Crank

The *Zählwerk Enigma* features a complex wheel-turnover mechanism that allows mistakes to be corrected in case of a typing error. In order to wind the mechanism back, one would insert a crank into a hole on the right side of the machine. The crank is usually stored inside the top lid of the wooden box. There is a crank present in the lid of the G-111, but it might not be the original one, as it is not built to the high German standards of the era. We do believe however that it is old and that it was probably made as a replacement for the original that got lost. Similar cranks of the same 'lower quality' build standard have been seen before with other *Zählwerk Enigma* machines. The dimensions of the crank are given below.



The crank of the G-111 (all sizes in mm)

2.3.4 Wheels

This machine has three removable wheels. The fourth wheel (i.e. the leftmost one) is the UKW which cannot be removed. Most *Zählwerk Enigma* machines were supplied with just three wheels that could be placed on the spindle in any given order (i.e. 6 possible combinations). Some machines, however, were supplied with more wheels in order to increase the number of possible permutations. This is also the case with the G-111. Although only three wheels have been found with the machine, they are numbered I, II and V, indicating that at least 5 different wheels were supplied with the machine.

As part of the investigation, the wiring of the three wheels and the UKW has been recovered. The UKW is wired in the standard fashion for commercial Enigma machines. As far as we know the wiring of the wheels does not match any known wheel wiring for *Zählwerk Enigma* machines. The wiring of the wheels is listed in the table below. The coloured cells indicate the position of the wheel-turnovers. When this letter is visible in the window, it will cause the wheel to the left of it to step by one position on the next key press. Please note that the actual turn-over notch is 8 positions further on the wheel. The rightmost column of the table gives the total number of notches on each wheel. The positions of the notches on wheel I and II are identical to those on wheels I and II found in other *Zählwerk Enigma* machines.

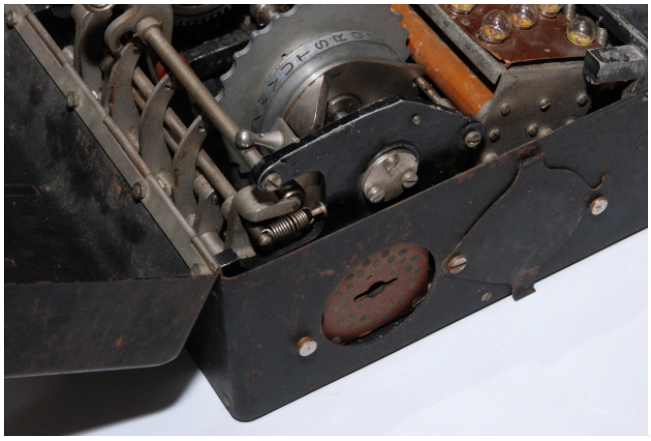
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
I	W	L	R	H	B	Q	U	N	D	K	J	C	Z	S	E	X	O	T	M	A	G	Y	F	P	V	I	17
II	T	F	J	Q	A	Z	W	M	H	L	C	U	I	X	R	D	Y	G	O	E	V	B	N	S	K	P	15
V	Q	T	P	I	X	W	V	D	F	R	M	U	S	L	J	O	H	C	A	N	E	Z	K	Y	B	G	7
UKW	I	M	E	T	C	G	F	R	A	Y	S	Q	B	Z	X	W	L	H	K	D	V	U	P	O	J	N	
ETW	Q	W	E	R	T	Z	U	I	O	A	S	D	F	G	H	J	K	P	Y	X	C	V	B	N	M	L	

The UKW has the standard wiring for the commercial Enigma D, which suggest that the *Zählwerk Enigma* was initially designed as a commercial machine. The same wiring for the UKW was found in a *Zählwerk Enigma* (A-865) in The Netherlands and a *Zählwerk Enigma* model G31 that was found in Argentina at the end of WWII (G-260). The latter is believed to have been used by the German *Abwehr*.

2.3.5 Printer connector

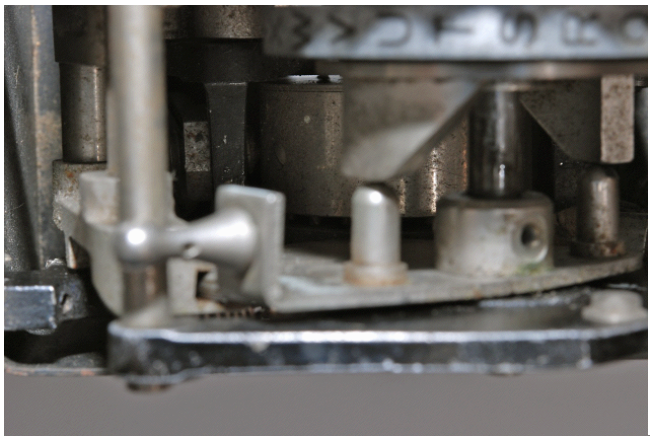
The G-111 has a special socket on the left, close to the UKW. This socket accepts a connector with a diameter of approx. 5 cm. A hole of roughly the same diameter is present in the wooden box as well. This is a unique feature of this particular *Zählwerk Enigma* model G31. Although the existence of such a connection is known and patents have been found to support this, it is the first machine of this type found with this special feature. A detailed description is given in the next chapter. The machine was internally known as Ch.15b by the manufacturer.

The socket is in fact a very complex set of contacts, combined with an integrated switch, allowing a printer to be connected whilst, at the same time, switching off the light bulbs. The entire assembly is mounted below the UKW and is fitted to some supporting stubs on the chassis. These stubs are part of the die-cast aluminum bottom plate. This either means that the chassis of the G-111 is different from the chassis of other known G31 models, or that the stubs are present in the other machines as well, but have never been noticed before.

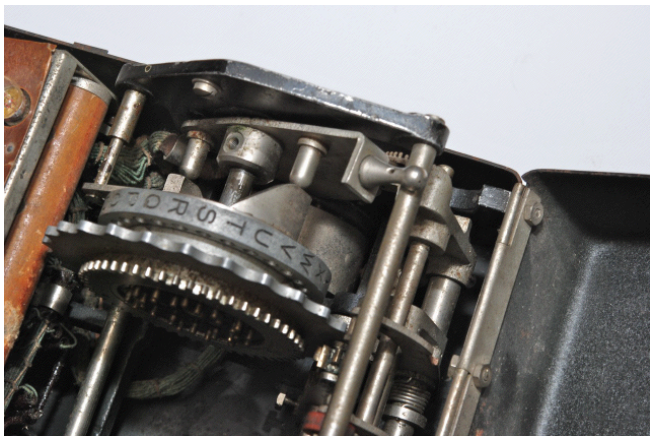


Relative position of the connector close to the UKW

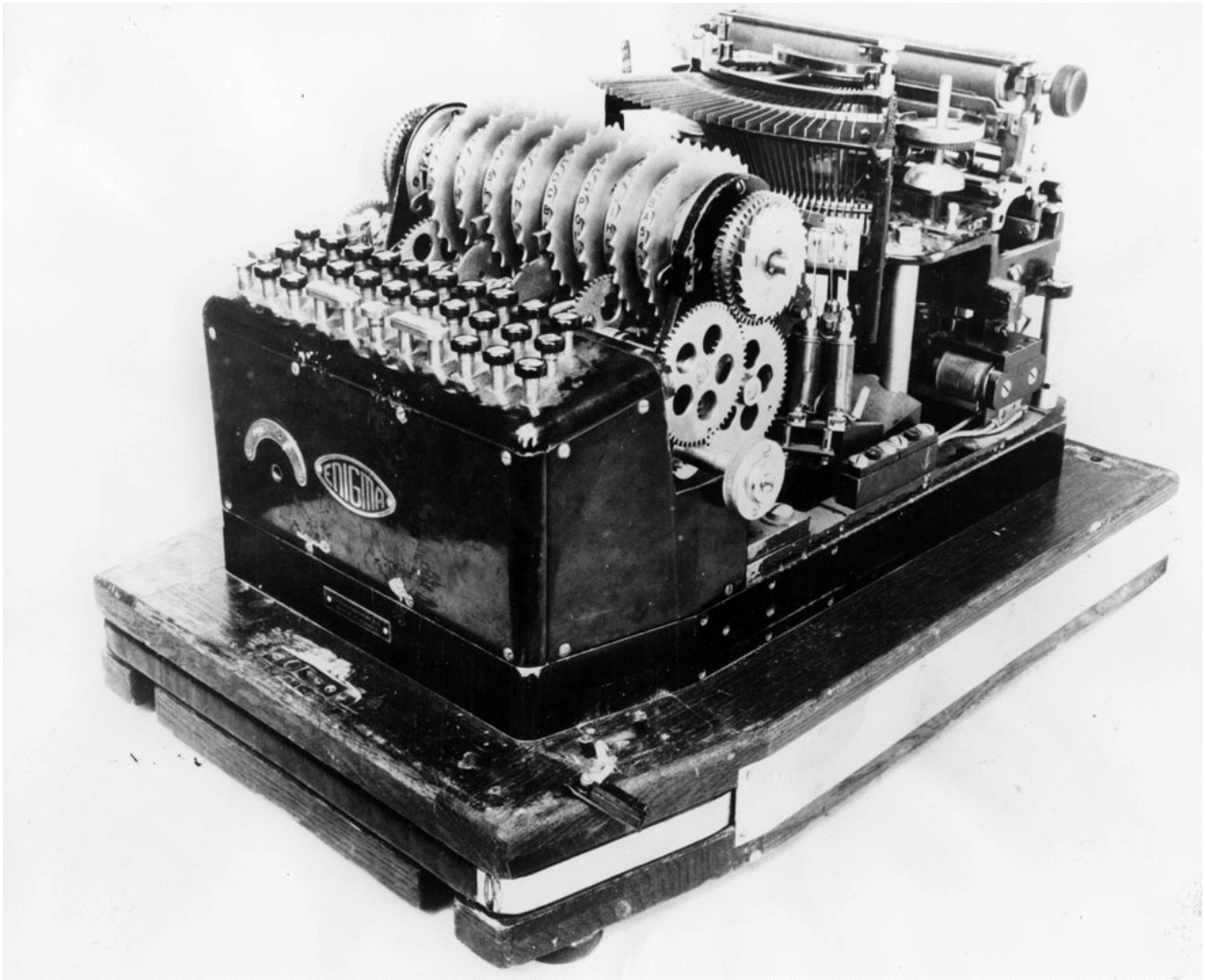
Looking into the connector



Top view of part of the switch below the UKW



Perspective view of the switch below the UKW



The Enigma H, model H29 (Ch.14), delivered to Hungary in 1929. It was used as a printing device for the G-111

3. The printer connection

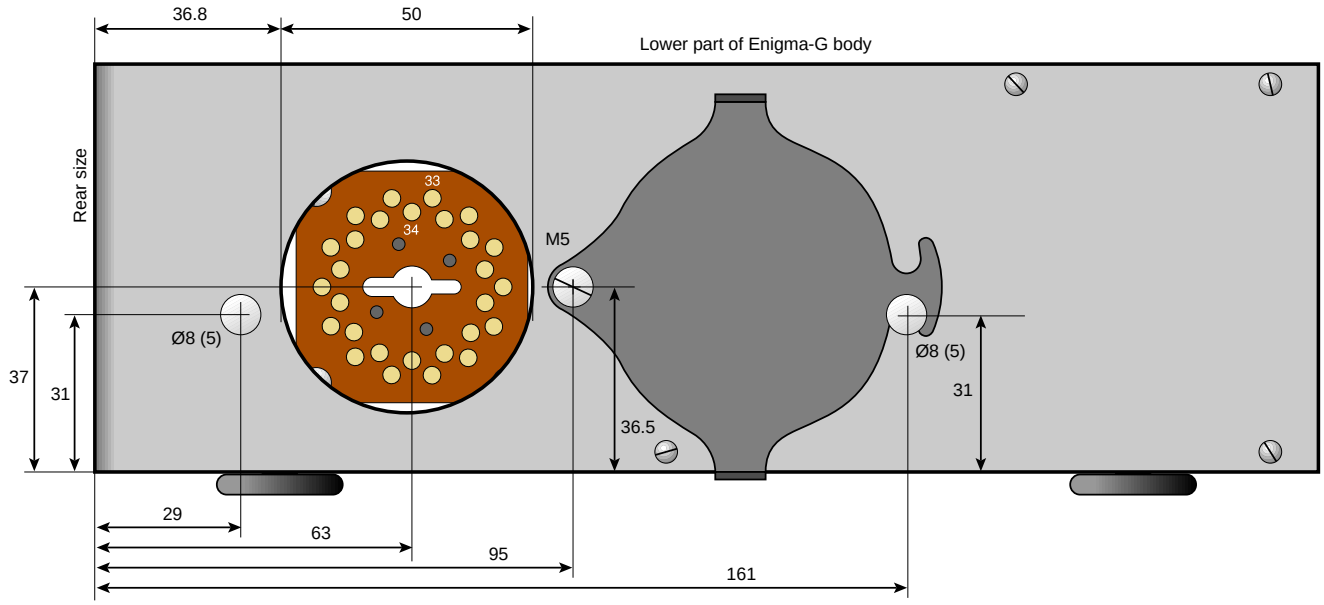
3.1 Introduction

A very special feature of this particular *Zählwerk Enigma*, is the presence of an expansion socket at the left, close to the UKW. So far, this feature has not been found on any other *Zählwerk Enigma* before. The expansion is described in patents DE536556 [8] and DE595075 [9]. It allows another – much larger – printing Enigma (such as the Enigma H) to be connected and used as a printing device. It is believed that the printer connection was an option that was also available for the Enigma I.

When used in this way, the Enigma H (see the picture on the left page) would only function as a printing machine; its cipher capabilities would be disabled. Connecting a printer allowed a cipher clerk to decipher any incoming messages much faster then when reading-off the lamps and writing down the letters. He could not use the Enigma H directly, as it wasn't compatible with the *Zählwerk Enigma* or the Enigma I.

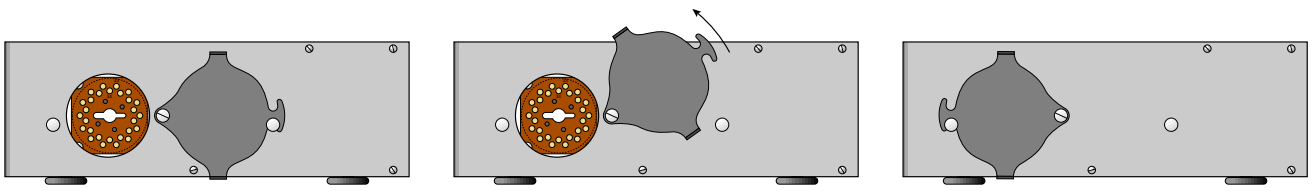
3.2 Physical position

The socket is located at the left side of the machine. A hole of approx. 50 mm is present in the lower part of the metal body. It gives access to the socket which is mounted behind the hole. When the machine is mounted inside the protective wooden box, a hole in the box provides access to the socket. The socket is actually mounted slightly off-center, but the hole in the metal body is large enough to accommodate the connector.



View of the left side of the lower part of the G-111 (all dimensions in mm)

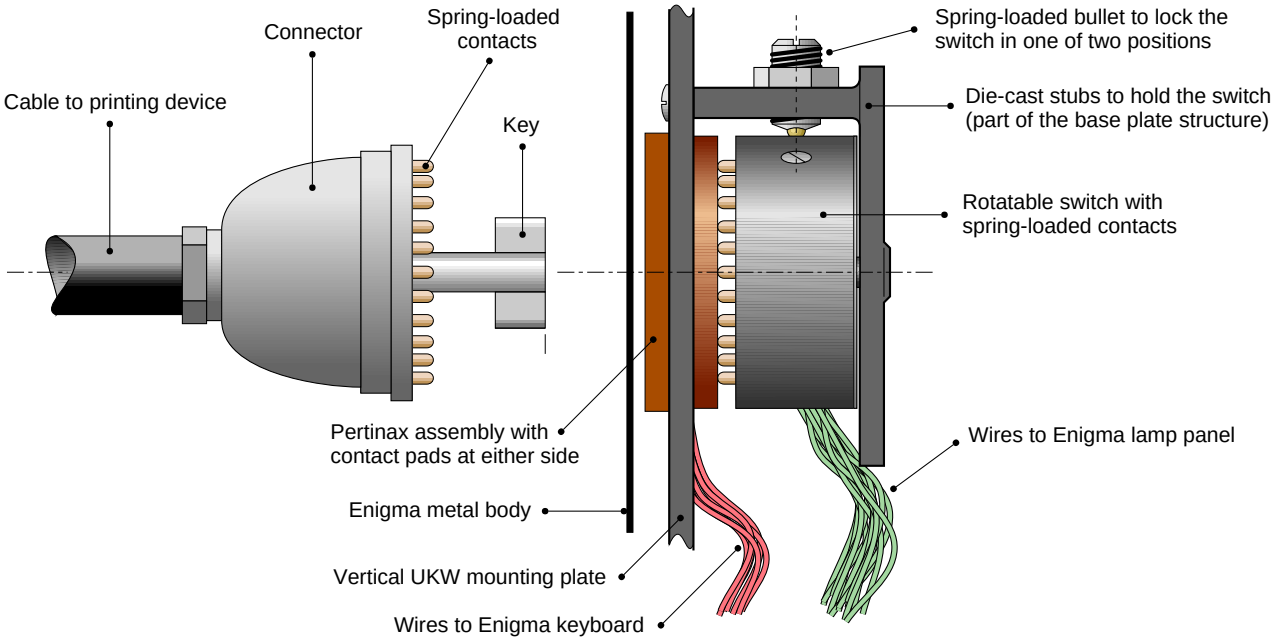
To the right of the socket is an oddly-shaped metal flap that pivots around an M5 bolt. It can be used to close the socket and protect its contacts when it is not in use. The flap has two small folded edges that allow it to be moved with, say, a finger nail. The upper edge reaches just above the lower part of the wooden box, so that the flap can be controlled even when the machine is mounted inside the wooden box. Below is an illustration of how the flap is moved.



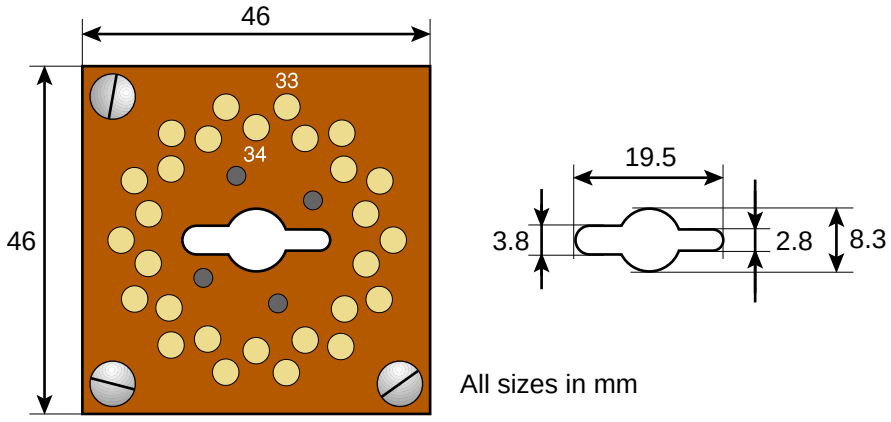
3.3 The Switch

The *Zählwerk Enigma* has 26 lamps on its lamp panel. These lamps are specified at 3.5 V or lower and are normally powered by a battery of approx. 4.5 V. The current trough the lamps is approx. 200 mA. When the printing device is attached however, the voltages and currents are much higher, as the machine has to drive the solenoids inside the Enigma H directly. As a result, the lamps would be blown. Removing the lamps was not considered an option, as one had to remove them each time a printing device was attached and put them back in when standard operation was desired. Therefore a solution was developed which allowed all lamps to be switched off when the printer connector was placed in the socket of the machine. This solution is described in patent DE595075 (Appendix E).

The patent describes a switch that is operated by the connector itself. The cable from the printing device has a connector with 28 spring-loaded contacts. When the connector is inserted into the socket, it must be turned somewhat in order to lock-in. When doing so, the contacts of the connector slide into position to make contact with the circular pads on the socket. At the same time, another connector – fitted permanently inside the Enigma – is moved out of position, so that the connection with the lamps is broken.

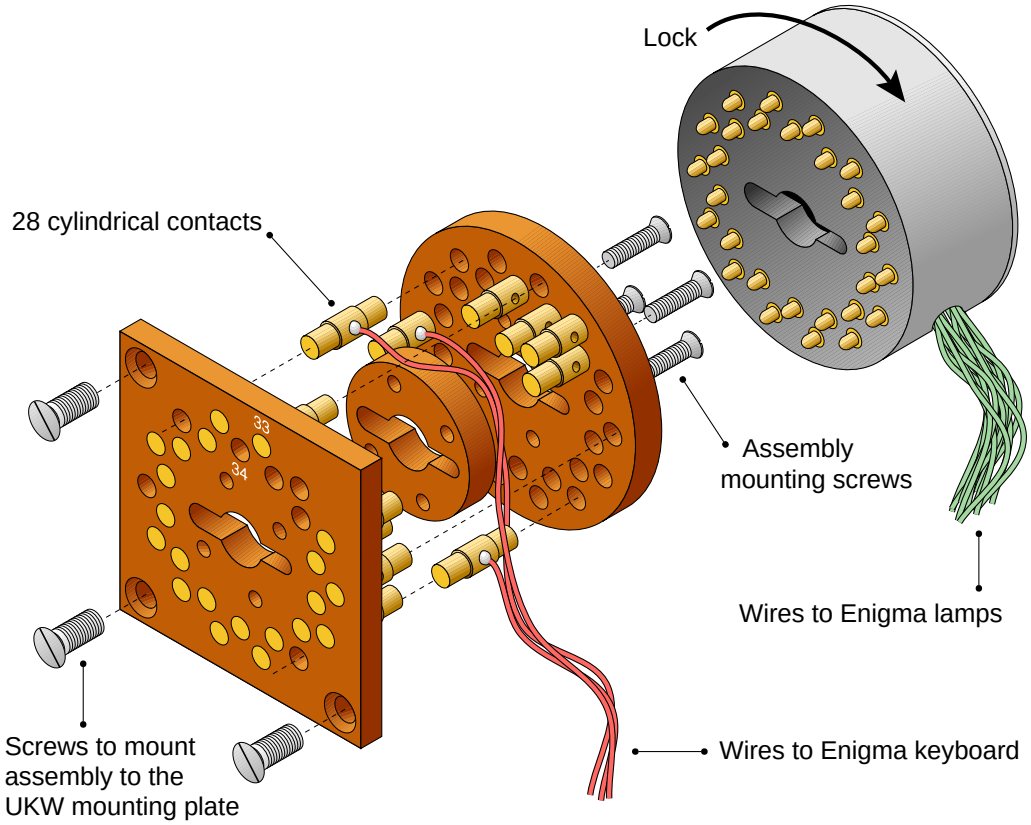


The above drawing shows the rather complex switch that consists of static and movable parts, both inside and outside the machine. The connector (not part of the machine) actually behaves as part of the switch. It has 28 spring-loaded contacts, organized in a zig-zag pattern, similar to the contact pads on the socket. At the center is a key that fits the key-hole at the center of the socket. The key consists of a rather long cylindrical pin with two 'wings' at the end. In order to prevent the connector from being inserted the wrong way around, the wings have different diameters.

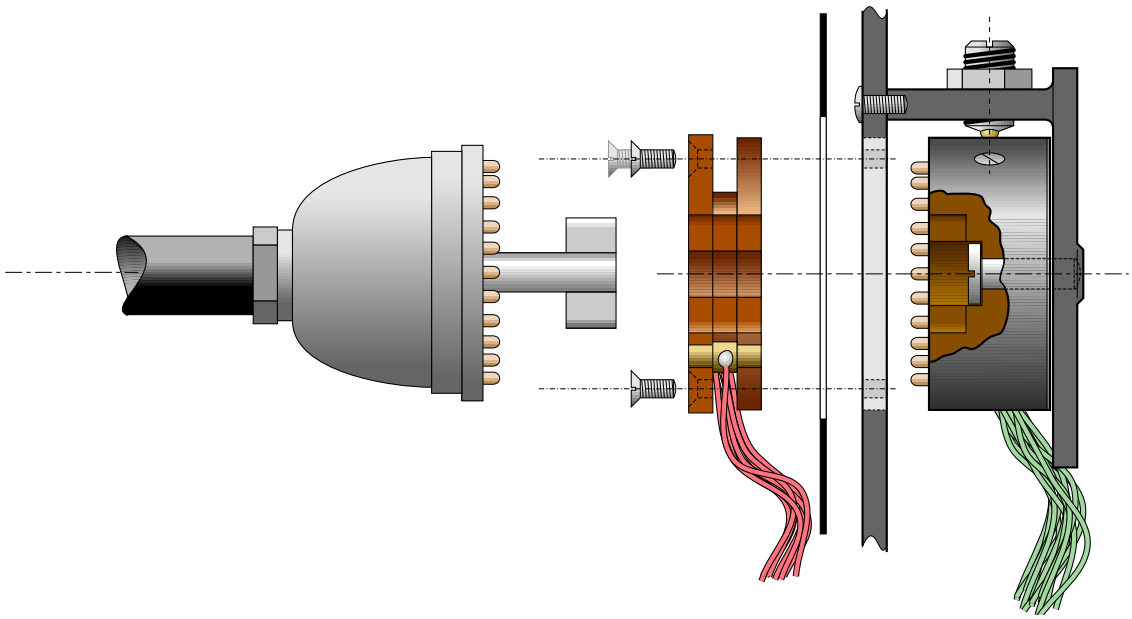


The exploded view below should clarify things somewhat. Please note that during our investigation, we were unable to dismount the switch assembly and are therefore uncertain about the shape of the center part and the cylindrical contacts. We had to make a few 'educated guesses', based on our knowledge of the German manufacturing skills. The same is true for the connector which we haven't seen yet.

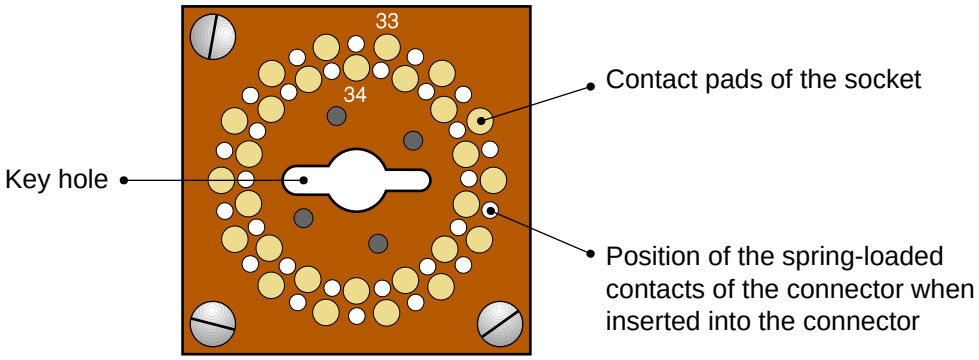
The socket assembly consists of a package of three pieces of pertinax. The leftmost one is square and is visible from the outside. The other parts are disc-shaped in order to fit through the hole in the vertical UKW mounting plate. The three parts are held together with 4 recessed M3 screws, fitted from the rear. The center part (i.e. the first disc-shaped unit) is smaller in order to accommodate the wires to the Enigma keyboard.



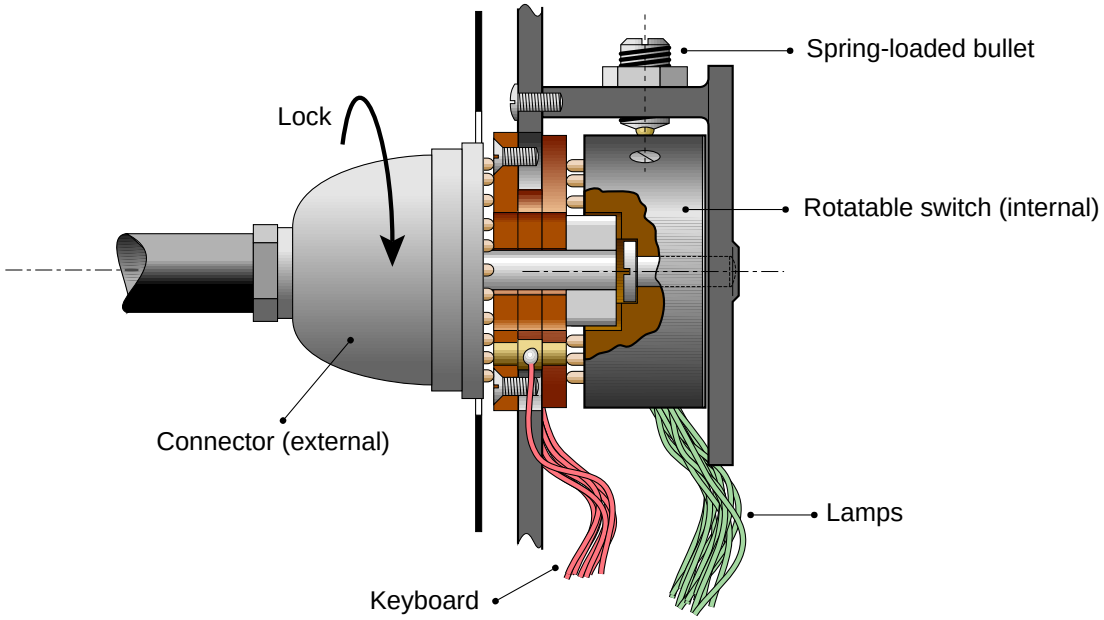
The switch assembly is inserted into the vertical UKW mounting plate from the left and is fixed with three recessed M4 screws. The drawing below shows a cross section of the assembly, the UKW mounting plate and the rotatable switch.



The spring-loaded contacts of the internal rotatable switch (to the right of the assembly) are aligned in such a way that they touch the contact pads of the assembly when in the default position. This way, the Enigma lamps are each connected to a switch of the Enigma keyboard.



The spring-loaded contacts of the connector are displaced by approx. 12.8° so that, when the connector is inserted into the socket, the spring-loaded contacts do not touch the contact pads of the assembly. When inserting the connector, the key – that is a permanent part of the connector – is pushed through the assembly, into the rotatable switch.



Once the connector is fully pushed in, is is rotated approx. 12.8° clockwise until the internal rotatable switch is locked in its second position. A spring-loaded bullet ensures that the switch is kept in place. The contacts of the connector – that were positioned in between the contact pads before – are now resting on the contact pads of the socket. At the same time, the rotatable switch is moved out of position and its contact are now resting in between the contact pads. In other words: when the connector is rotated clockwise, the contacts from the Enigma keyboard to the lamps are broken and are connected to the external connector instead.

3.4 Keyboard locking solenoid

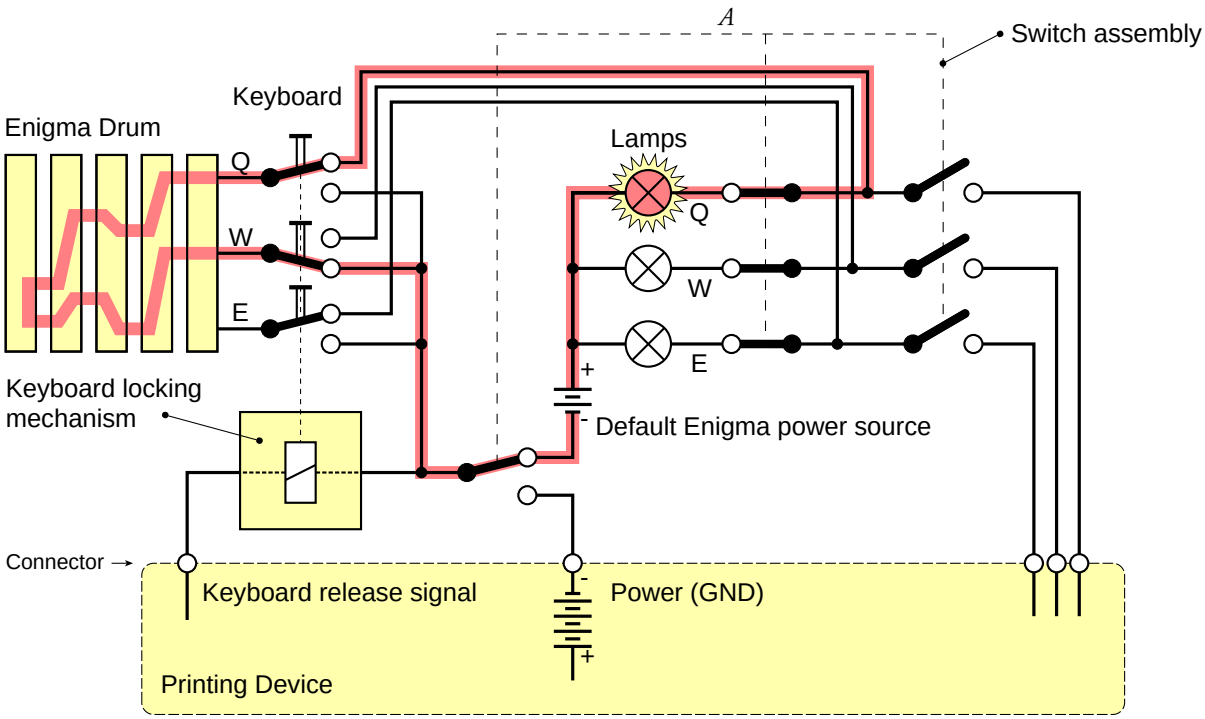
According to patent DE595075, there should also be a keyboard unlocking solenoid present inside the Enigma. When a key was pressed, it would be locked in place to allow the printing device to do its work. Once the letter was printed and the printing device had finished its printing cycle, the solenoid would release the Enigma keyboard again, so that the next letter could be pressed. The solenoid probably resides somewhere below the keyboard. During our investigation we have not been able to locate the solenoid as the machine would have to be (partly) disassembled for that. Whether or not we will be able to investigate this part of the machine in the future, depends on the future owner of the machine.

> *Remark: In chapter 2.2.3 we mentioned that currently the wheels do not move when a key is pressed. Although this might be caused by a broken spring or a blocked turnover mechanism, it is also possible that the (mechanical) key locking mechanism has been engaged. It would be useful to investigate this possibility further.*

3.5 Wiring

One of the goals of our investigation was to establish the wiring of the printer socket. Unfortunately however, all contacts of the G-111 are heavily corroded. As a result, we have been unable to measure a single wire between ETW, keyboard, lamp panel and printer switch. Although the contacts of the machine are currently in bad condition, we believe that they are not beyond repair. In order to clean and preserve the contacts in a proper manner, the machine has to be largely dismantled. We hope that a future restoration job will eventually reveal the wiring of the printer connection. Again, this is up to the future owner.

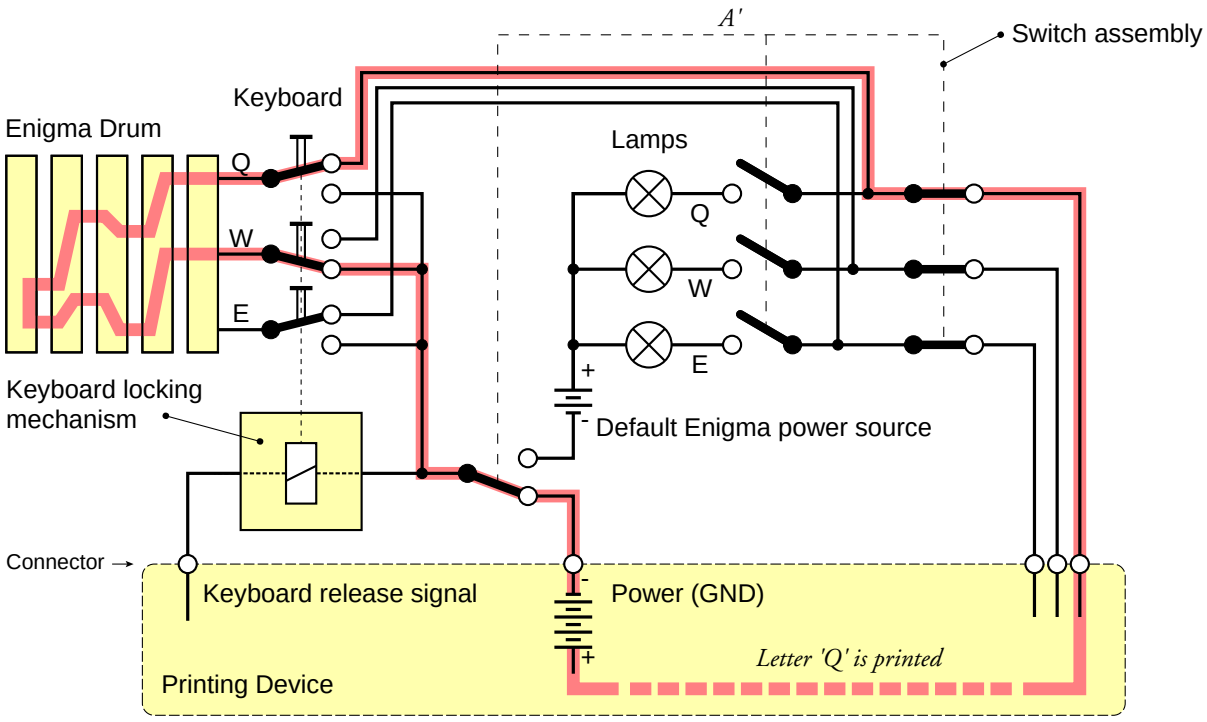
The printing connector has 28 contacts, whilst the machine only has 26 letters. The two remaining contacts were used for the ground line (-) and the keyboard-release signal. The drawing below shows a simplified circuit diagram of the Enigma with the printing switch *(A)* set to the neutral position. The standard Enigma power source is connected and the lamps are enabled. When a key is pressed (W in this case), they current flows in the usual manner through the drum and a light will be lit (Q in this case). The red line shows the current.



Simplified circuit diagram with printer not connected

Continued on the next page...

When a printing device is connected and the switch is enabled *(A')*, the Enigma is powered from the alternative source and the lamps are disabled. Instead, the output is routed to the printing device. The drawing below shows how the current flows in that case. Please note that all parts of the switch move at the same time.



Simplified circuit diagram with printer connected

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Paul Reuvers & Marcus Simons, Le Sage ten Broeklaan 7, 5615 CP Eindhoven, The Netherlands
http://www.cryptomuseum.com/
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[3] **Weierud, Frode** (Enigma historian)
Frode.Weierud@cern.ch

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Bletchley, Milton Keynes, United Kingdom
http://www.bletchleypark.org/

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Hamer, David H., Cryptologia January 2000, Volume XXIV, Number 1.
dhhamer@comcast.net

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[7] **German Patent DE534947** (Zählwerk Enigma)
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[8] **German Patent DE536556** (Printer connection)
Reichspatentamt, currently called *Deutsches Patent- und Markenamt*, München, Germany.

[9] **German Patent DE595075** (Printer switch)
Reichspatentamt, currently called *Deutsches Patent- und Markenamt*, München, Germany.

[10] Correspondece between Chiffriermaschinen A.G. and Herr Direktor Walter Edström
Dated 16 September 1929

[11] **Actions involved in the 'double stepping' of the middle rotor**
Hamer, David H., Cryptologia January 1997, Volume XX, Number 1.

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