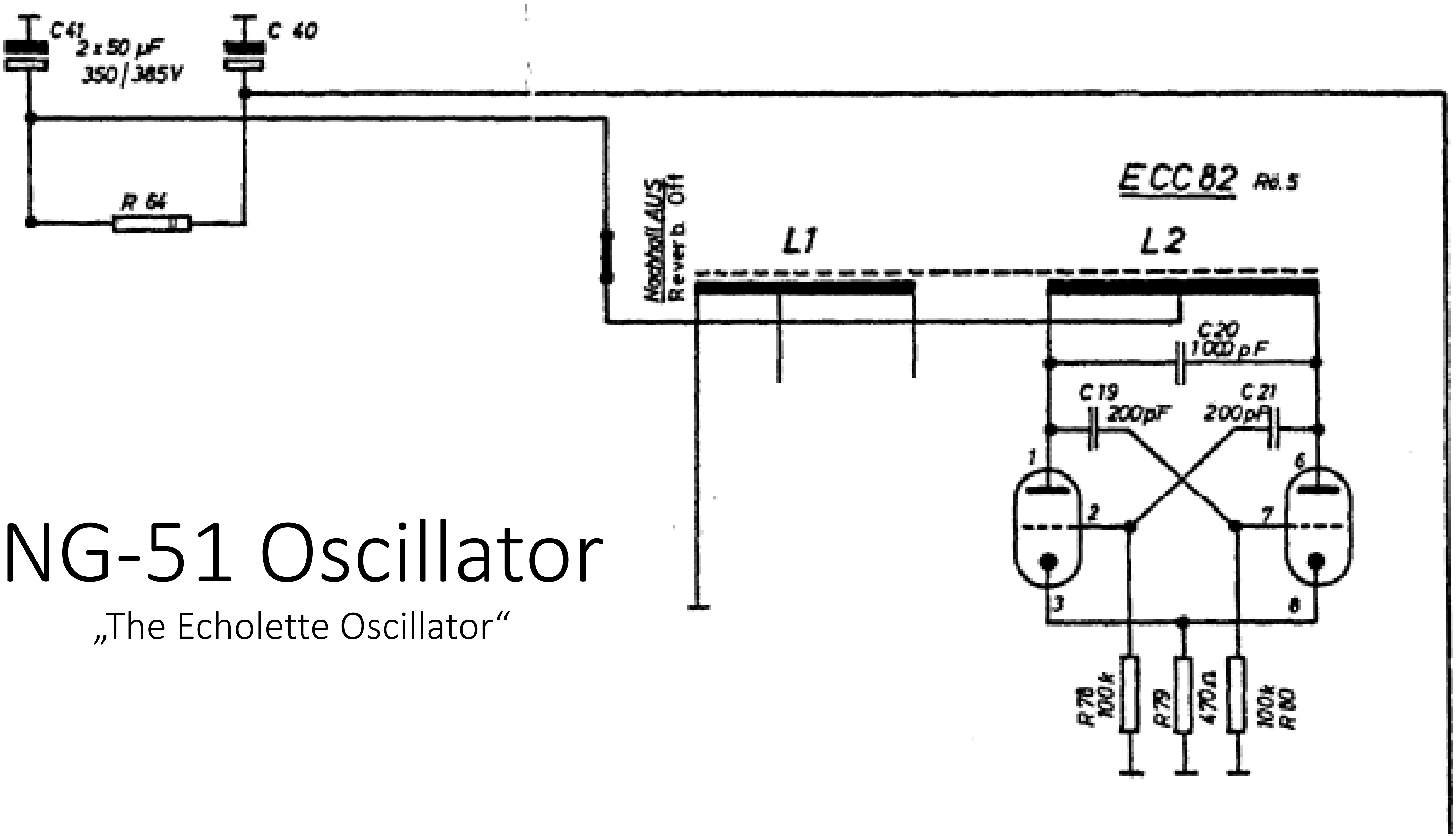
NG-51 Oscillator

„The Echolette Oscillator“



Overview

- Backgrounds
  - What is an oscillator?
  - Why is an oscillator needed in tape applications?
  - Variants of the Echolette oscillator

- NG51 S: Oscillator Circuit
  - Test setups with reduced voltage
  - The ECC82 tube
  - Workings of the astable multi-vibrator
  - The parallel LC-resonant circuit
  - The oscillator coil

What is an oscillator?

„ An oscillator (from the Latin word 'oscillare', 'to swing') is a system capable of oscillating. This means that it allows its state variables to oscillate, usually over time. Oscillation means that there is a continuous change between two states, or around a central point, which usually corresponds to the resting point of the system.“

Source: https://de.wikipedia.org/wiki/Oszillator

„Oscillation is the repetitive or periodic variation, typically in time, of some measure about a central value (often a point of equilibrium) or between two or more different states.”

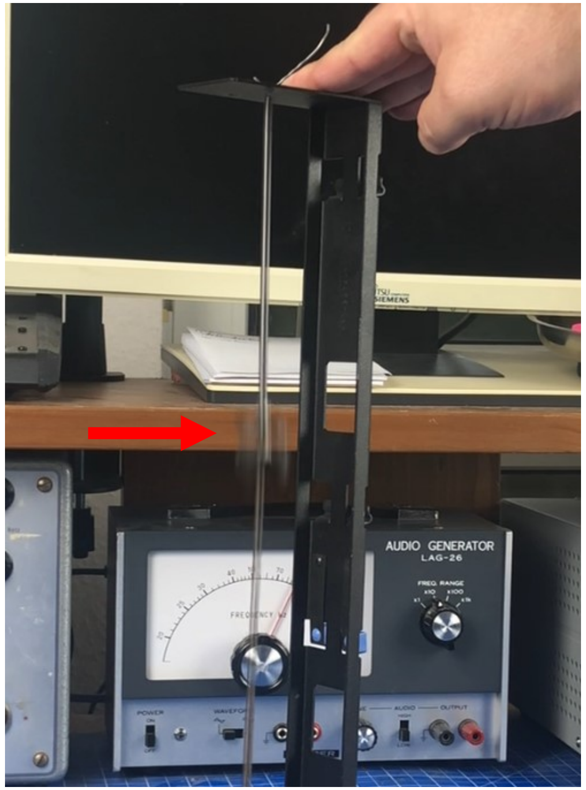
Source: https://en.wikipedia.org/wiki/Oscillation

What is an oscillator?
Mechanical examples

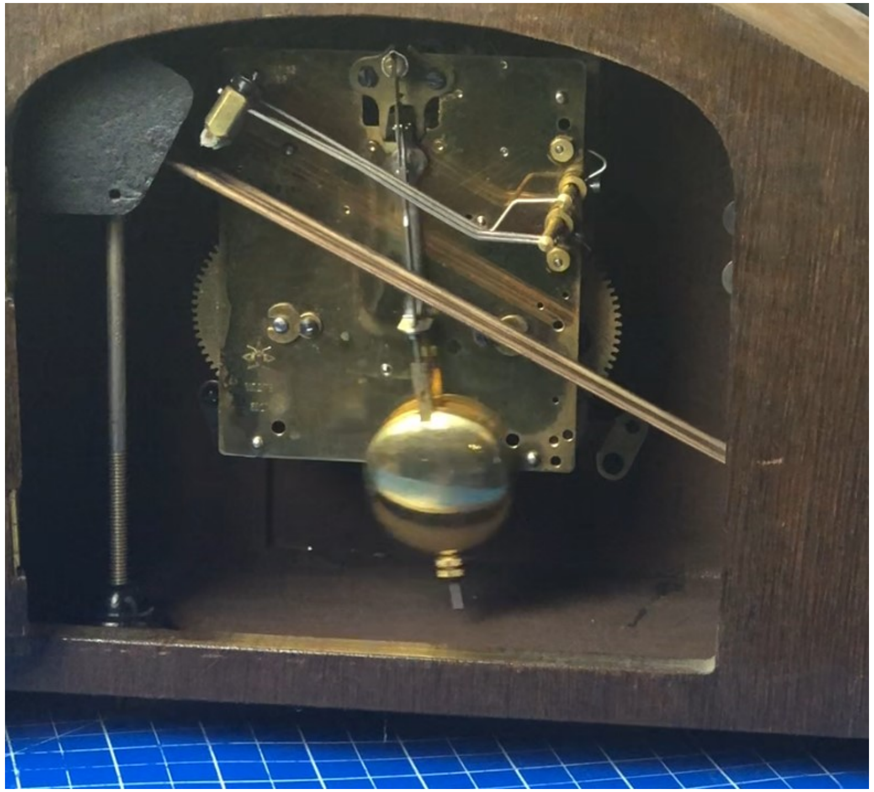
// Movie examples spring system and pendulum of a clock

We will examine two examples that are also oscillators!

A metal disc is balanced and suspended between two springs. The disc is deflected downward and released. The disc now oscillates up and down between the two springs for some time. The oscillation occurs around the rest point of the spring system.



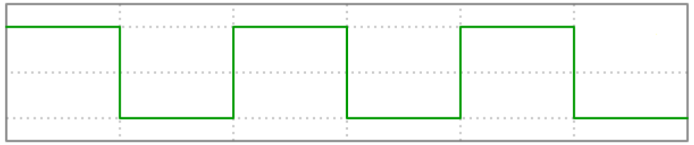
Pendulum as pacemaker in a mechanical clock



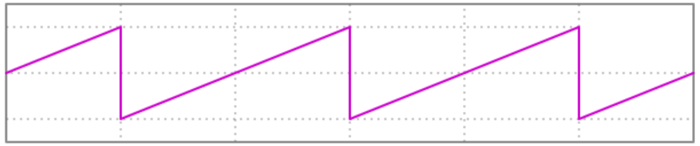
Both examples describe oscillators with "damped oscillation". Once set in motion, they do not continue to oscillate forever, it fades away again after some time. Unless energy is added again and again: renewed deflection of the metal body or winding up of a spring as with the clock.

What is an oscillator?
Examples from electrical engineering

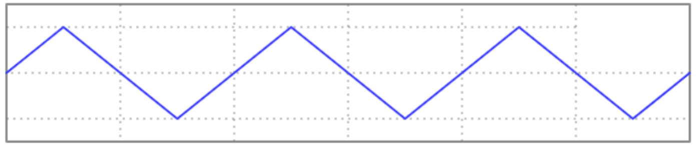
- Rectangular Wave-Generator



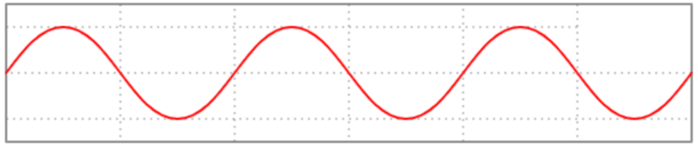
- Sawtooth-Generator



- Triangle-Generator



- Sine Wave-Generator



Source : https://de.wikipedia.org/wiki/Oszillatorschaltung

In audio technology one meets different oscillation generators (oscillators) which produce different wave forms.
Only the pure sine tone consists of only one frequency!
All other oscillations have a more or less distinctive and different spectrum of overtones.

What is an oscillator?

Examples from electrical engineering

Einteilung von Oszillatorschaltungen

nach Prinzip	nach Signalform	nach Namen des Erfinders	nach Verwendungszweck
Backward-wave Oszillator	Rechteck-Generator	Meißner-Schaltung	Lokaler Oszillator
Digitally Controlled Oscillator	Sägezahn-Generator	Leithäuser-Schaltung	Wobbelgenerator
Dreipunktschaltung	Sinus-Generator	Huth-Kühn-Schaltung	Referenzoszillator
Differenzverstärker-Oszillator	Impulsgenerator	Hartley-Schaltung	Abstimmoszillator
Quarzoszillator	Dreieck-Generator	Colpitts-Schaltung	Funktionsgenerator
MEMS-Oszillator		Clapp-Schaltung	CTCSS-Generator
Ringoszillator		Pierce-Schaltung	
Phasenschieberoszillator		Seiler-Oszillator	
Maschinensender		Vackář-Oszillator	
Tunneldioden-Oszillator		Butler-Schaltung	
Gunndioden-Oszillator		Franklin-Oszillator	
Kippschwinger		Heegner-Schaltung	
Sperrschwinger		Tesla-Oszillator	
Gegentakt-Oszillator		Wienbrücken-Oszillator	
Stimmgabel-Oszillator			
Direct Digital Synthesis			
Atomuhr, z. B. Rubidium-Oszillator			

EN: „rectangular wave generator"

EN: „sine generator"

EN: „3 point oscillator"

EN: „relaxation oscillator"

EN: „push/pull oscillator"

• Abraham-Bloch Multivibrator

Quelle/Source: https://de.wikipedia.org/wiki/Oszillatorschaltung

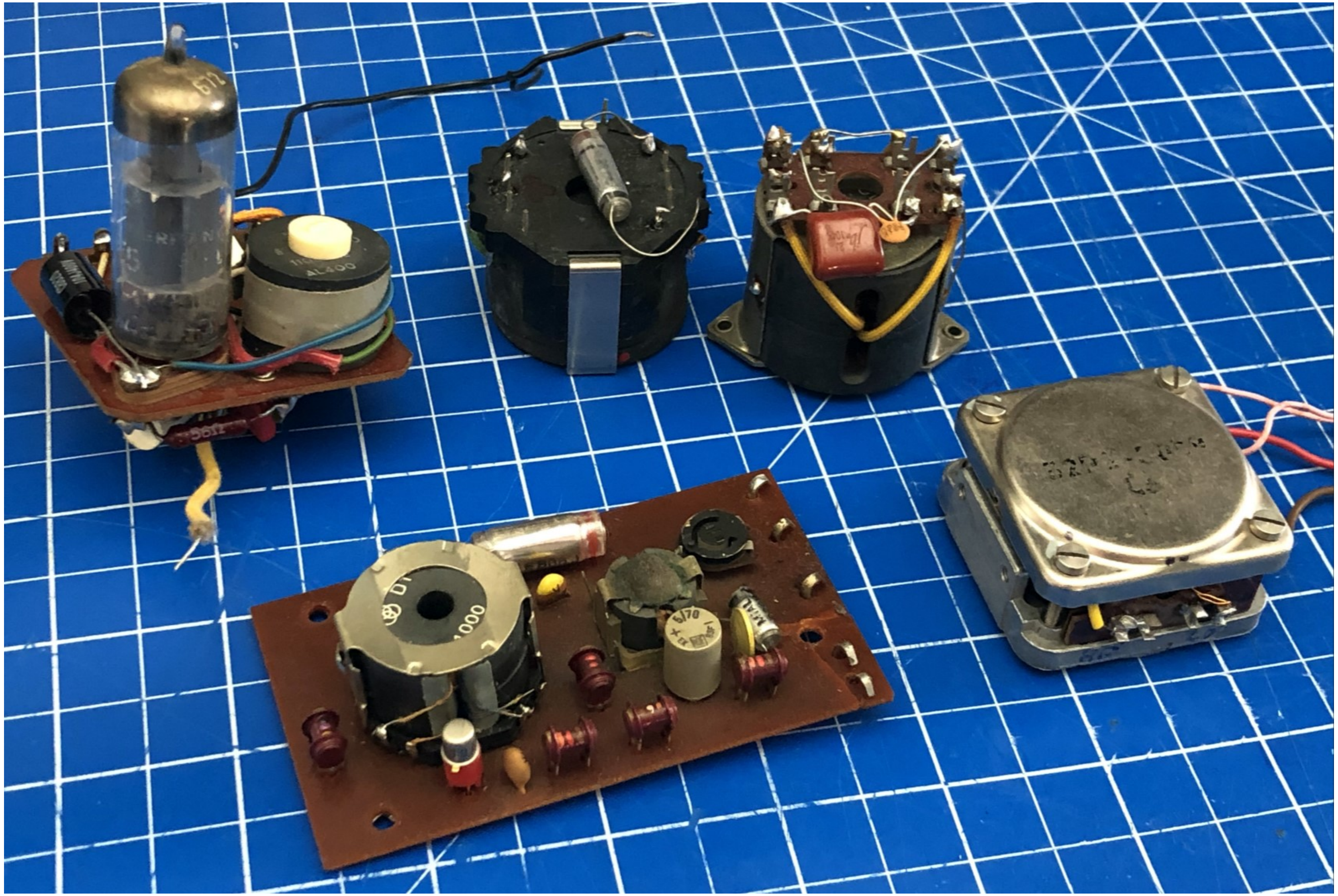
There are a lot of oscillator circuits. But for the "Echolette Oscillator" actually only a few of these keywords are of interest in terms of content!

Other keywords of interest are missing!

You won't find the exact Echolette oscillator here at all...

What is an oscillator?

Practical examples



Various oscillator modules and oscillator coils.

Bottom left:
Oscillator board from Dynacord Echocord (transistor version). To be found in Echocord Mini, Super 75/76, Echocord 100, and many more.

Why is the oscillator needed?

Physical basics 1

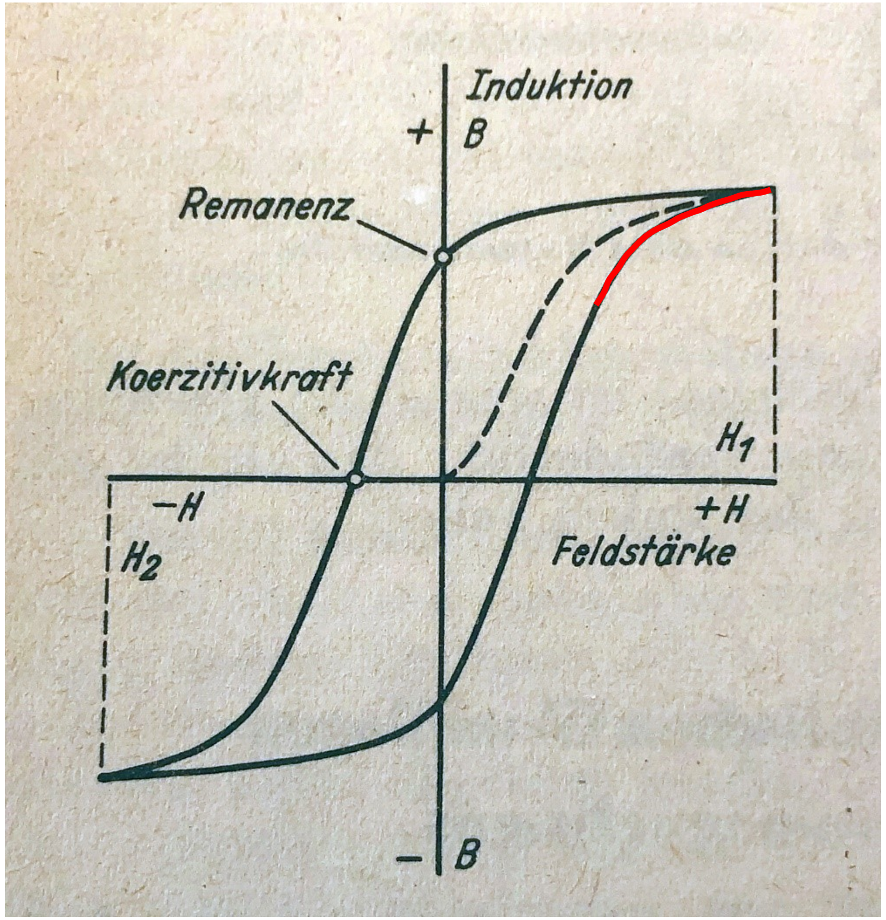


Illustration from: Wolfgang Junghans: *Magnetbandspieler-Praxis*, Radio Praktiker Bücherei 9, Franzis-Verlag, 4th edition, Munich 1953.

- Given be a magnetic field from a coil that is excited by direct current. We can increase (increase voltage) and decrease the direct current excitation and change its direction (reverse polarity).

- For each magnetizable body which is brought into the sphere of influence of this magnetic field, a relationship can now be recorded between the magnetic field strength (H) influencing it and the magnetic flux density (formerly: "magnetic induction"; B) occurring in it as a result. These relationships are represented in the form of loops, the so-called hysteresis loops (see figure).

- However, the relationship between H and B is not linear: a doubled magnetic field strength does not result in a magnetic flux density that is twice as strong, but saturation occurs at some point (example: area marked in red).

Why is the oscillator needed?

Physical basics 1

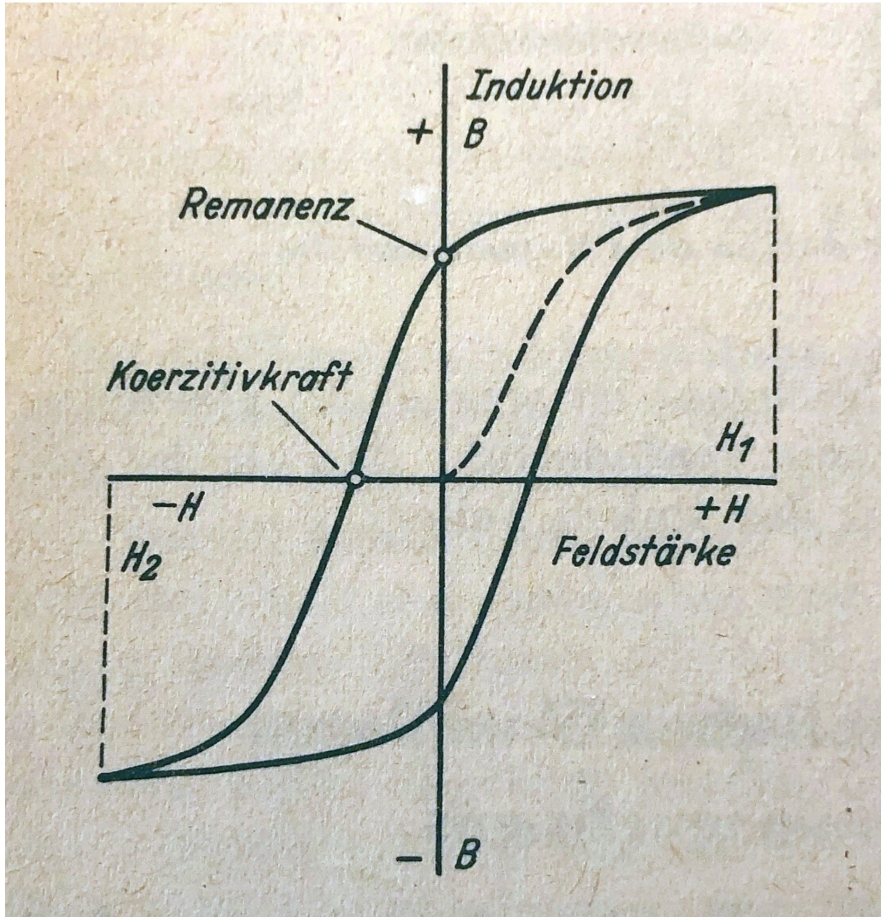


Illustration from: Wolfgang Junghans: *Magnetbandspieler-Praxis*, Radio Praktiker Bücherei 9, Franzis-Verlag, 4th edition, Munich 1953.

- If the magnetic field strength decreases, however, B does not return to the original starting point, but a residual magnetization (remanence) remains. This is exactly the reason why music remains recorded on a recorded tape, even if we switch off the tape recorder.

- To cancel the remanence, a magnetic field with opposite field direction and corresponding strength ("coercive force") is required.

Why is the oscillator needed?

Physical basics 1

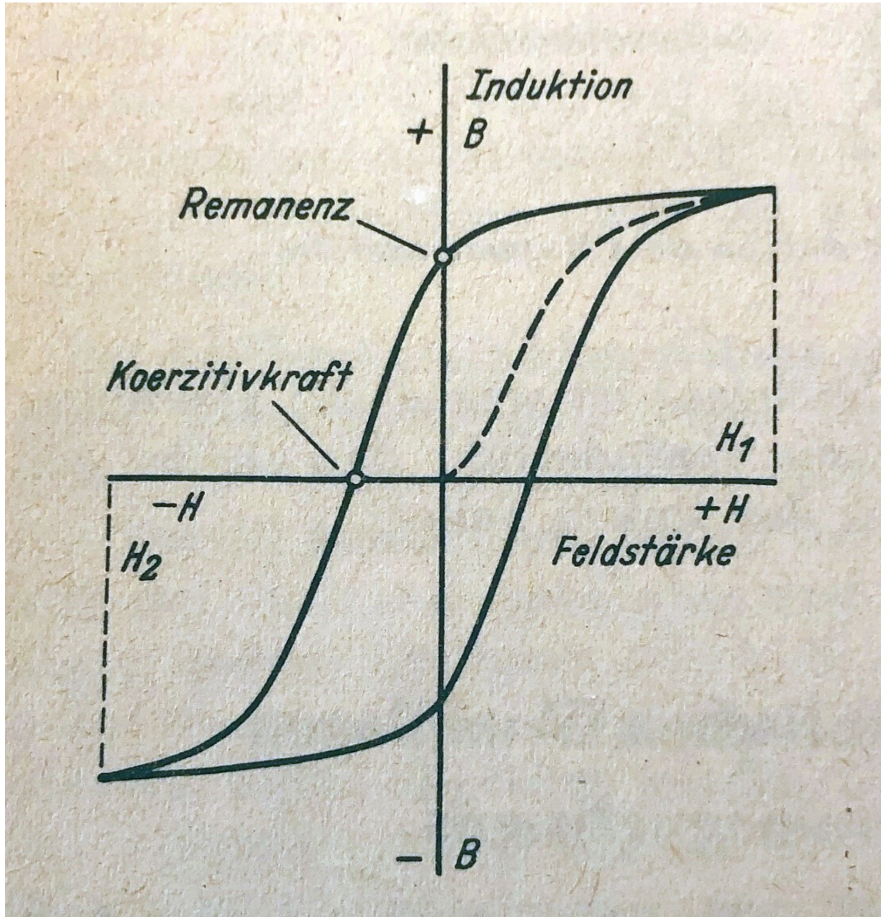


Illustration from: Wolfgang Junghans: *Magnetbandspieler-Praxis*, Radio Praktiker Bücherei 9, Franzis-Verlag, 4th edition, Munich 1953.

- It is important to understand that "magnetization" and "demagnetization" are on different legs of the hysteresis loop. Thus, demagnetization does not simply follow the path of magnetization backwards.
- The dashed "virgin" curve is traversed only on the first pass. To cancel the magnetization of our test body completely (point of origin / intersection of the coordinate axes), a certain "counterforce" is required. Switching off the original force alone does not bring this result.

Why is the oscillator needed?

History

- The use of direct current (DC fields) for erasing wires at first and later magnetic tapes, added an audible noise floor to the recordings, because the recording AC current could not completely overwrite the remanent magnetization left by the DC erase field.

- First U.S. patents regarding AC erasing in wire recorders in the 1920s => Forgotten because the wire recording method never really caught on, although there were wire recorders in the home sector up to the 1950s, which were also in competition with the tape recorder.

- 1940/41 "Rediscovery" of the HF process in Germany by Dr. Hans-Joachim von Braunmühl and Dr. Walter Weber in Berlin.

Why is the oscillator needed?

Physical basics 2

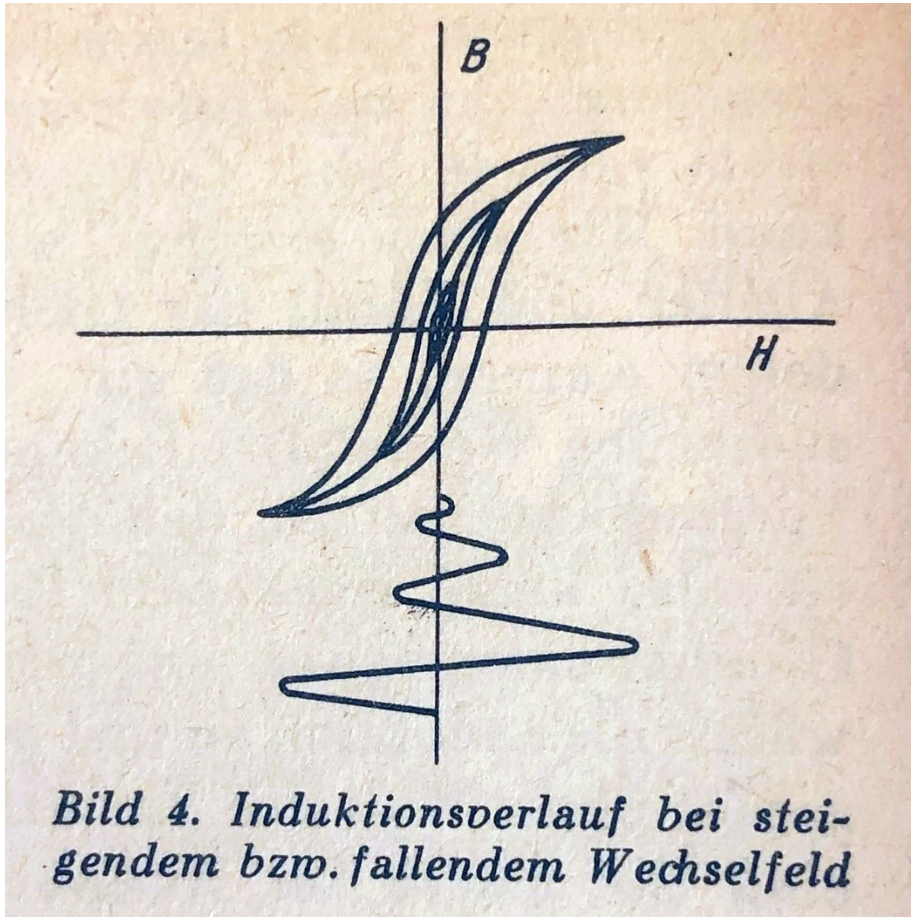


Illustration from: Wolfgang Junghans: *Magnetbandspieler-Praxis*, Radio Praktiker Bücherei 9, Franzis-Verlag, 4th edition, Munich 1953.

Features of the high-frequency erasing process:

- Demagnetization by a rising and falling alternating field.
  Rising: Tape approaches the erase head
  Falling: Tape moves away from the erase head

- Alternating field: High frequency = many re-magnetizations. The magnetizable particles are magnetized and demagnetized several times until saturation.

- The strength of the alternating erase field must be greater than the field previously used for the recording magnetization.

- The decreasing strength of the alternating field opens a narrower hysteresis loop at each oscillation pass until complete demagnetization occurs at the intersection of the axes (see figure).

- The high frequency is not audible and, since its force fields do not penetrate deep into the tape (skin effect), does not remain for long.

Why is the oscilator needed?

Physical basics 2

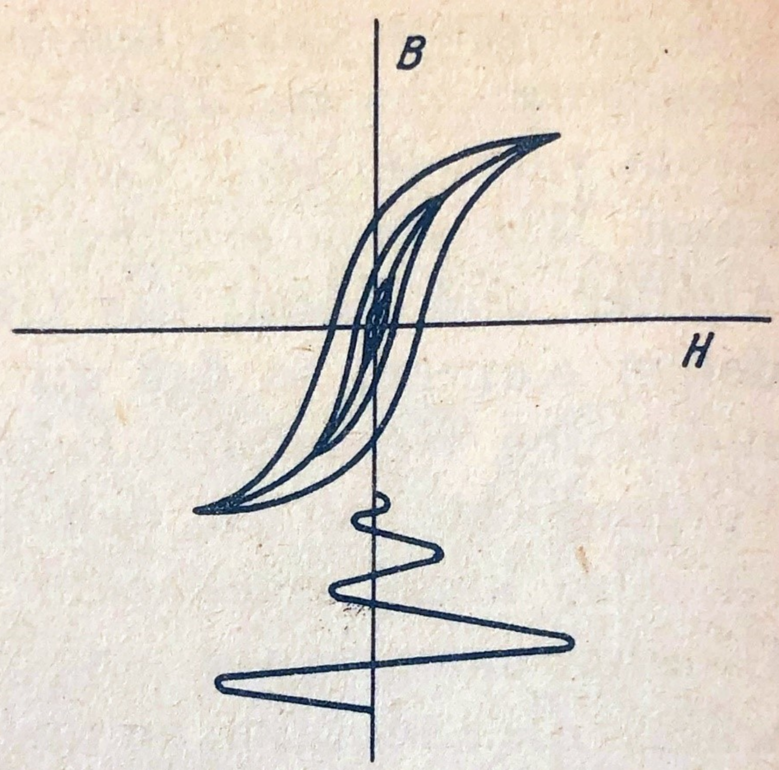


Bild 4. Induktionsverlauf bei steigendem bzw. fallendem Wechselfeld

Illustration from: Wolfgang Junghans: *Magnetbandspieler-Praxis*, Radio Praktiker Bücherei 9, Franzis-Verlag, 4th edition, Munich 1953.

- On the one hand, the bias magnetization frequency should be selected so low that the RF losses occurring in the speech head remain small.
- On the other hand, the bias magnetization frequency should be so high that a combination formation between the harmonics of the AF and the fundamental of the bias magnetization frequency is largely avoided or occurs outside the audible range.
- The bias magnetization frequency should be selected so that it>= 5 · f0 of the highest cutoff frequency transmitted by the instrument.
- For the Echolette NG-51 S this would mean:

Frequenzgang: Original: 50 - 16.000 Hz
Echo/Nachhall: 50 - 12.000 Hz -3 dB

Source: Hans Ohms

5 · 12 kHz = 60 kHz

=> More on this below and when we take a closer look at the clay heads in a later review!

Why is the oscilator needed?

Physical basics 2

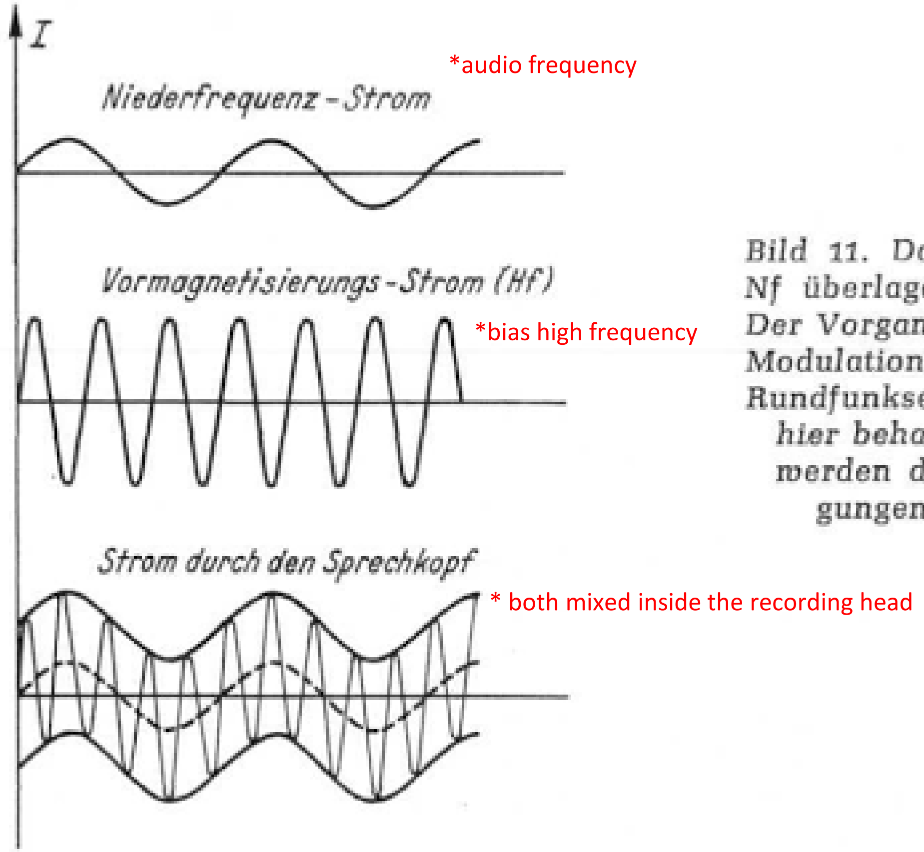


Bild 11. Darstellung einer mit Nf überlagerten Hochfrequenz. Der Vorgang hat nichts mit der Modulation der Hf z. B. in Rundfunksendern zu tun. Beim hier behandelten Verfahren werden die beiden Schwingungen einfach addiert

- A bias magnetization by high frequency provides better signal-to-noise ratio, significantly better reproduction of higher frequencies and less distortion. Therefore it is not only interesting for erasing, but also for recording!
- The high frequency and the audio frequency are simply given on the same line and thus mixed.

Illustration from: Wolfgang Junghans: *Magnetbandspieler-Praxis*, Radio Praktiker Bücherei 9, Franzis-Verlag, 4th edition, Munich 1953.

Why is the oscilator needed?

Physical basics 2

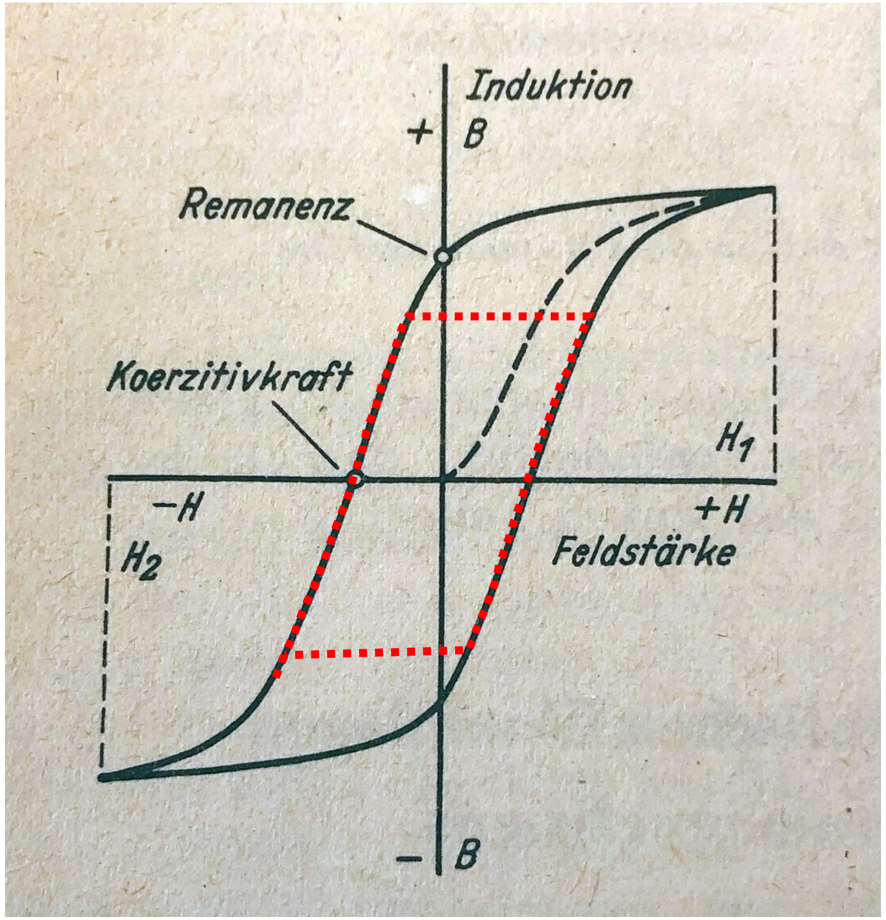


Illustration from: Wolfgang Junghans: *Magnetbandspieler-Praxis*, Radio Praktiker Bücherei 9, Franzis-Verlag, 4th edition, Munich 1953.

- The high frequency bias sets the operating point (bias) on the hysteresis loop for recording the audio frequency.

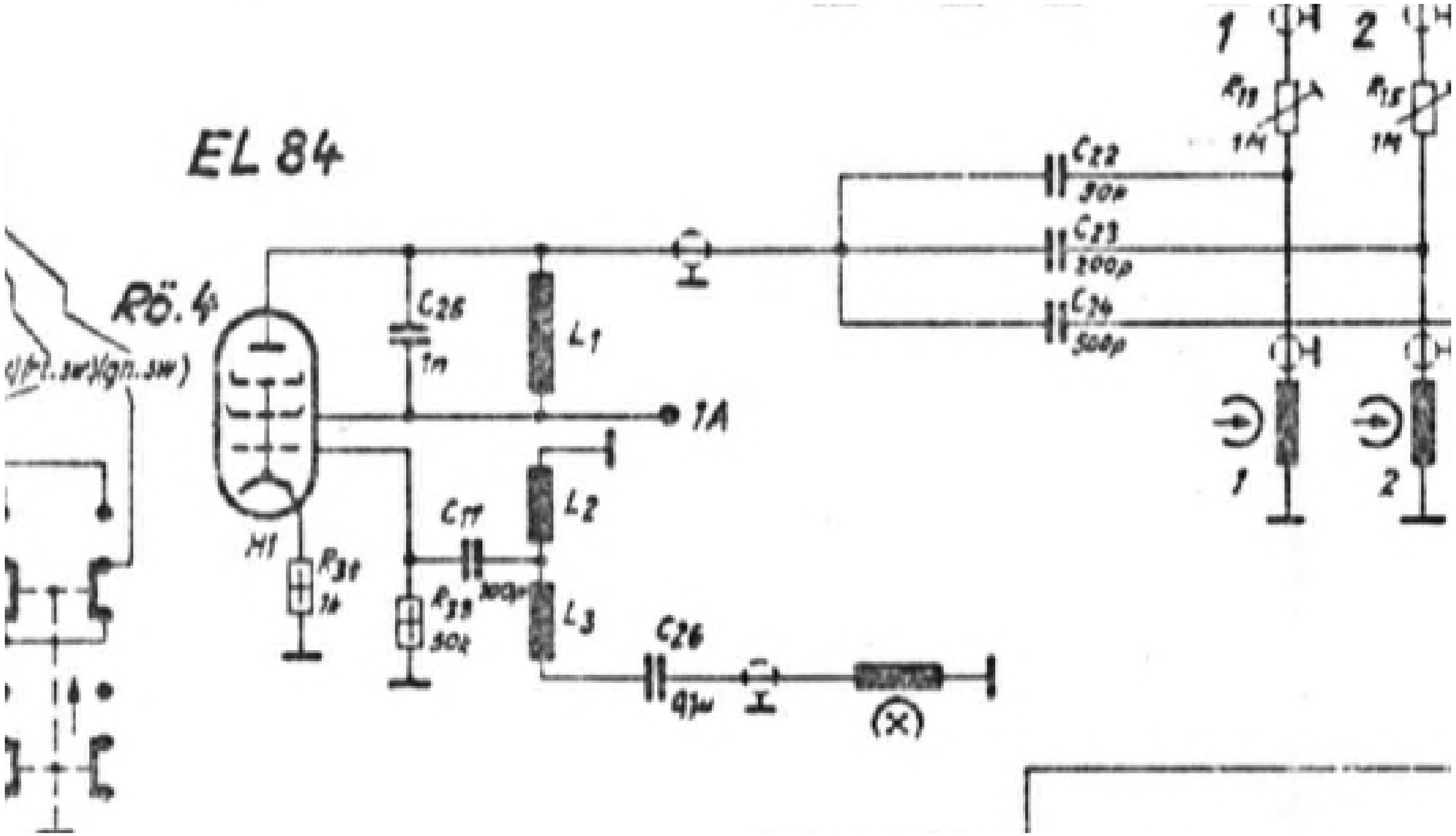
- Meaning: Within the linear range of the hysteresis loop (marked red).

=> More on this when we take a closer look at the tape heads in a later review!

Echolette Variants

The predecessors:

On the Internet you can find exactly one schematic, but no photos, of the potential predecessor model "NG-2". Here you can find a completely different oscillator circuit with a single pentode:

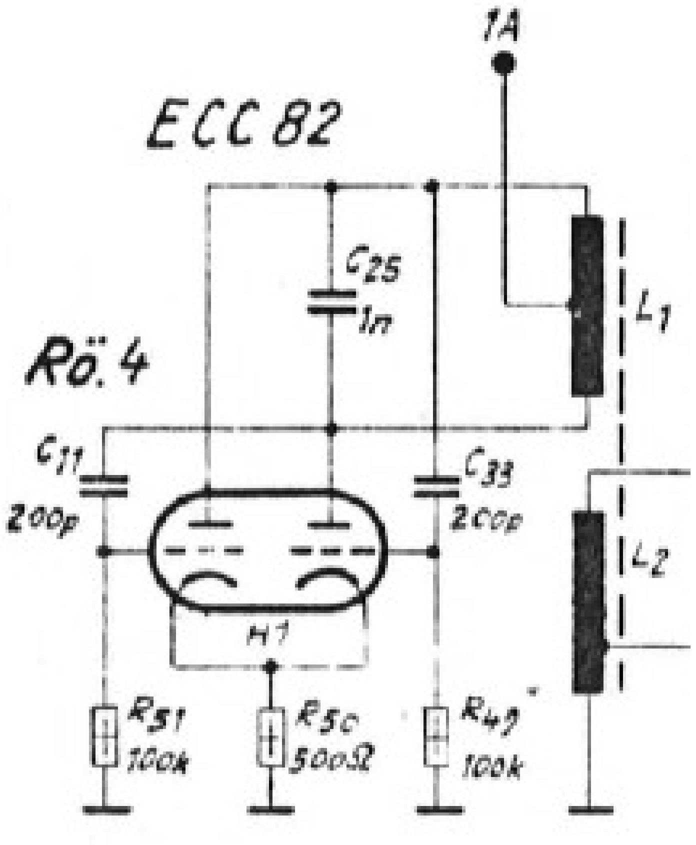


Echolette Variants

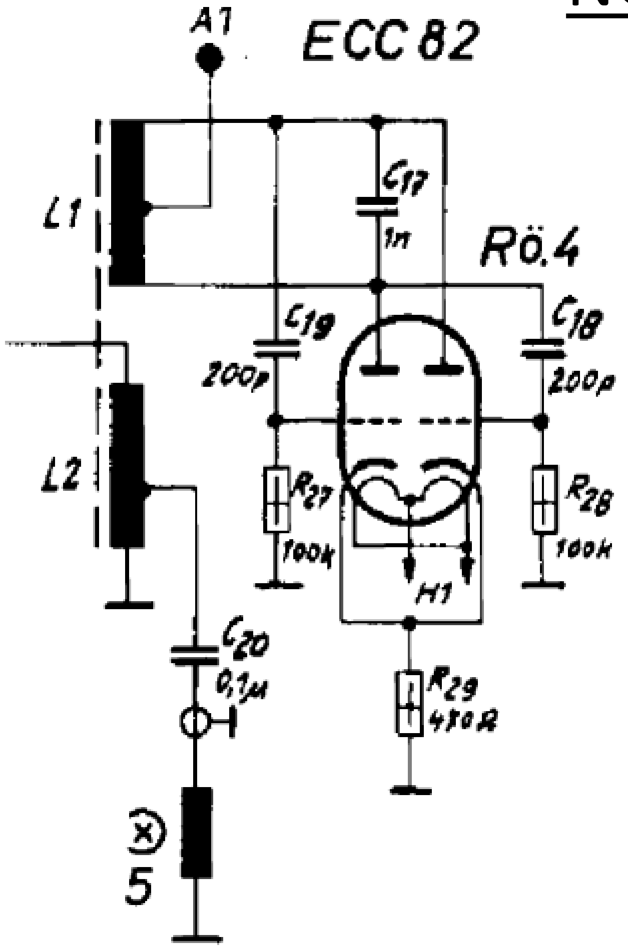
The predecessors :

At least from the NG-4 model onwards, you will find the familiar circuit:

NG-4

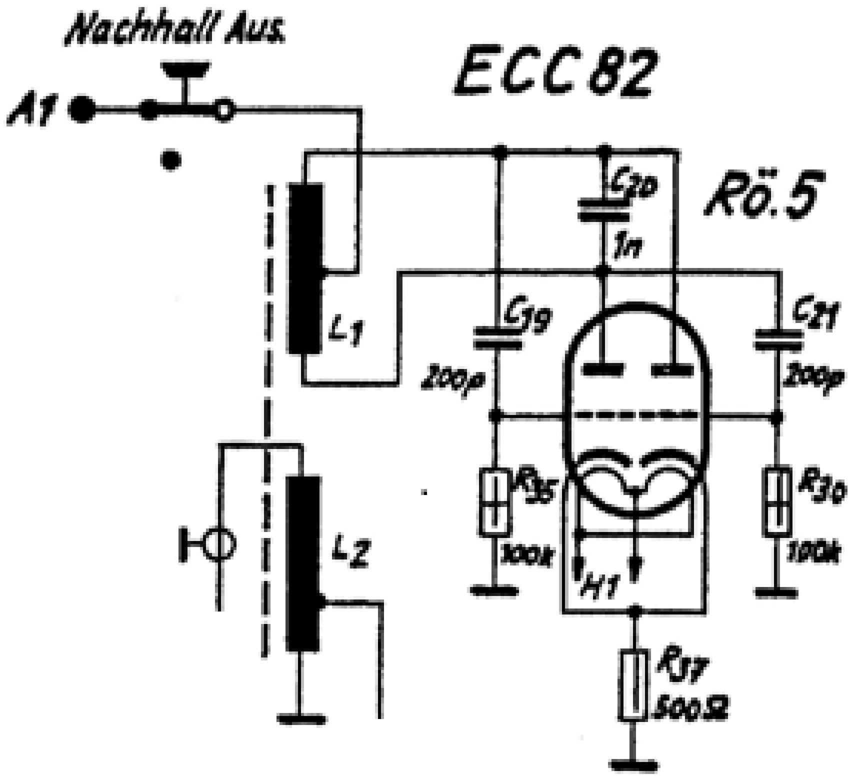


NG-41



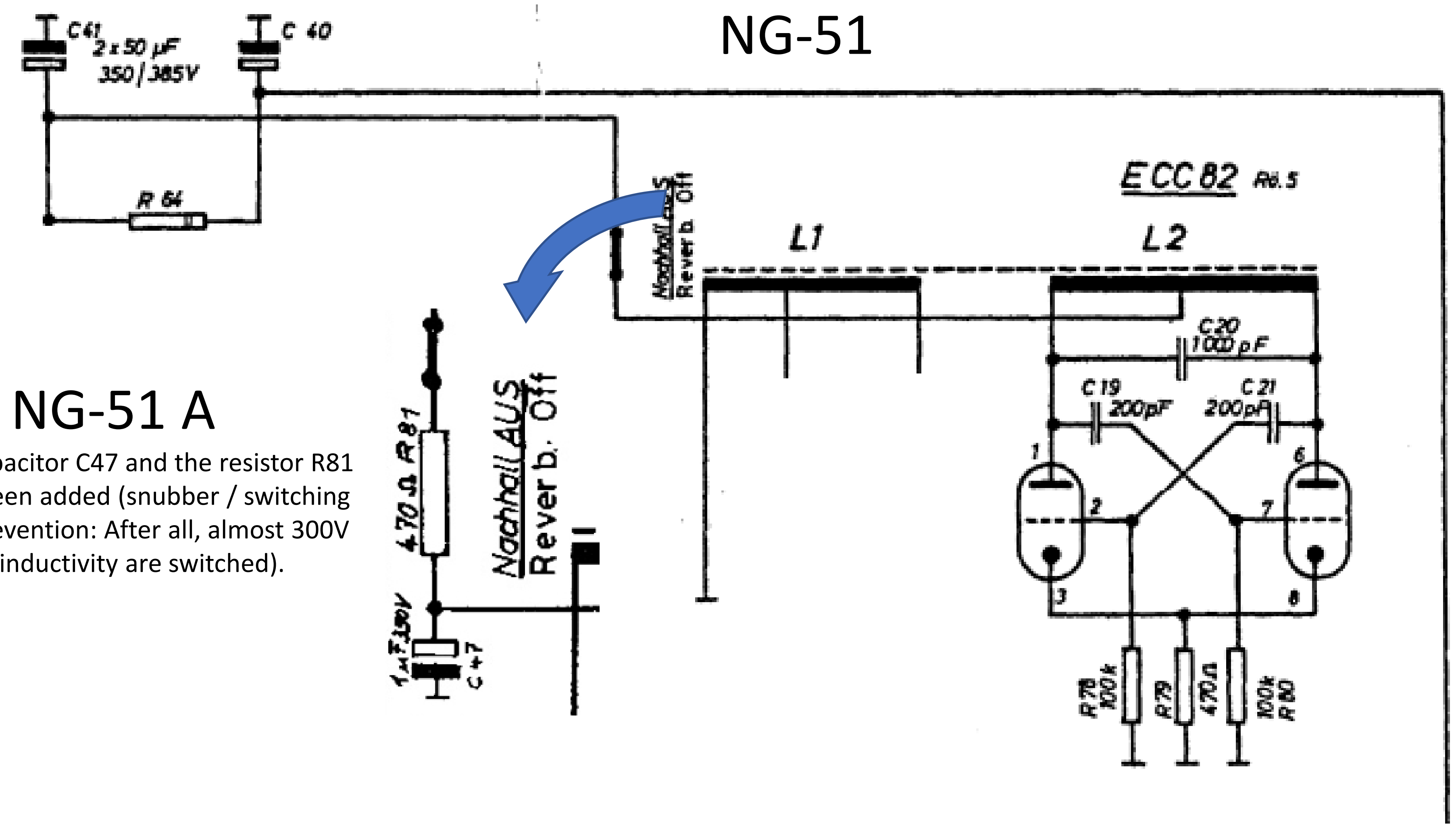
Echolette Variants

Early schematics NG-51:



Echolette Variants

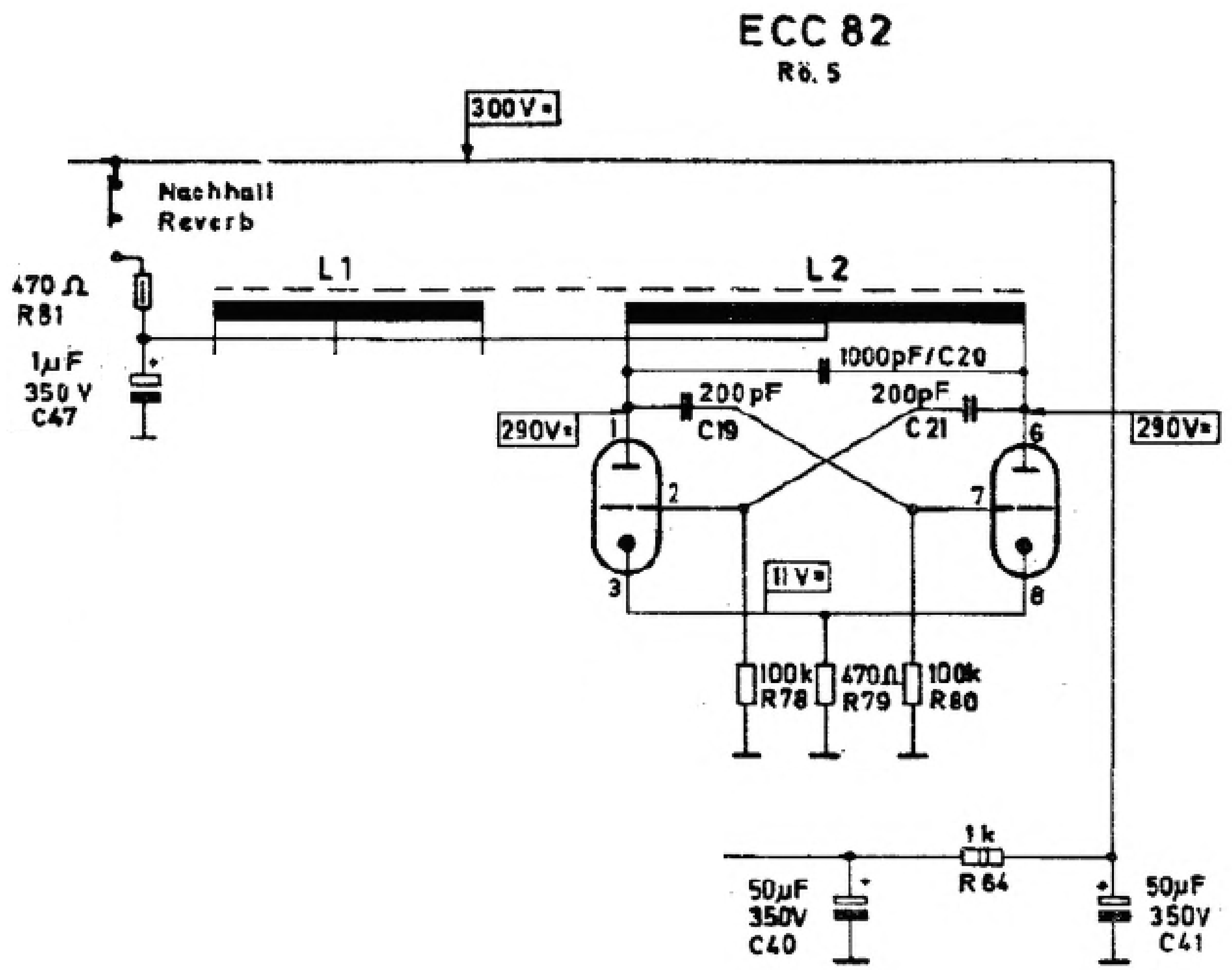
Revised schematics, Model update NG-51A



The capacitor C47 and the resistor R81 have been added (snubber / switching pop prevention: After all, almost 300V and an inductivity are switched).

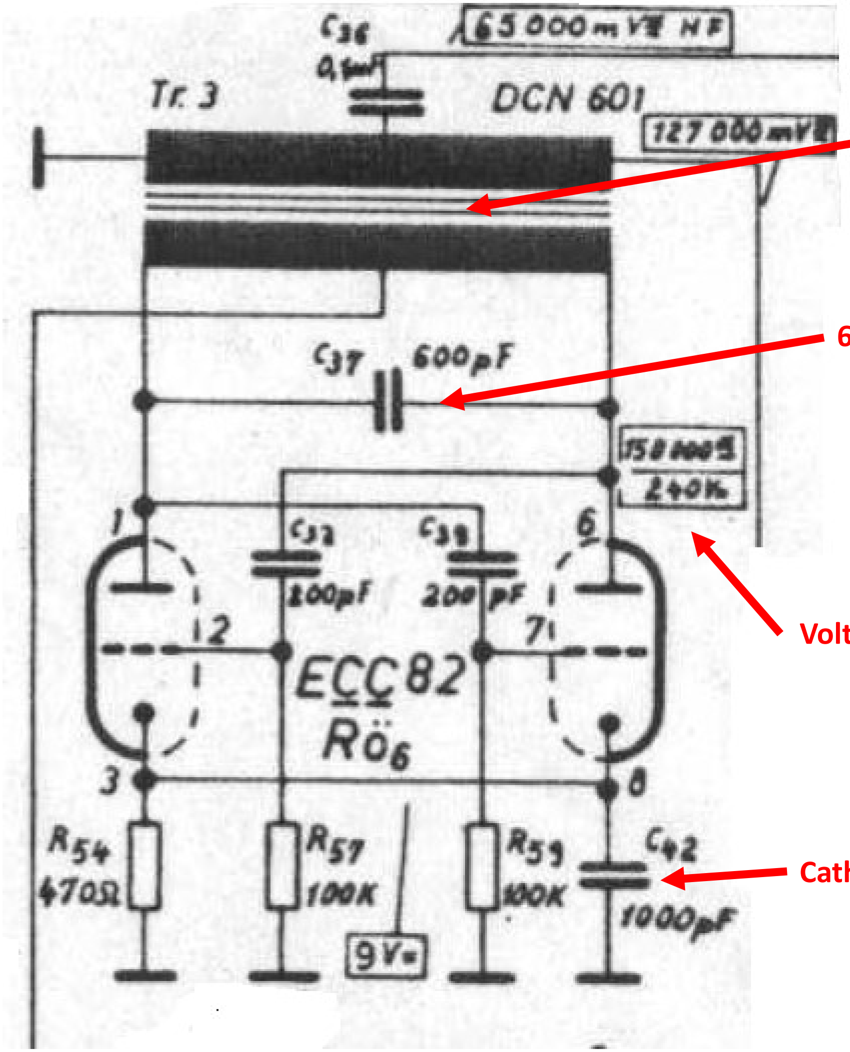
Echolette Variants

Successor model E-51 (new drawing, otherwise as NG-51 A)



Echolette Variants

Dynacord Echocord (slightly different)



Probably different coil inductance, if Dynacord aimes for the same RF frequency

600 pF instead of 1000 pF

Voltage slightly lower

Cathode Bypass Capacitor

The similarity is probably not accidental, if you look at the very first Echocord model:

ECHOCORD SUPER

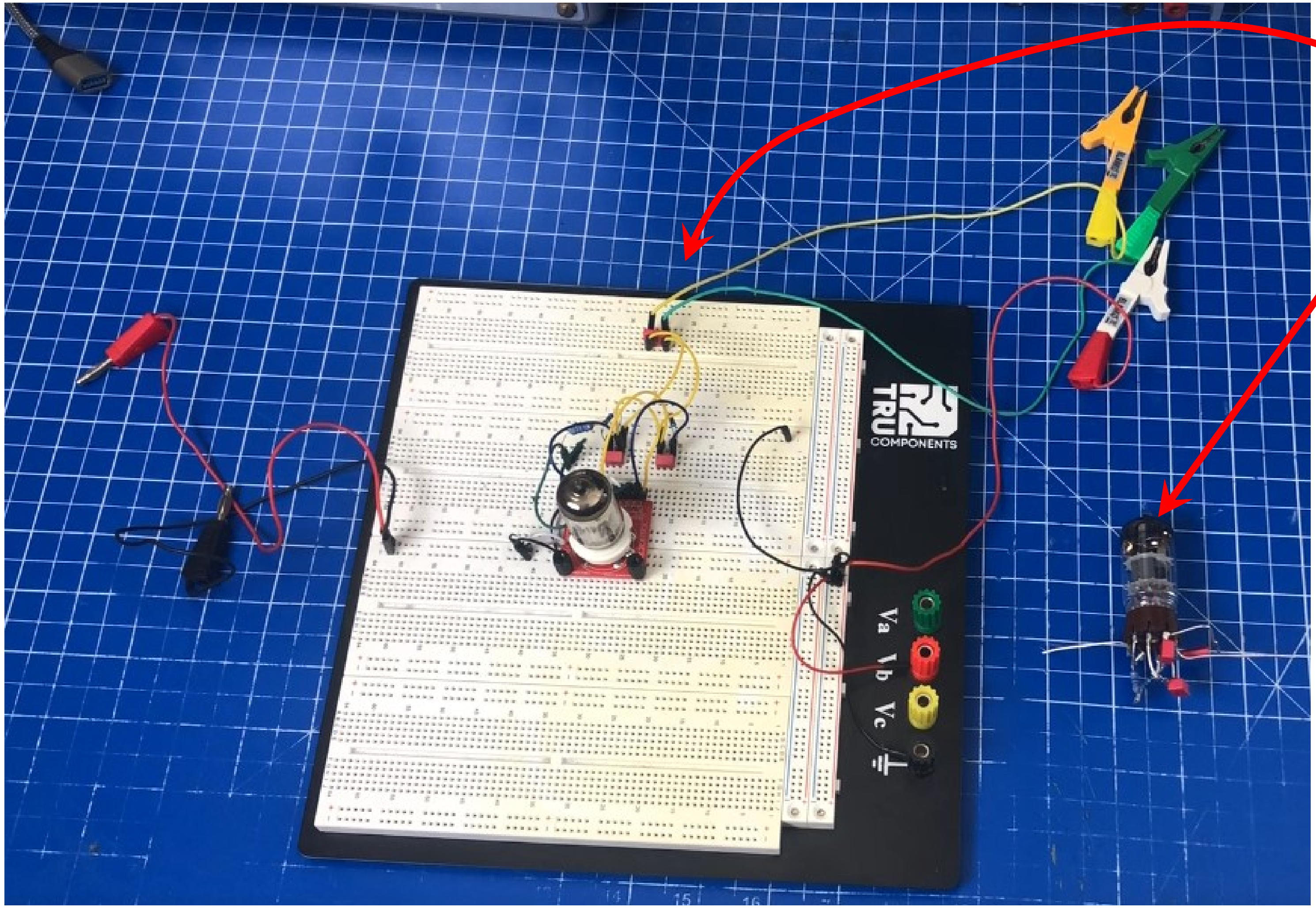
Das erste Modell des Echogerätes ECHOCORD SUPER erscheint 1960. Genauer betrachtet verbirgt sich hier aber ein Bekannter der nur ein etwas anderes Gesicht hat. Drin steckt nämlich das bekannte NG 51 (Echolette S) vom damaligen Konkurrenten Echolette und wurde bei der Firma Klemt in München für Dynacord nur mit einer anderen Frontblende produziert. Von diesem Modell wurden 1960 noch in reiner Handarbeit nur 300 Stück gefertigt. 1961 bringt Dynacord dann sein erstes selbst entwickeltes und gebautes ECHOCORD SUPER auf den Markt welches dann bis 1967 mit verschiedenen Verbesserungen gebaut wird. Diese legendären Effektgeräte sind heute noch bei Oldie-Musikern im Live-Einsatz auf der Bühne zu bewundern und sind ebenso ein begehrtes Sammlerobjekt.

Source: Hans Ohms

NG 51 S: Oszillator Circuit

Test setups with reduced voltage

The Echolette oscillator is well suited for experiments with reduced operating voltage. I have experimented here with two test setups:



1) Breadboard setup

2) Capacitors ans resistors directly soldered to a tube socket

For the operating voltage I took 30V DC from a laboratory power supply.

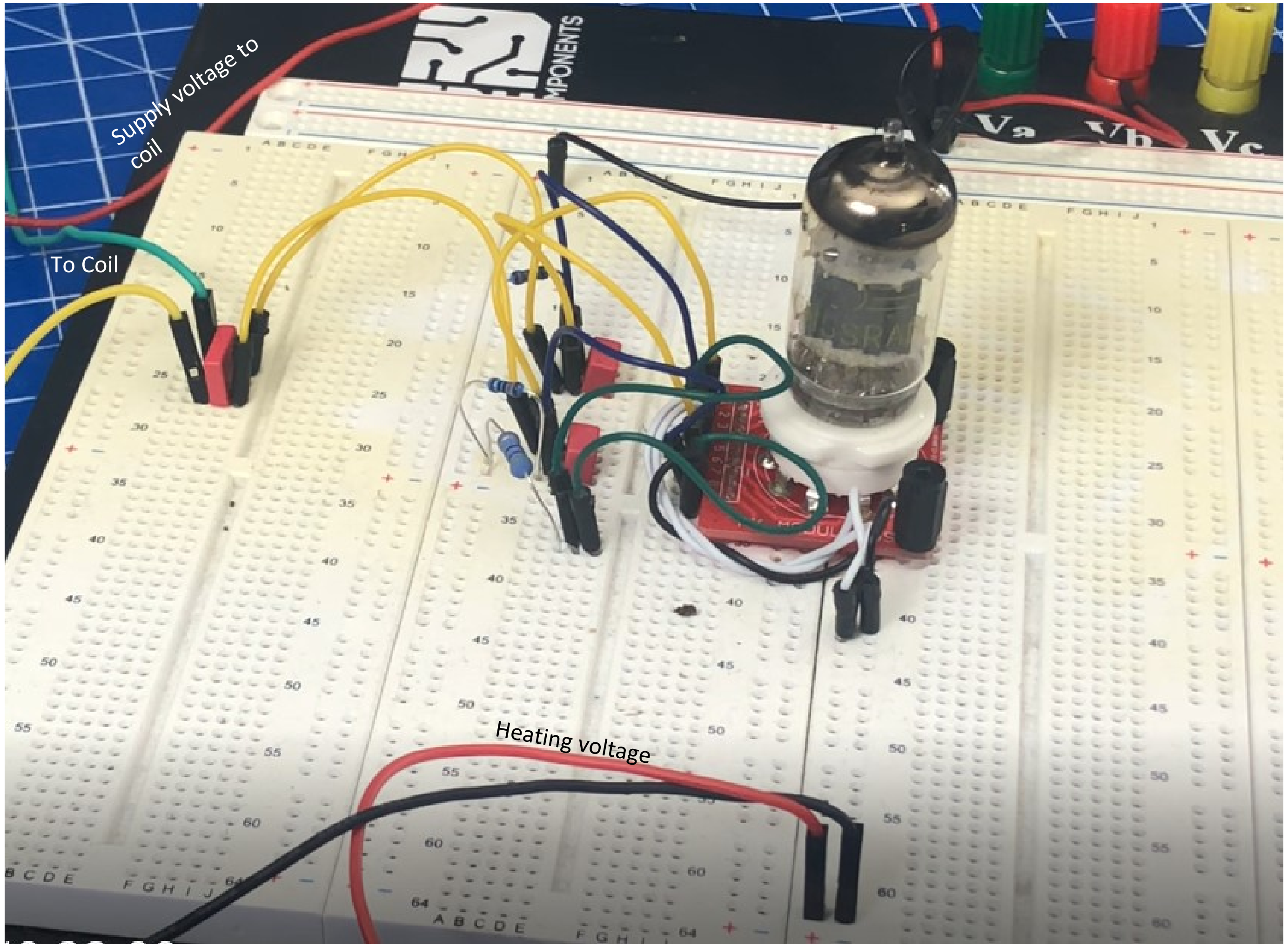
The heater voltage of 6.3 volts AC I got from my variable isolating transformer.

All oscilloscope images in this document are taken from these two experimental circuits.

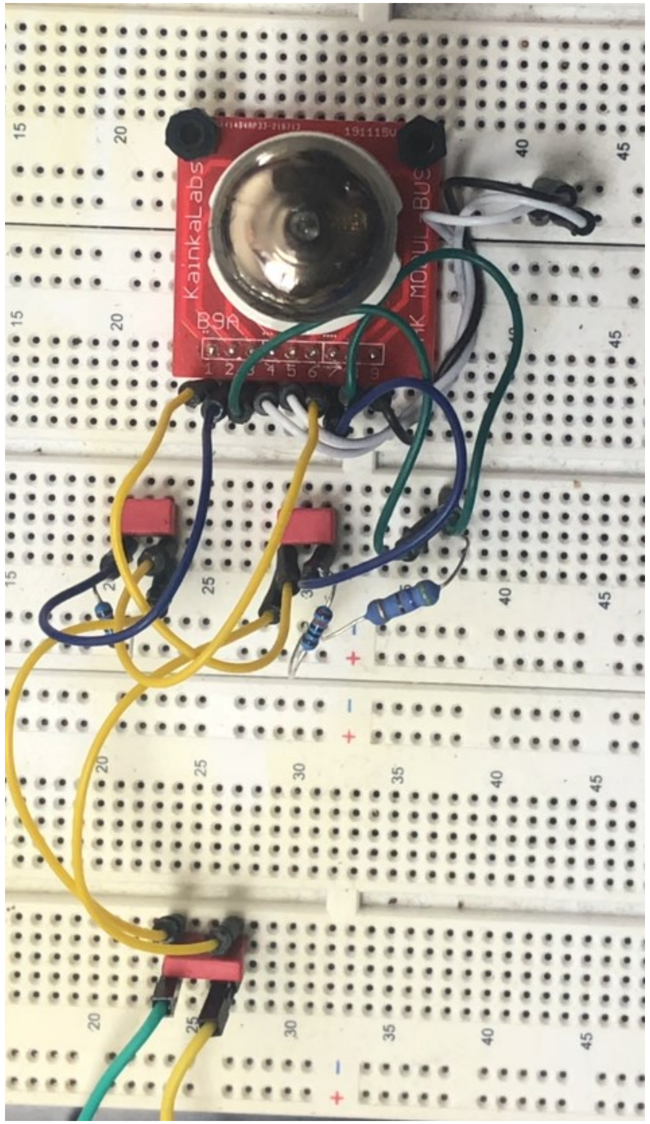
NG 51 S: Oszillator Circuit

Test setups with reduced voltage

Detail view of breadboard experimental setup (coil is connected externally via the yellow and green cable on the left in the picture).



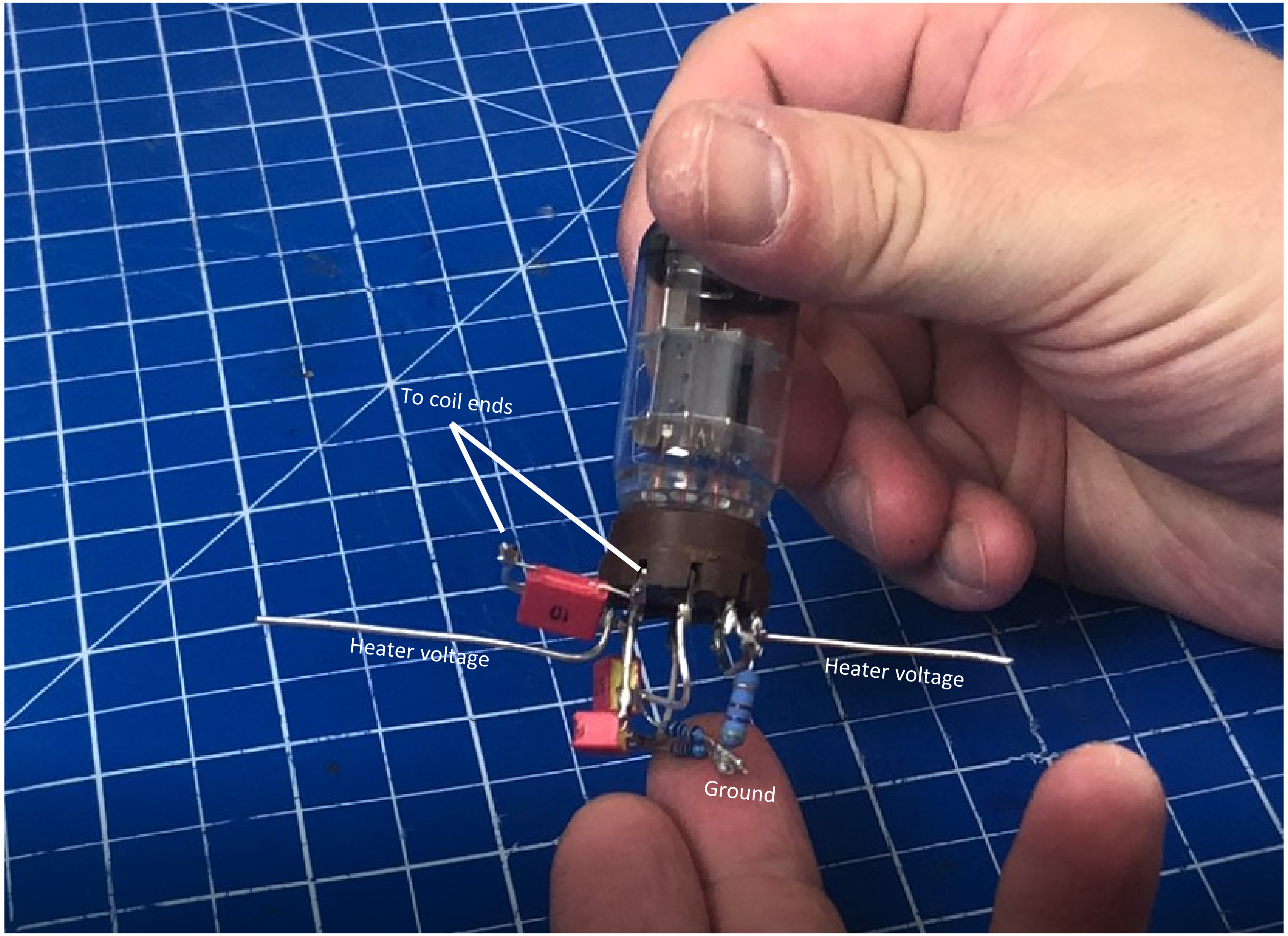
Tube socket for breadboards.

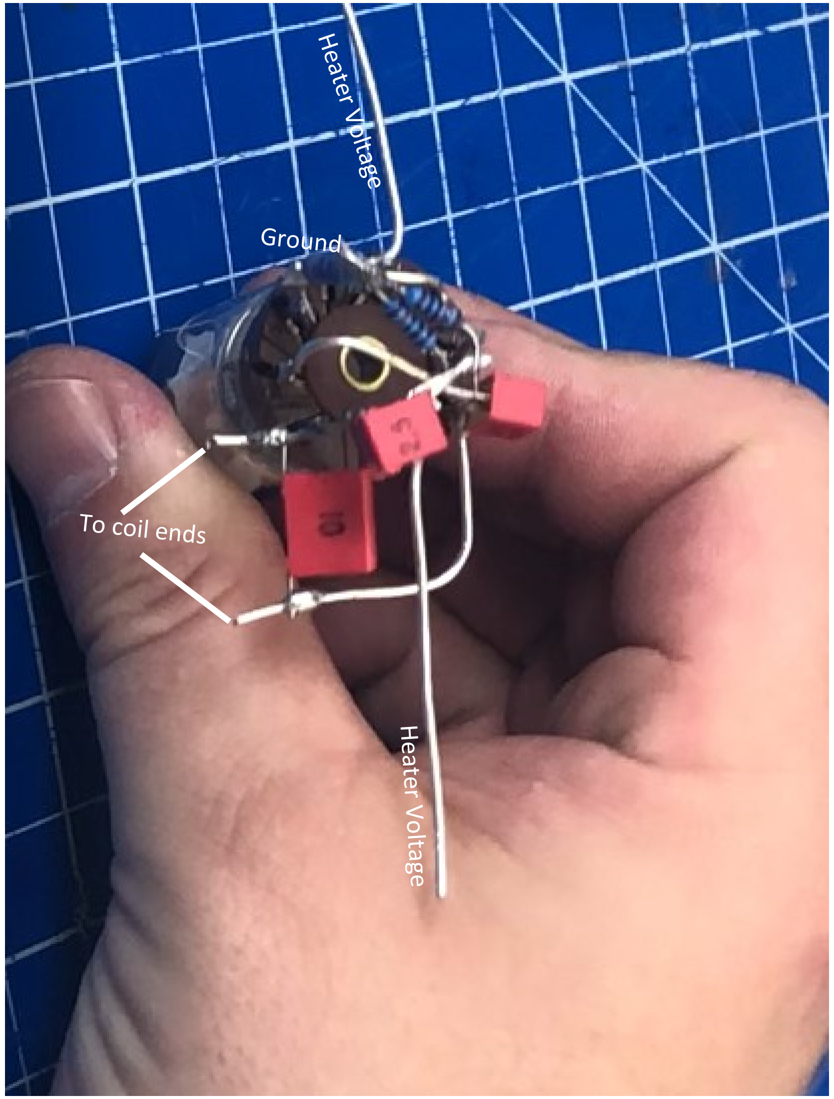


NG 51 S: Oszillator Circuit

Test setups with reduced voltage

Detailed view of tube socket test setup (coil is externally connected).





NG 51 S: Oszillator Circuit

The oscillator tube:

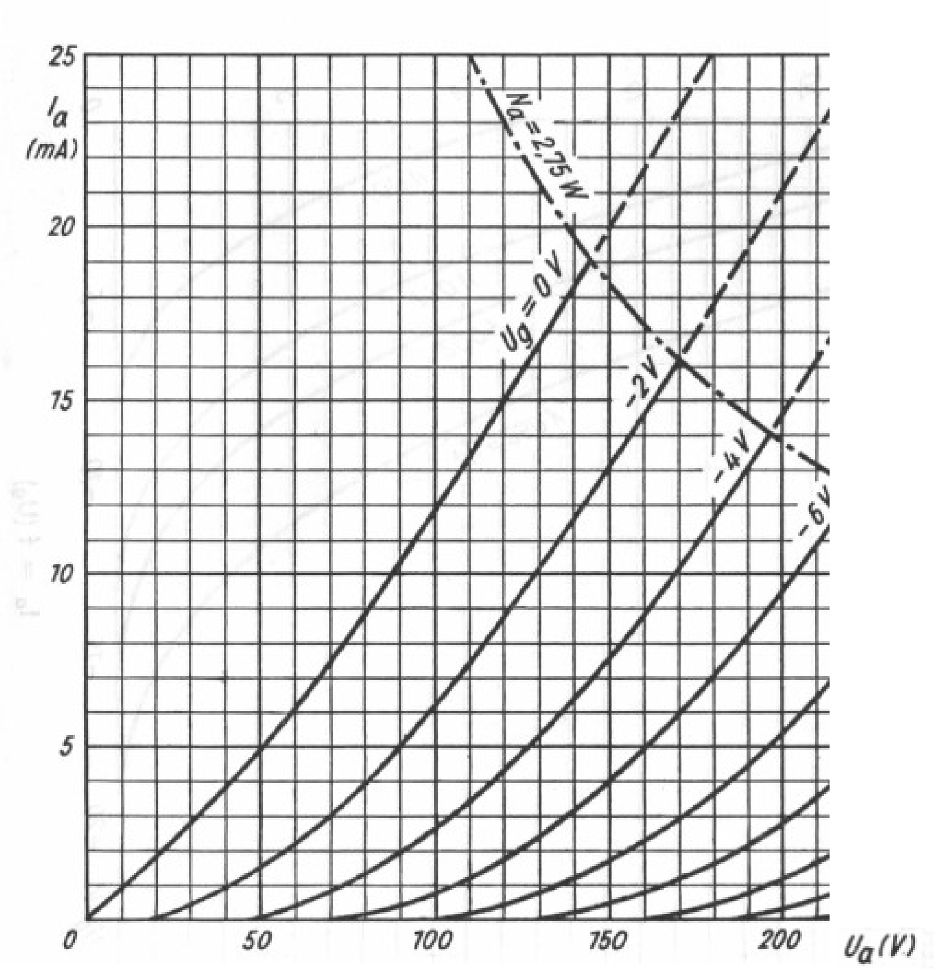
E	=	Parallel heating 6,3 V
C	=	Triode
C	=	Triode
8(0)	=	Noval-Socket
2	=	Type

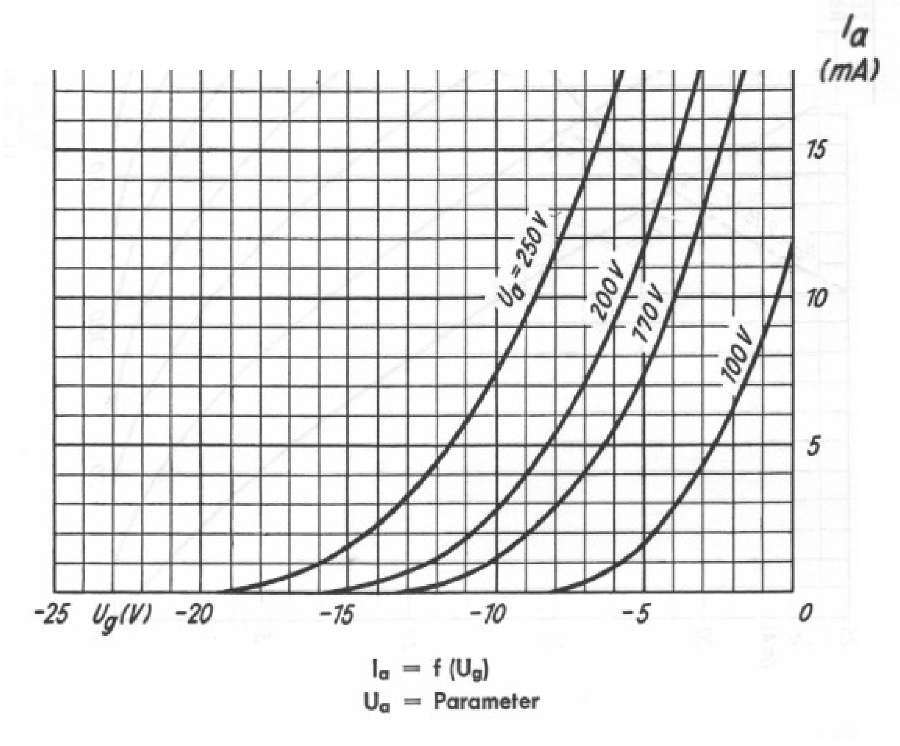
US = 12AU7

NG 51 S: Oszillator Circuit

The oscillator tube:

The experiment with reduced plate voltage works in this case of course only because the ECC82 also works quite well with reduced plate voltage, among other things because it has a low internal resistance. However, this special application case 30V is not specified by the manufacturer in the data sheet:



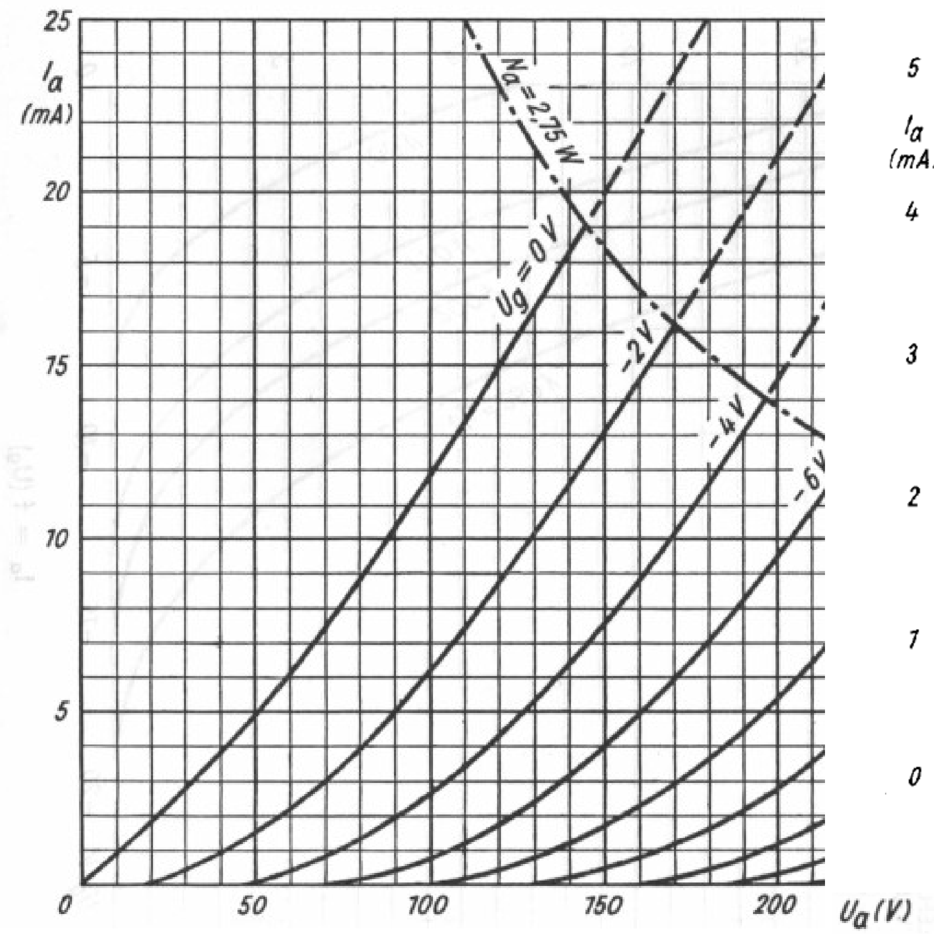


NG 51 S: Oszillator Circuit

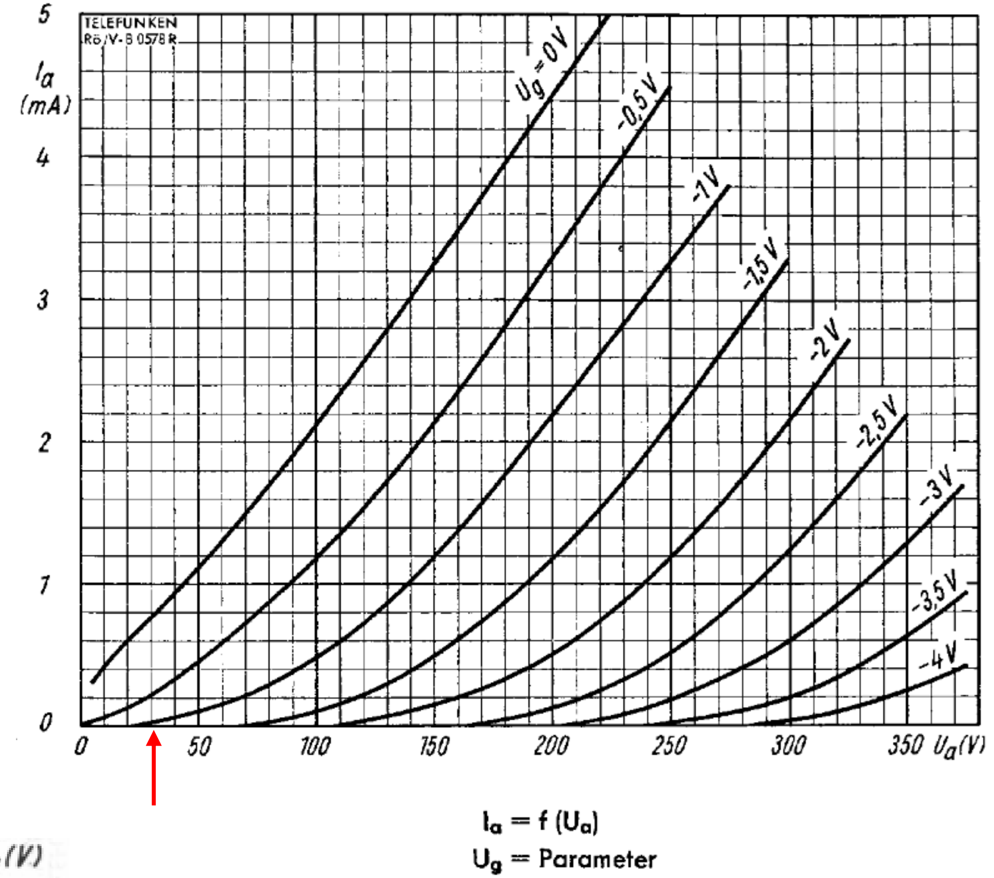
The oscillator tube:

The comparison with the ECC83 shows that experiments with 30V plate voltage and approx. -1V grid bias voltage, as they were accomplished in the context of this document with the ECC82, would lead to nothing with a ECC83. There is practically no plate current flowing.

ECC82



ECC83



NG 51 S: Oszillator Circuit

It is suitable for use in the oscillator because it has a much higher slope (S) than, for example, an ECC83 (per volts changed on the grid a greater anode current change than the ECC83).

We will see why, but this much in advance: linearity is not decisive for the use in an oscillator, because it is even expected that the resulting output signal is a square wave with many harmonics, in other words: distorted. High slope promotes the back-and-forth oscillation of the two tube systems.

The voltage gain (see idle gain µ) of the ECC82 is much lower than that of the ECC83. High voltage gain is also not important in the oscillator. The height or the fast rise of the anode current (Ia) is the decisive factor here.

Last but not least, the ECC82 was developed specifically as an RF tube, the ECC83 as an AF tube.

ECC82

Meßwerte · Measuring values

per System

U_a	**100**	**170**	**250**	V
U_g	0	−4	−8,5	V
I_a	11,8	10,0	10,5	mA
S	3,1	2,4	2,2	mA/V
µ	19,5	19	17	
R_i	6,25	7,1	7,7	kΩ

ECC83

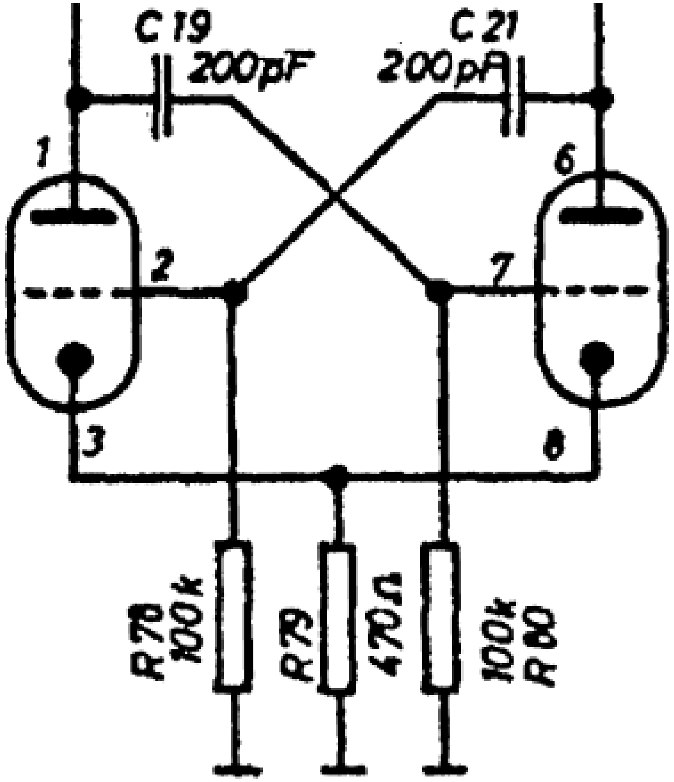
Meßwerte je System

U_a	**100**	**250**	V
U_g	−1	−2	V
I_a	**0,5**	**1,2**	mA
S	1,25	1,6	mA/V
R_i	80	62,5	kΩ
µ	100	100	

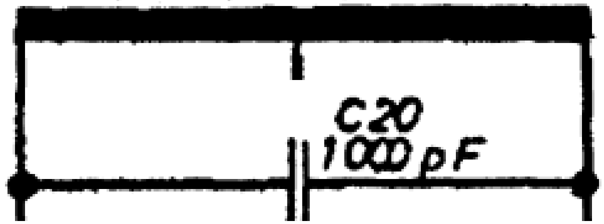
NG 51 S: Oszillator Circuit

We will now separate the oscillator into its two subassemblies and look at their operation separately for the time being:

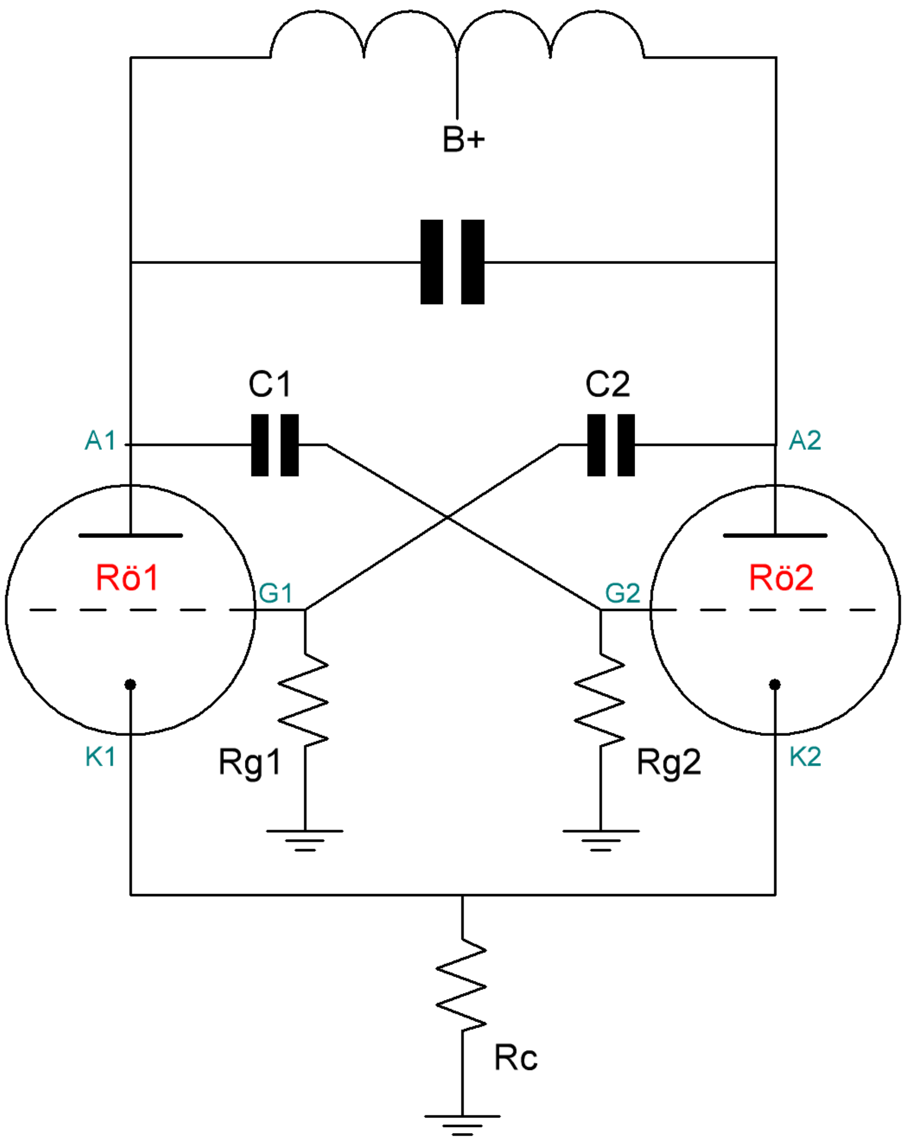
Astabile Multivibrator

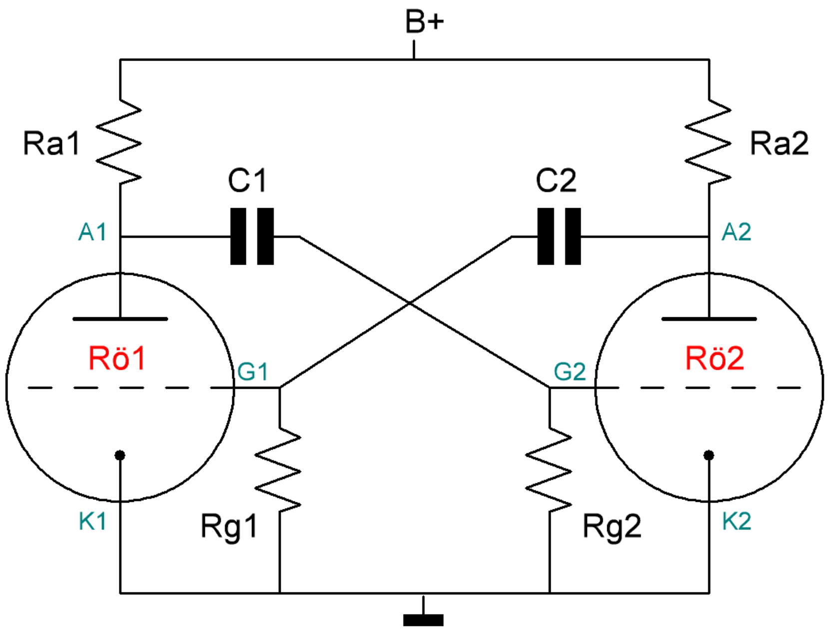


Parallel LC-resonant circuit



Astabile Multivibrator: Mode of operation



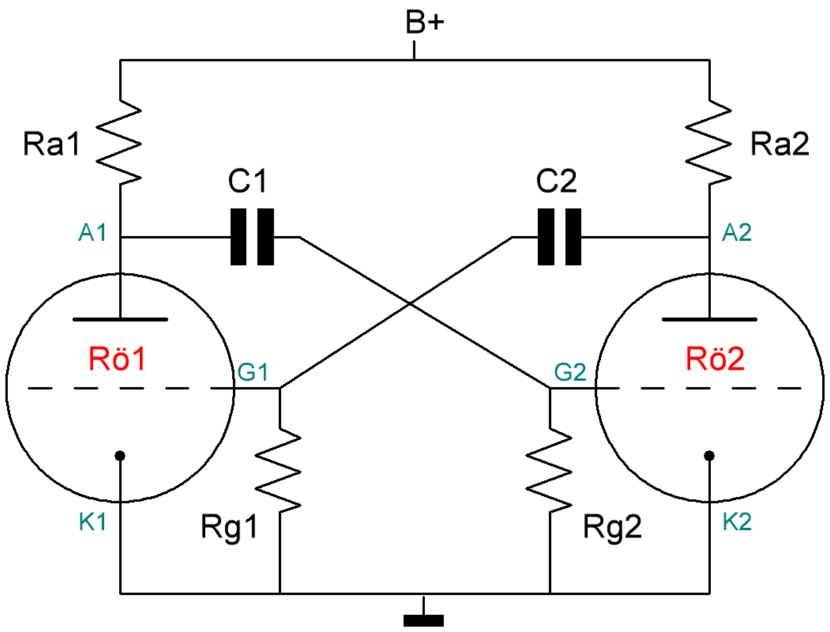


For the understanding of the oscillator we consider first only the astable multivibrator and look deeper into this assembly in slightly modified arrangement (right picture).

The parallel LC resonant circuit has been removed from the arrangement for now, as has the common cathode resistor.

Instead, the plate resistors Ra1 and Ra2 have been added.

Astabile Multivibrator: Mode of operation



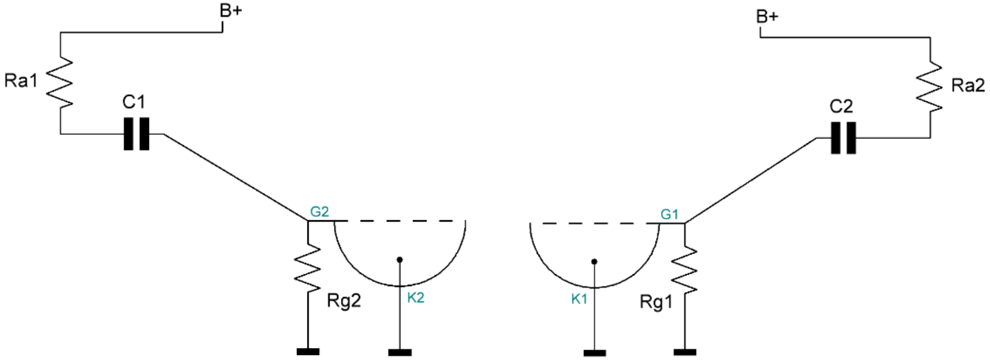
Hint:

The processes shown below occur in reality in fractions of a second. The oscillation starts at the moment when the heating and plate voltages are switched on and the cathode has reached operating temperature.

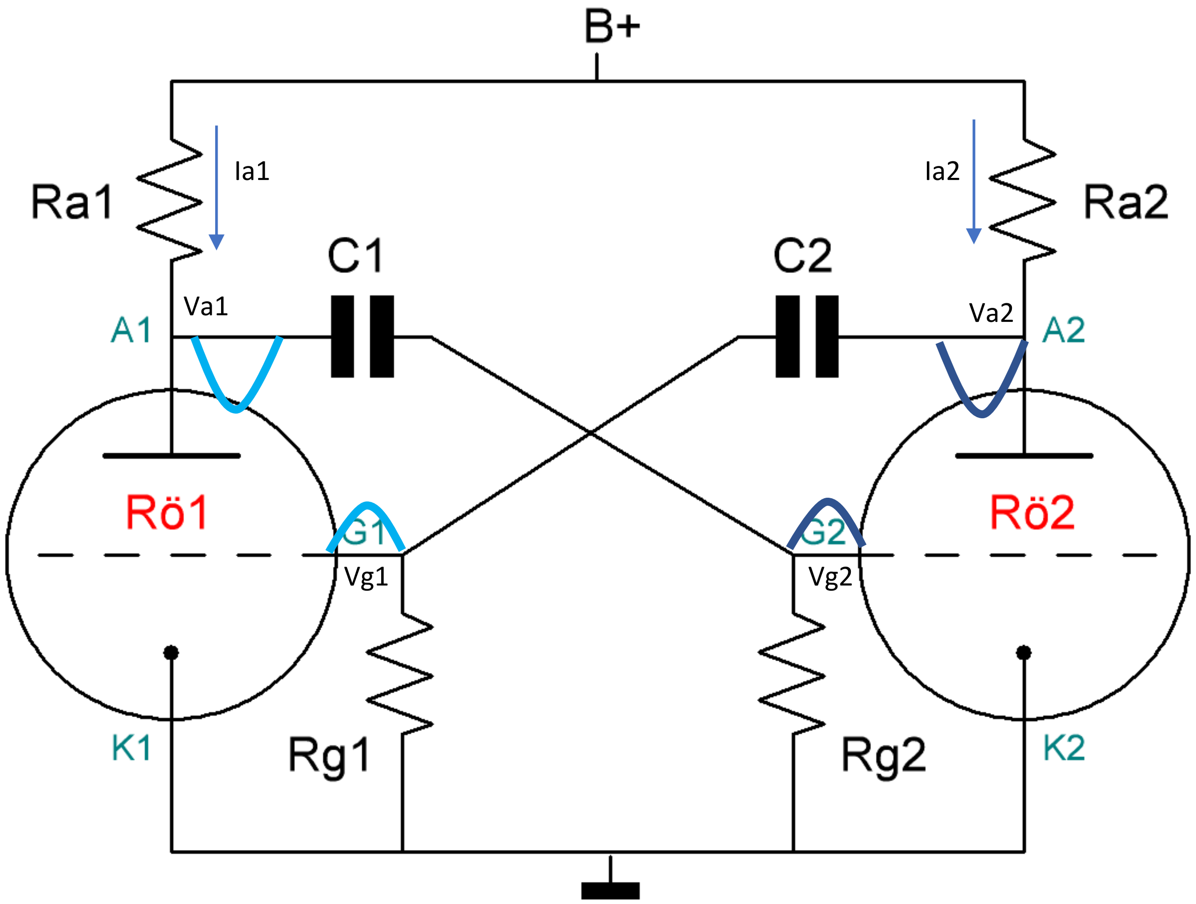
t_0

At the moment when the operating voltage B+ is switched on, the capacitors C1 and C2 charge up. Charging takes place via the respective charging circuits (path between supply voltage and circuit ground).

For the sake of completeness, the resistance between grid and cathode is also drawn in as a "half tube", because it is parallel to the grid leakage resistors and is therefore of course also effective.

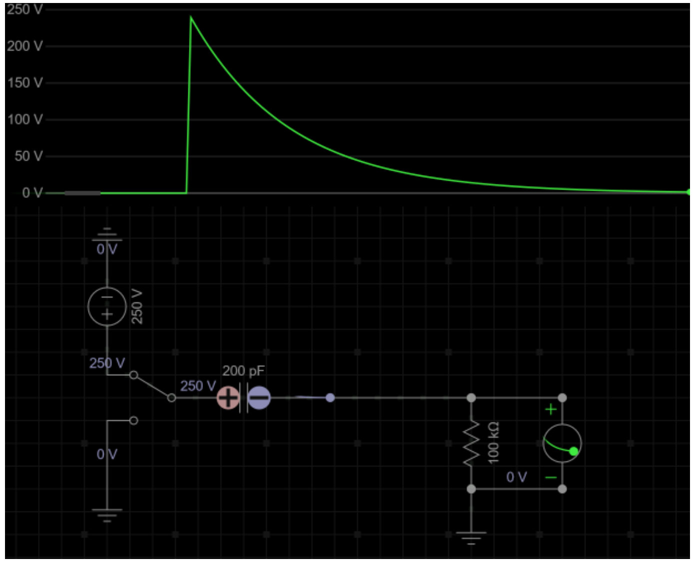


Astabile Multivibrator: Mode of operation



t_0

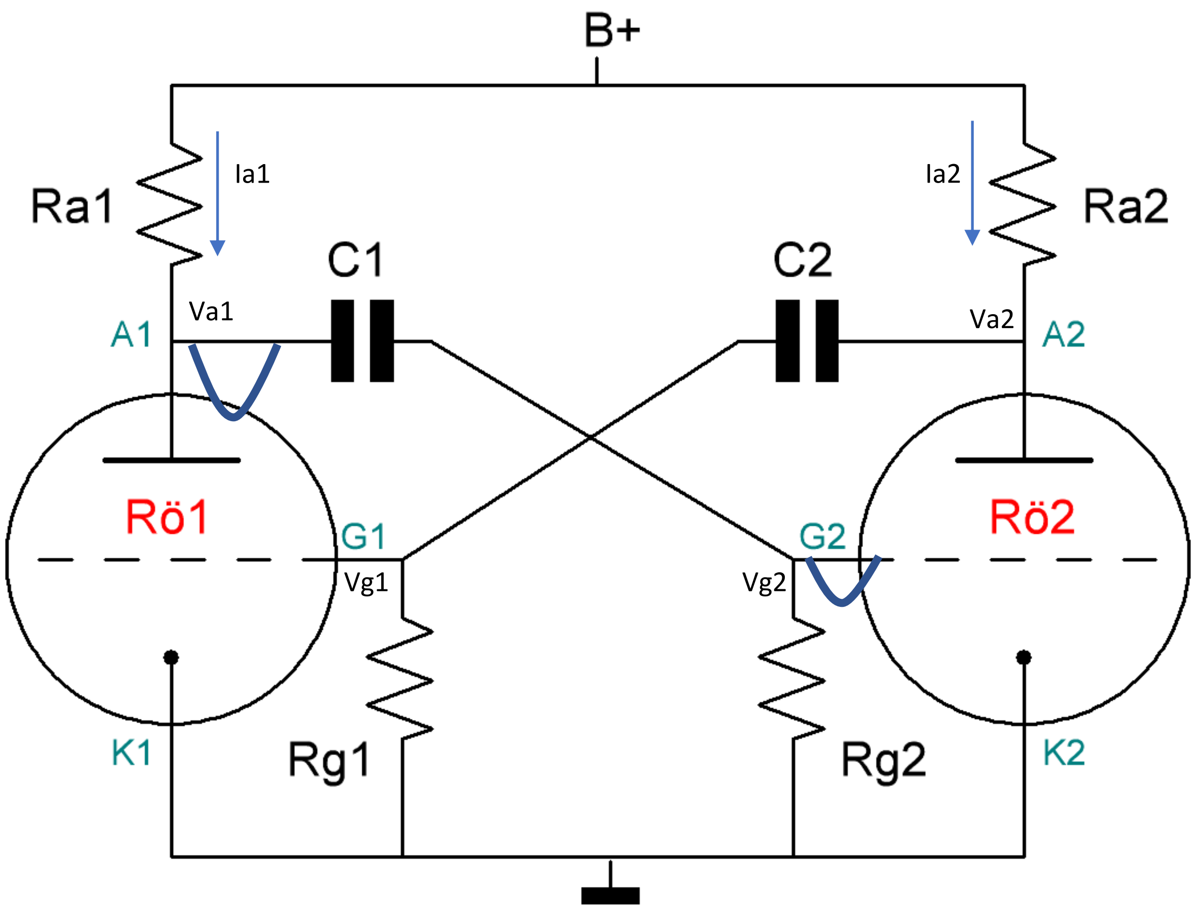
Charging C1 causes a positive voltage peak to drop across Rg2. The same happens for C2 at Rg1. This pulse causes both tubes to open (plate current increases) and both plate voltages (Va1, Va2) drop equivalent to the positive voltage pulse at the plate resistors.



Test circuit. The voltage dropping at the "grid leakage resistor" is measured when charging the capacitor. The tube was replaced by a switch.
You can see that the voltage shoots up steeply like a pulse and then drops exponentially back to zero.

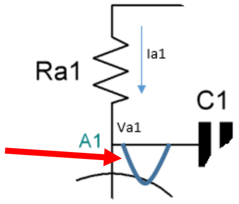
One might now think that both tubes go parallel into a state where they are either both fully open or both half open - i.e. they follow an exactly identical course in some way. However, this is not true because there are usually tiny asymmetries between tubes:
Unevenly strong tube noise, unevenly distributed emissions along the cathode, and many more.

Astabile Multivibrator: Mode of operation

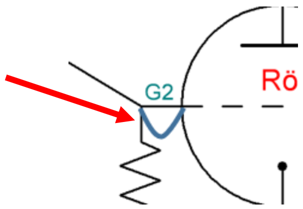


t_0

We therefore assume for example that the plate current Ia1 rises faster than Ia2 due to these asymmetries. Therefore, at t0, the voltage Va1 drops further than Va2.

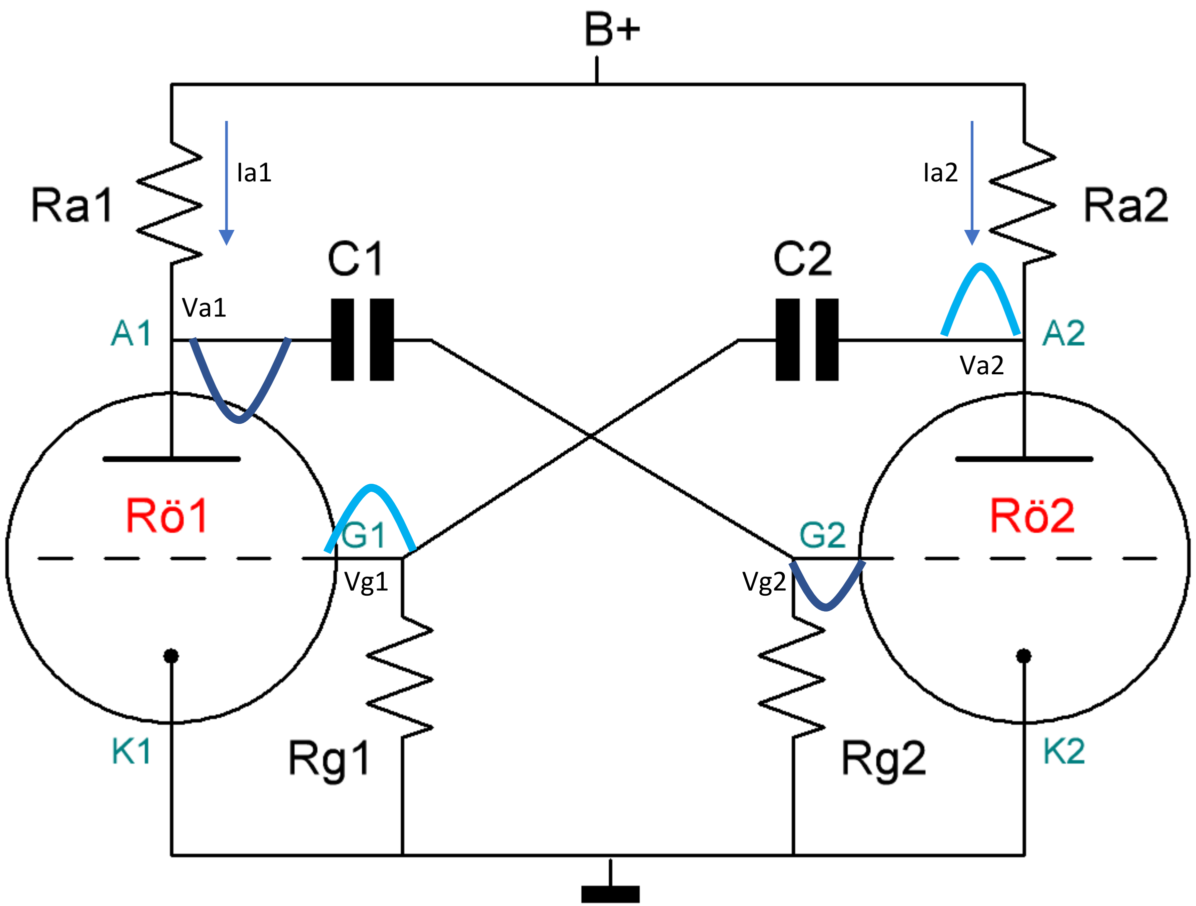


The capacitor C1 transfers this negative voltage change of Va1 to the grid G2 of Rö2, where it arrives somewhat reduced in magnitude. The grid voltage Vg2 becomes more negative.



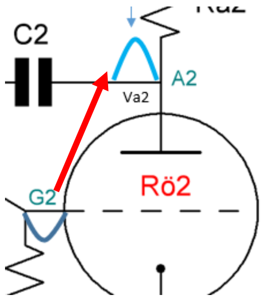
Vg2 is now more negative than Vg1, but still within the range defined by the operating point of the tubes.

Astabile Multivibrator: Mode of operation

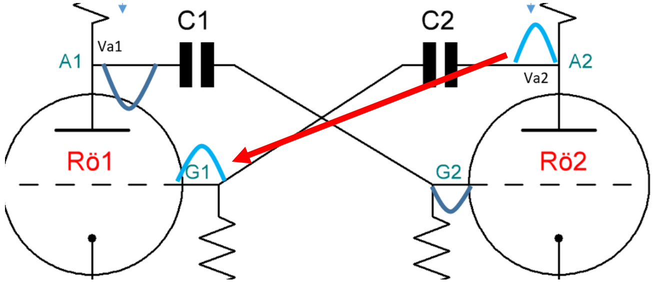


t_0

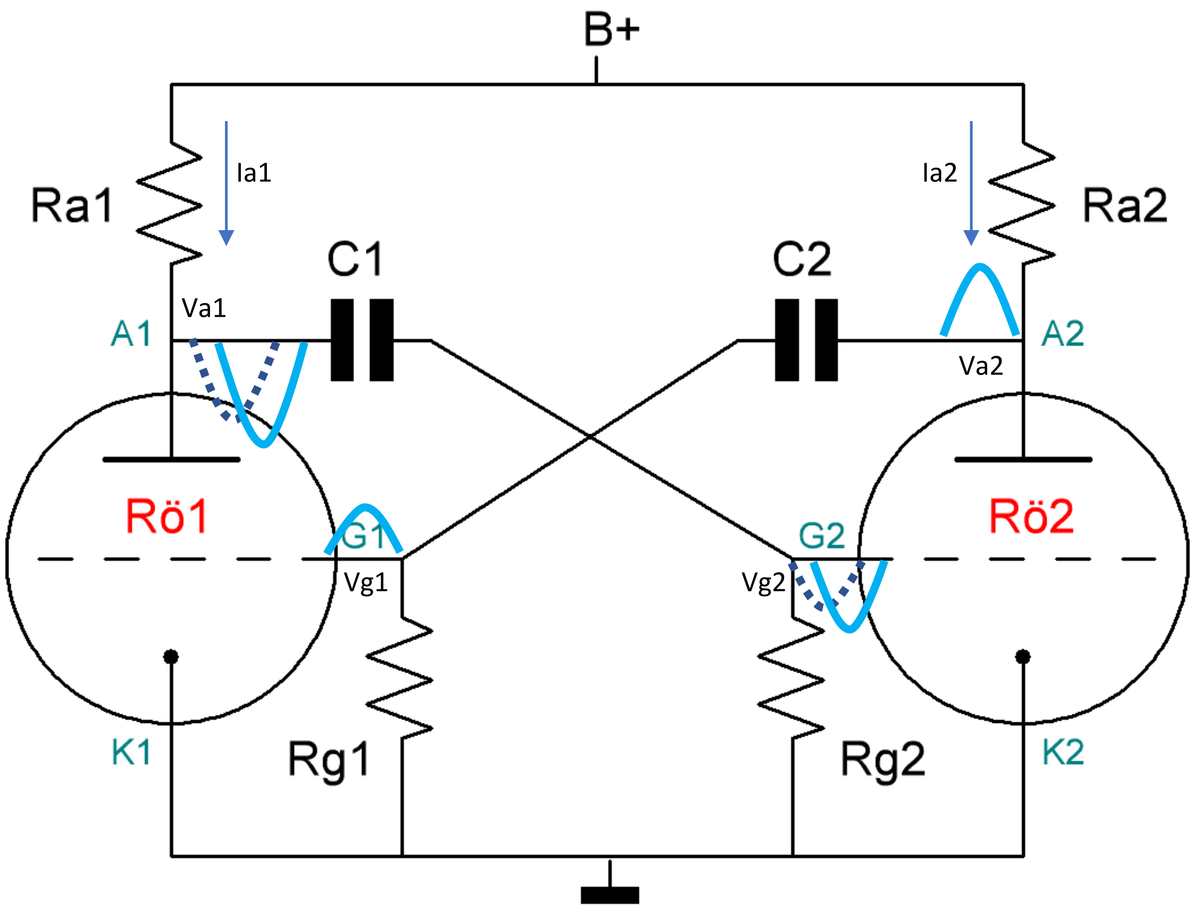
The voltage drop at Rg2 is amplified by Rö2. The plate voltage Va2 increases accordingly.



The capacitor C2 transfers this positive voltage change to the grid of Rö1, where it arrives somewhat reduced in amount, but altogether larger than shortly before at G2.

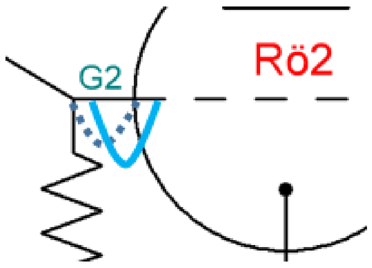


Astabile Multivibrator: Mode of operation



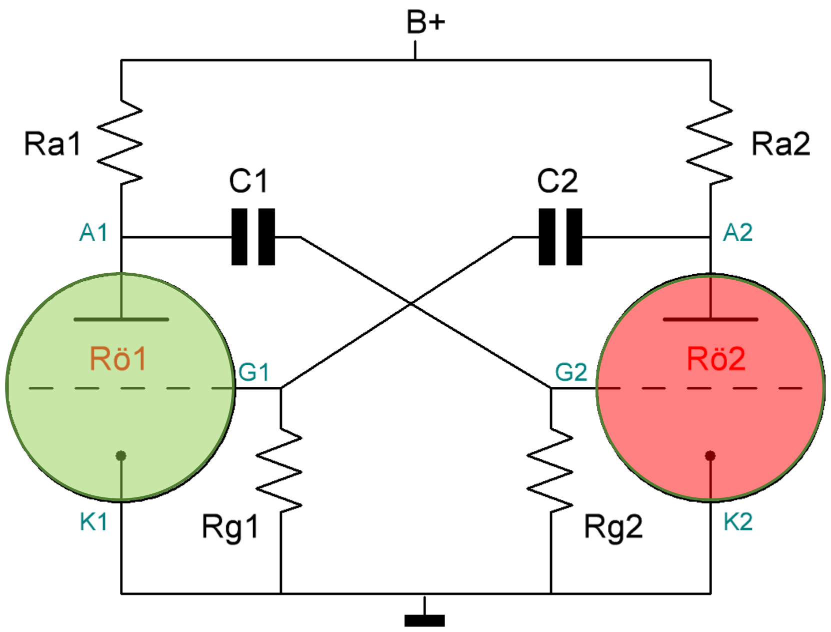
t_0

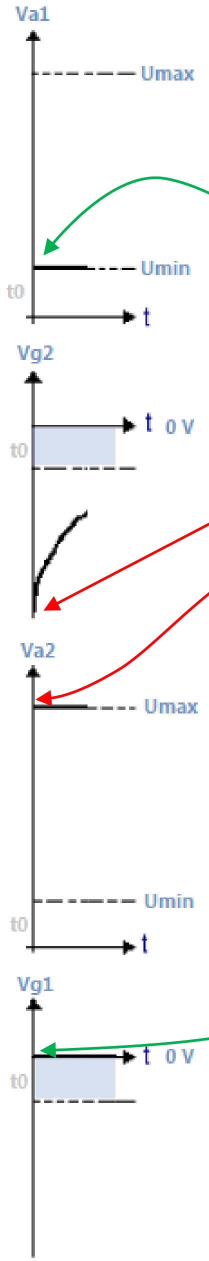
Vg1 becomes more positive, the plate current of Rö1 increases further. The drop of the plate voltage Va1 at the plate resistor Ra1 becomes larger than at the first pass (dashed line). This negative voltage change is transferred back to the grid of tube 2 via C1.



The effect now amplifies and cumulates rapidly: the original voltage pulse is amplified more and more, and the tube Rö1 opens more and more until it fully saturates. Vg2 moves out of the driveable range downwards ("direction negative") until the tube Rö2 blocks completely.

Astabile Multivibrator: Mode of operation





t0

Summary at time t0:

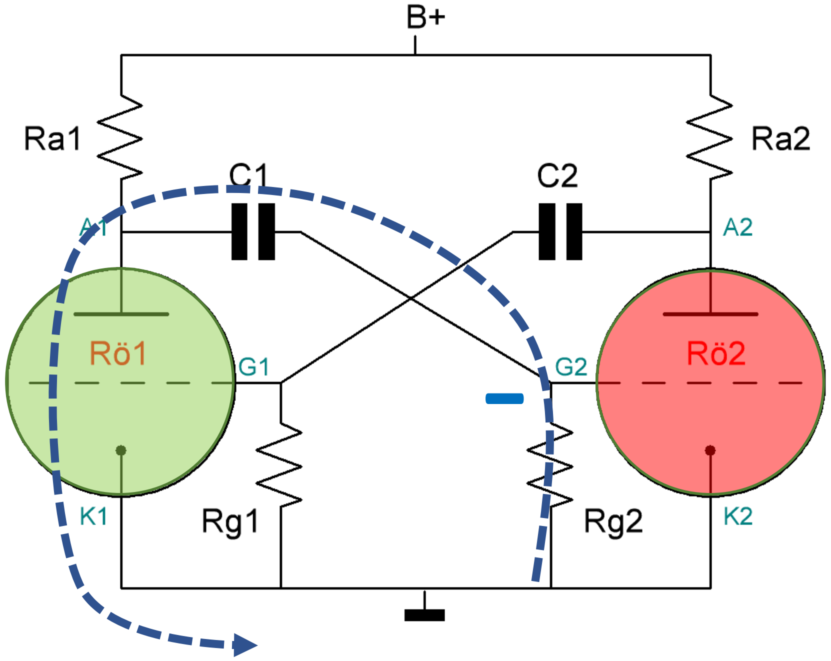
Rö1 vonducts fully: Va1 = Umax-(Ra1*Ia1) → "*Umin*"
Umin (U minimum) is not zero! But the minimum of the plate voltage in this circuit.

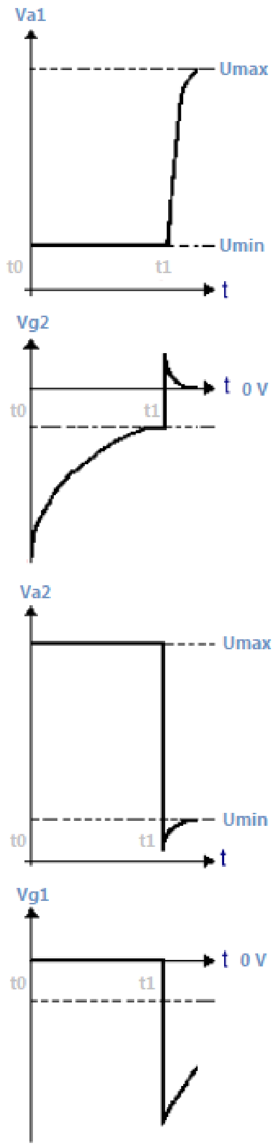
Vg2 is strongly negative, far below the driveable range
→ Rö2 is closed. Va2 is at Umax

Vg1 is close to ground potential, because no more voltage changes come from Ra2.

C1 and C2 are fully charged, so close to Umax.

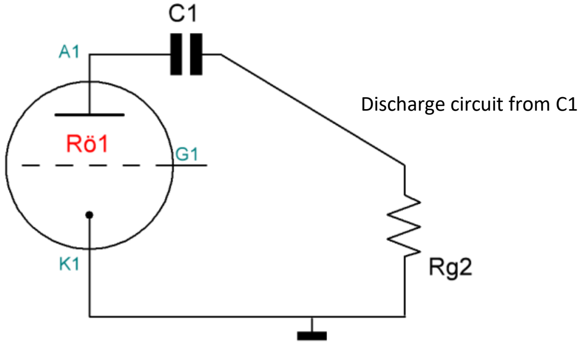
Astabile Multivibrator: Mode of operation



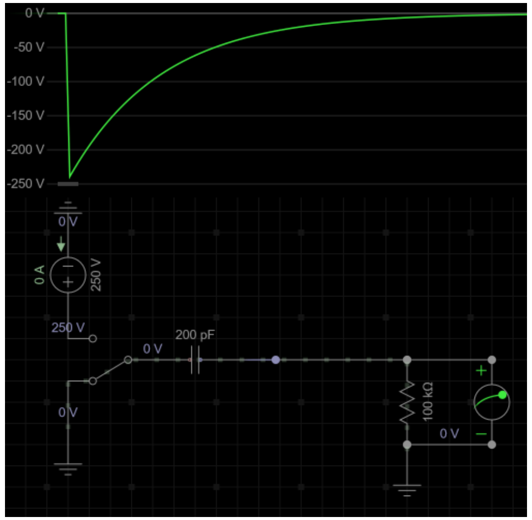


t0 → t1

When the tube Rö1 is fully conducting, its internal resistance decreases and the capacitor C1 can discharge through the tube via its discharge circuit.

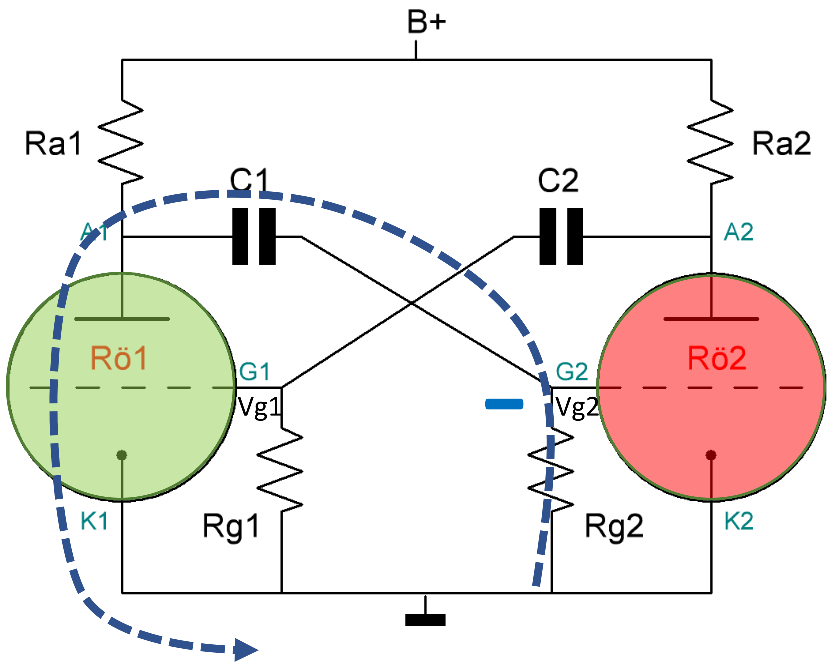


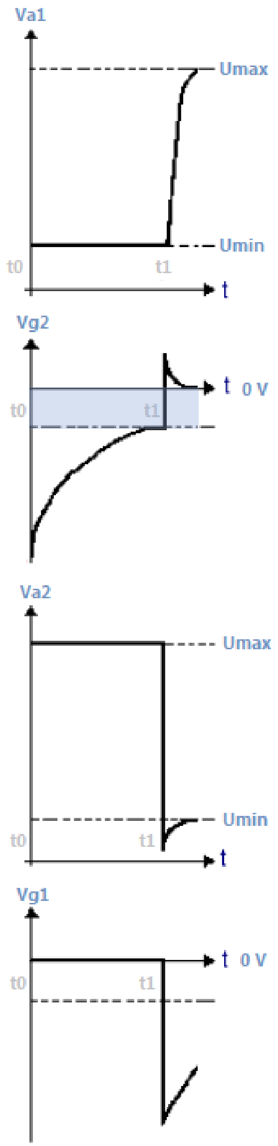
The discharge current of C1 also causes a (negative) voltage drop at Rg2:



Test circuit. The voltage at the "grid leakage resistor" is measured when discharging the capacitor. The tube was replaced by a switch. The voltage drop shoots impulsively into the negative range and then rises exponentially again towards zero.

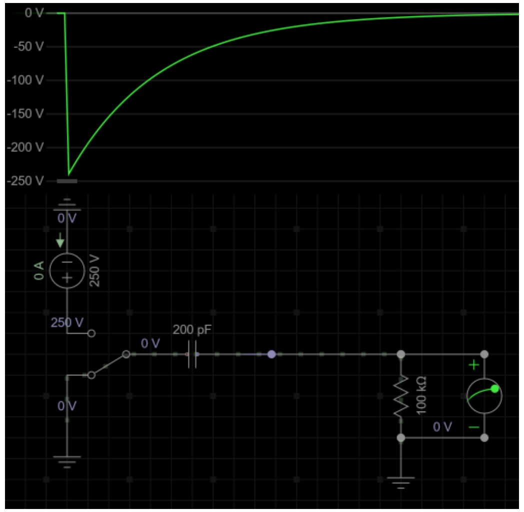
Astabile Multivibrator: Mode of operation



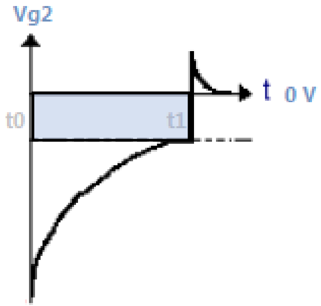


$t_0 \rightarrow t_1$

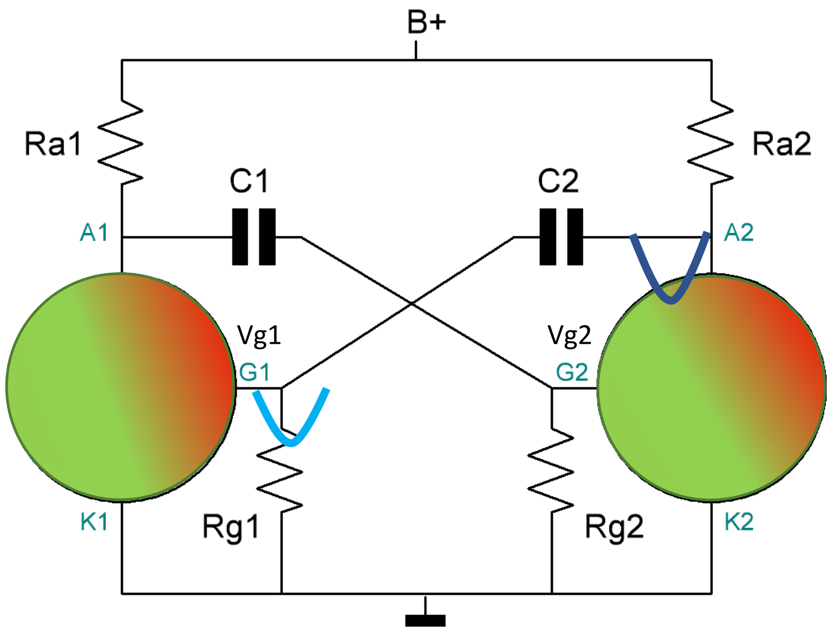
Test circuit. The voltage at the "grid leakage resistor" is measured when discharging the capacitor. The tube was replaced by a switch. The voltage drop shoots impulsively into the negative range and then rises exponentially again towards zero.

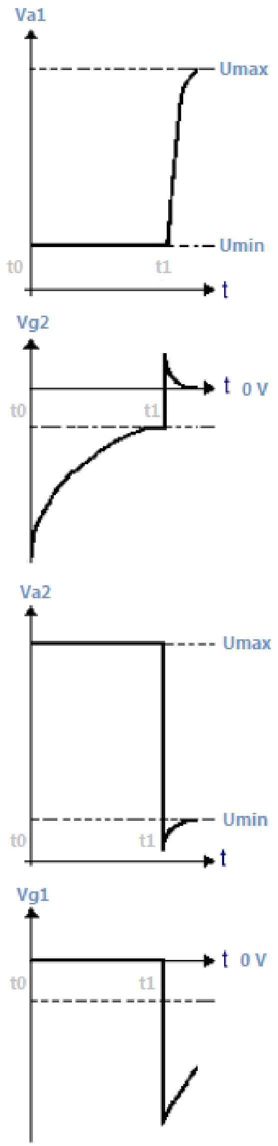


The discharge current of C1 also causes a (negative) voltage drop at Rg2, which shifts the grid voltage Vg2 strongly into the negative range and keeps Rö2 closed. However, the discharge current slowly decreases, so the voltage drop across Rg2 also decreases. The grid voltage slowly moves back towards the ground potential or initially towards the range in which the tube can be controlled.



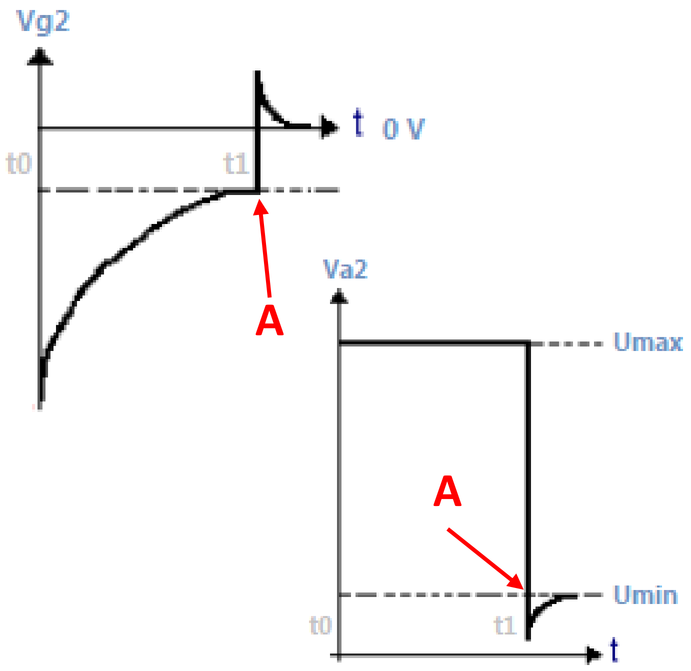
Astabile Multivibrator: Mode of operation



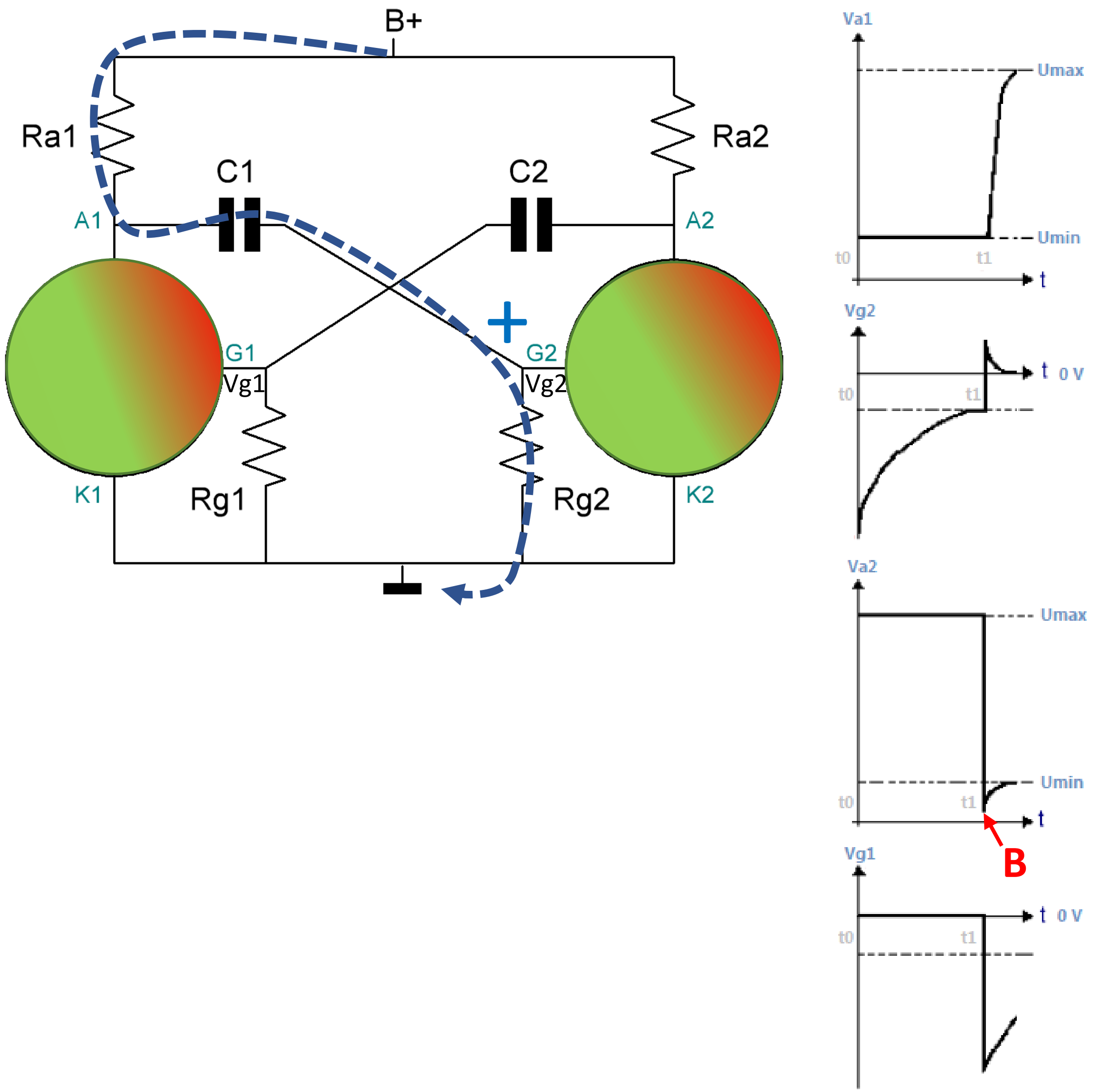


$t_0 \rightarrow t_1$

Arrived at point **A**, tube Rö2 opens again and plate current flows. Va2 drops, C2 passes the negative voltage change to the grid of tube Rö1. Tube Rö1 closes a little.

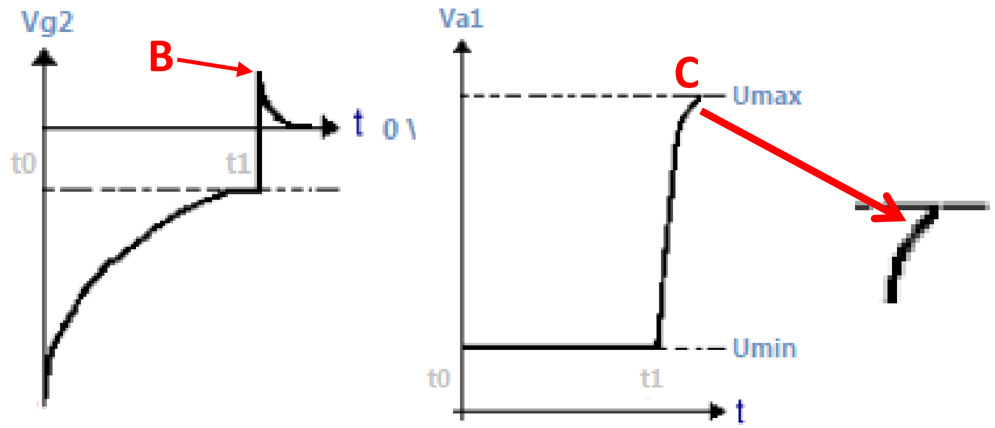


Astabile Multivibrator: Mode of operation



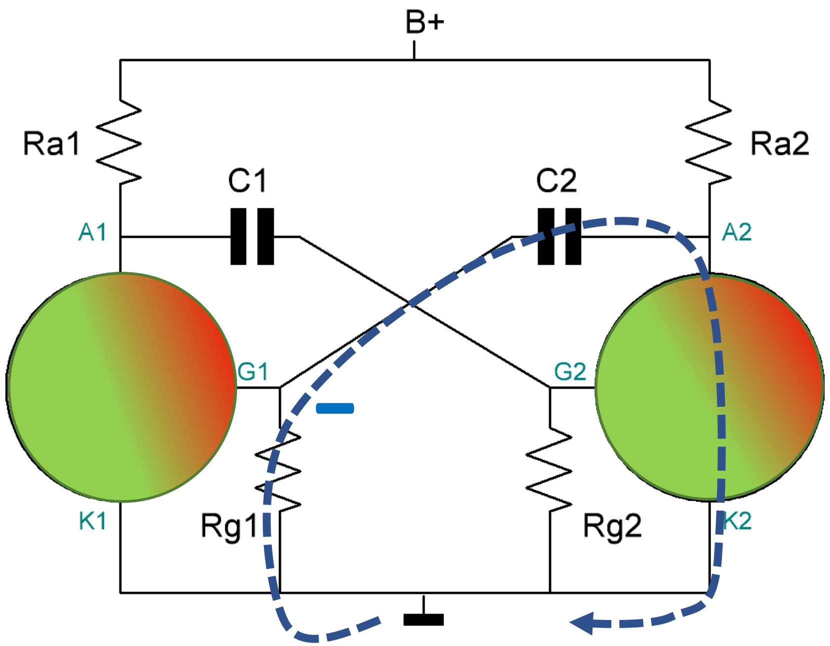
$t_0 \rightarrow t_1$

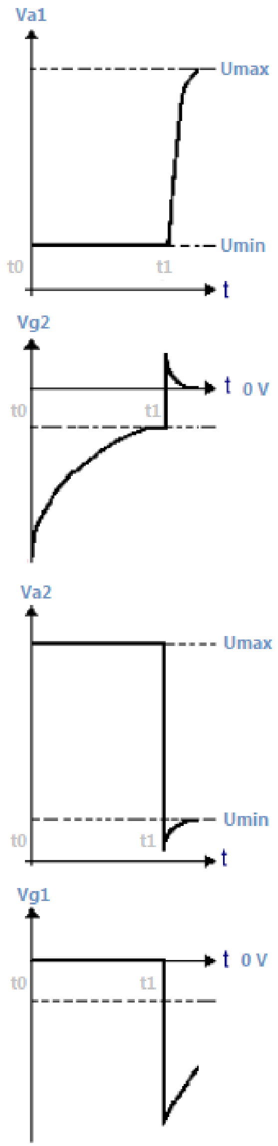
C1 can now charge up again, as the internal resistance of tube Rö1 increases. The charging current, which also flows through Rg2, causes a positive voltage drop at the grid of tube Rö2. As a result, the grid voltage Vg2 briefly shoots up into the positive range (**B**).



The charging current of C1 is also noticeable in the waveform of the plate voltage Va1. It causes a flattening of the rise (**C**).

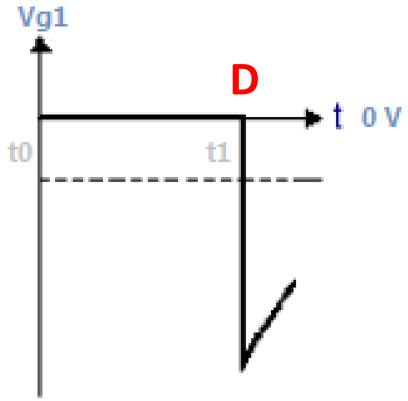
Astabile Multivibrator: Mode of operation



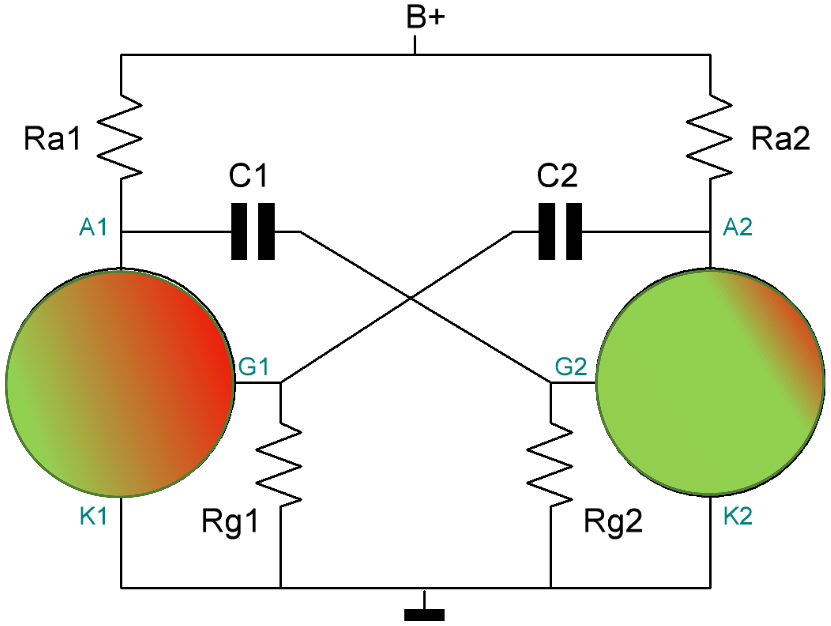


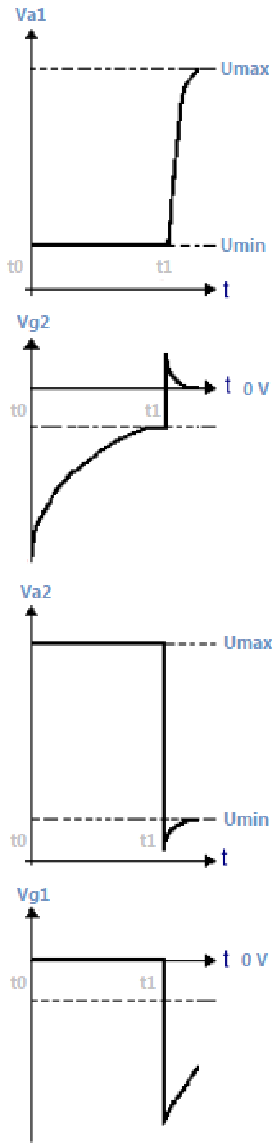
$t_0 \rightarrow t_1$

C2 now discharges across Rö2 and Rg1, causing a negative voltage drop across Rg1 (**D**).



Astabile Multivibrator: Mode of operation



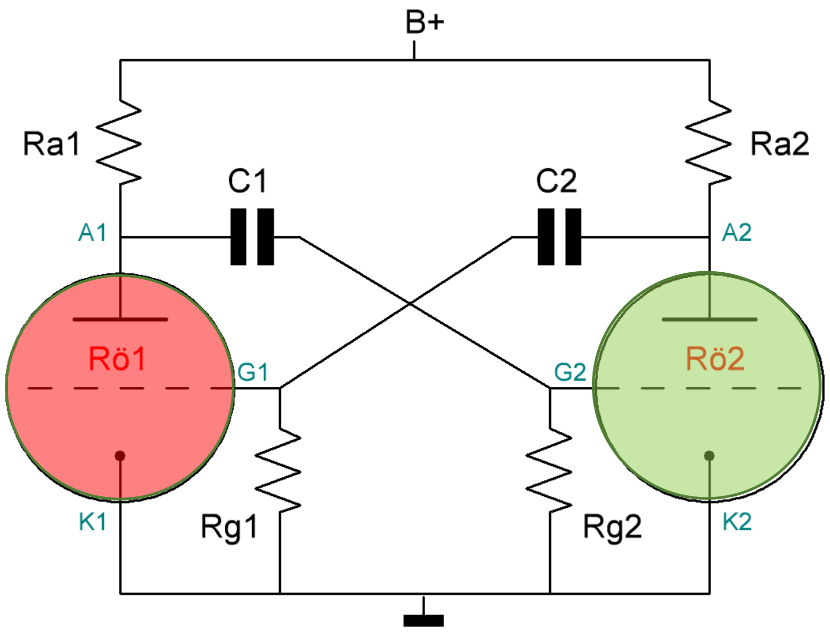


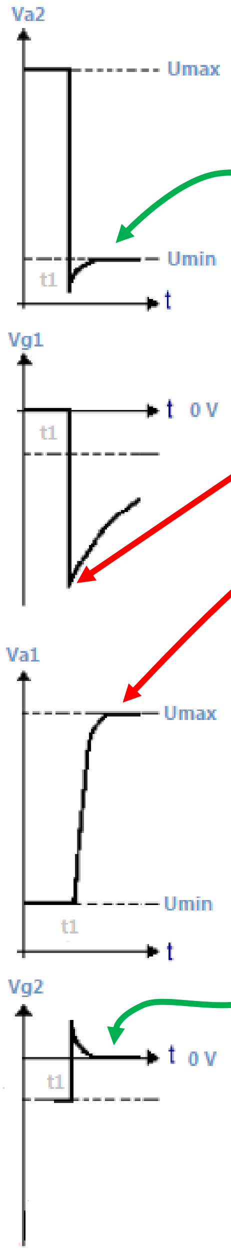
$t_0 \rightarrow t_1$

Summary t0 → t1 :

- The full switching through of Rö1 at the output time t0 ensures the discharging of C1.
- The discharging process fades away, causing the grid G2 to approach the region where Rö2 opens again.
- Rö2 opens, making the grid G1 more negative. The effect cumulates strongly so that Rö1 closes.

Astabile Multivibrator: Mode of operation

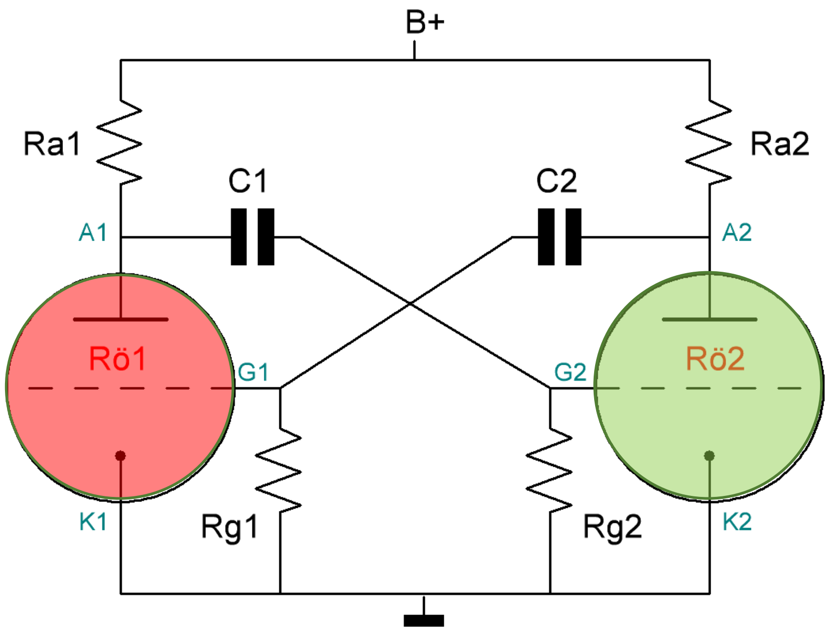


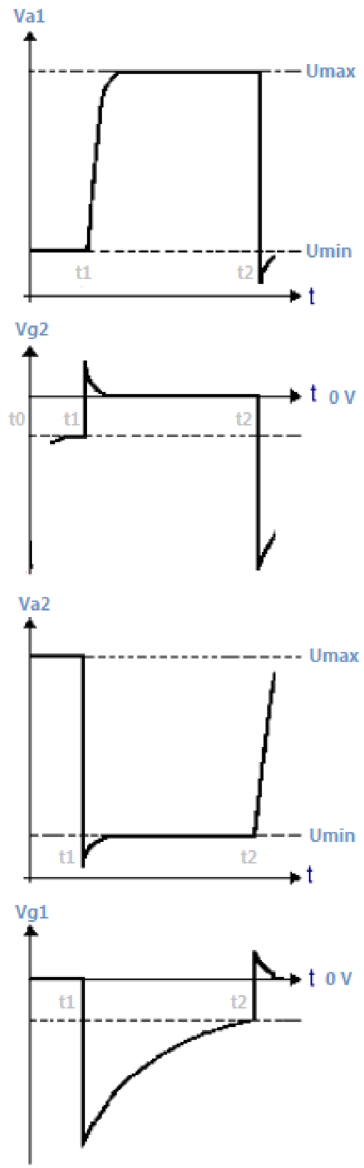


t_1

- Tube Rö2 switches fully through: $V_{a2} = U_{max} - (R_{a2} \cdot I_{a2})$ → U_{min}
  Umin does not equal zero! It means just the minimum plate voltage achievable in this setup.
- Grid voltage Vg1 is strongly negative, far below the driveable range of the tube → Tube Rö1 is closed. Plate voltage Va1 s at Umax
- Grid voltage Vg2 is near ground potential, because there are no more voltage changes coupled in from tube Rö1's output.
- C1 and C2 are fully charged, so near Umax.

Astabile Multivibrator: Mode of operation





$t_1 \rightarrow t_2$

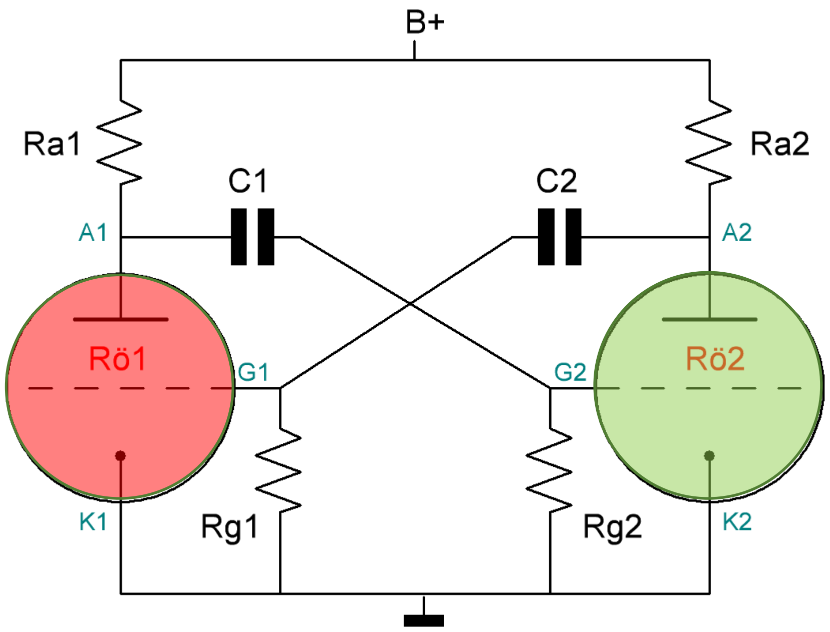
Now everything is exactly the same again, only with swapped sides:

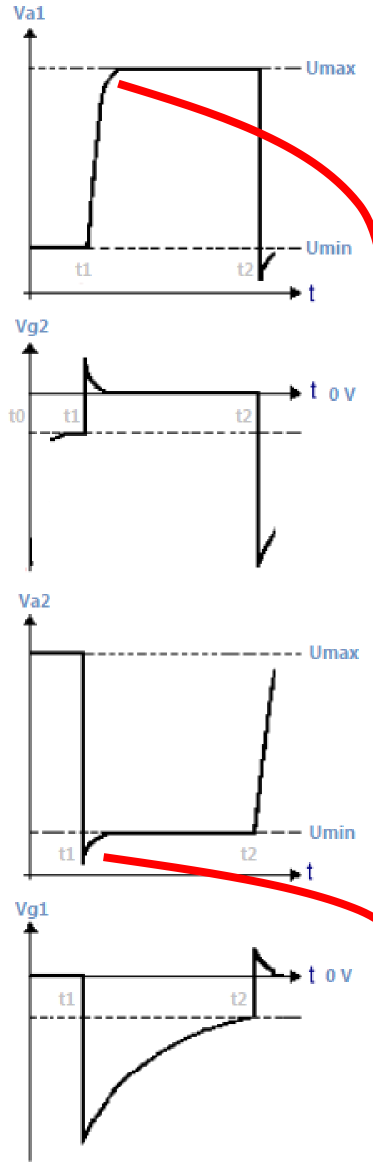
- C2 discharges via Rö2 and Rg1
- The discharge current from C2 causes a very negative voltage drop across G1, so Rö1 is stable closed.
- However, the discharge current of C2 slowly decreases, so that G1 again runs "in a more positive direction" from below into the area where Rö1 can open again.

From here, it always goes back and forth like this:

- One tube opens up: Va = Min
- One tube closes: Va = Max

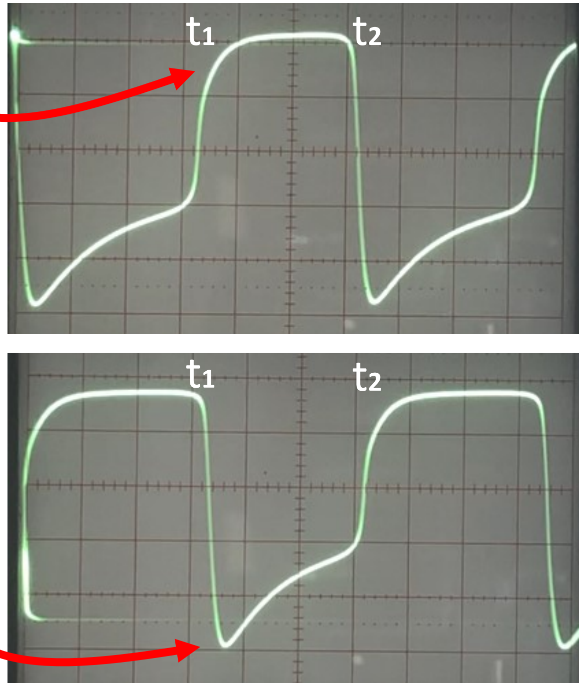
Astabile Multivibrator: Mode of operation





$t_1 \rightarrow t_2$

Both tubes therefore show the same waveform at the plates, but are 180° out of phase with each other. This phase shift is essential for the oscillation of the oscillator => **positive feedback**.



The waveforms were recorded from the experimental setup with the breadboard.
They are not ideal, which comes from the stray capacitances that are always present
on the breadboard, which is particularly annoying at higher frequencies.

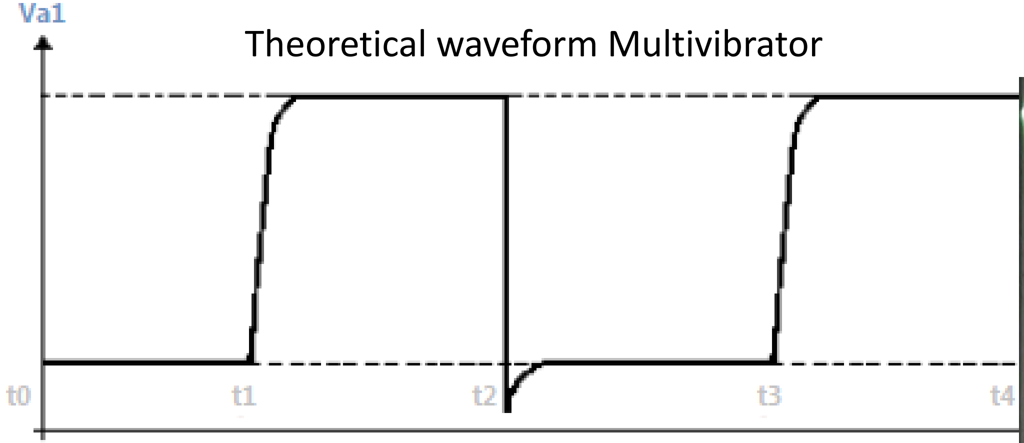
In addition, longer connection cables are required in this test setup, the capacities of which are unfortunately no longer negligible.

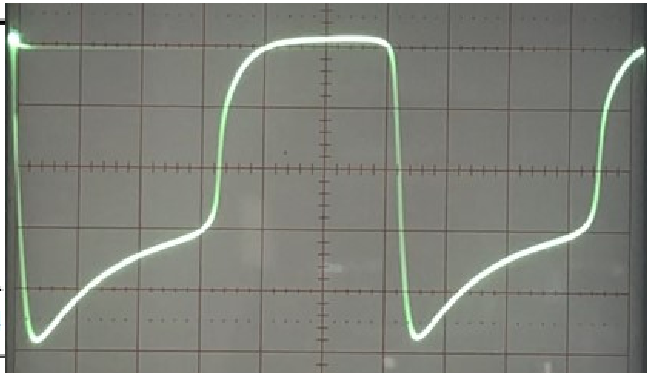
This slightly distorts the waveform (see lower half-wave).

Astabile Multivibrator: Mode of operation

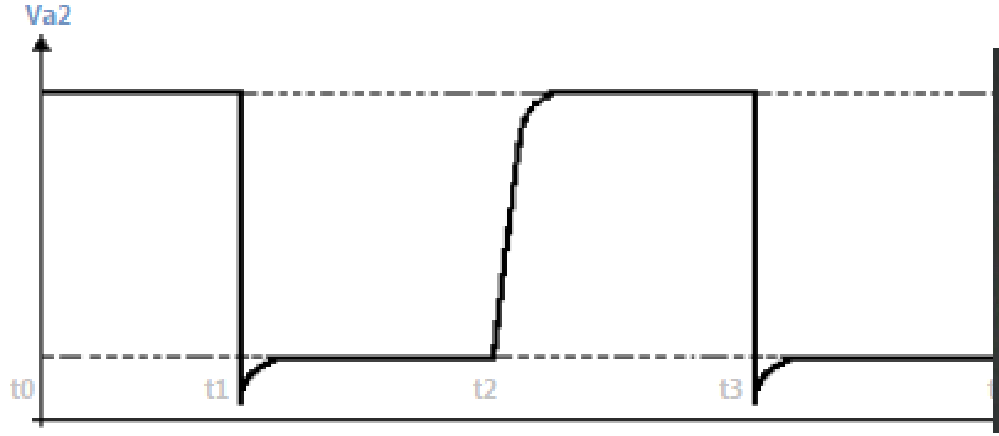
Theoretical waveform Multivibrator

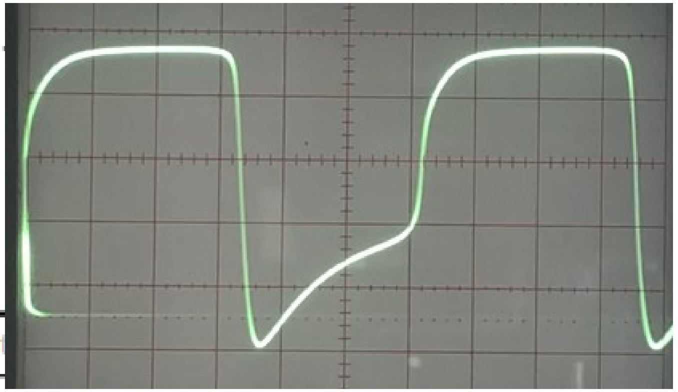
Measured waveform*





* Test setup with breadboard an 30V plate voltage





Astabile Multivibrator: Mode of operation

- A number of conditions must be met for a permanent and stable oscillation:

  See “Barkhausen stability criterion”:

  https://en.wikipedia.org/wiki/Barkhausen_stability_criterion

Astabile Multivibrator: Mode of operation

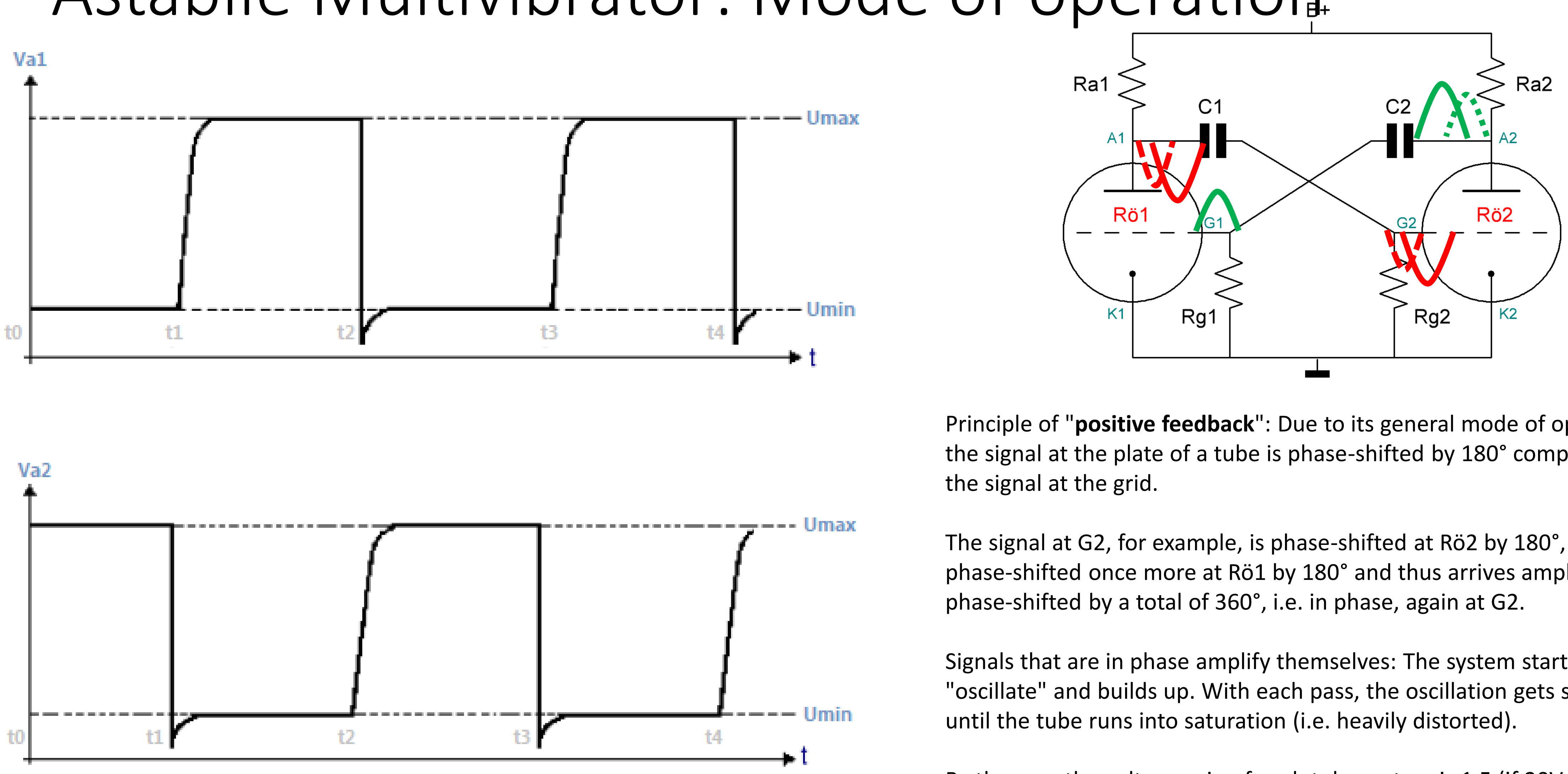
- The phase shift must be 0° or 360°.

  ➔ The amplified signal must fed into the loop again in phase (positive feedback).
  ➔ Otherwise phase cancellations.

- If the loop gain is at least 1, then the circuit generates an oscillation:

  ➔ If the loop gain is < 1, the amplitude decreases again.
  ➔ With loop gain > 1, the amplitude will continue to increase until the amplifier goes into distortion

Astabile Multivibrator: Mode of operation



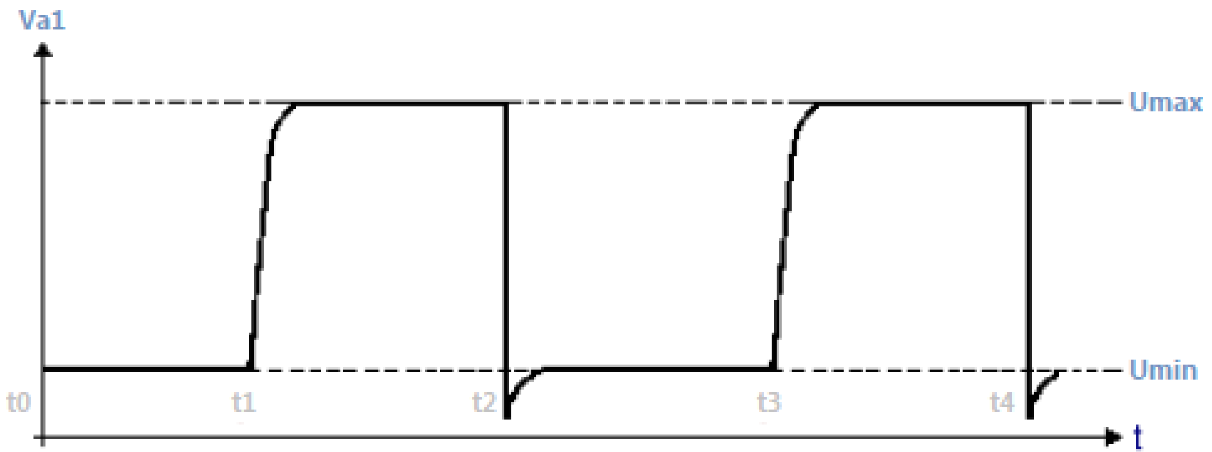
Principle of "**positive feedback**": Due to its general mode of operation, the signal at the plate of a tube is phase-shifted by 180° compared to the signal at the grid.

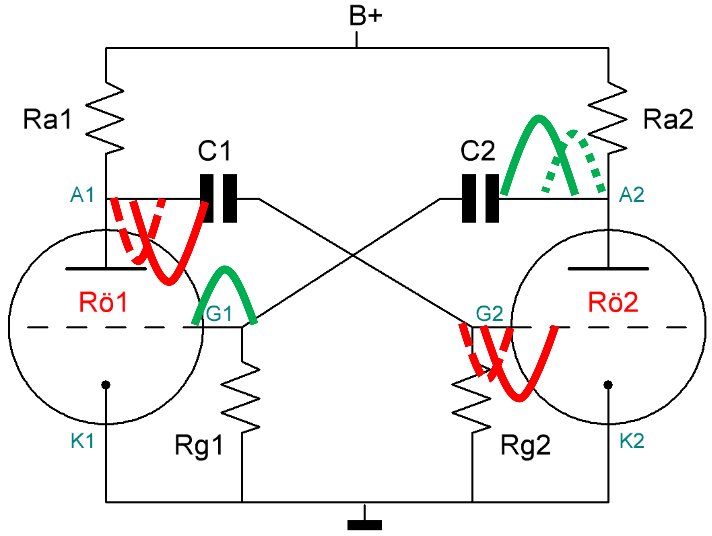
The signal at G2, for example, is phase-shifted at Rö2 by 180°, then phase-shifted once more at Rö1 by 180° and thus arrives amplified and phase-shifted by a total of 360°, i.e. in phase, again at G2.

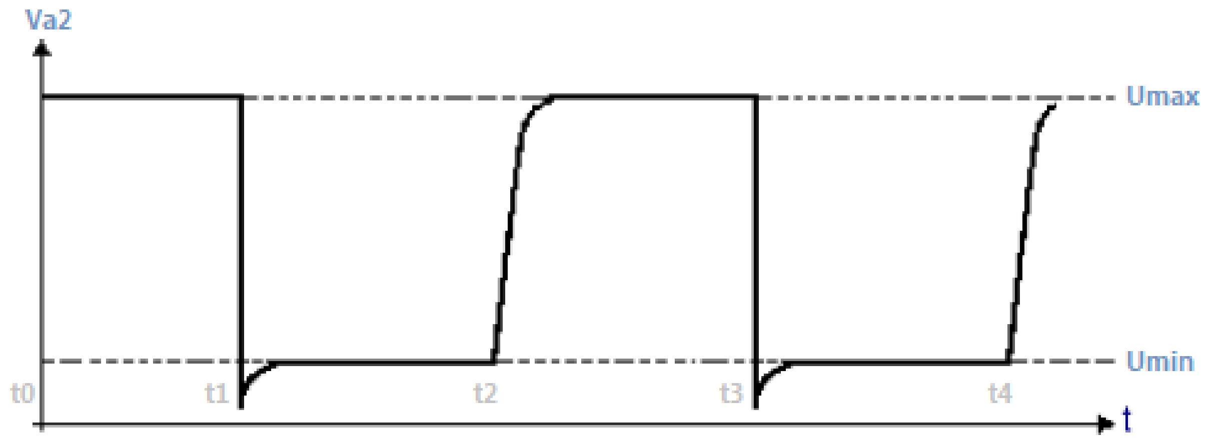
Signals that are in phase amplify themselves: The system starts to "oscillate" and builds up. With each pass, the oscillation gets stronger until the tube runs into saturation (i.e. heavily distorted).

By the way, the voltage gain of each tube system is 1.5 (if 20V p-p at the grid, then 30V p-p at the anode).

Astabile Multivibrator: Mode of operation

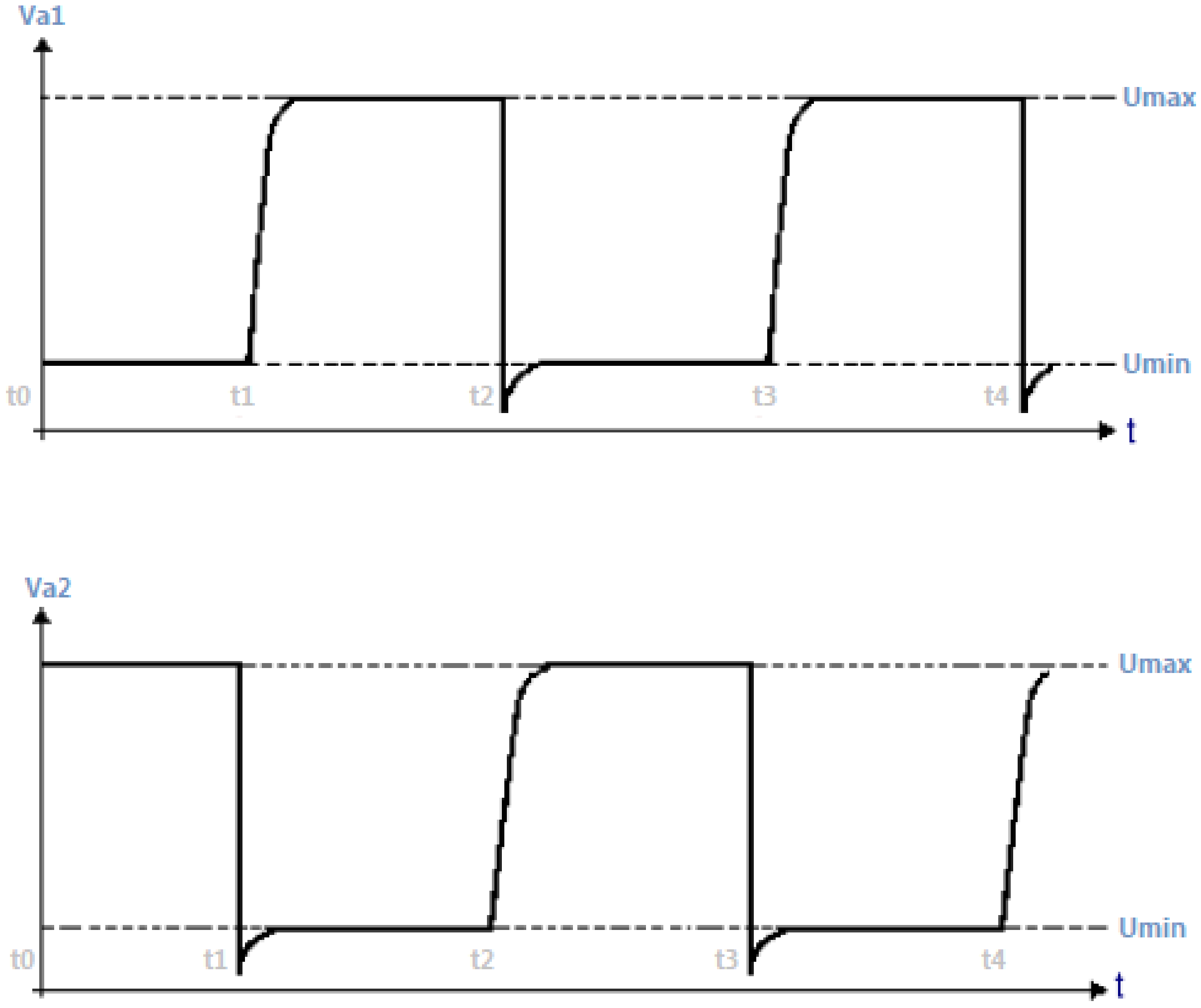


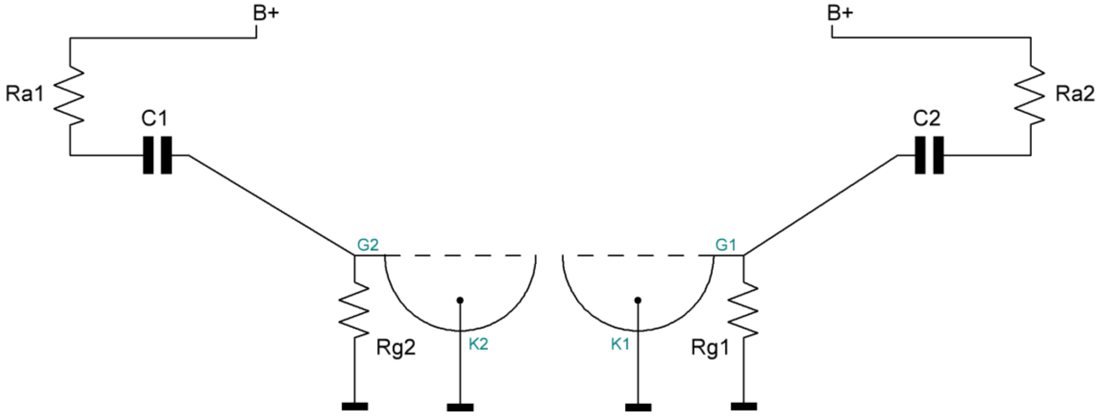




The **astable** thing about the astable multivibrator is that the swinging up of a tube does not remain stable up to a maximum state, but tilts by itself in such a way that the other tube alternately swings up to its maximum state.

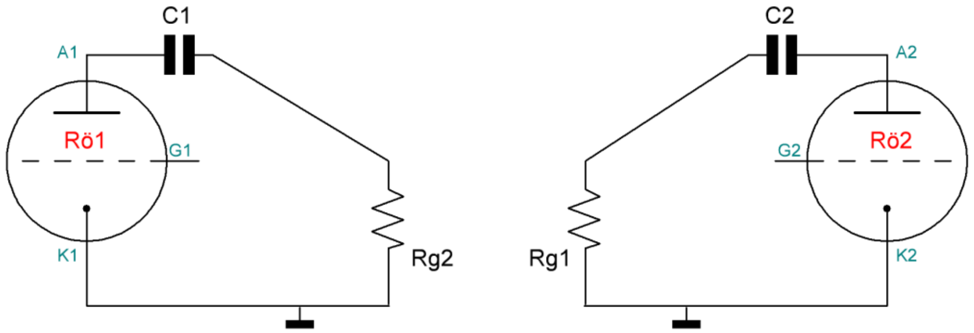
Astabile Multivibrator: Mode of operation



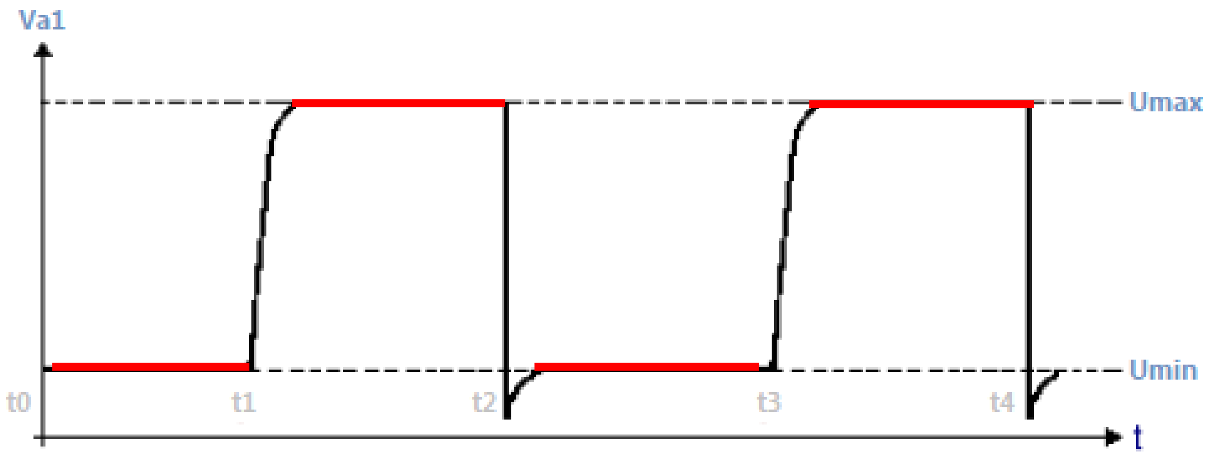


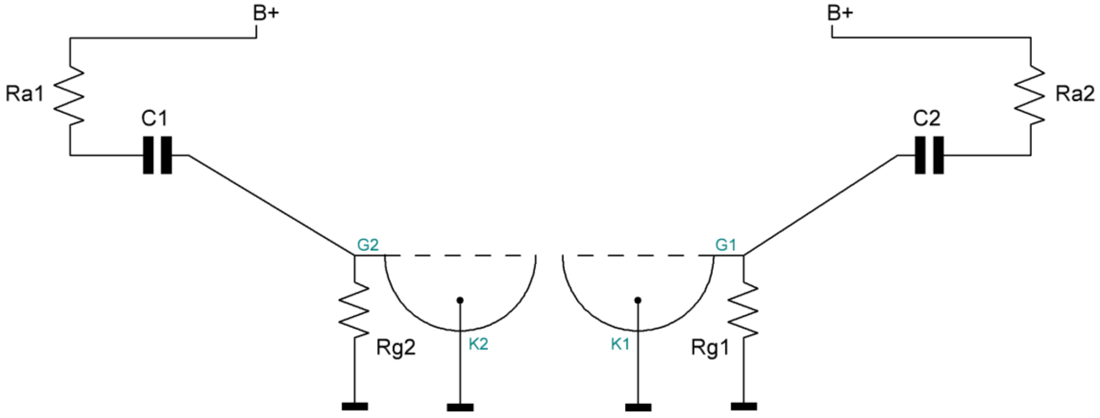
The charging and discharging circuits have "**time constants**" that determine the duration of the charging and discharging processes of the capacitors: A current must flow in order to charge and discharge the capacitor. The resistances in the circuit determine the amount of current. The capacitance of the capacitor is its ability to store charges. The time constant therefore varies with the dimensioning of R and C!

This ultimately determines the **frequency** of the multivibrator (= frequency of transitions, charging/discharging processes).

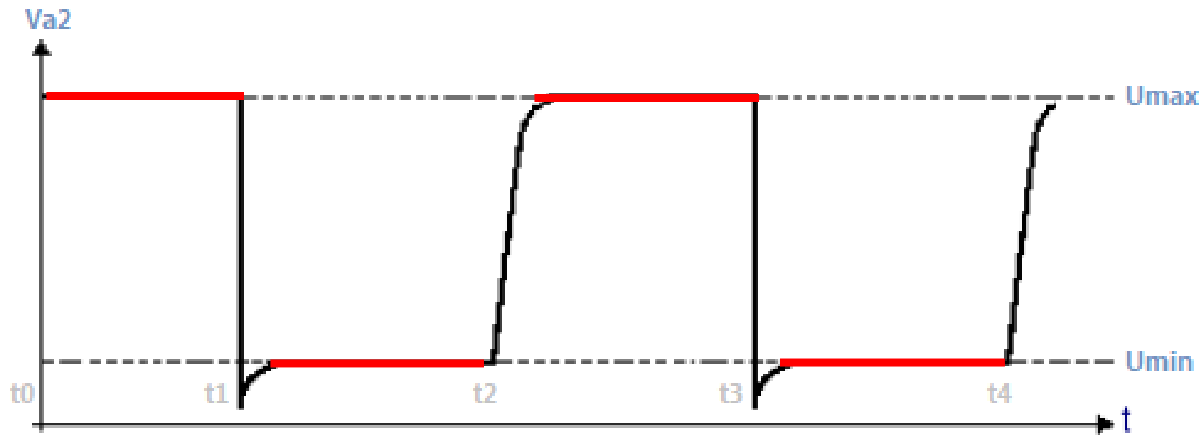


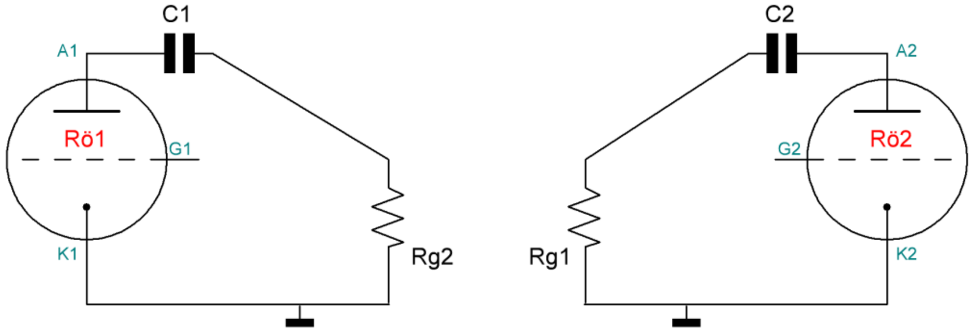
Astabile Multivibrator: Mode of operation



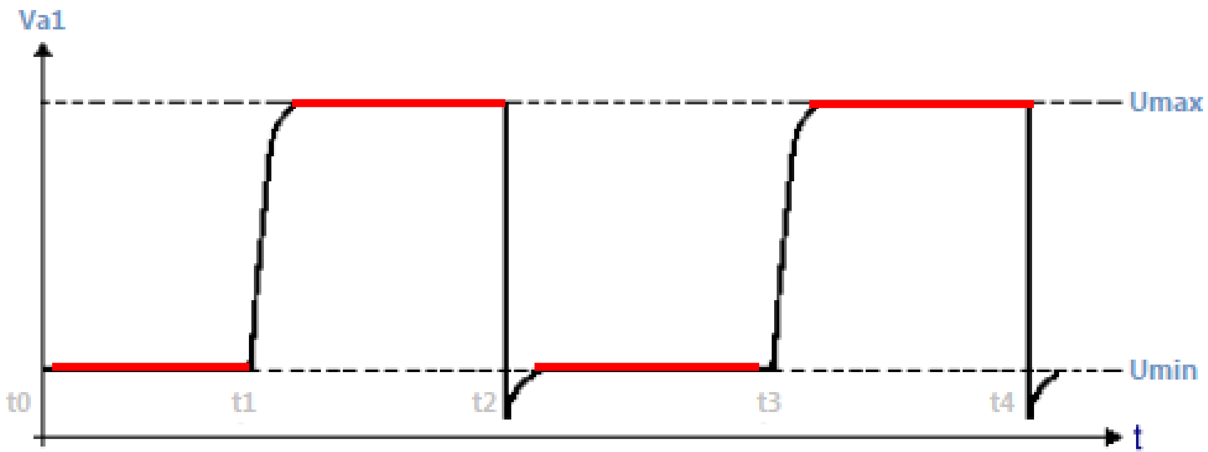


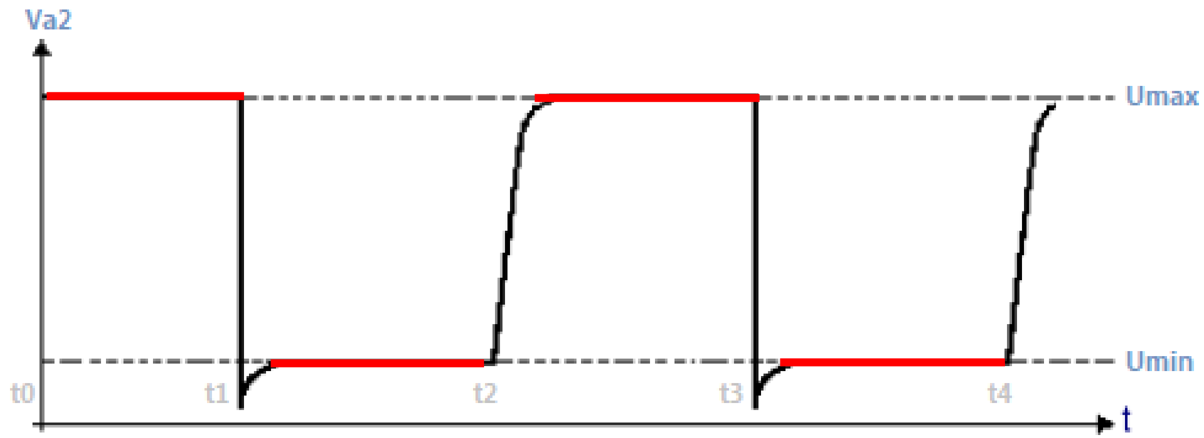
If C1 has a larger capacitance than C2, then tube Rö2 will stay closed longer than Rö1. The distances marked in red are then no longer of the same length.





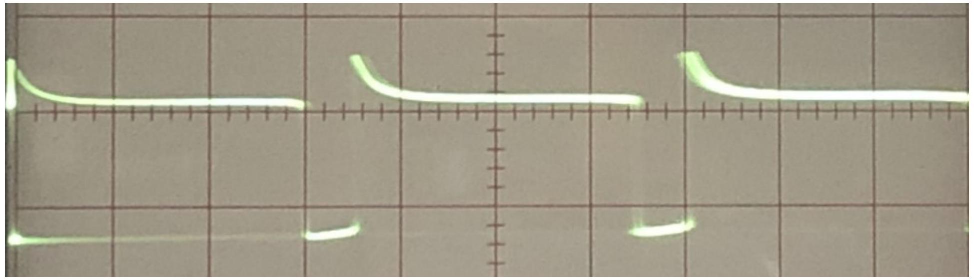
Astabile Multivibrator: Mode of operation

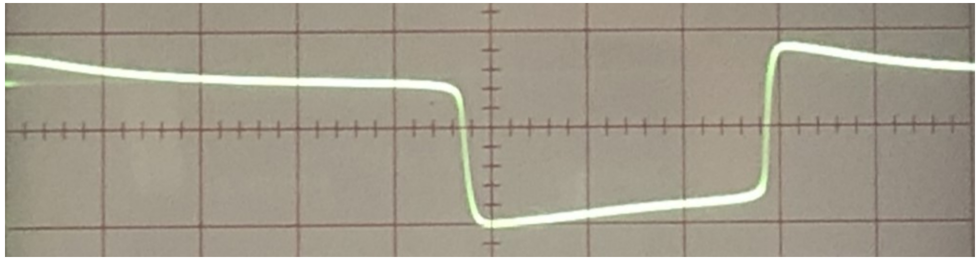




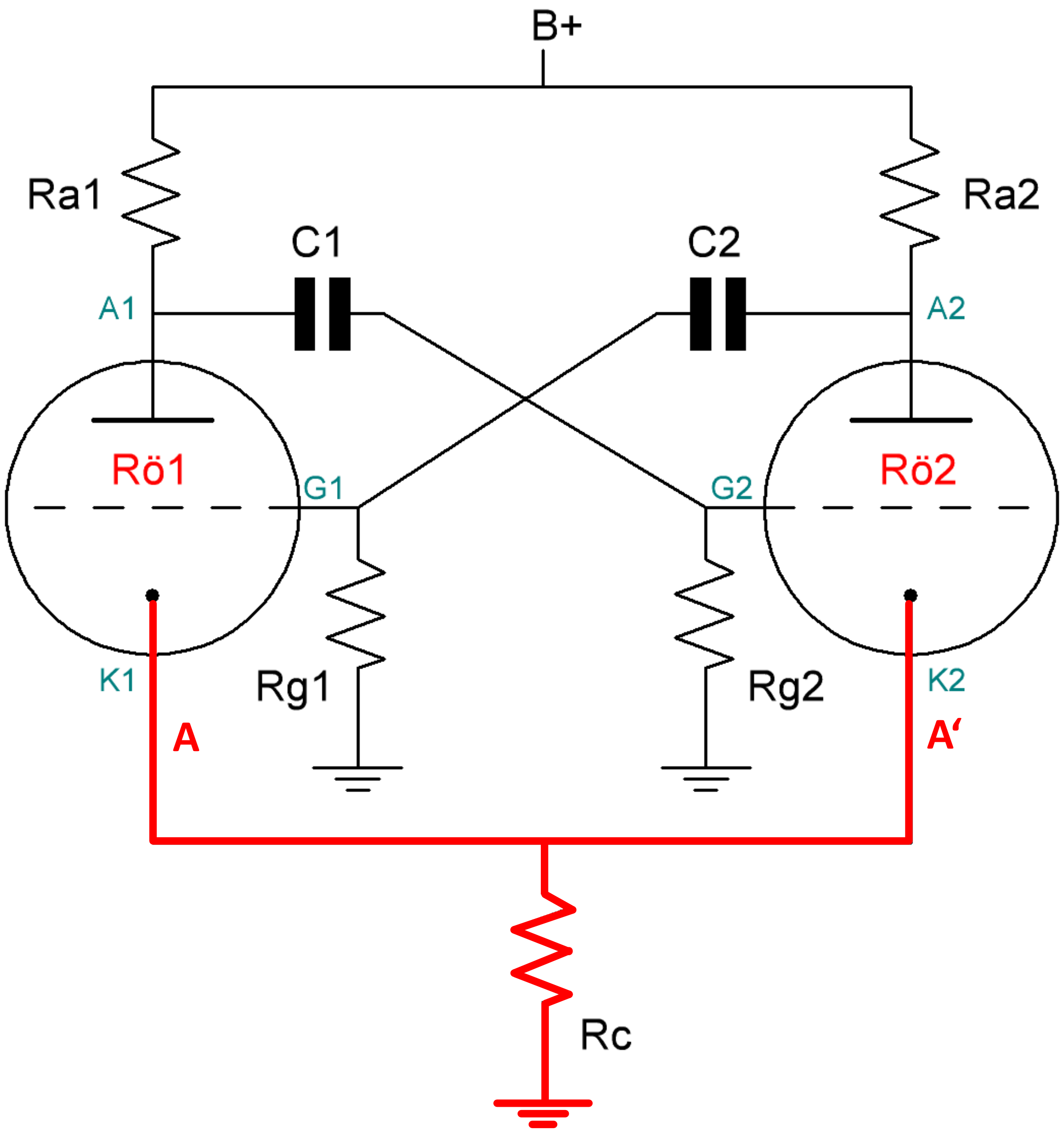
If C1 has a larger capacitance than C2, then tube Rö2 will stay closed longer than Rö1. The distances marked in red are then no longer of the same length.

We see two separate examples here, measured against one of the grids. Here the capacitors C1 and C2 had greatly different capacitances.





Astabile Multivibrator: Mode of operation



Coupled cathodes with a common cathode resistor

The cathode resistor Rc is used to automatically adjust the grid bias. When anode current flows through Rc, a positive voltage drops across the cathodes (K1, K2).

Since the grids are at ground potential (0 V) via Rg1 and Rg2, the grids are automatically more negative than the cathodes (= negative grid bias).

The values of the resistors result from the data sheet of the tubes according to the desired degree of negative bias.

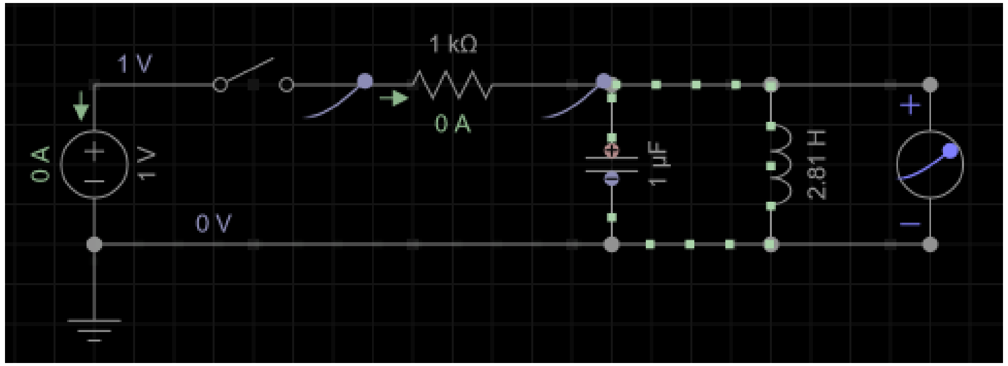
Now consider the following situation: :

- Tube Rö1 switches fully through, the plate current through Rc increases to maximum. At **A** there is an even more positive voltage drop.
- However, this voltage drop also occurs at K2 (A'), since both points are at the same potential. This causes K2 to become even more positive relative to ground and G2 becomes even more negative relative to K2. Tube Rö2 blocks even more.
- The coupled cathodes make the ON/OFF effect of the tubes even more stable.
- Because there is a cathode resistor with no bypass capacitor, we have current feedback, which also lowers the overall voltage gain of the tubes.

Theory LC-resonant circuit 1

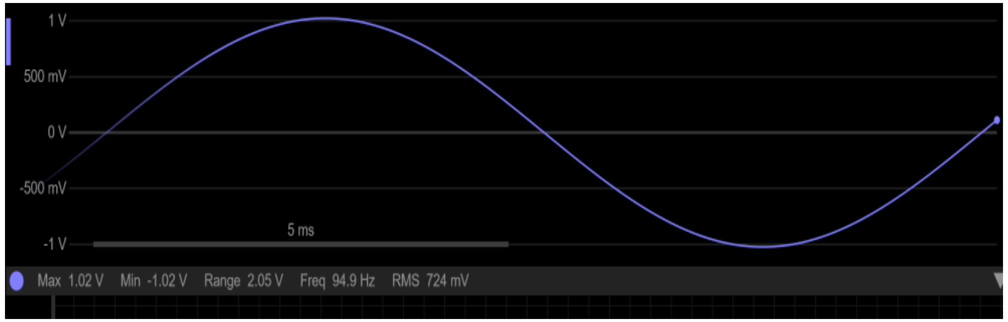
// Film example: Simulation in *EveryCircuit*: Oscillation after brief charging of the capacitor in a parallel oscillating circuit

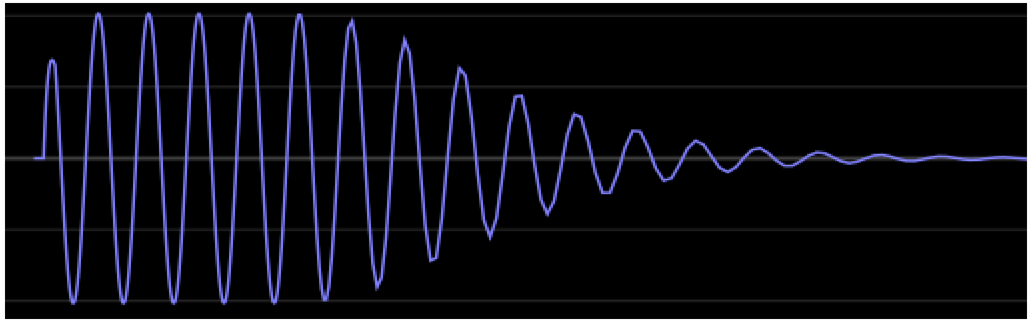
As in the example circuit below, a parallel resonant circuit consisting of a coil and a capacitor is supplied with a DC voltage via a switch. The switch is closed, allowing the capacitor to fully charge. The switch is then opened and the capacitor is thus disconnected from the voltage source.



A free oscillation now occurs at the natural frequency of the resonant circuit. However, this oscillation is damped and decays quite quickly (see bottom right).

This way of starting up the oscillation of resonant circuit is not the direct explanation for its use in the Echolette Oscillator, but it opens up an understanding for the topic of *resonance*, which will be useful for further understanding.



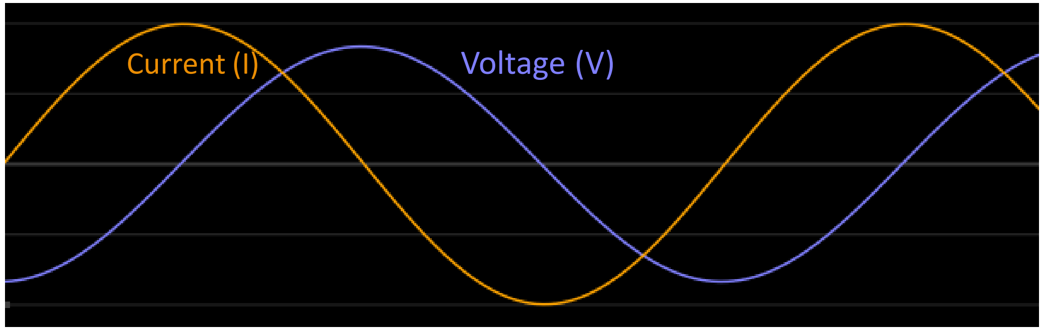


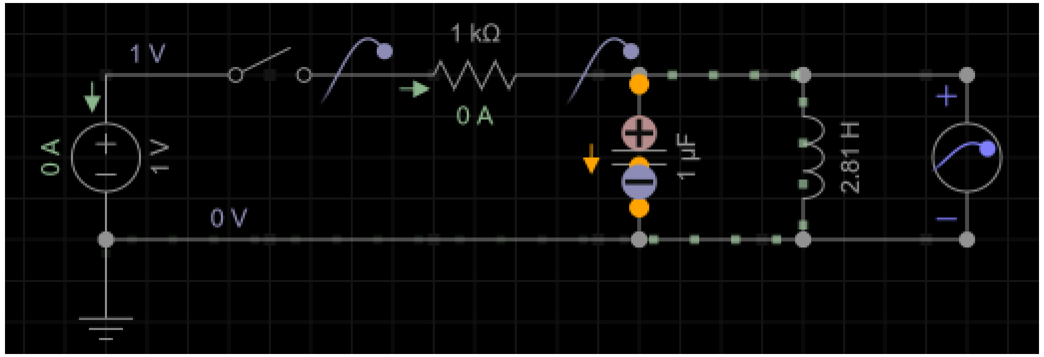
Theory LC-resonant circuit 1

The resonant circuit consists of two types of energy storage: capacitor and inductor. Both have different properties in a circuit. Two of these properties are briefly presented here:

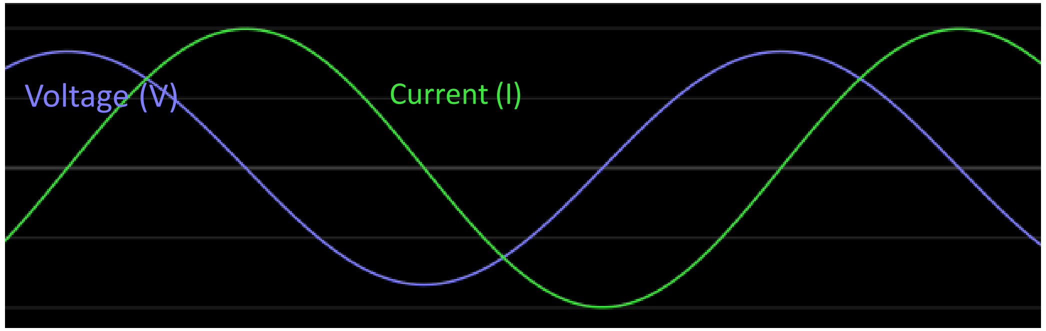
Phase relationship of current & voltage

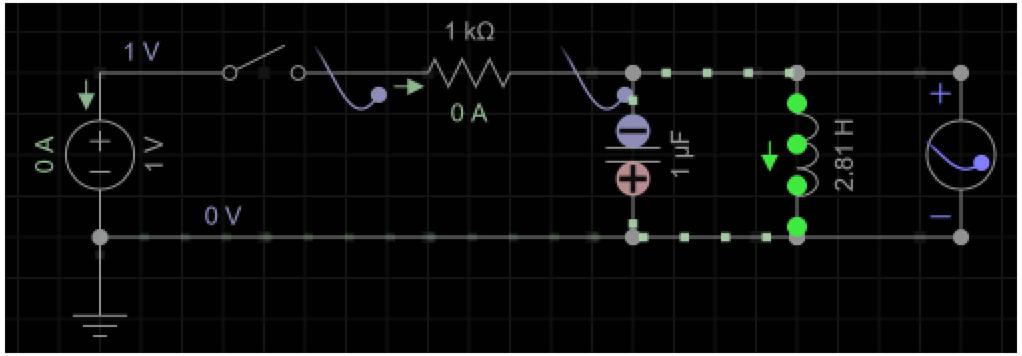
Capacitor
The current leads the voltage by about 90°.





Inductivity
The current lags behind the voltage by about 90°.





Theory LC-resonant circuit 1

The resonant circuit consists of two types of energy storage: capacitor and inductor. Both have different properties in a circuit. Two of these properties are briefly presented here:

Reactances

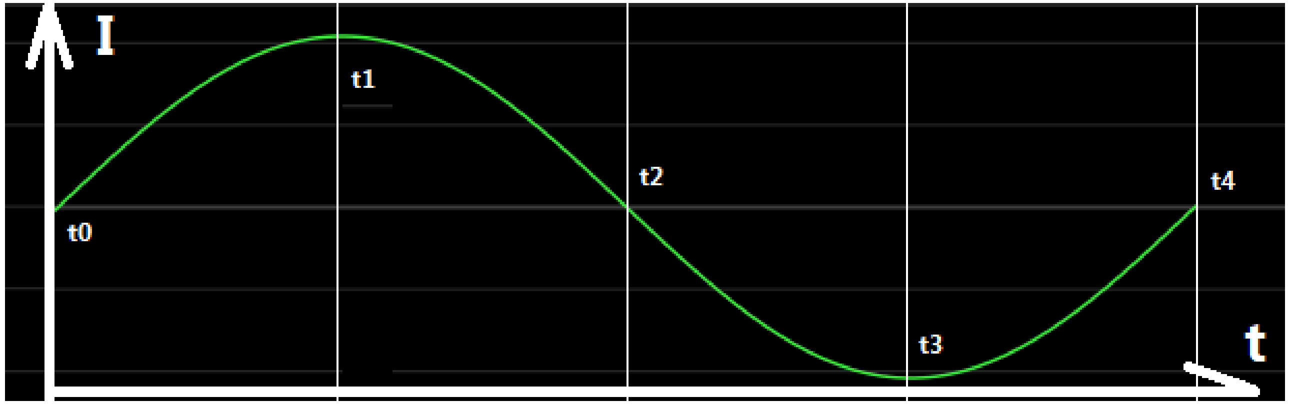
Capacitor

The capacitive reactance X_C decreases with increasing frequency and with increasing capacity of the capacitor.

Inductivity

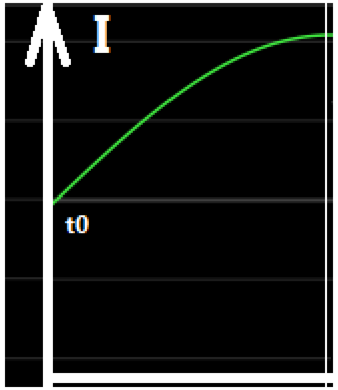
The inductive reactance X_L increases with increasing frequency and with greater inductance of the coil.

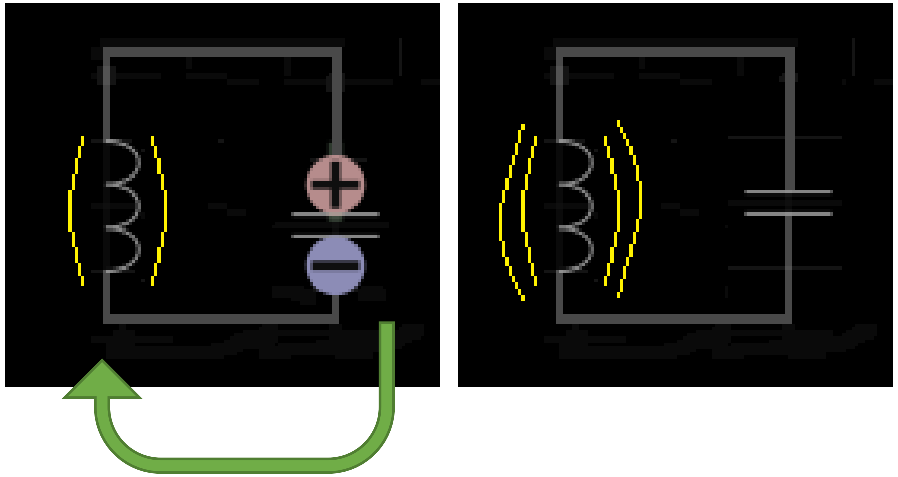
Theory LC-resonant circuit 1

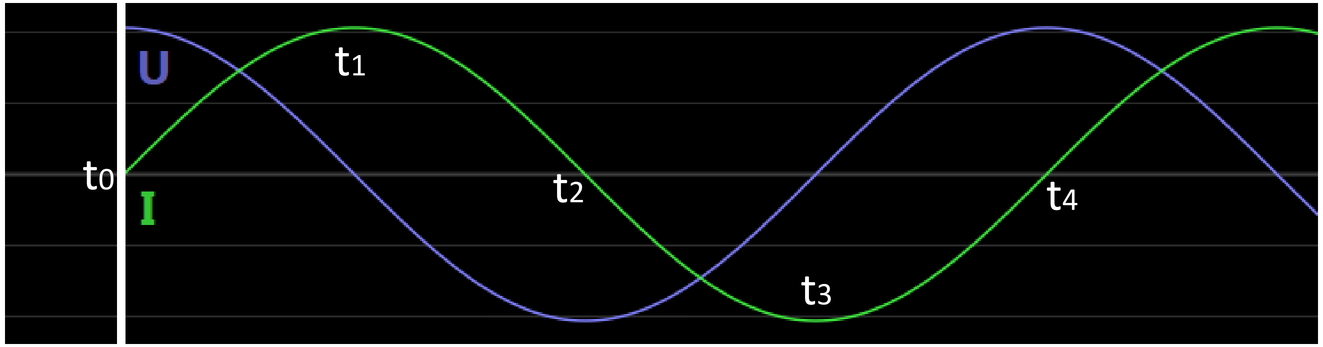


For a better understanding of the processes, we now divide a full free oscillation of the parallel LC resonant circuit into four parts of equal size and examine them individually in detail.

Theory LC-resonant circuit 1





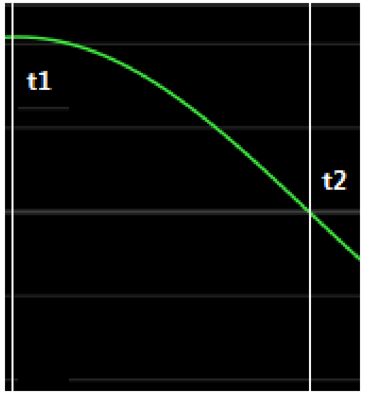


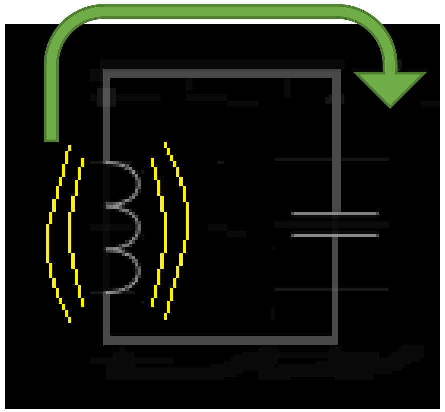
$t_0 \rightarrow t_1$

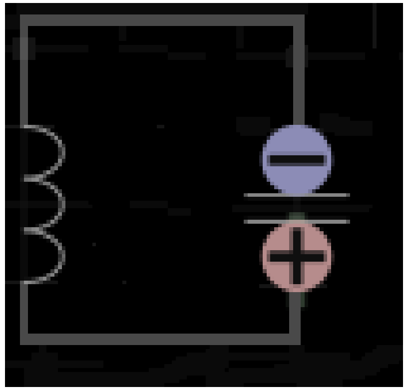
The capacitor discharges through the coil (**t0**). The flow of current through the coil creates a magnetic field around the coil in which electrical energy is converted into magnetic energy and stored.

However, the inductance resists an abrupt change in the current flow, so that it does not rise steeply, but rather in the shape of the curve shown (green) (**t0** → **t1**). When the current flow has reached its maximum (capacitor discharged, **t1**), then the magnetic field around the coil collapses...

Theory LC-resonant circuit 1

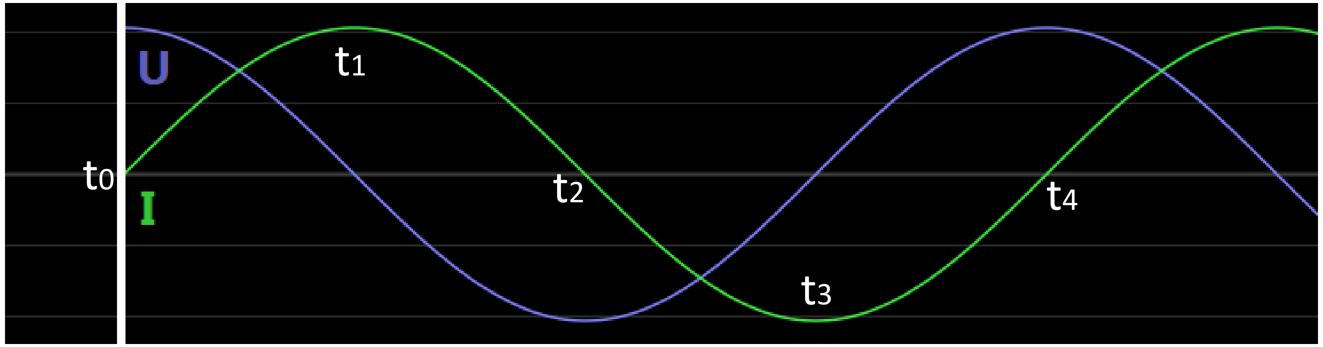




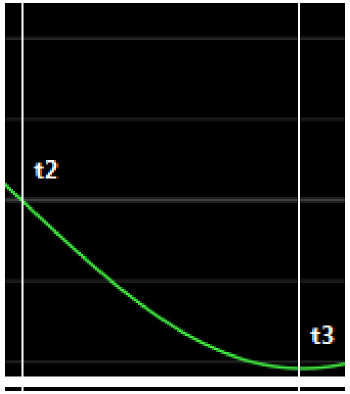


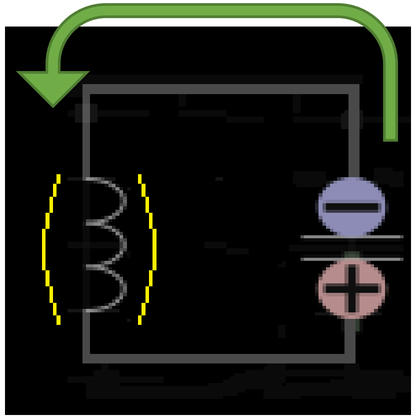
$t_1 \rightarrow t_2$

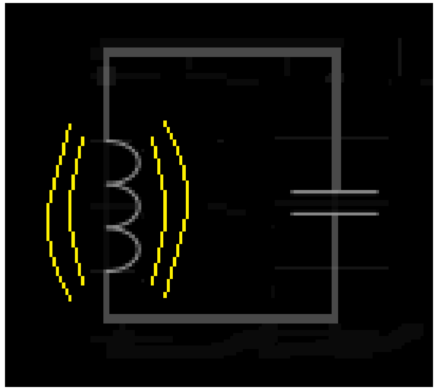
...and induces a voltage into itself. This voltage is used to charge the capacitor in the opposite direction (**t1** → **t2**) until it is full (**t2**).



Theory LC-resonant circuit 1

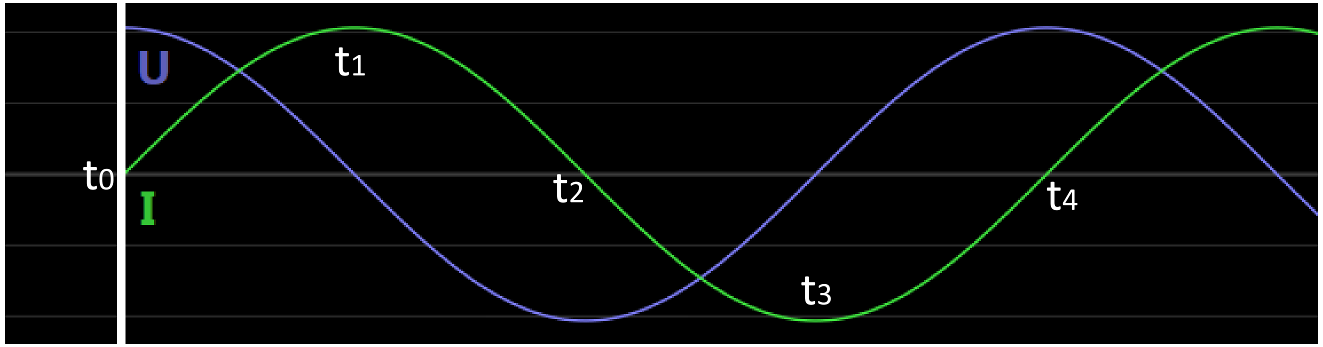




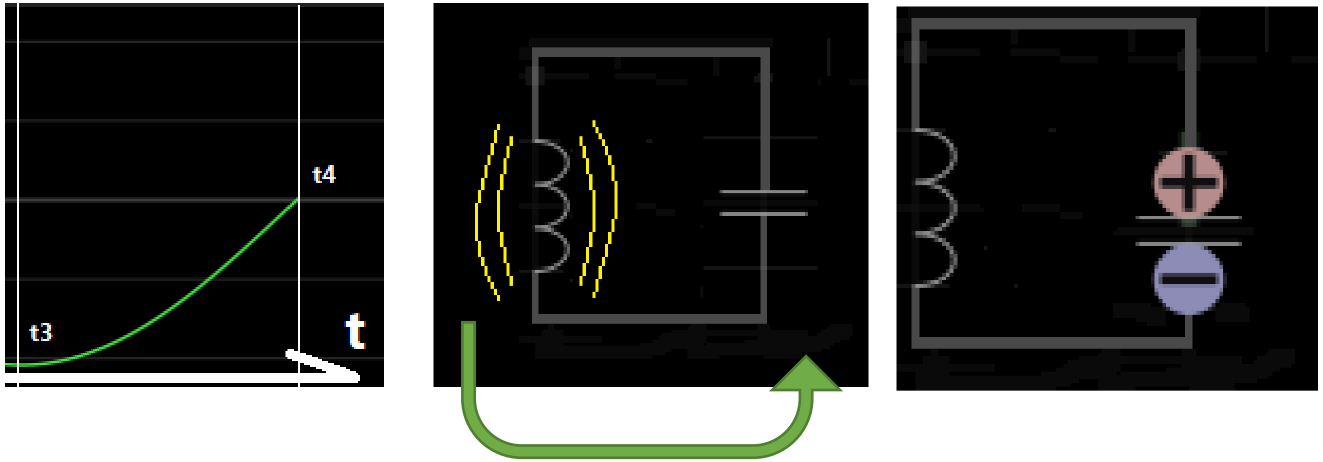


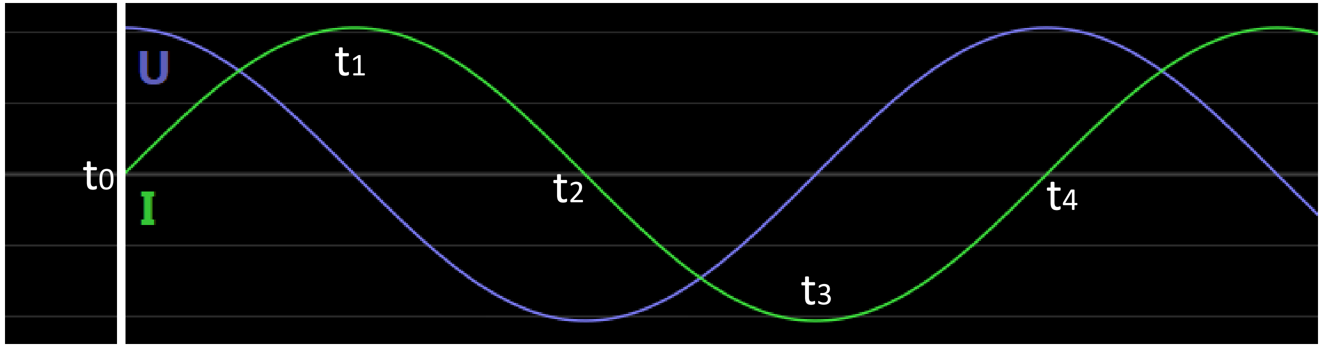
$t_2 \rightarrow t_3$

The capacitor discharges again through the coil (**t2** → **t3**). When the current flow has reached its maximum (capacitor discharged, **t3**), the magnetic field collapses again...



Theory LC-resonant circuit 1





$t_3 \rightarrow t_4$

...and again induces a voltage into itself. This voltage is used to recharge the capacitor in the opposite direction (**t3** → **t4**).

Theory LC-resonant circuit 1

https://www.redcrab-software.com/en/Calculator/Electrics/Resonant-Frequency-Calculator

The values of L and C determine the frequency of the "polarity reversals" / the duration of the individual processes shown - i.e. *the frequency of the oscillation*. This particular frequency is called the **resonant frequency**, or **f0**. Lower inductance and lower capacitance increase **f0**, see following equation:

$$f_0 = \frac{1}{2 \cdot \pi \sqrt{C \cdot L}}$$

L in *Henry*
C in *Farad*

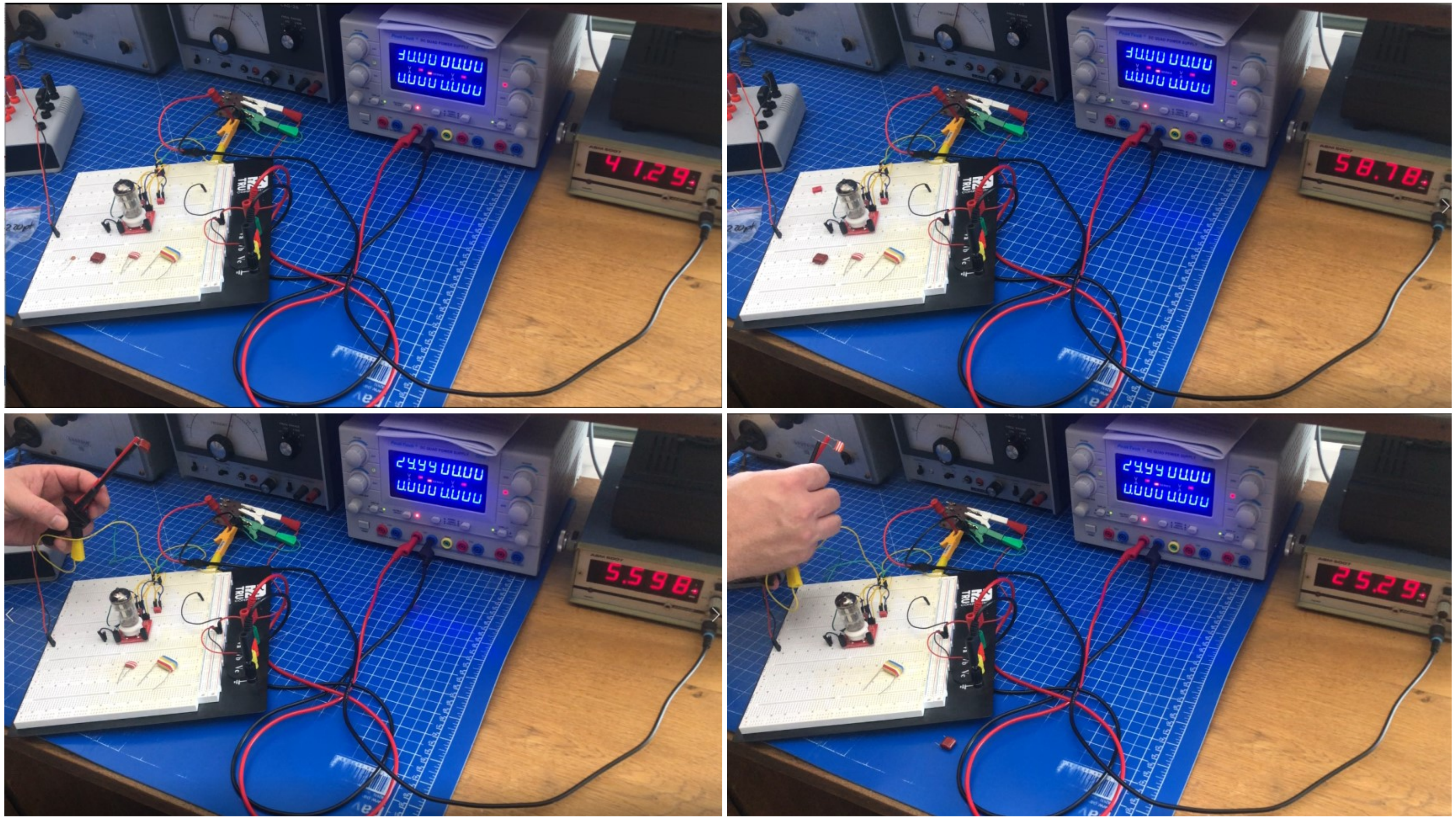
Online calculators, like the one shown on the left, make testing and trying things out easier.

In the top left row only the capacitance of the capacitor is changed, in the bottom left row only the inductance of the coil.

Note the respective frequency changes as visible in the individual images on the bottom right.

Theory LC-resonant circuit 1

// Film example: changing the frequency of the oscillator by replacing the capacitor in the parallel LC resonant circuit
Frequency measurement on an example device



Picture top left: 1000 pF (original), HF frequency 41.29 kHz.
The test setup does not oscillate to 55kHz because both the breadboard and the cables (connecting the components off the breadboard) have stray capacitances that change the capacitive part of the LC resonant circuit. With other cable combinations, I've already got it close to 50 kHz.

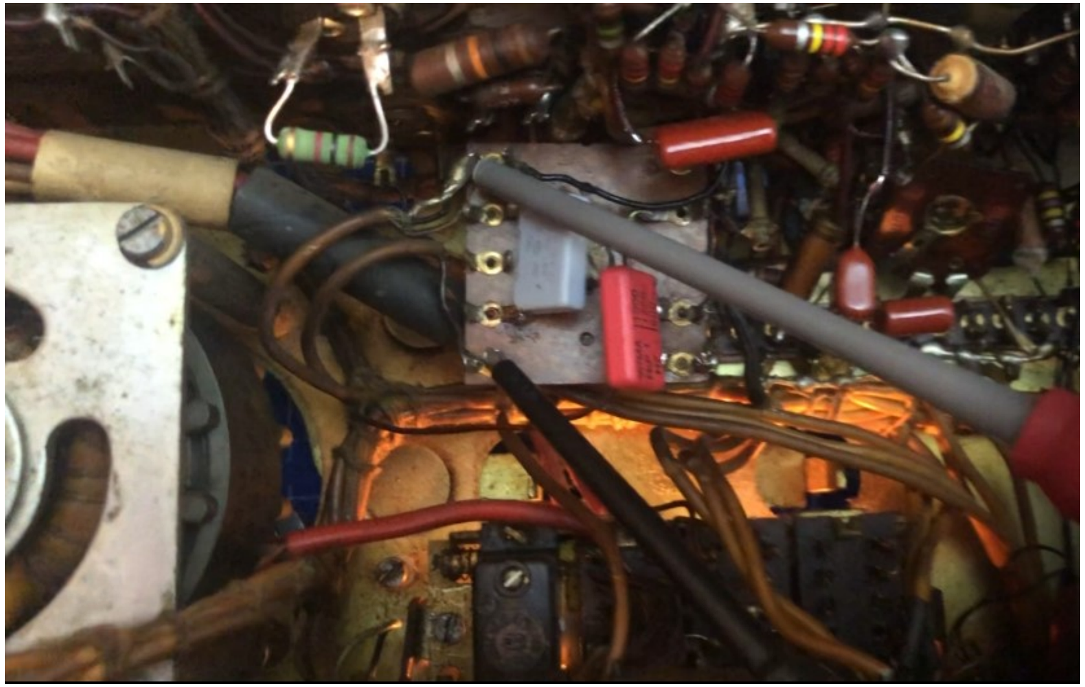
Picture top right: 220 pF. The frequency increases to 58.7 kHz.

Picture bottom right: 3.8 nF. The frequency drops to 25.29 kHz.

Picture bottom left: approx. 95 nF. The frequency drops to 5.59 kHz.

Theory LC-resonant circuit 1

Film example: Frequency measurement on an example device

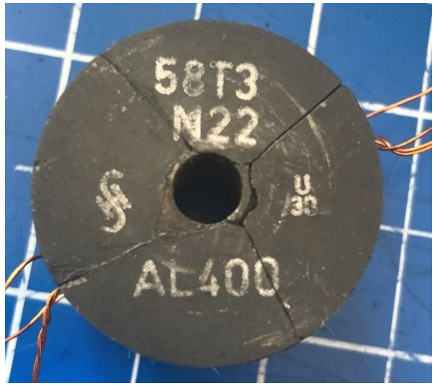


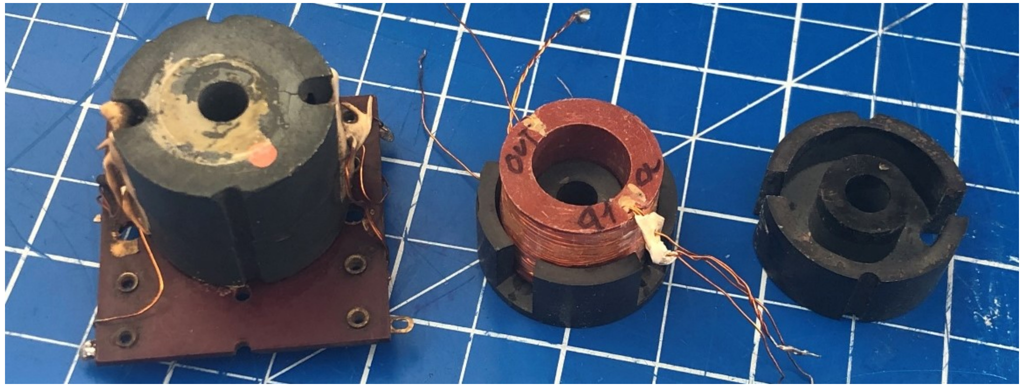
Test measurement on L1 of an NG-51 S: 56.31 kHz.

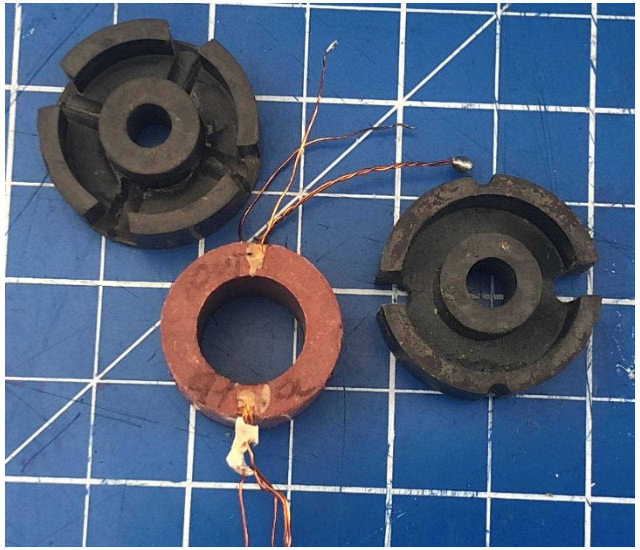
We had already seen in the theoretical considerations that the high frequency for the desired frequency range of the NG-51 S should be somewhere around 60 kHz.

55/56 kHz is what you will usually find on the device.

The Oscillator-Coil 1





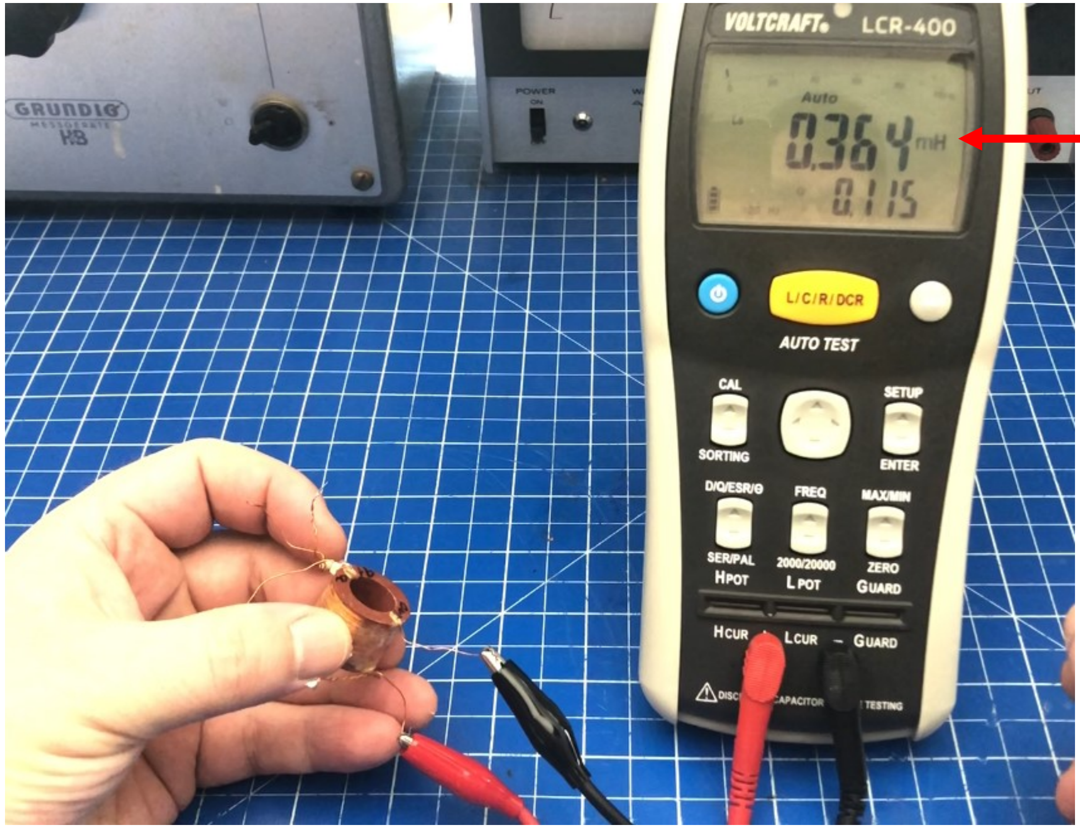


Cornerstones of the oscillator coil:

- Design: „pot core“, P-Core
- Pot core made of ferrite = high magnetic permeability (magnetic fields do not penetrate into the air space around the coil),
  low electrical conductivity (minimization of eddy current losses)
- Core almost completely encloses coil = high magnetic shielding, very low leakage inductance,
  very low electromagnetic emissions
- Pot-core inductors are usually used where a lot of magnetic energy has to be stored in a small space at high frequencies
- Air gaps to delay core saturation and lead out the windings (but: if there are too many or too large air gaps, then the magnetic stray fields will increase and possibly additional copper losses)

The Oscillator-Coil 1

// Movie example: Effects of the pot core on inductance



Inductance measurement of one coil side without core material:

0,364 mH

The Oscillator-Coil 1

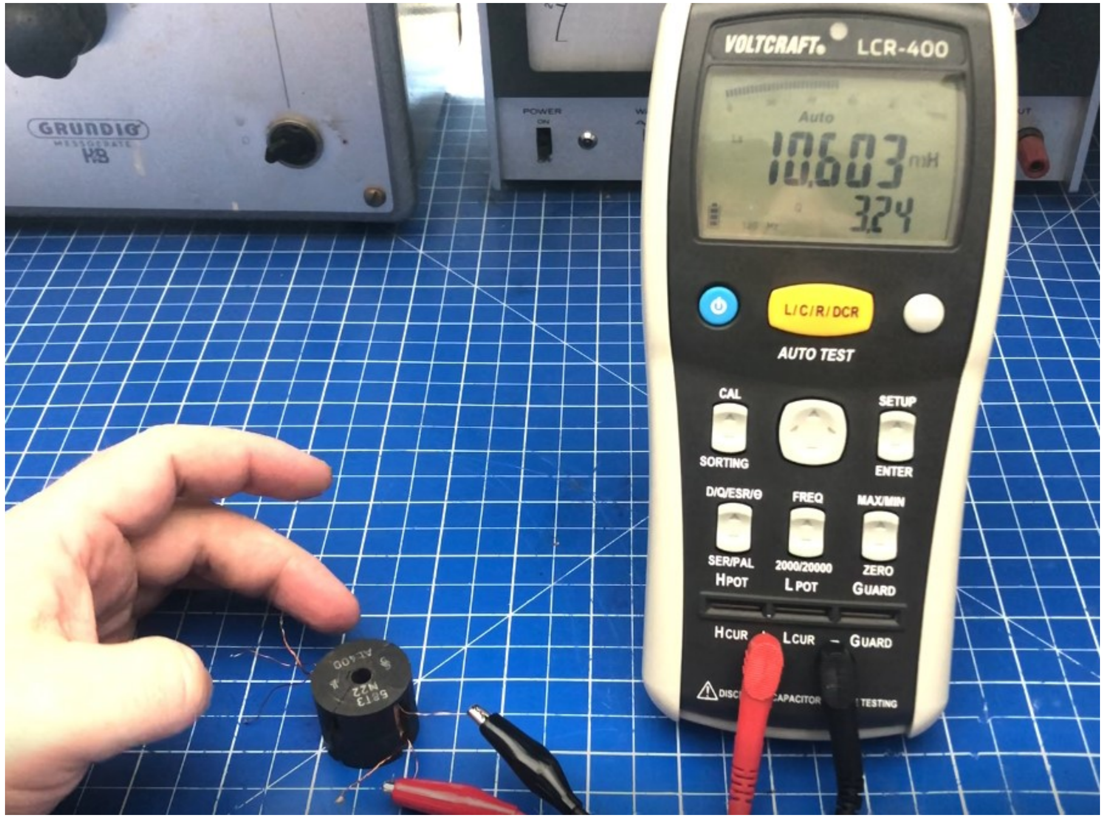
// Movie example: Effects of the pot core on inductance

Inductance measurement of one coil side with only the lower pot core half:

0,942 mH

The Oscillator-Coil 1

// Movie example: Effects of the pot core on inductance



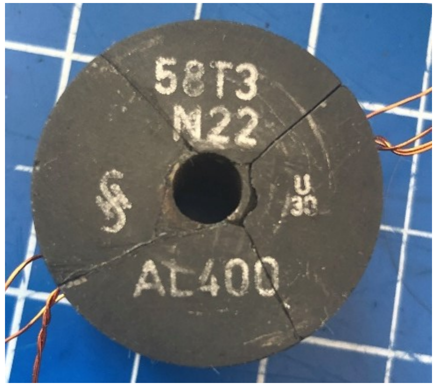
Inductance measurement of one coil side with both core halves:

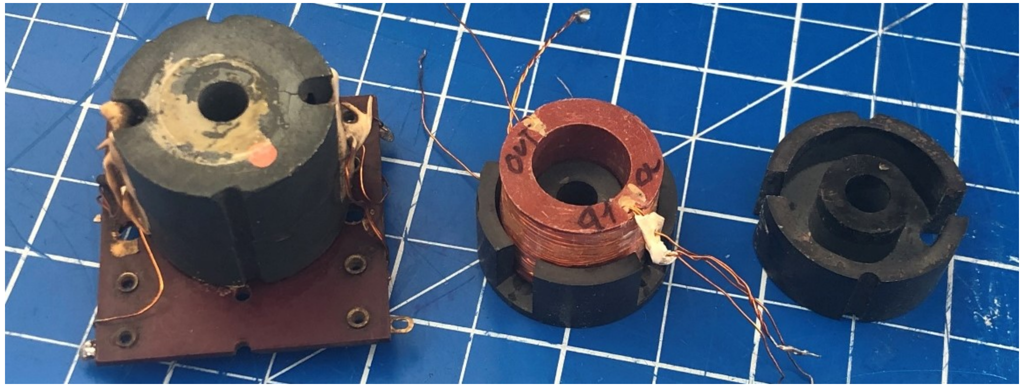
10,60 mH

→ The core plays a significant role in achieving the required inductance. Pot-core inductors are particularly effective here in a relatively small space.

The inductance also changes again a little when the Chassis mount is attached to the coil (screw straight through core)

The Oscillator-Coil 1





Cornerstones of the oscillator coil:

- Material: N22 (Siferrite), A_L-Value (Inductivity constant) = 400 (nH)

$L=N^2*A_L$ $N=\sqrt{(L/AL)}$ $A_L=L/N^2$

$A_L = nH / N^2$ (*"Nano-Henry per square turn"*)

$L = 1\,000\,000$ nH (10 mH)
$A_L = 400$
$N = 50$ (Drahtdurchmesser 0,33 mm)

L = Inductance, N = Amount of windings

A_L-Value

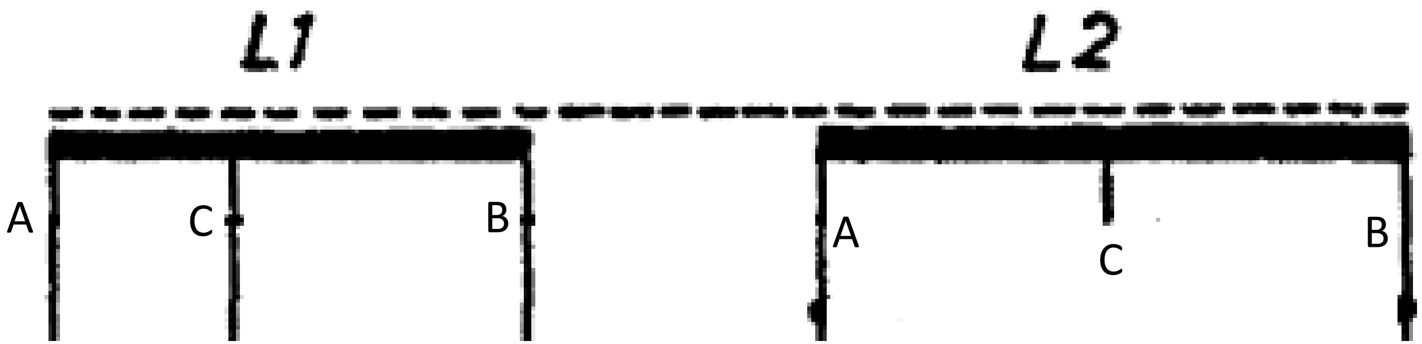
Anyone who makes coils needs to know how many turns of a suitable wire are needed to achieve a specific inductance. Since the core material, as just shown, has a significant impact on the inductance, the core manufacturers give an inductance constant for each of their products. The coil manufacturer can work more easily with this, because they only have to worry about the number of windings.

The Oscillator-Coil 1

Test-Measurements

Spule 1 Coil 1		A-C	B-C	A-B	Spule 2 Coil 2		A-C	B-C	A-B
Seite Side	L2				Seite Side	L2			
Induktivität Inductivity		2,262 mH	2,311 mH	9,171 mH	Induktivität Inductivity		2,445 mH	2,5 mH	9,95 mH
Q				3,62	Q				3,47
R		0,98 Ω	0,92 Ω	1,91 Ω	R		0,98 Ω	1,03 Ω	2,17 Ω
Seite Side	L1				Seite Side	L1			
Induktivität Inductivity		0,783 mH	5,678 mH	10,69 mH	Induktivität Inductivity		0,8 mH	6,06 mH	11,5 mH
Q				3,35 !	Q				3,17 !
R		0,62 Ω	1,77 Ω	2,41 Ω	R		0,66 Ω	0,53 Ω	2,72 Ω

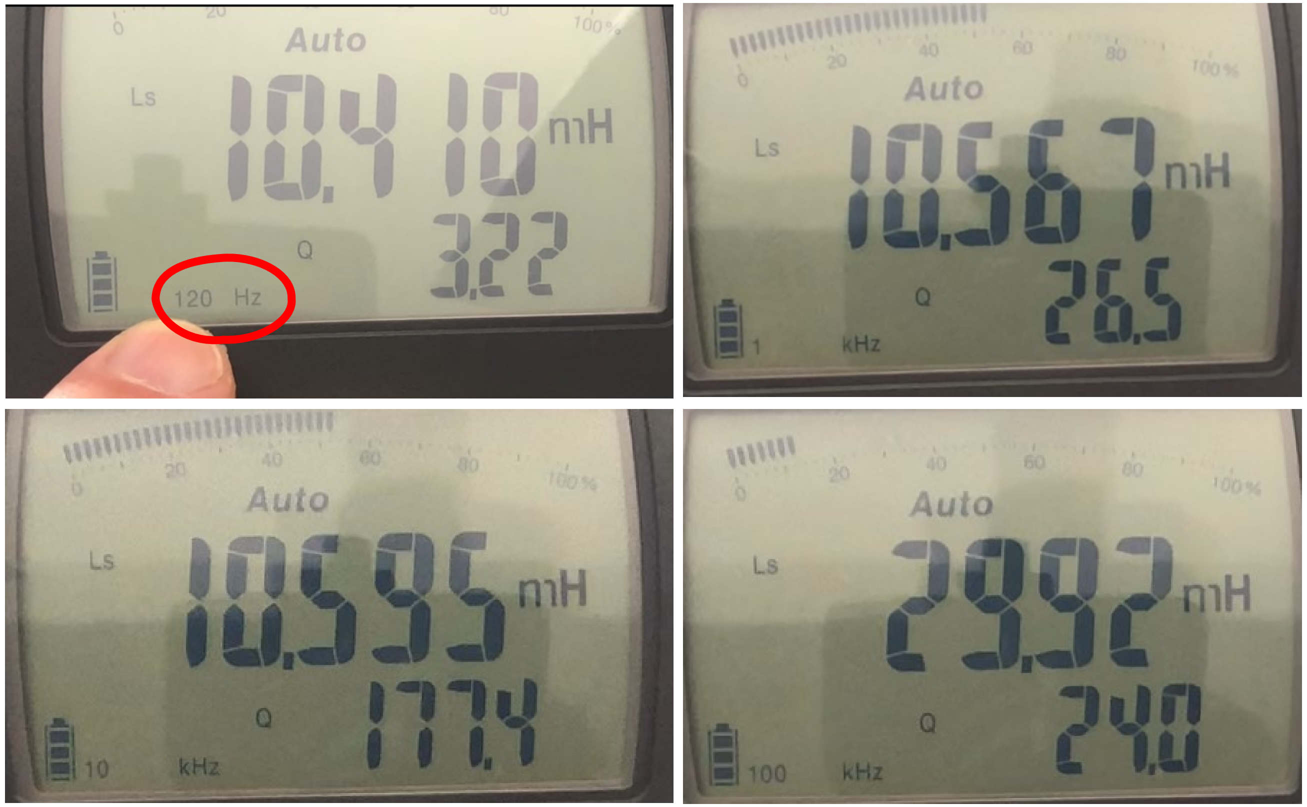
Measuring freqency 120 Hz



The Oscillator-Coil 1

// Film example: Inductance measurement on coils – inductance and quality depend on the frequency. The measuring frequency influences the result and should always be specified.

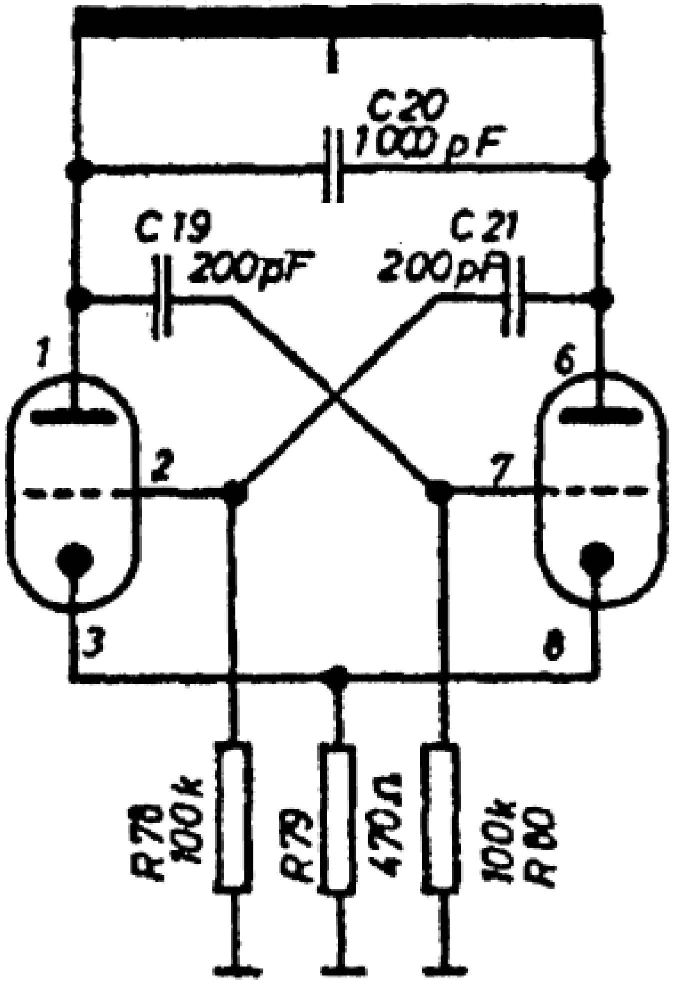
The same coil side is measured with different measuring frequencies:



Both the inductance and the coil quality factor are frequency-dependent quantities.

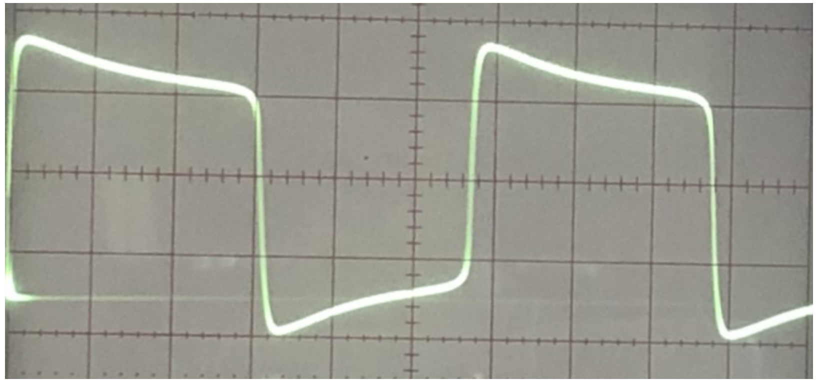
This must of course be taken into account in measurements, but also with regard to the intended use of the coil, since inductance and quality usually have to be achieved at certain target frequencies. For example at the so-called resonance frequency.

Theory LC-resonant circuit 2



We will now reassemble the two assemblies of the oscillator and see how the parallel LC resonant circuit specifically works together with the astable multivibrator.

We have found that the astable multivibrator - within the limits of its construction - produces an approximately square-wave signal.



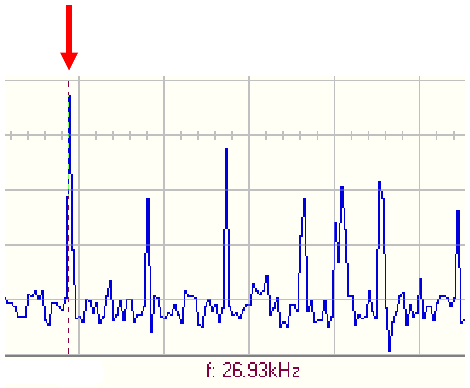
If you take a closer look at the frequency spectrum of this signal, it becomes clear that it is a broadband signal with overtones.

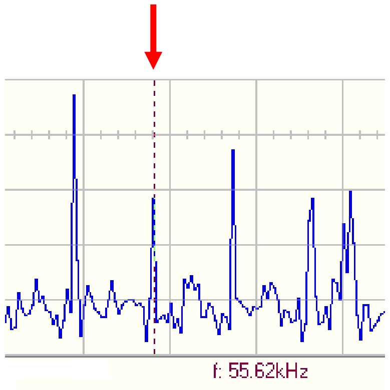
Theory LC-resonant circuit 2

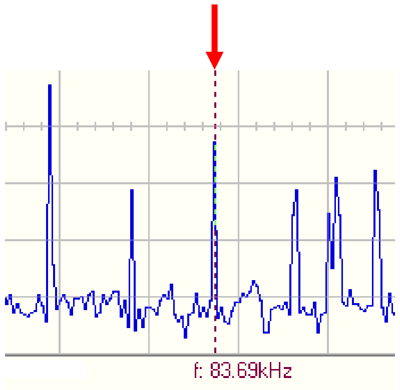
If you take a closer look at the frequency spectrum of this signal, it becomes clear that it is a broadband signal with overtones.

There is a lot of noise in the signal I measured and the signal-to-noise ratio is significantly lower "than normal". On the one hand, this is due to the unideal experimental setup with a breadboard and reduced operating voltage, and on the other hand, to the limited measuring equipment for frequency spectra available to me.

It is for illustration, not reference!

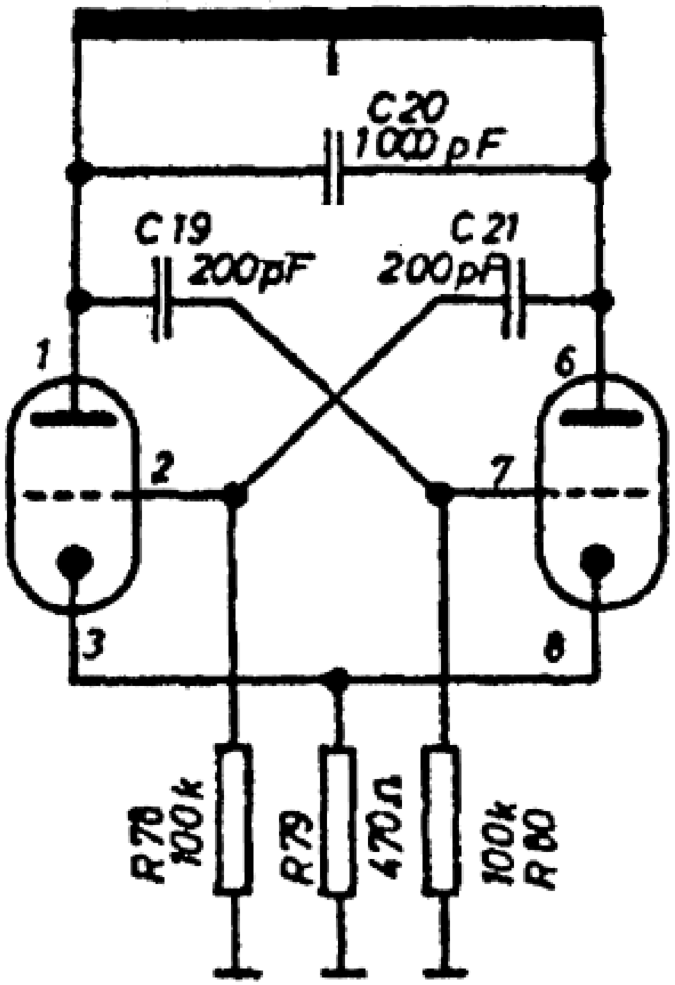






f0 of the astable multivibrator appears to be around 27 kHz. The first overtone is approximately in the region around 55 kHz, that according to theory should be the frequency at which the HF for the Echolette Oscillator should lie.

Theory LC-resonant circuit 2



On the following pages we now want to look at how the parallel LC resonant circuit behaves when it is excited by such a signal and how it happens that the HF oscillator only oscillates at one frequency in the end.

Theory LC-resonant circuit 2

A combination of coil and capacitor in the resonant circuit has a natural frequency, the resonant frequency, as shown. The LC combination adapts to this in **free oscillation**.

It now becomes interesting if one excites such an oscillating circuit with the broadband spectrum of the astable multivibrator. The resonant circuit will also oscillate here, but not freely, but in the form of **forced oscillations**.

At the resonant frequency, the LC resonant circuit has some interesting properties when it is forced to oscillate:

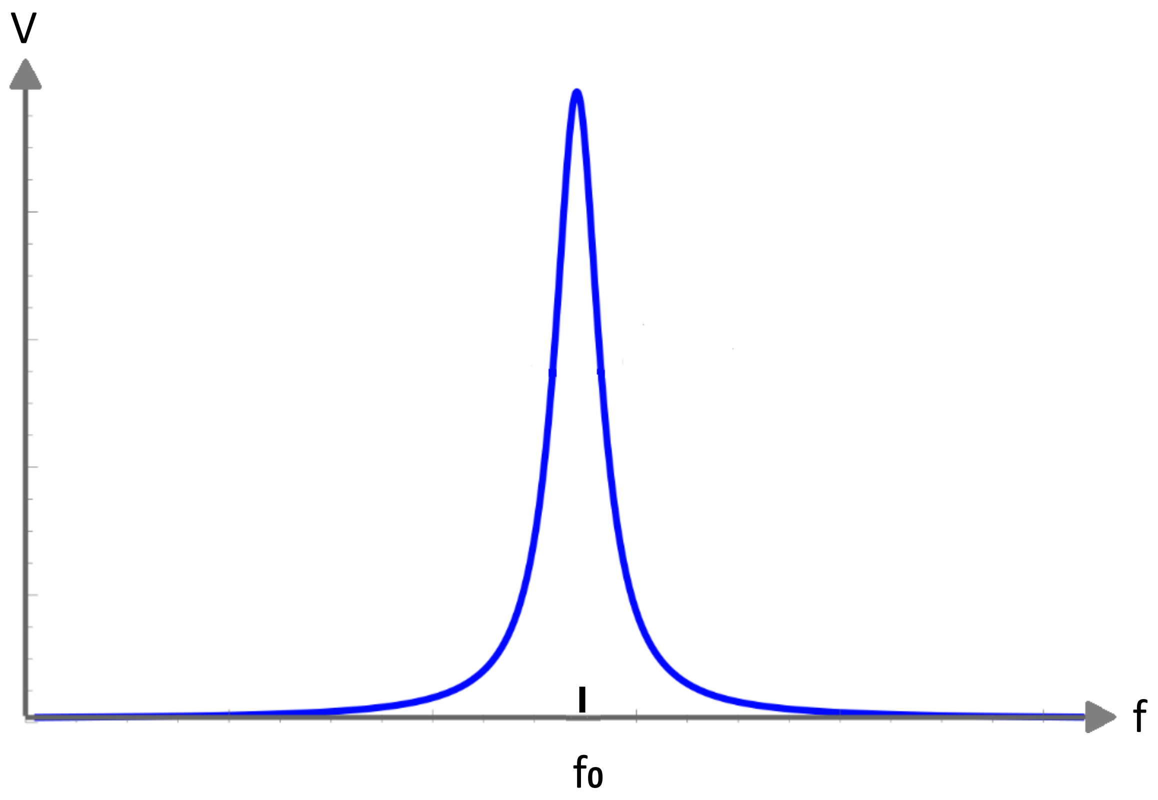
- The phase angle between current and voltage is 0 at resonance
- The reactances of the coil and the capacitor are equal at resonance
- The reactance of the oscillating circuit is at its maximum at resonance
- The highest signal amplitude can be measured on the oscillating circuit at its resonant frequency

If the forced oscillation deviates downwards or upwards from the resonant frequency, then the most noteworthy property of the resonant circuit in the focus of this consideration is that the impedance decreases for higher or lower frequencies, almost to the point of short-circuiting.

The reason for this is that a phase angle between current and voltage opens up again above and below the resonance frequency.
The oscillating circuit behaves inductively at lower frequencies and capacitively at higher frequencies. We remember: the reactance of the capacitor decreases at higher frequencies; the coil reactance does this at lower frequencies.

Theory LC-resonant circuit 2

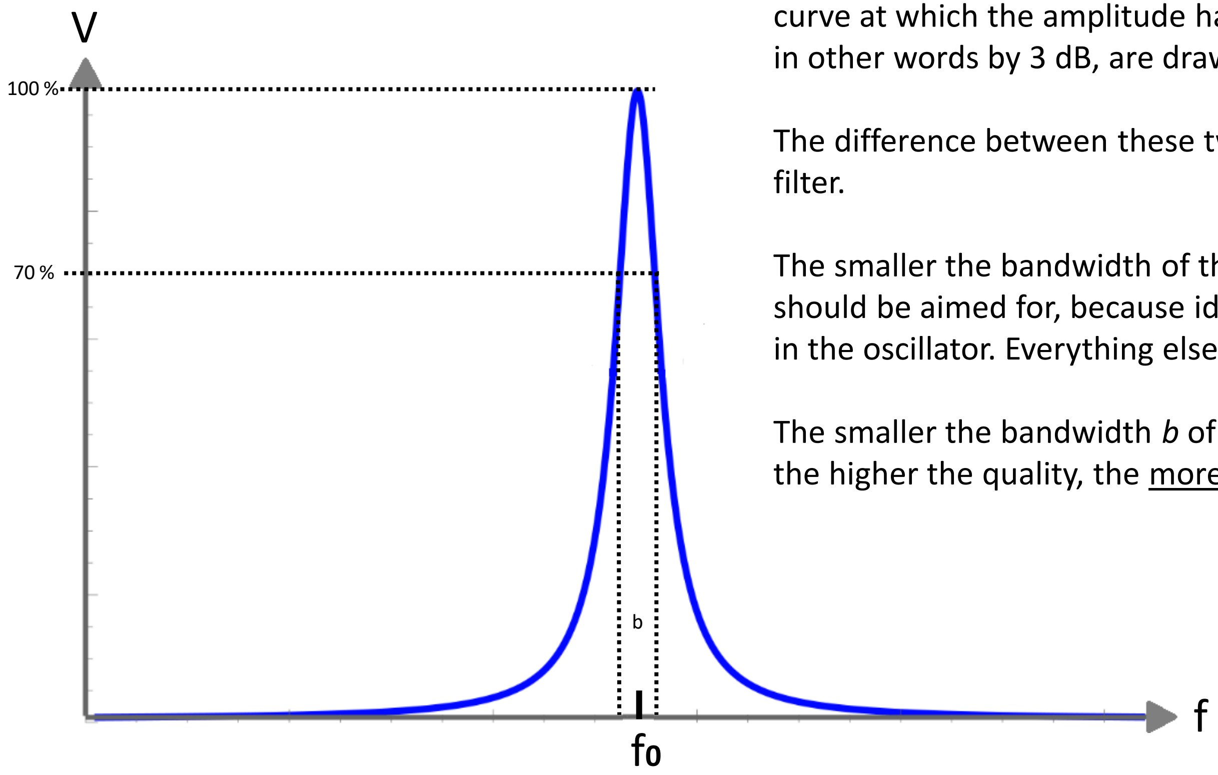
If you plot the voltage that can be measured on the resonant circuit against the frequency in a graph, then something like the following results:



Above and below a more or less narrow range around the resonant frequency **f_0**, the signal amplitudes in the parallel resonant circuit decrease rapidly. The parallel LC resonant circuit is therefore suitable as a **filter** to filter out the frequency from a mixture of frequencies that corresponds to the resonant frequency of the resonant circuit.

Theory LC-resonant circuit 2

How accurate is this filter? This is where the term "**quality**" comes into play.



Starting from the maximum amplitude at resonance, the two points on the curve at which the amplitude has dropped to 70% of the maximum value, or in other words by 3 dB, are drawn to the left and right of the resonance.

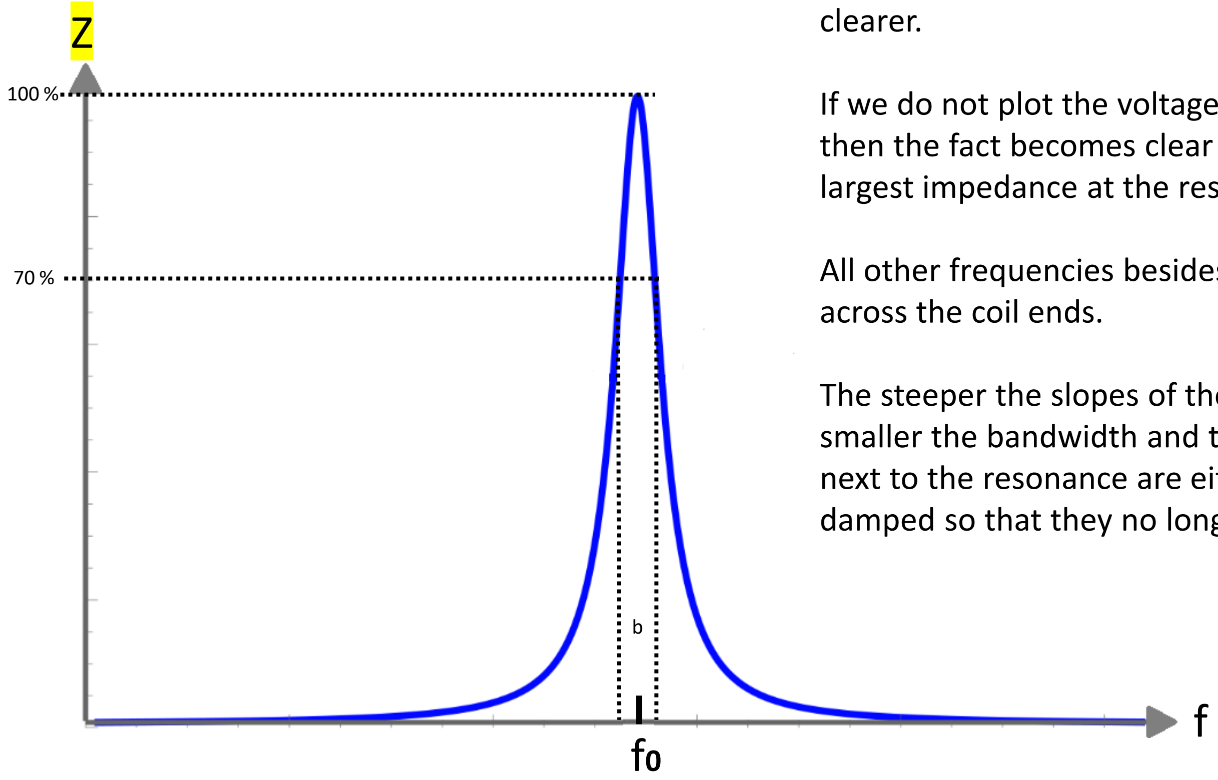
The difference between these two frequencies is the **bandwidth** *b* of the LC filter.

The smaller the bandwidth of the filter, the higher the *quality*. A high quality should be aimed for, because ideally we only want to use a single frequency in the oscillator. Everything else should be filtered out.

The smaller the bandwidth *b* of the filter, the higher its *Q*
the higher the quality, the more selective the resonance.

Theory LC-resonant circuit 2

How is the resonance frequency filtered out?



We can read the curve a little differently, then this connection becomes clearer.

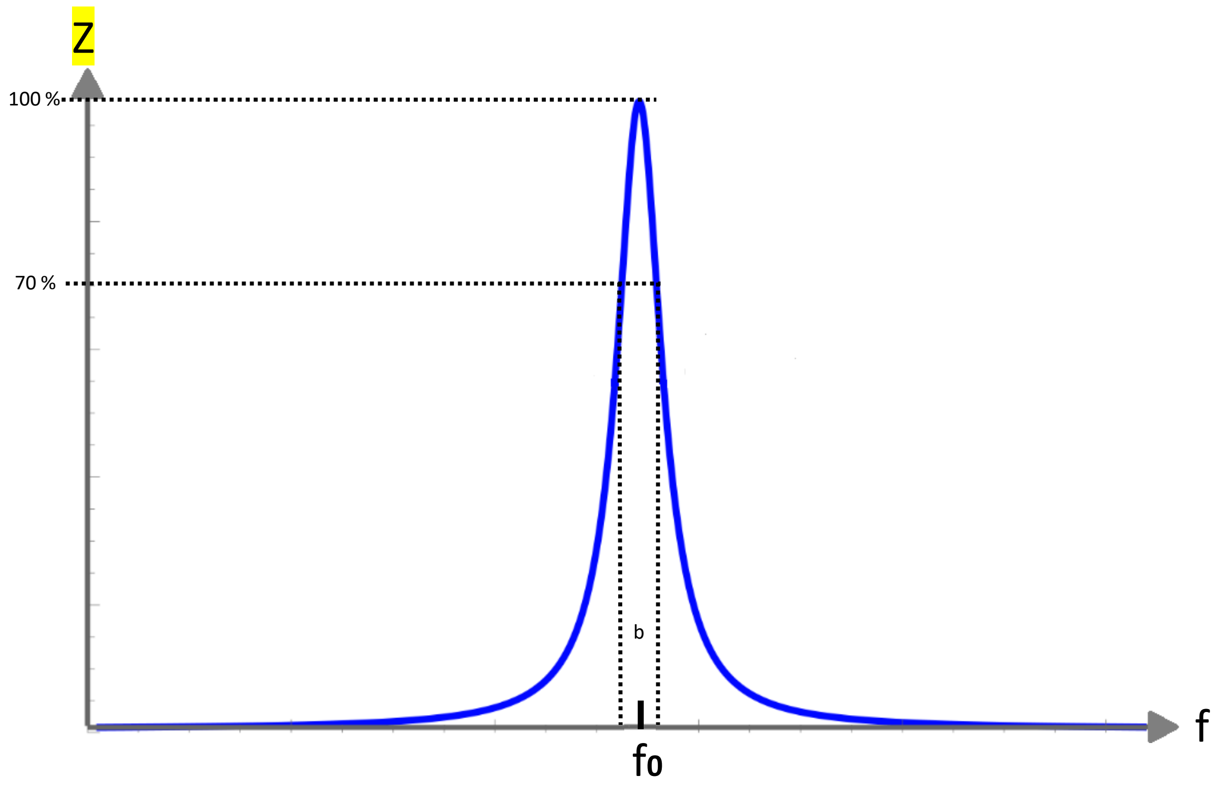
If we do not plot the voltage V on the Y-axis, but rather the **impedance Z**, then the fact becomes clear that the parallel LC resonant circuit has the largest impedance at the resonant frequency.

All other frequencies besides the resonant frequency are short-circuited across the coil ends.

The steeper the slopes of the impedance frequency curve rise/fall, the smaller the bandwidth and the higher the quality: Ideally, all frequencies next to the resonance are either completely short-circuited or sufficiently damped so that they no longer play a role.

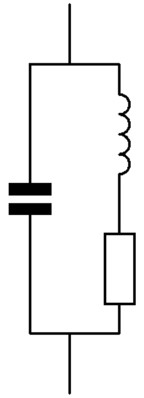
Theory LC-resonant circuit 2

How is the resonance frequency filtered out?



The quality of the oscillating circuit mainly depends on the quality of the coil, so special attention should be paid to this when replacing this coil.

Different factors are relevant for the quality of the coil, which a look at an equivalent circuit diagram of a coil reveals:



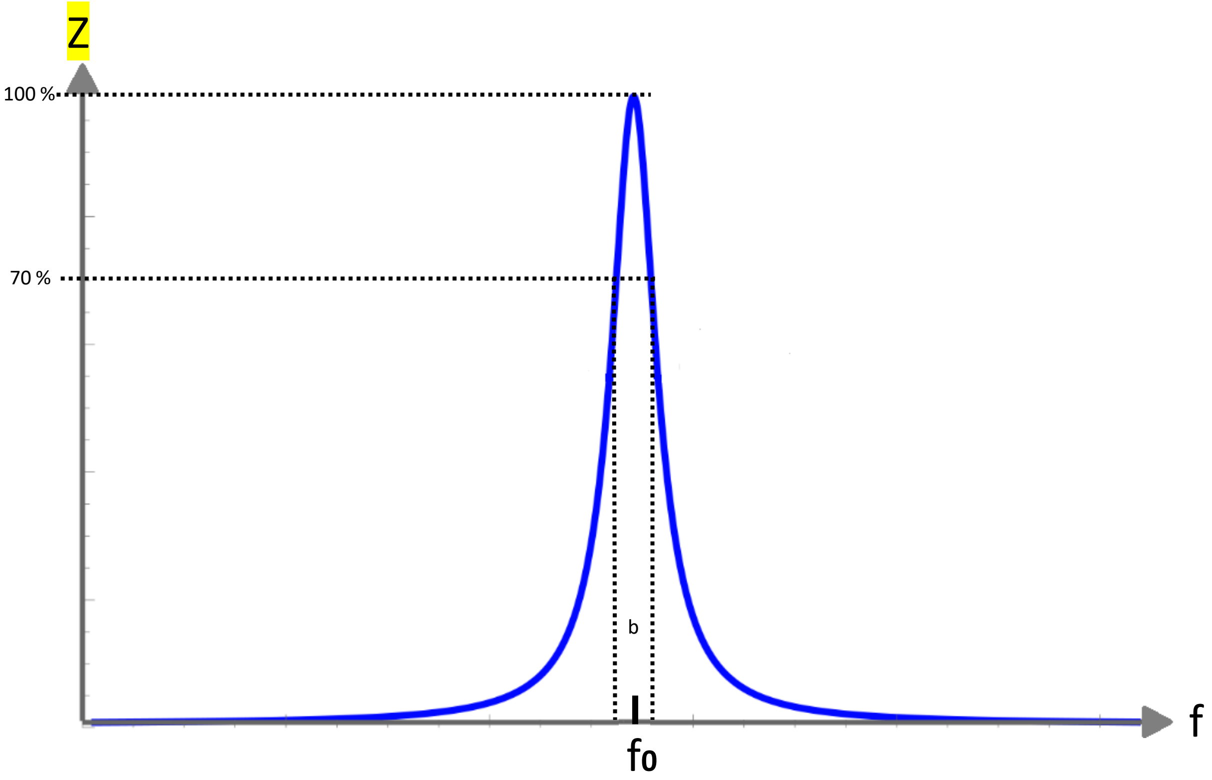
- The DC resistance of the coil, which depends on the wire length and number of turns.
- The capacitance of adjacent turns, which increases with the number of turns.

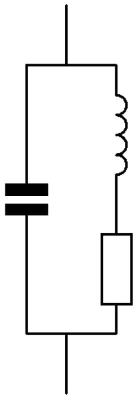
→ Equation:

$$Q = 2\pi \frac{L f_0}{R}$$

Theory LC-resonant circuit 2

How is the resonance frequency filtered out?





→ Equation:

$$Q = 2\pi \frac{L\, f_0}{R}$$

- The smaller the DC resistance *R* in the equivalent circuit diagram, the higher the quality.
- In order to reduce R, among other things, special wire ("HF braids") can be used, which reduce the "skin effect" at high frequencies.

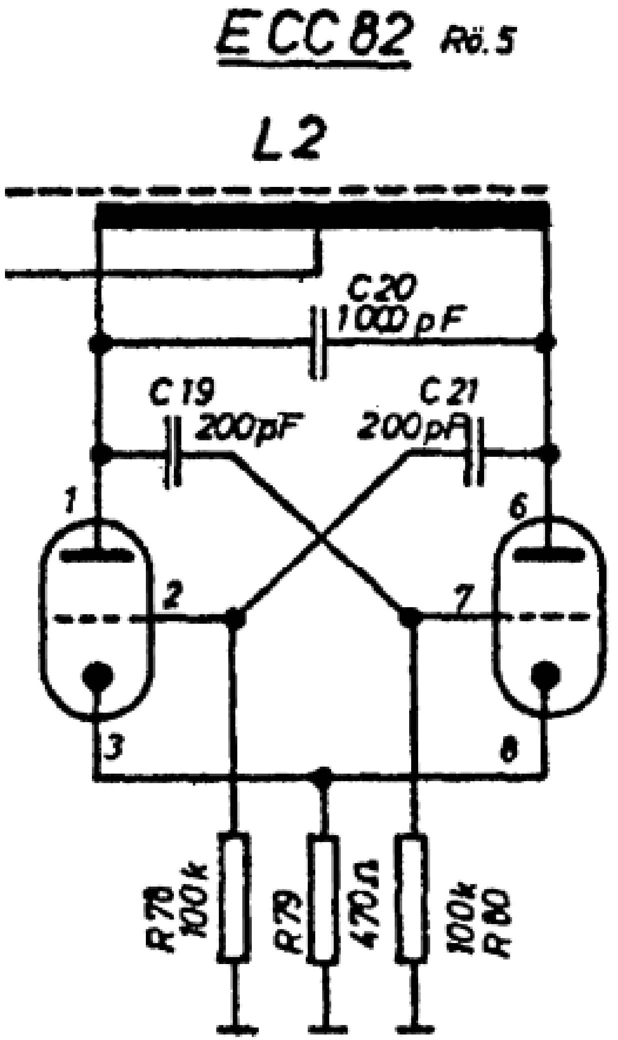
Inductance and reactance increase with the square of the number of turns, but R increases linearly.

Low-loss core material (siferrite!) also improves the quality.

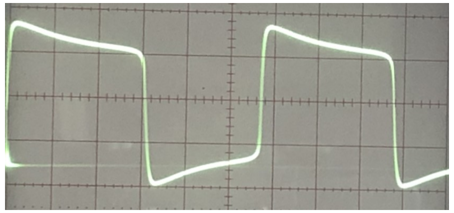
The capacitance between the wire windings can be minimized by special winding techniques (“cross winding”).

In the worst case, this capacitance has the effect that the coil has a natural resonance even without the oscillating circuit capacitor. Above the frequency of this natural resonance, it is actually no longer usable.

The Oscillator-Coil 2

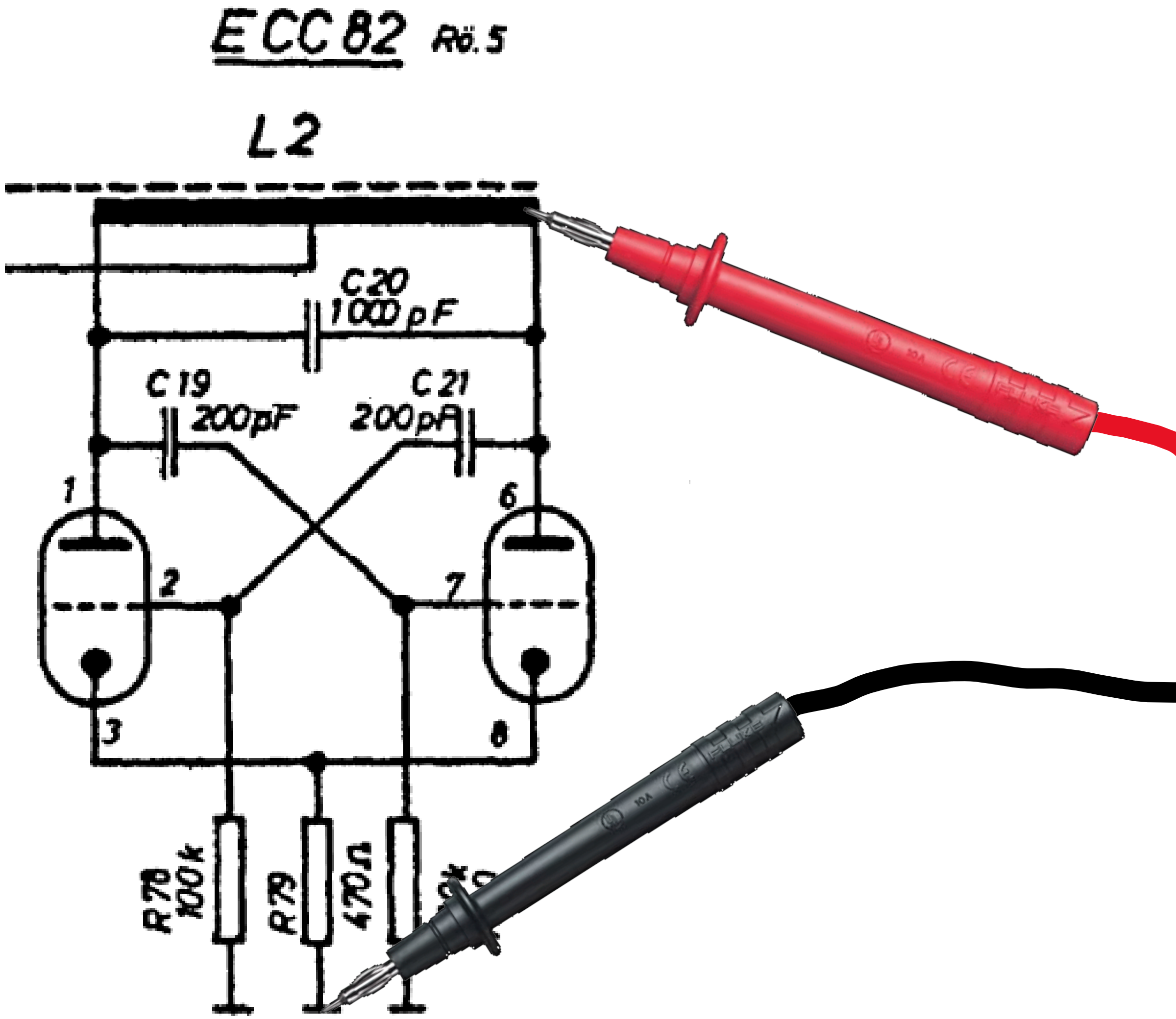


Now that the basics of the LC filter have been covered, let's look at what it does with the multivibrator's square wave!

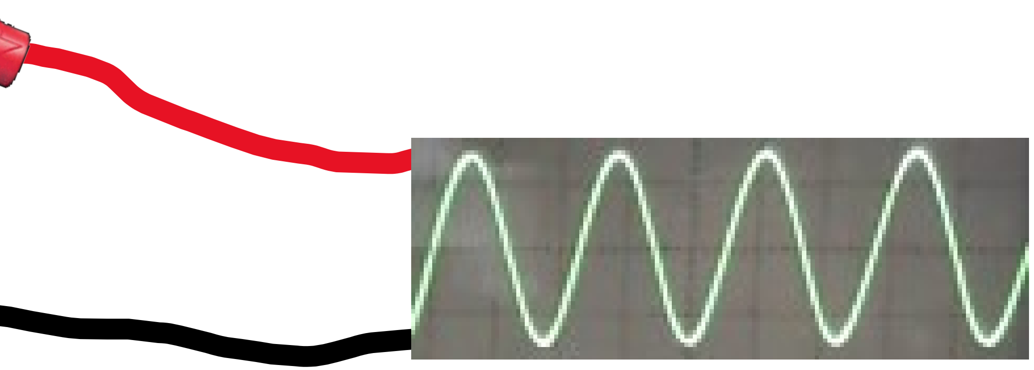


?

The Oscillator-Coil 2



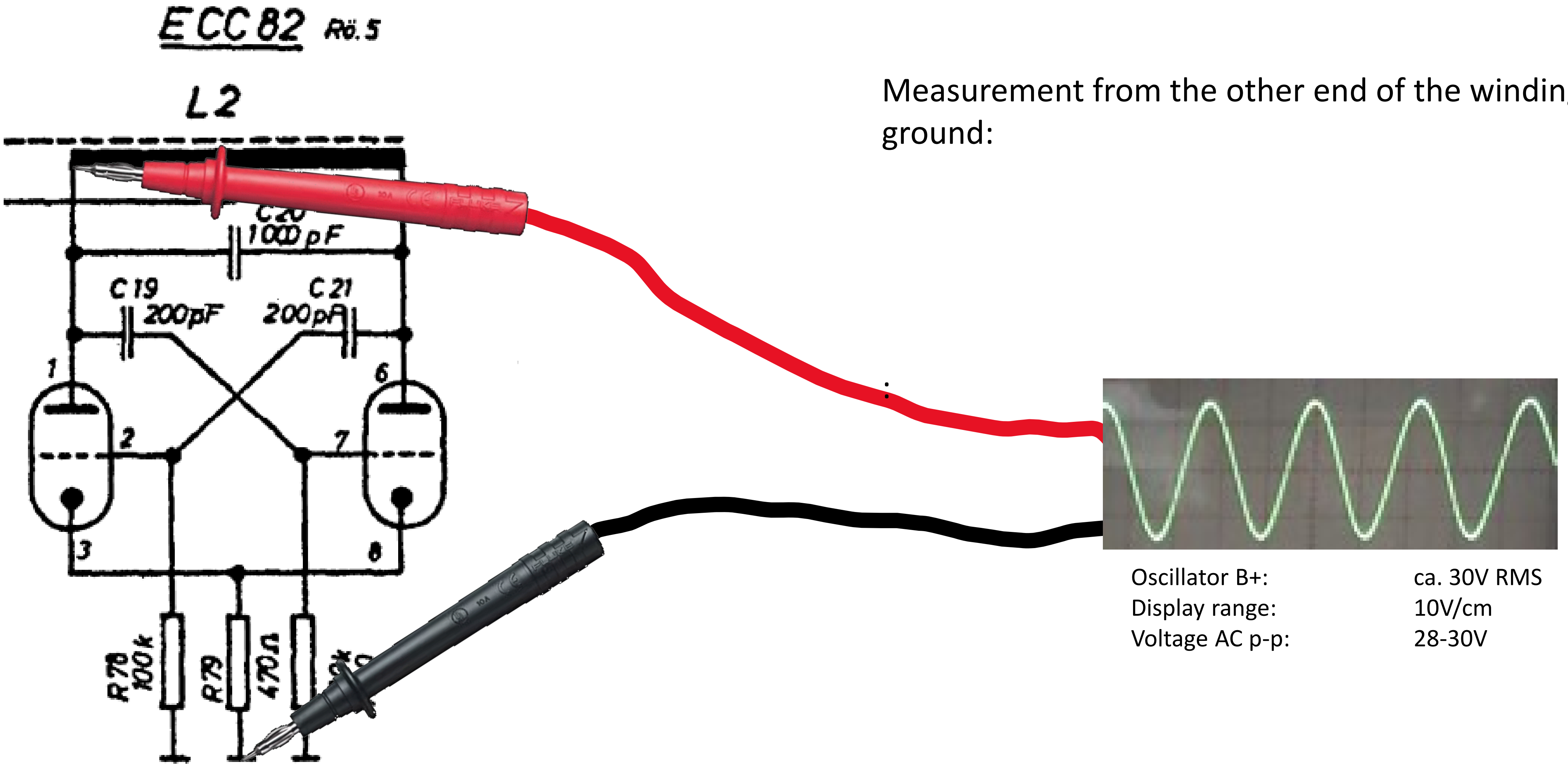
Measurement from one winding end to ground:



Oscillator B+:	ca. 30V RMS
Display range:	10V/cm
Voltage AC p-p:	28-30V

The Oscillator-Coil 2

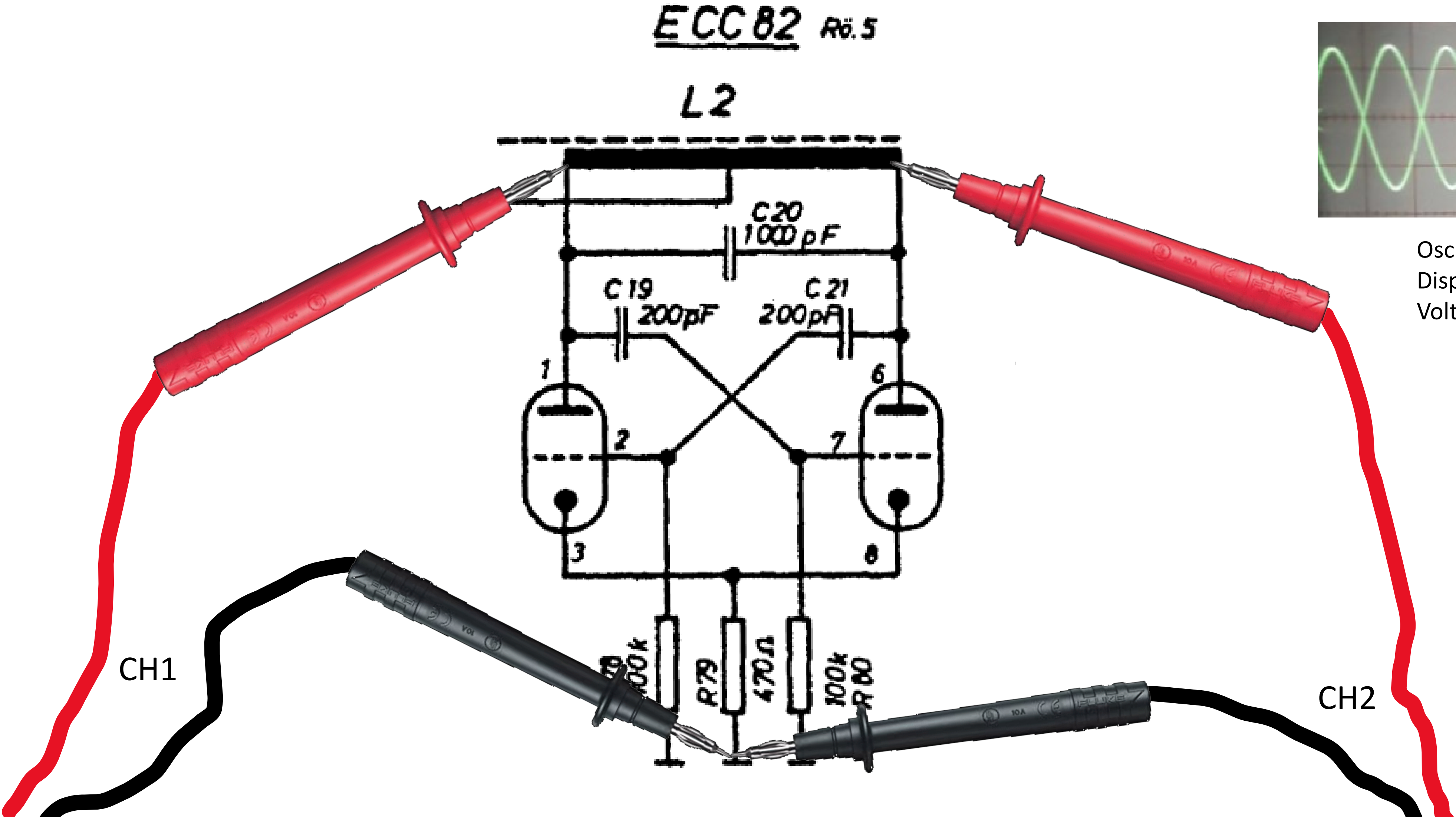
Measurement from the other end of the winding to ground:

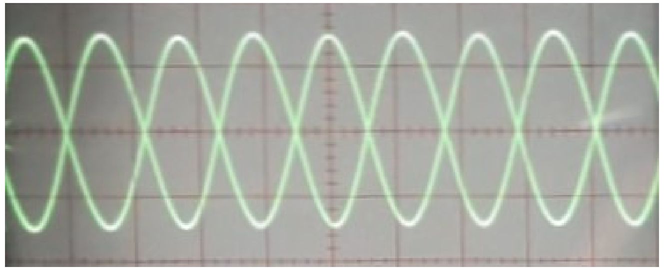


Oscillator B+:	ca. 30V RMS
Display range:	10V/cm
Voltage AC p-p:	28-30V

The Oscillator-Coil 2

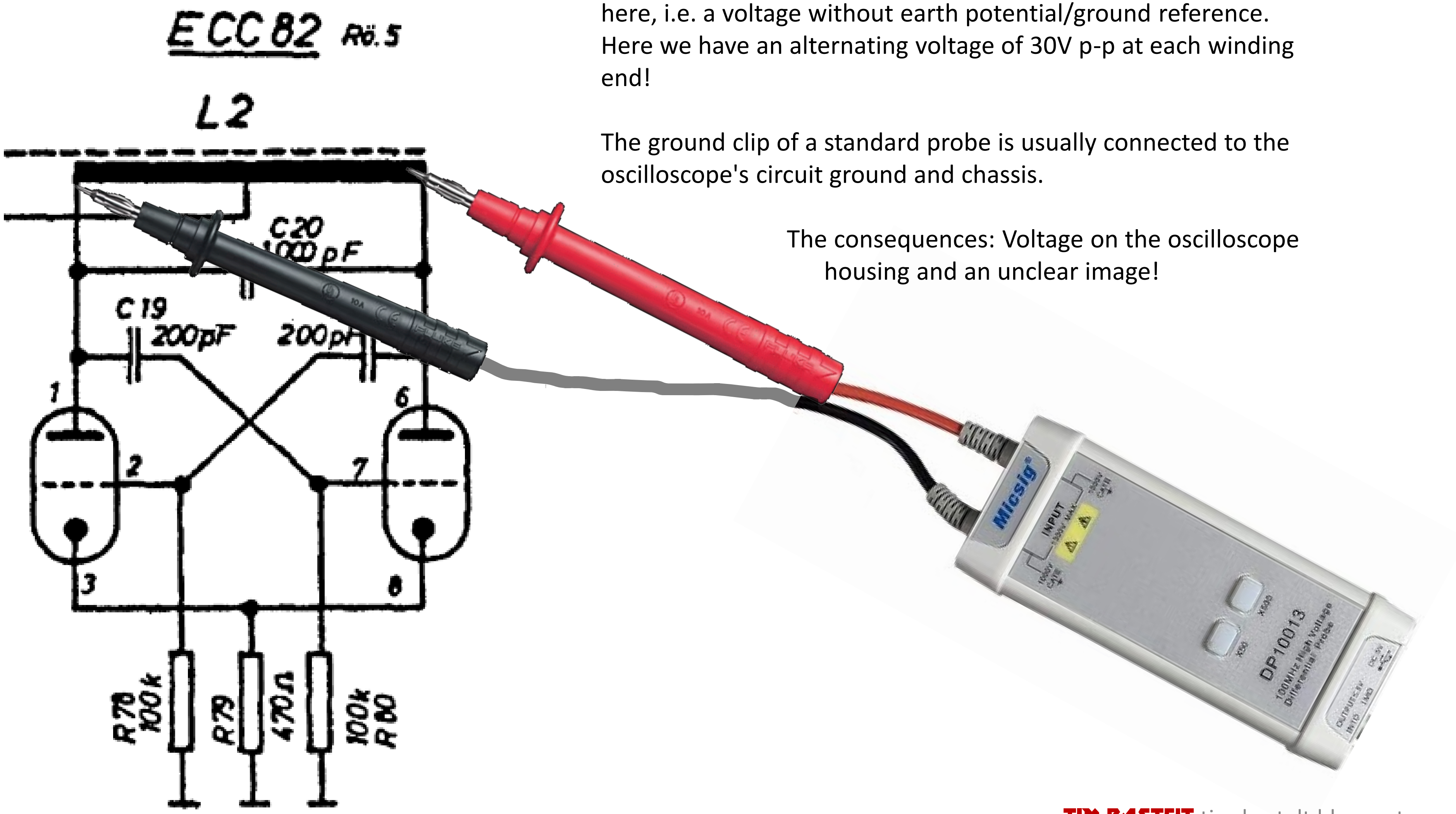
Both ends measured to ground:
Signals phase shifted by 180°





Oscillator B+:	ca. 30V RMS
Display range:	10V/cm
Voltage AC p-p:	28-30V

The Oscillator-Coil 2



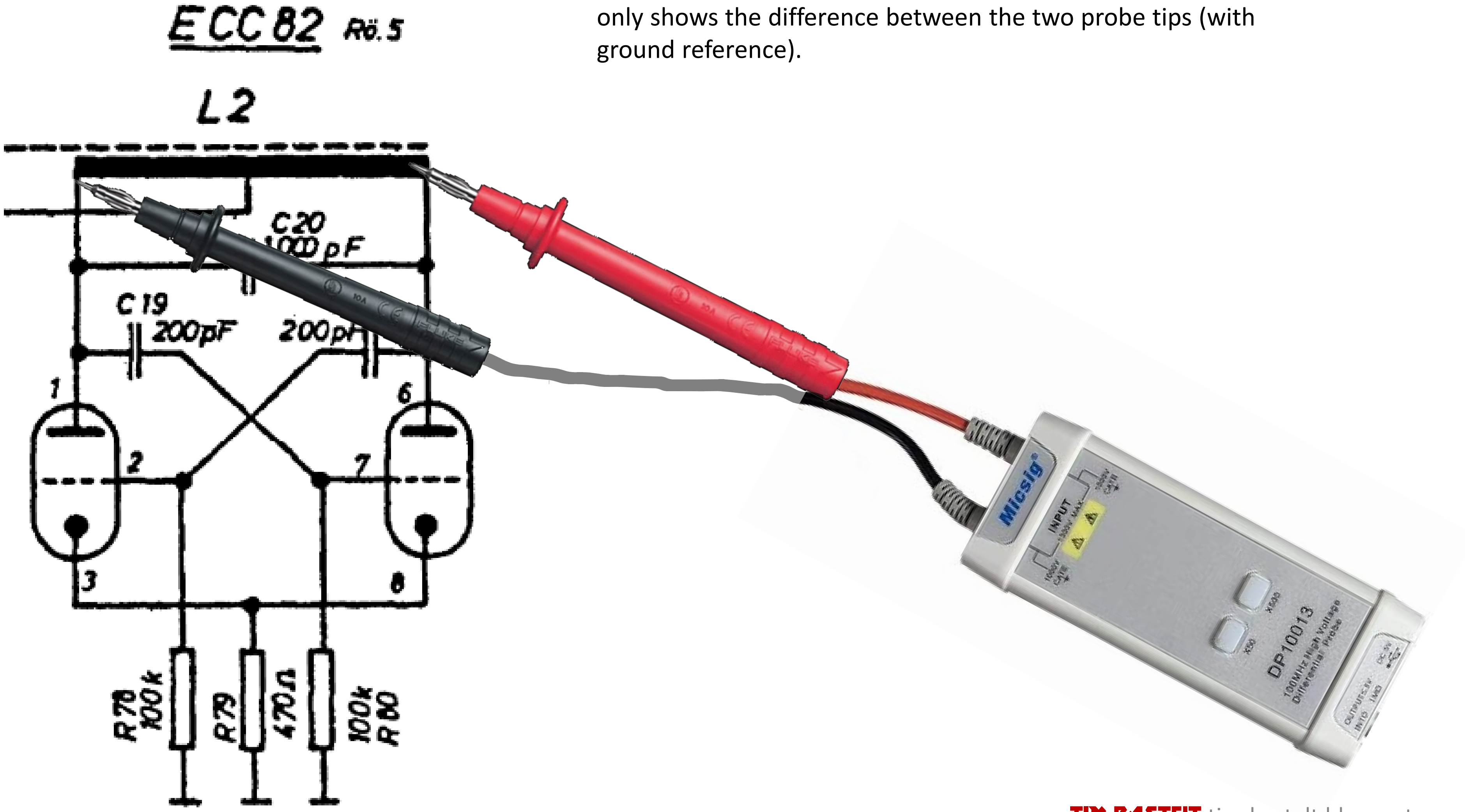
Measurement across the winding ends:

It should be noted here that a "floating" voltage is measured here, i.e. a voltage without earth potential/ground reference. Here we have an alternating voltage of 30V p-p at each winding end!

The ground clip of a standard probe is usually connected to the oscilloscope's circuit ground and chassis.

The consequences: Voltage on the oscilloscope housing and an unclear image!

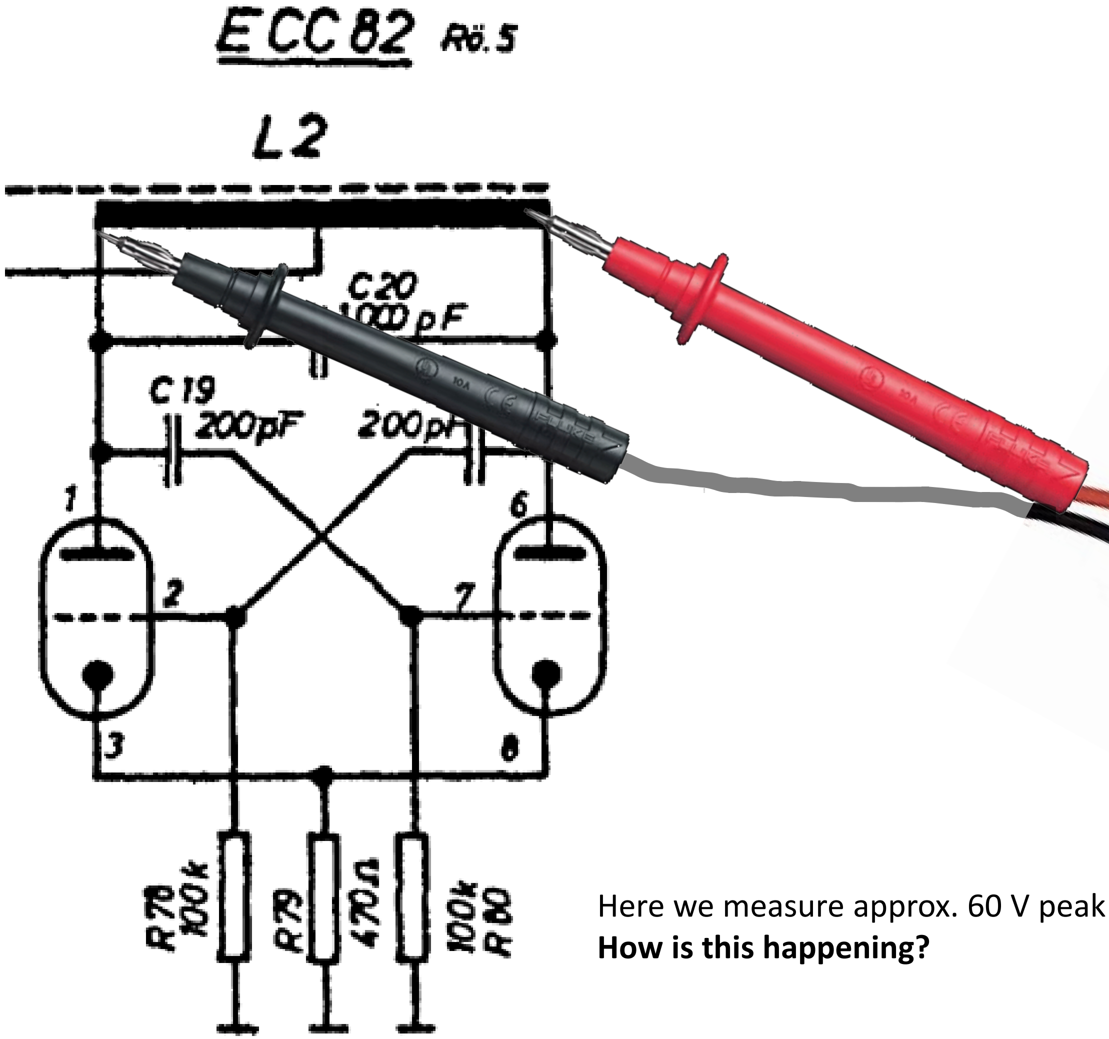
The Oscillator-Coil 2

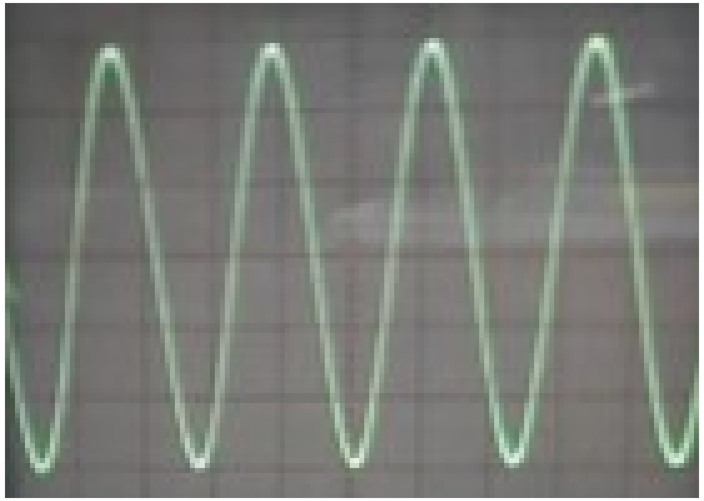


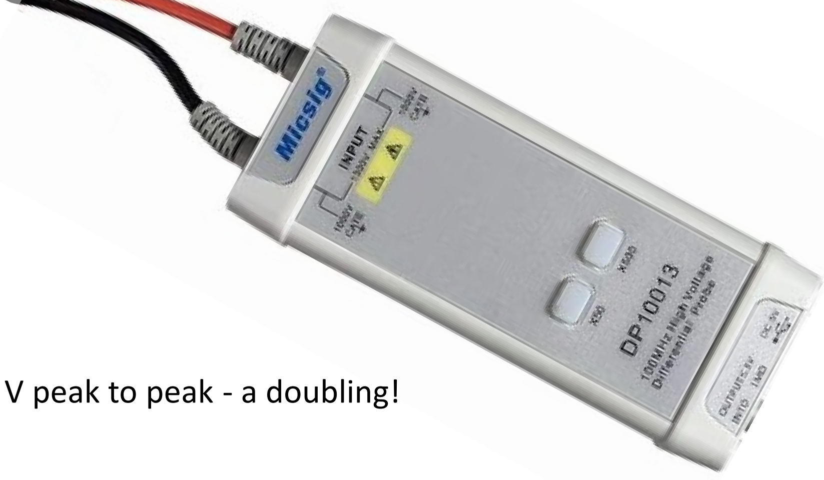
Measurement across the winding ends:

Here you need a **differential probe**, this is an active probe that only shows the difference between the two probe tips (with ground reference).

The Oscillator-Coil 2

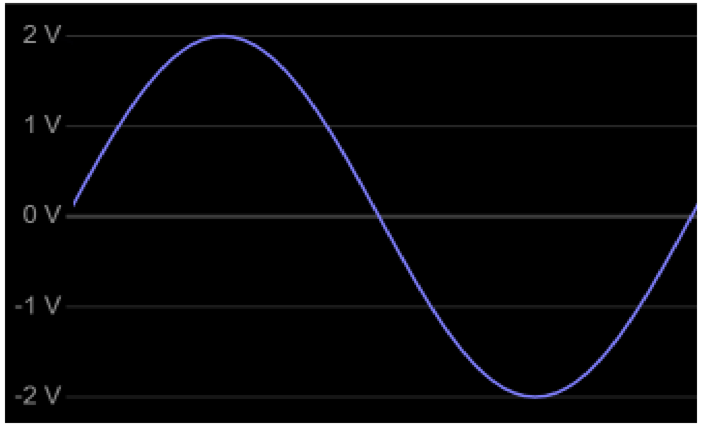


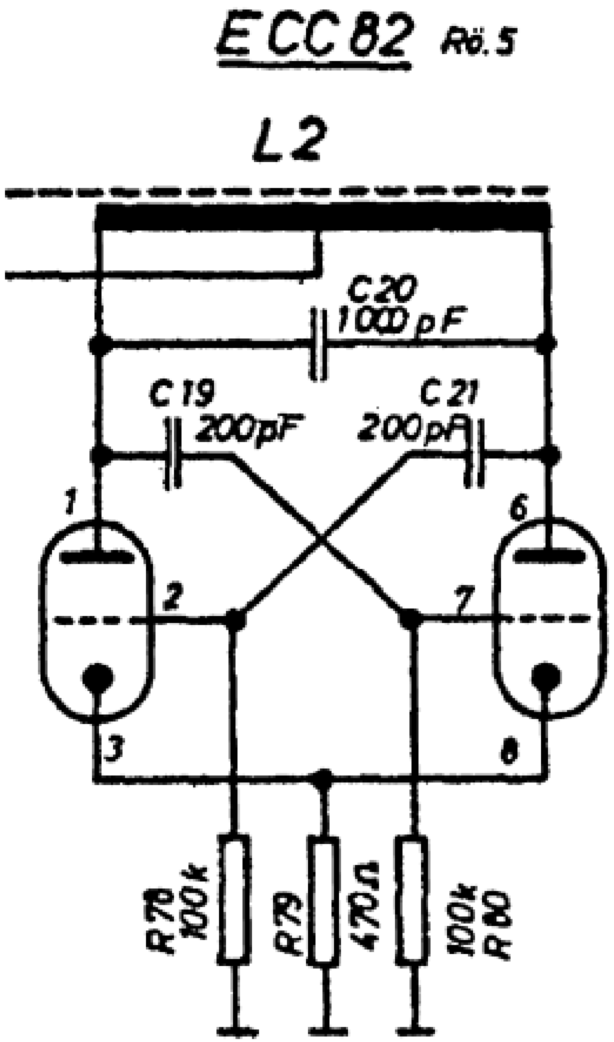


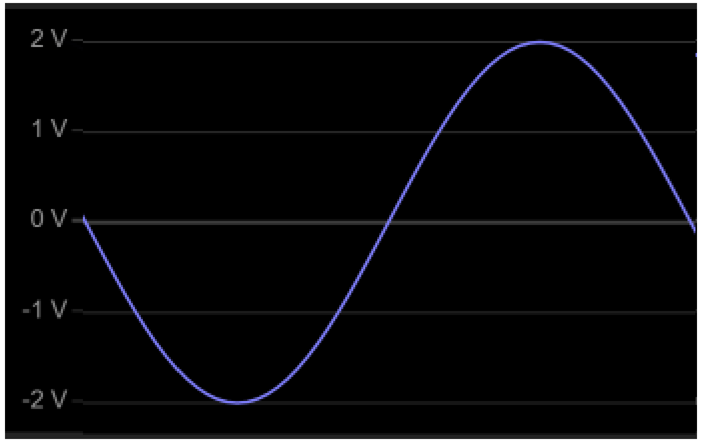


Here we measure approx. 60 V peak to peak - a doubling!
How is this happening?

The Oscillator-Coil 2







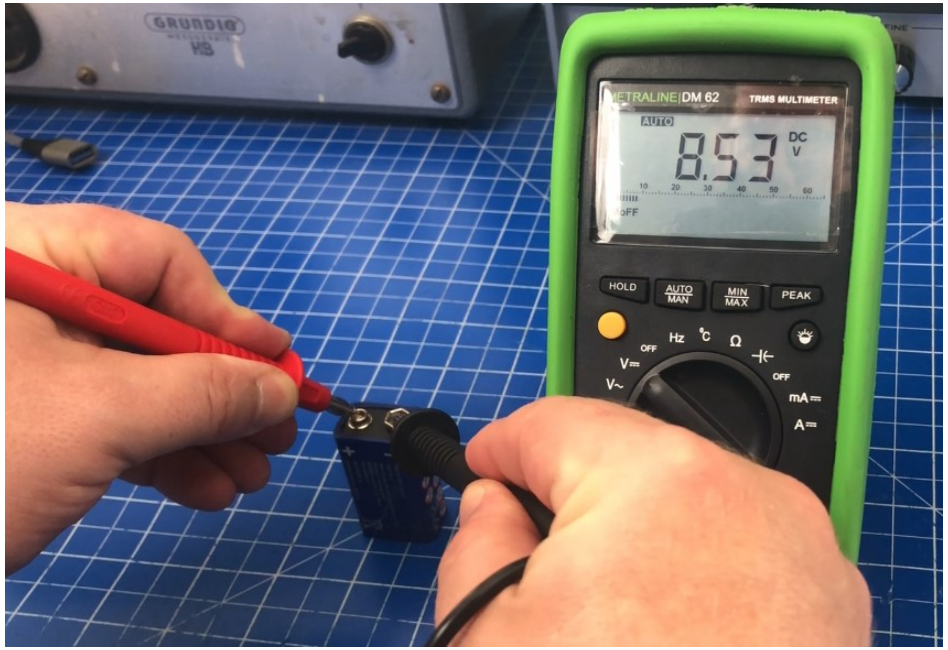
The voltage doubling is easy to explain: it is related to the reference potential of the voltage.

Let's look at a very simple experiment:

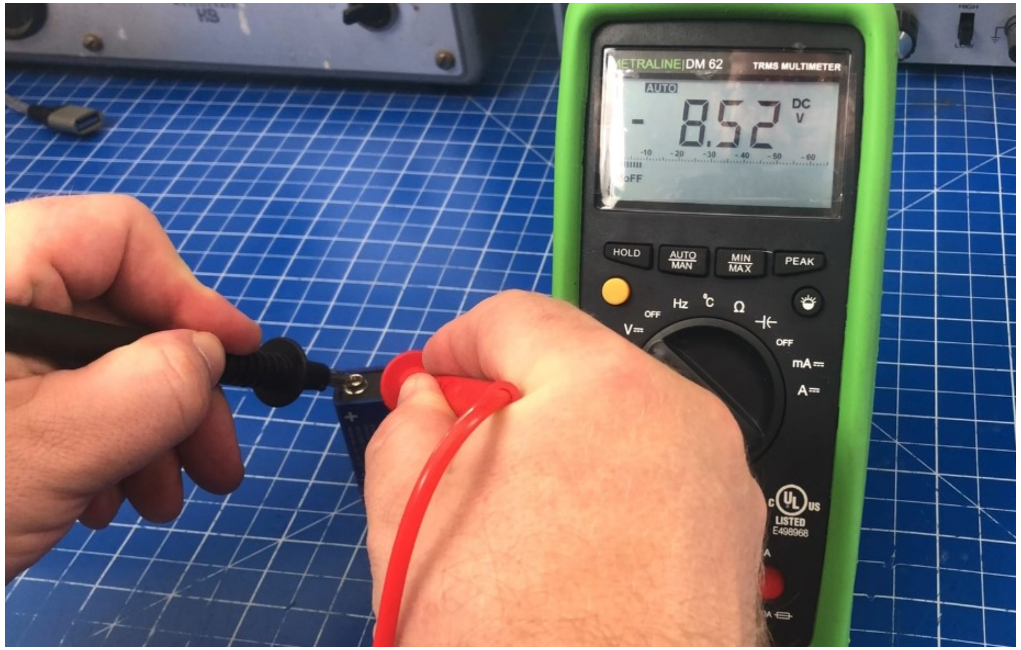
The Oscillator-Coil 2

// Short clip for better understanding: reference potential – measurement of 9V battery; 1x +9V and once -9V depending on whether the black probe is set to the lower or higher potential

If we measure the voltage of a 9V battery with a multimeter, the displayed voltage depends on the reference potential of the ground probe (black measuring tip). By convention, the black tip is to be placed on the negative pole and the red tip on the positive pole. The multimeter then shows +8.53 V. If we swap the tips, then the black is now on the higher potential (positive pole) and the red on the lower (negative pole). The voltage is then -8.53 V although it is the same battery.

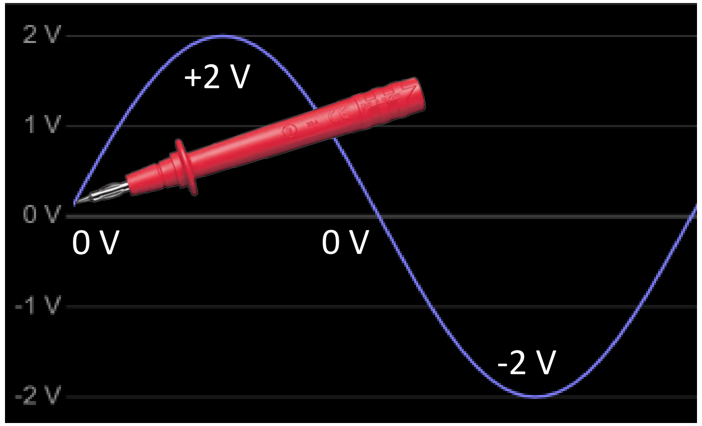


Red on + : +8,53 V



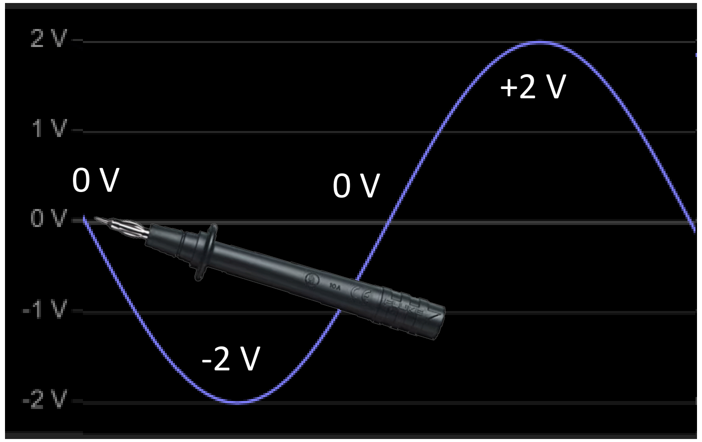
Red on - : -8,53 V

The Oscillator-Coil 2

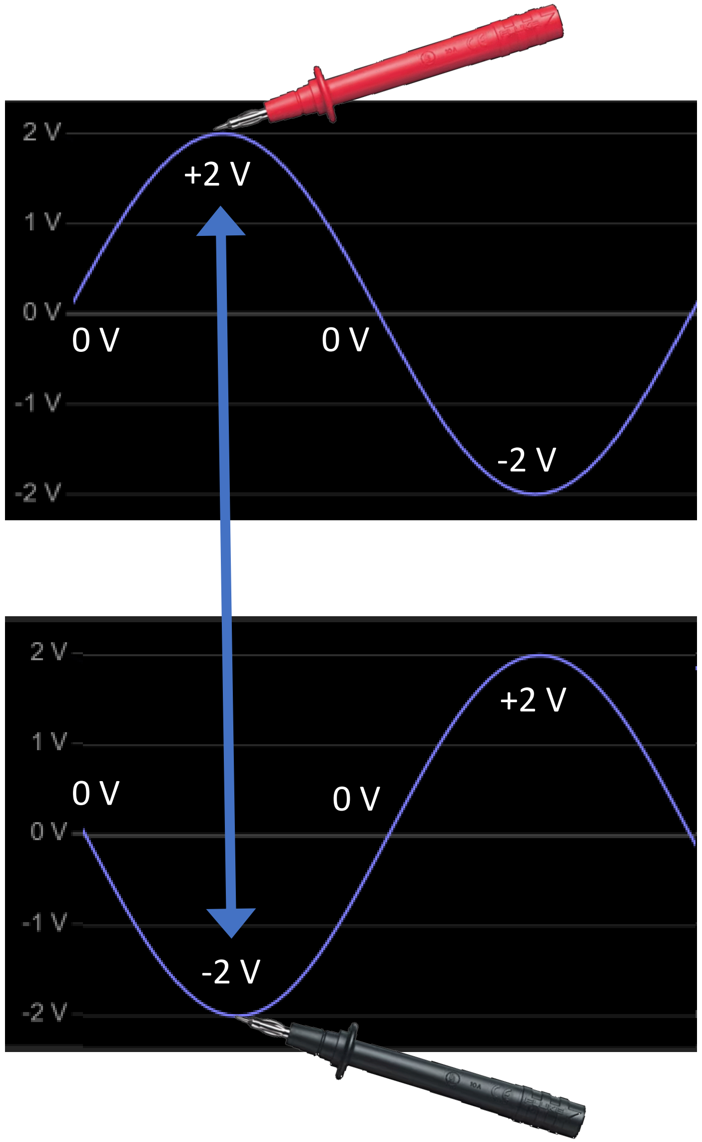


We now have the two voltages at the winding ends rotated by 180° and start measuring at the "zero point". The displayed voltages are freely chosen to explain the principle.

The voltage difference is **0V** at the first measuring point.

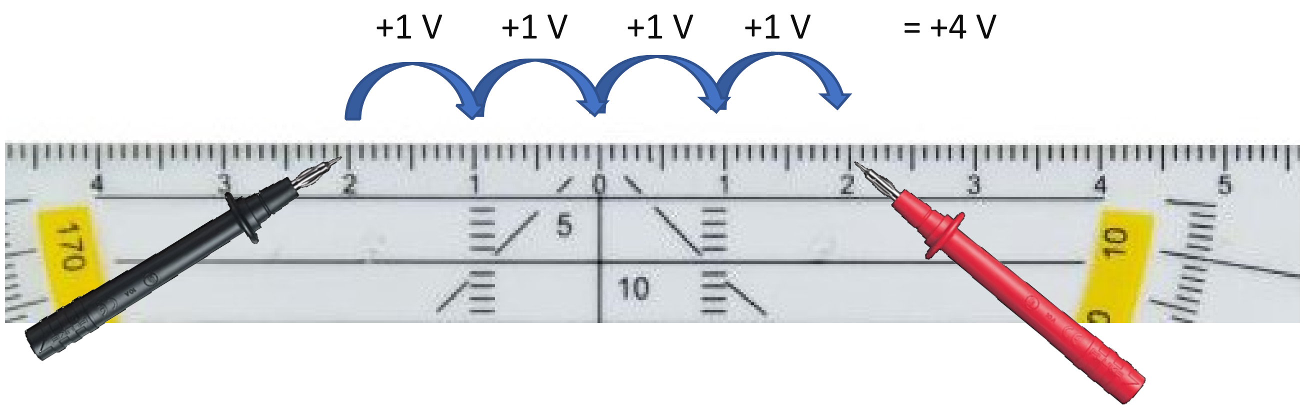


The Oscillator-Coil 2



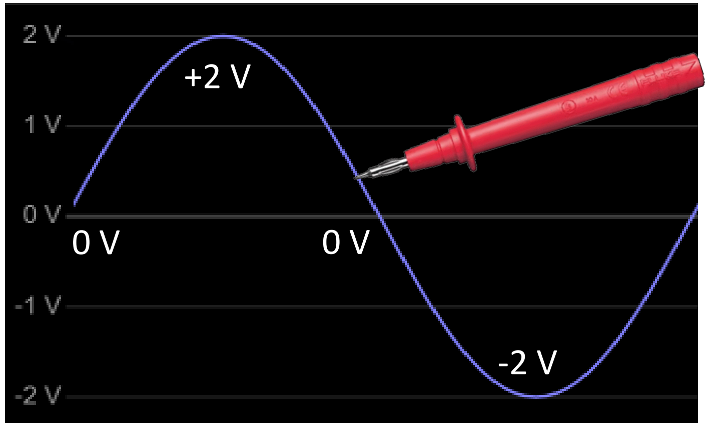
We now measure at the next point, a quarter of a cycle further.

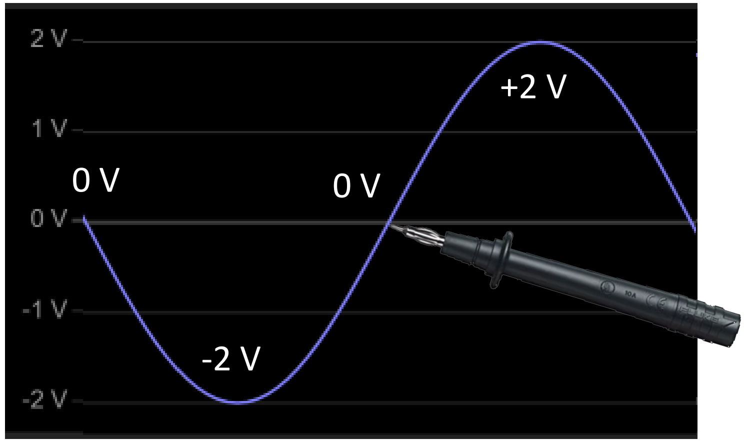
The voltage difference between -2V and +2V is **+4V**. Positive since the black probe is at the lower potential.



The Oscillator-Coil 2

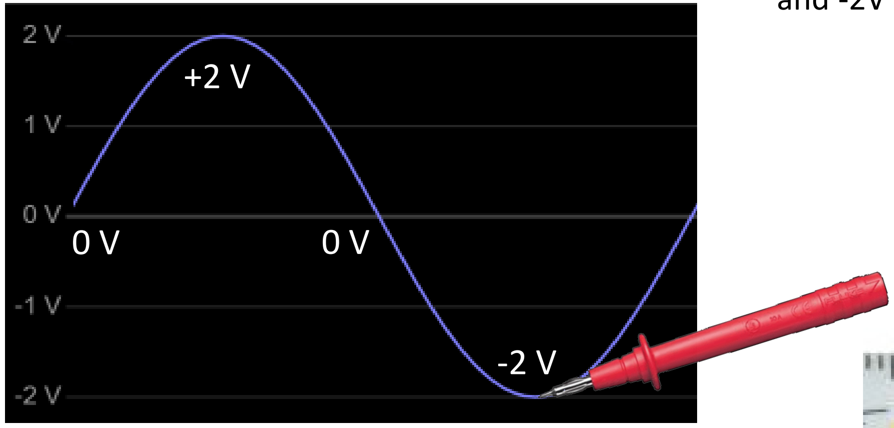
At the third measuring point, both curves are at 0V, i.e. voltage difference: **0V**.

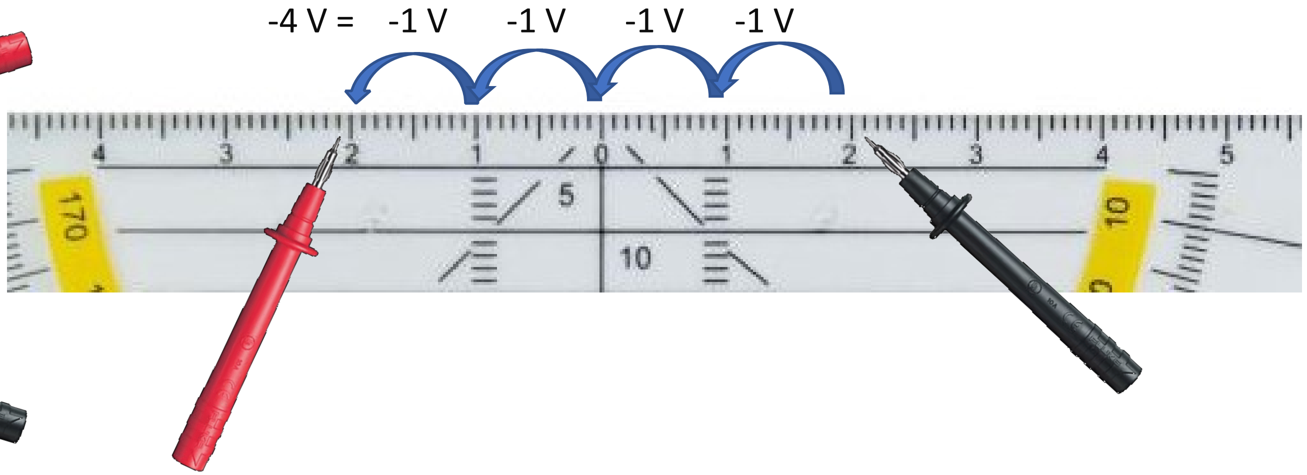


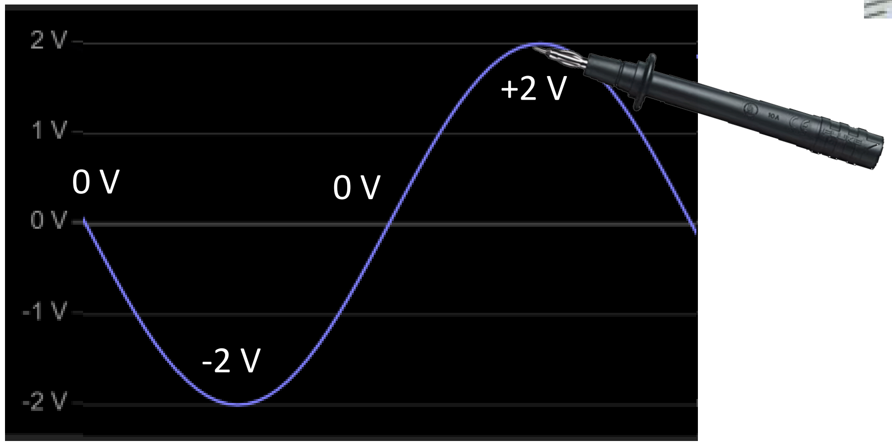


The Oscillator-Coil 2

At the last measuring point, red is now on the lower potential and black on the higher. Between +2V and -2V we have a voltage difference of: **-4V**.

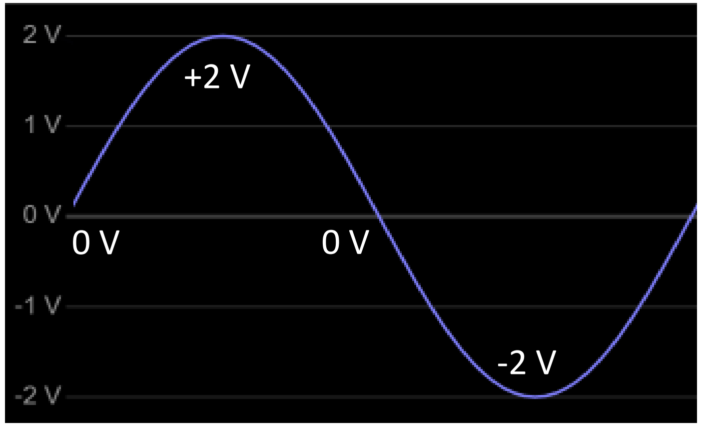




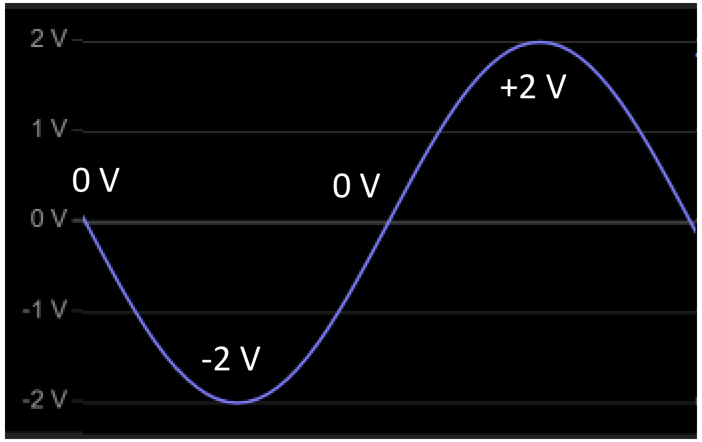


The Oscillator-Coil 2

Winding end 1



Winding end 2

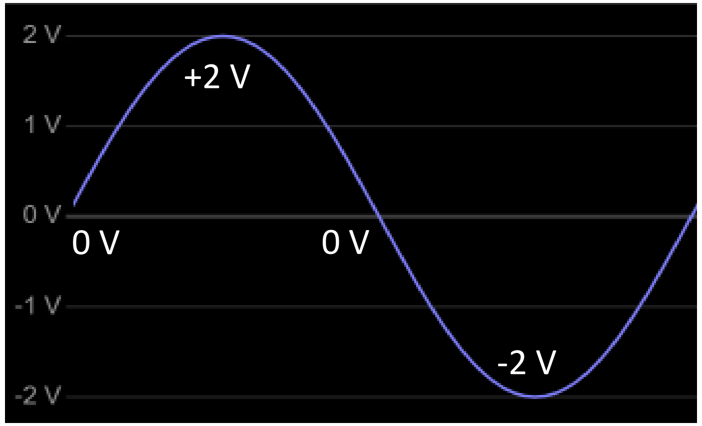


So we measured: 0V, +4V, 0V, -4V

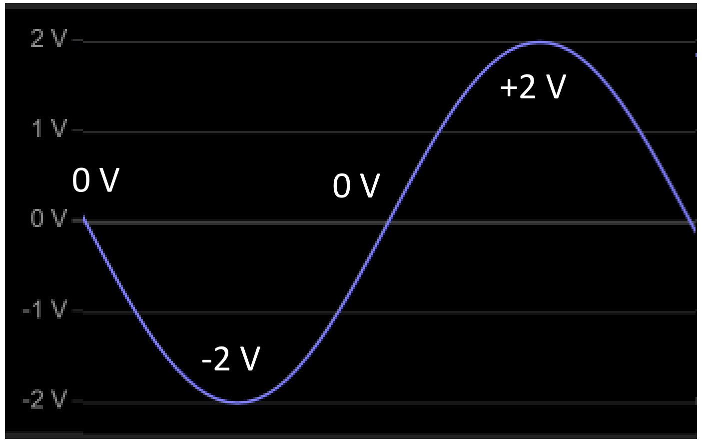
This results in…

The Oscillator-Coil 2

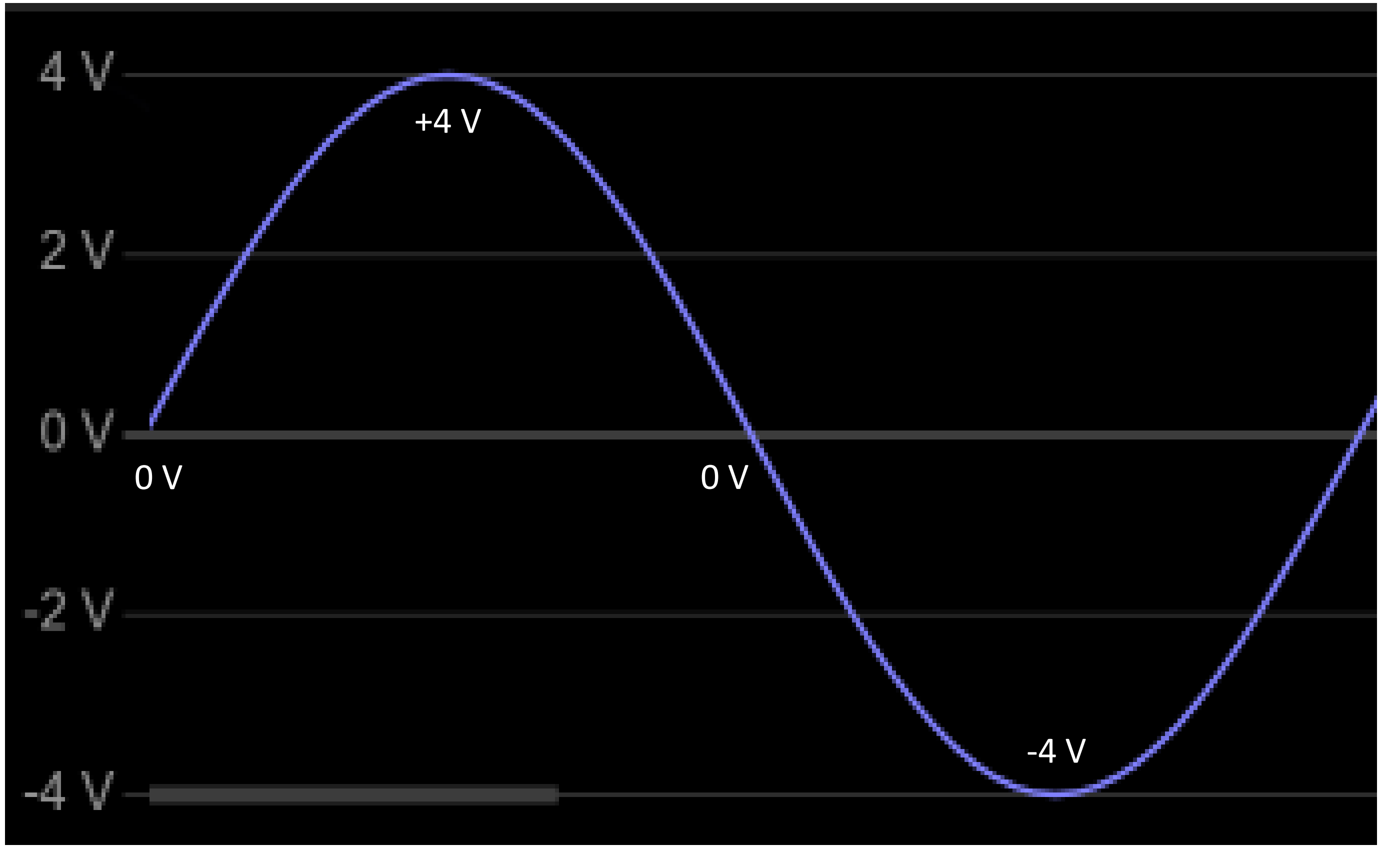
Winding end 1



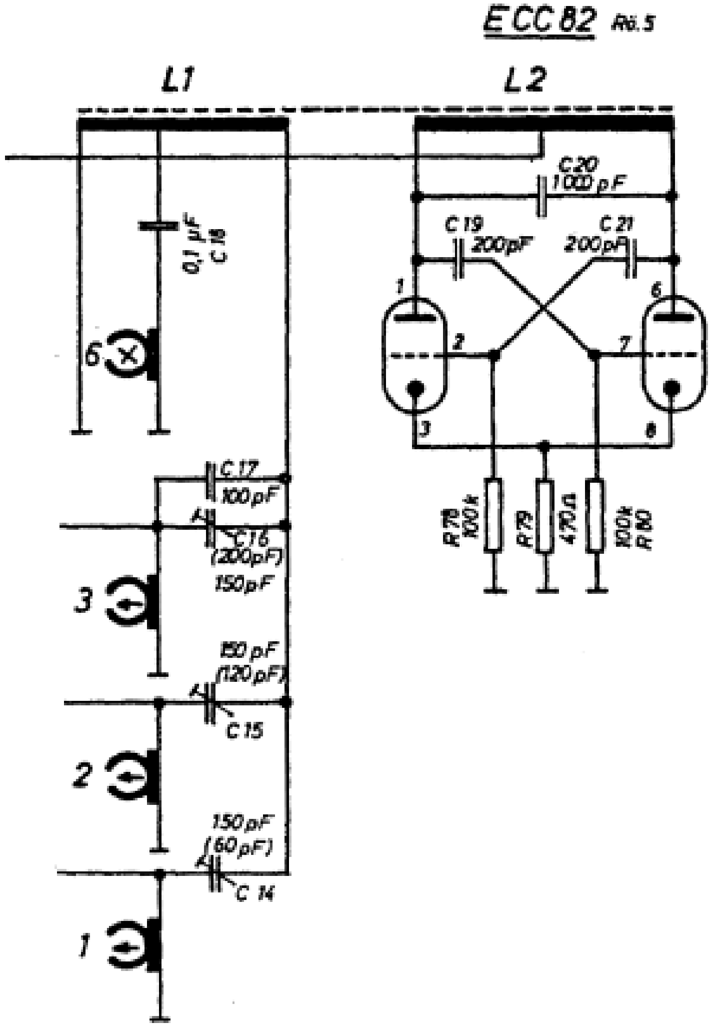
Winding end 2



Combined voltage across coil ends



The Oscillator-Coil 2



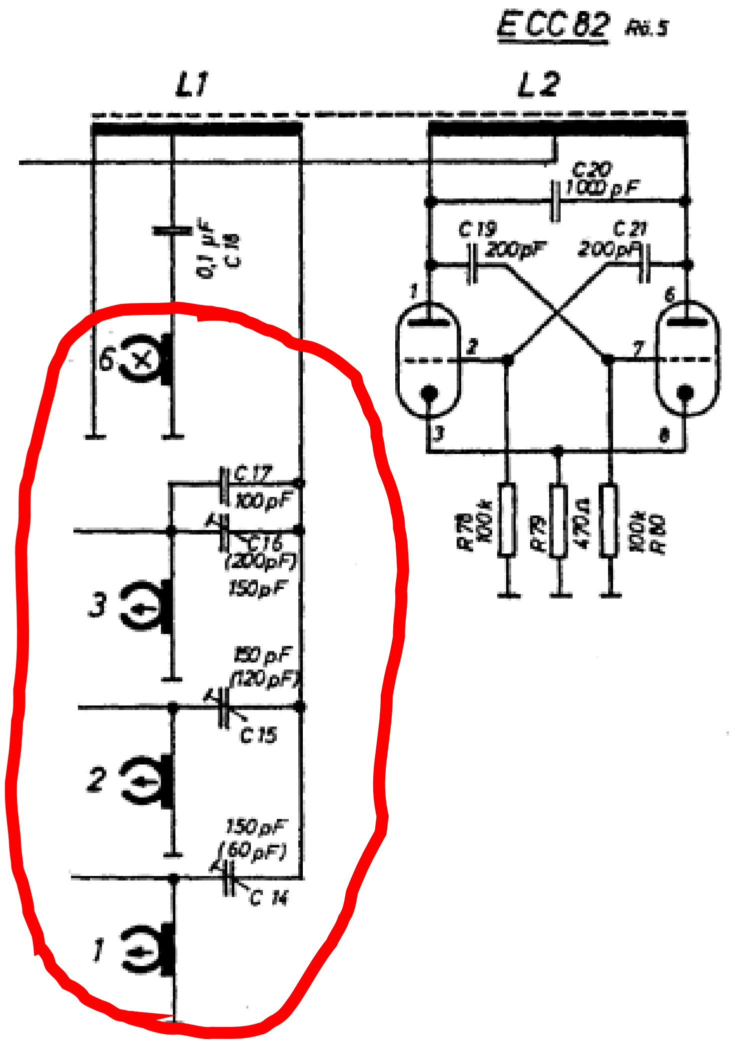
So far it has not been explicitly mentioned, but the operating voltage B+ of the tubes (approx. 290V DC) is fed to the L2 side of the oscillator coil via the center tap. This guarantees a completely symmetrical feeding of both triodes.

Ultimately, the high-frequency is not tapped directly at the LC resonant circuit for use on the tape heads, but on the L1 side of the transformer coil. The transmission ratio of L2 to L1 is approximately 1:1.

The primary purpose of the transformer is to decouple the anode voltage.
DC voltage on the tape heads would be for the reasons mentioned abovenot beneficial and even devastating at the given level.

It is also necessary because two different voltages for the erase head and tape heads are tapped on the L1 side.

Wie geht es weiter?

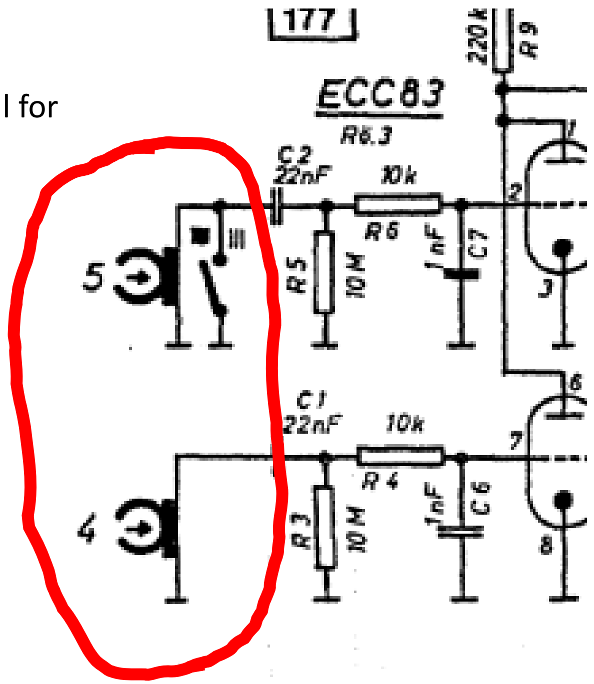


Next time we'll take a look at what's actually essential to the Oscillator/RF topic, but for the sake of clarity visibility must be omitted here:

Sound recording and playback

The NG-51 S / E51 has a very special structure
of sound and playback heads as well as the use of the HF, This is crucial for the very special sound of the device.

In this context we will of course also deal with recording and playback amplifiers.



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