La SCALA PARLANTE

COLLEZIONISMO DI RADIO D'EPOCA

e quant'altro attiene alla storia delle telecomunicazioni

ENGLISH EDITION

Associazione Italiana Radio d'Epoca

Sede legale: Museo dei Mezzi di Comunicazione - Arezzo

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(In copertina - Il Microfono a vena liquida di Quirino Majorana)

SOMMARIO

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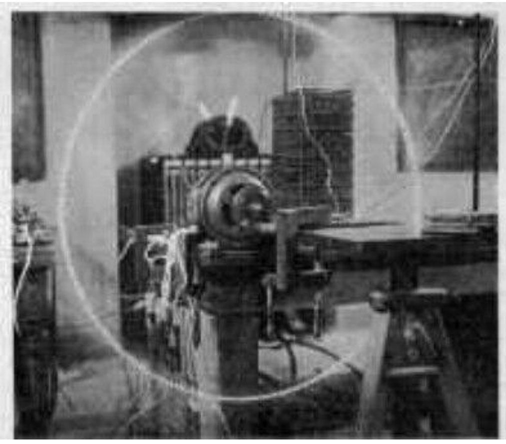

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"The Jurassic of the Radio"

Quirino Majorana's liquid-vein microphone used to drive a Poulsen arc transmitter built by the G.CAMPOSTANO company

Alberto Genova, I1 VXA

Turin, Museum of Radio and Television; located in Via Giuseppe Verdi 16, a stone's throw from the Mole Antonelliana; the museum is owned by the RAI Turin production Center.

The museum is open every day from 9:30 am to 6:30 pm except Tuesdays when it is closed.

On Sundays, in addition to the RAI staff, some A.I.R.E members are present to accompany visitors on guided tours.

Photograph N° 1

In the museum's exhibition spaces, objects are carefully collected witnessing to the history of telegraphy, telephony, the evolution of radio technology and television.

Upon entering the museum, even the most novice of visitors is attracted by a series of strange and unusual objects for our time.

Personally, I have always looked with attention and curiosity at two objects collected in the same display case: the first identified as a Poulsen arc transmitter (photograph No. 1) built by the **G.CAMPOSTANO** company and the second as a liquid vein microphone by **Quirino Majorana** (photograph N° 2).

Both these objects were built in the first decade of the 1900s.

Photograph N° 2

I knew about the existence of different types of microphones: carbon, magnetic dynamic, crystal, condenser but I had never had the opportunity to see a water microphone.

The same applies to the Poulsen arc transmitter. Transmitters today are small, housed in a case with several knobs on the front panel, and a large display for controlling all the parameters. The more I look at the Poulsen arc transmitter in the display case, the more I realize that our transmitter truly belongs to the **jurassic** era of the radio.

Who knows what operations will be required to make it work, how will be necessary to operate it to have it oscillate? And in what way and with what circuit solution will the water microphone have to be configured to be able to control the transmitter ?.

This curiosity is growing ever more; I involve my friend Alberto Erbea, also an A,I,R,E member, and we obtain some documentation to better understand the operating principles of these systems. My technical curiosity gradually prevails over the difficulties we will encounter.

Finally, one day, we were convinced to begin this project. We spoke with our A.I.R.E President, Andrea Ferrero, to contact the Director of the RAI Museum, Dr. Alberto Allegranza, to whom we explained how we planned to bring these museum objects back to life. We were persuasive enough; they granted us the permission to remove the material for conservative restoration and a subsequent historical-scientific demonstration before returning it after the event. Excellent !,

I remember it was a Sunday in January 2022. We loaded everything into the trunk of our Fiat 500 family car and arrived in the evening at the Borgosesia workshop, a space made available by Lanificio Colombo technical service. The possibility to use this space and the equipment available there were crucial to the success of the restoration of our machines. For this reason, we are grateful to Lanificio Colombo management for this concession.

A BIT OF HISTORY

We are in London, England, at the end of the 19th century. Public lighting was provided by arc lamps. A direct current was applied between two carbon electrodes, striking an electric arc that produced a very bright and clear light, but with a small problem: the arc also produced annoying noises such as buzzing and hissing.

William Duddell

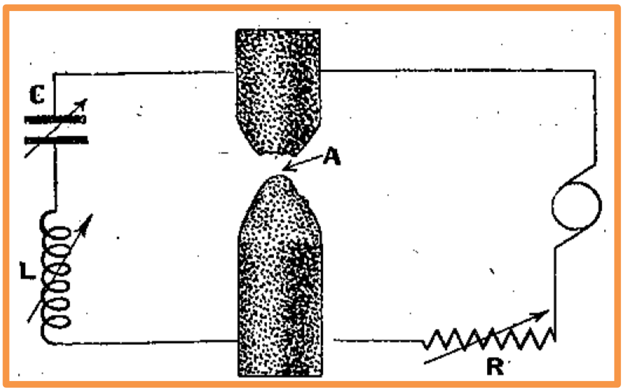


Fig. 1 William Duddell Singing Bow Circuit

The community entrusted physicist and electrical engineer William Duddell (Kensington, July 1, 1872; Wandsworth, November 4, 1917) with the task of eliminating these problems. Duddell began his work by connecting capacitors and inductors in series to the electric arc. He failed to reduce the noise, but to his amazement, Duddell discovered that, depending on the applied capacitance and inductance, the system became a generator of musical notes, later called the **"singing arc"** (Fig.1).

Duddell, among other things, practically created an electric oscillator, limited to audio frequencies, laying the foundations for the birth of electric music and arc transmitters later used in wireless telephony.

However, this Duddell arc, in the way it was produced by its inventor, did not allow oscillations above 30 kHz and this frequency was insufficient for wireless telephony.

It was therefore necessary to increase the frequency of the singing bow and this is where the Danish engineer Valdemar Poulsen (Copenhagen 23 November 1869 - Copenhagen 23 July 1942) comes into play.

Valdemar Poulsen in his laboratory

In the Poulsen system, the arc (Fig. 2) is produced between 2 electrodes, one carbon "cathode" connected to the negative side of the generator and one copper "anode" connected to the positive side. A dynamo provides a voltage of about 500 Volt.

The carbon cathode rotates slowly to ensure even consumption, the anode is a copper tube cooled from the inside with water.

Poulsen no longer strikes the arc in open air but in a chamber saturated with an atmosphere of hydrogen and hydrocarbons. Poulsen also positions two large electromagnets perpendicular to the arc; this is done to increase the arc's fractionation and achieve the ideal resonant frequency $\frac{1}{2\pi\sqrt{LC}}$

With these improvements, Poulsen was able to produce oscillations up to 500 kHz; this was in 1903, when Poulsen created the world's first **persistent-wave** transmitter.

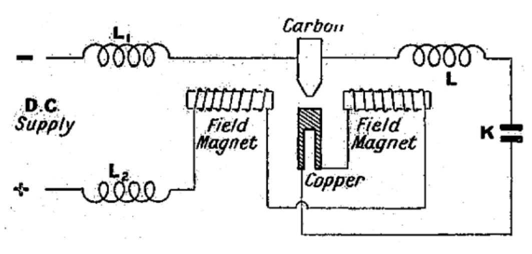


Fig. 2 Principle of the Poulsen arc circuit

The Poulsen system (see Fig. 3) was immediately applied to radiotelegraphy and subsequently to radiophony.

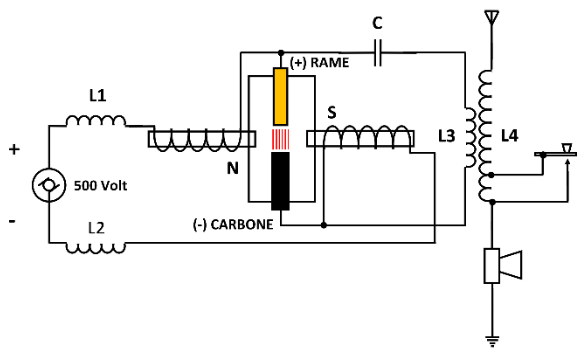


Fig. 3 The Poulsen system used with the telegraph key or with a microphone

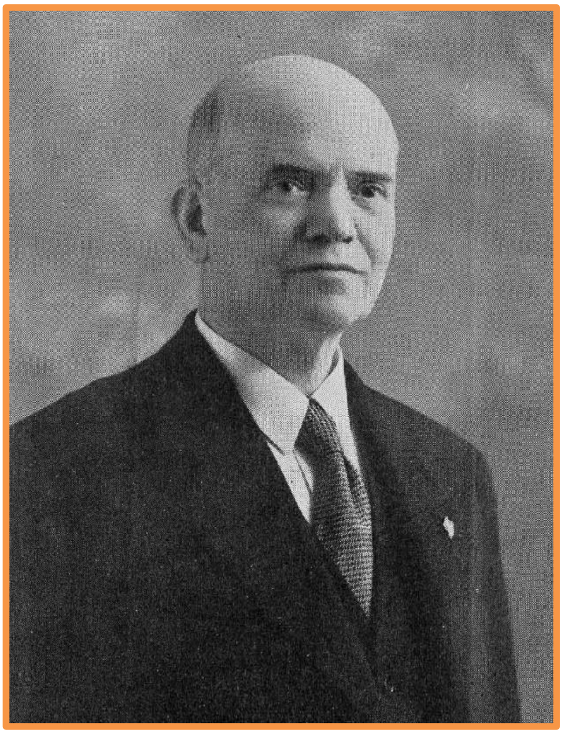
During transmissions, the arc is always active; it cannot be turned off and on only when necessary because it would be difficult for it to resume its regular oscillatory regime. Manipulation occurs by positioning the telegraph key on the antenna circuit to short-circuit some turns of the inductor **L4**, thus obtaining a radiotelegraphic transmission by frequency shift.

When the key is up, the emitted frequency is lower than when the key is down. The frequency with the key up is called stand-by frequency, while the frequency with the key down is the working frequency, to which the receiving device is tuned.

Subsequently, a microphone is connected in series to the same antenna coil, obtaining high frequency waves suitable for transmitting the entire spectrum of the human voice over a distance.

The transmitter built by G. Campostano, whose restoration and commissioning are illustrated in the following pages, uses these circuit solutions.

Let us now talk about the microphone created by the Italian physicist Quirino Majorana (Catania, 28 October 1871 – Rieti, 31 July 1957)



Quirino Majorana

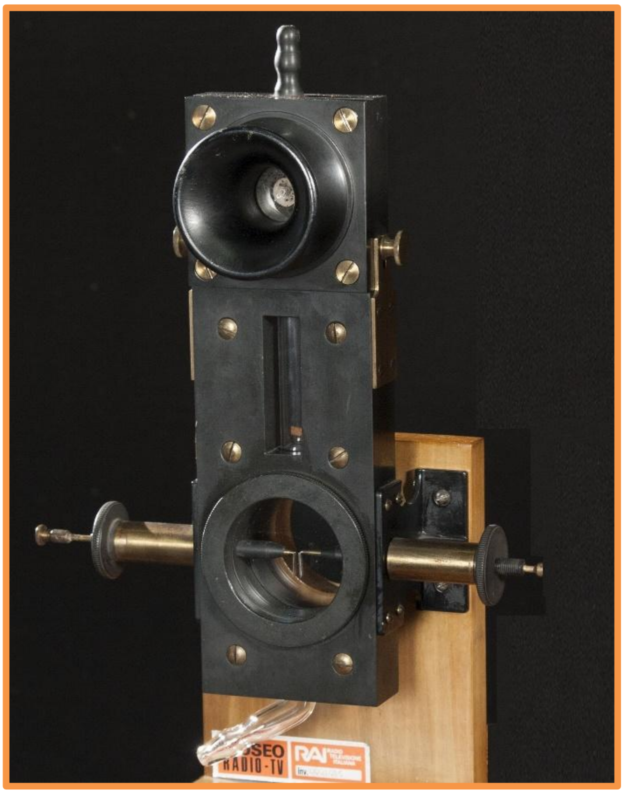
Majorana, who graduated in engineering in 1891 and experimental physics in 1893, was Director of the Central Institute of Telephones and Telegraphs in Rome from 1904 to 1914. He subsequently held the position of Professor of Experimental Physics at the Polytechnic University of Turin until 1921.

In that year, he was called by the University of Bologna to the chair of experimental physics that was held by Augusto Righi.

Majorana dedicated much of his technical and scientific life to the study of wireless telephony; he was the first to transmit speech and music over a distance of about 5 km between the station of the Istituto Superiore dei Telegrafi in Rome and the Monte Mario station belonging to the Navy.

At the beginning of the 1900s, carbon granule microphones were the most popular, suitable for use in the telephone field but completely unsuitable for withstanding strong currents such as those present in the circuit of a Poulsen arc transmitter.

To overcome these difficulties, Majorana created his liquid-vein microphone (simply called the **water microphone**).



Liquid vein microphone (water microphone)

This microphone uses water that conducts electricity to which a small amount of sulfuric acid, approximately 5%, is added to make it work.
The water is circulated by a pump and a special circuit, allowing for the use of currents of a reasonable intensity without overheating.

Let's now see how this microphone works.

If a liquid vein comes out vertically from a conveying tube **T** through a narrow section (Fig. 4) it flows maintaining a cylindrical shape for a stretch and then in **G** it begins to contract and subsequently transforms into drops.

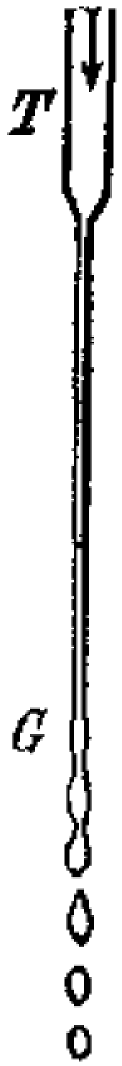


Fig. 4

Let's now look at Fig. 5, the tube **T** has a small opening **A** where there is a thin elastic membrane mechanically connected to the membrane **M**.

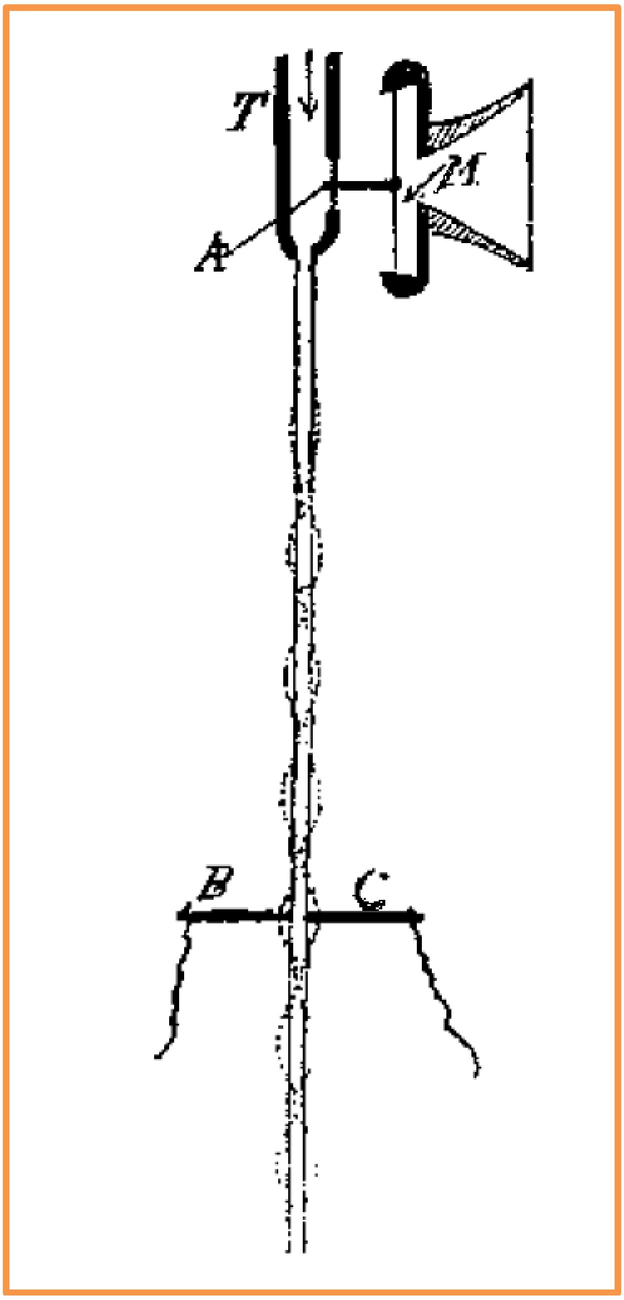


Fig. 5

M is a mica membrane that produces mechanical vibrations when struck by voices or sounds. In this condition **M** modifies the position of **A** which compresses the water contained in **T**.

In the presence of mechanical vibrations, the pressure value of the outgoing liquid varies as shown in the dotted line.

B and **C** are the two electrodes connected to the Poulsen arc transmitter through which the water jet passes. Variations in the shape and flow of the acidulated water jet cause variations in the electrical resistance of the jet. As a result, a change in the antenna current is observed which makes it possible to transmit voices or sounds in the Poulsen arc transmitter.

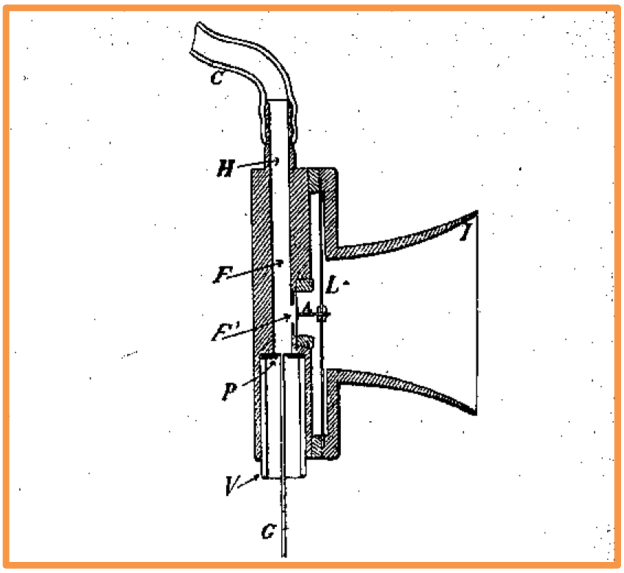


Fig. 6

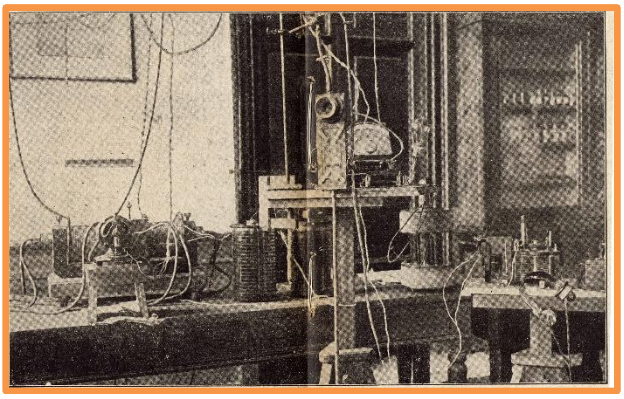
In fig. 6 a section of the microphone made by Majorana; the hatched parts are in ebonite.

At the top a 5 mm diameter hole is connected via a rubber tube **C** to the acidulated water pump.

The hole **F** in the lower part is closed by a cylindrical platinum nozzle **P** having a calibrated hole of 0,80 mm in diameter in the centre; blocked in its position by the tube **V**.

The hole **F^I** is closed with a thin platinum membrane which in the centre houses a metal rod **A** connected to the mica membrane **L^I**.

When speaking through the trumpet **I**, the mechanical vibrations of the voice or sounds are concentrated on **L^I** for good microphone performance.



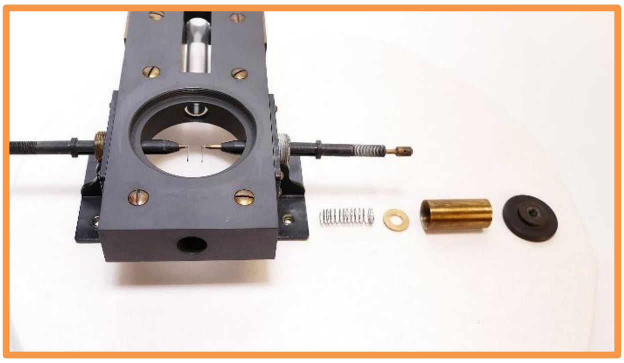
Quirino Majorana's laboratory, with the water microphone in the center and a Poulsen arc transmitter on the left

WE NOW COME TO THE RESTORATION AND COMMISSIONING OF THESE OBJECTS

The commissioning process began with the restoration of the water microphone; the task seemed simple but in reality proved to be quite delicate. In particular, we had in our hands a one-of-a-kind historical piece; even a partial breakage would have precluded the possibility of completing the restoration.

Our microphone is exactly the same as the one illustrated in Fig. 6 on the previous page.

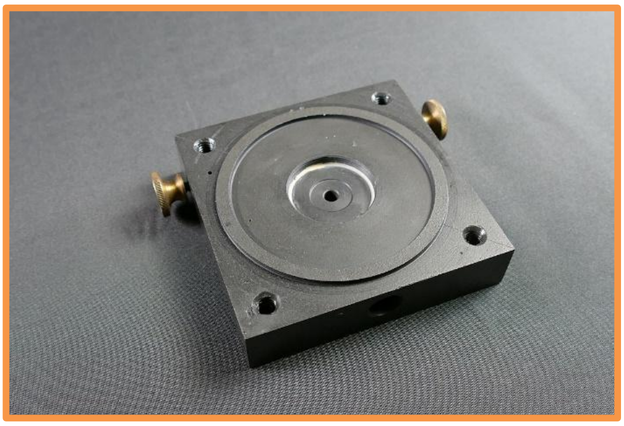
Initially, we connected a plastic tube to the input and output to test the microphone's behaviour in the presence of water. It was a real disaster; jets of water were coming out of every part of the microphone, hence the decision to dismantle it into its component parts.



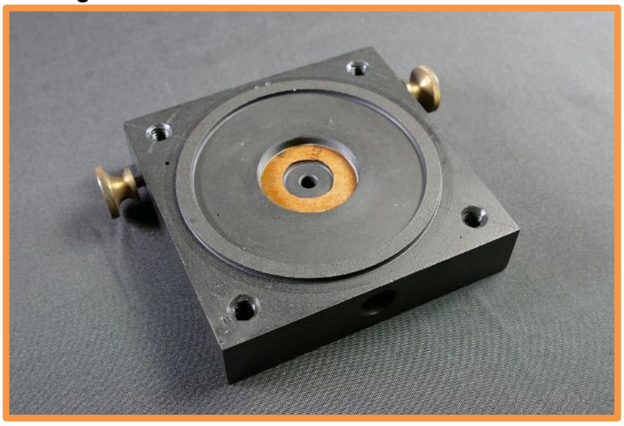
Microphone partially disassembled

Platinum membrane on the left and mica membrane I on the right

Most of the gaskets were completely missing, while those that were present were dry and broke at the slightest contact. Hence the decision to completely redo all the necessary gaskets with modern products. We used O-RING of various diameters, sealing compound, and special gasket paper.

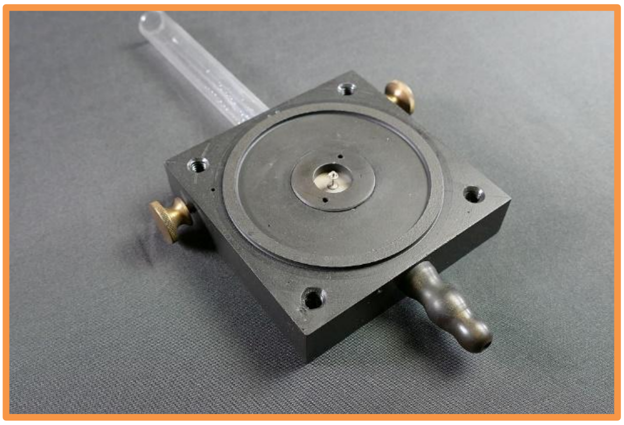


Platinum membrane seat with application of sealing mastic



The same seat with the final paper gasket

Platinum membrane



The platinum membrane was replaced and locked into place

Great attention has been paid to the movement of the $\mathbf{L}^{I}$ mica membrane in Fig. 6 and also to the movement of the thin platinum membrane also in Fig. 6. The platinum membrane is connected to the centre of the mica membrane by means of a 1 mm diameter micro screw locked with a nut and counter nut.

At the end of all these activities, we reconnected the microphone to the water circuit and were satisfied that we no longer observed any leaks; from here we began the functional tests.

We connected the microphone to a 12-Volt DC power source and placed a light bulb in series. After circulating the acidulated water and turning on the power supply, we were pleased to see that our voice was capable of significantly vary the brightness of the light bulb. This proved that this microphone is very sensitive, capable of picking up sounds quite far from the laboratory where we were conducting the tests.

Bas news, however, were not long in coming: after a test period of about 30 minutes, the microphone stopped working. Surprisingly, the two platinum plates B and C connected to the DC source, through which the acidulated water flowed, turned reddish and immediately disappeared into thin air.

Most likely these blades were not made of platinum but a nickel-plated brass copy to give the impression of good functioning without using a very expensive metal such as platinum.

Plates B and C (thought to be platinum) connected to the DC source

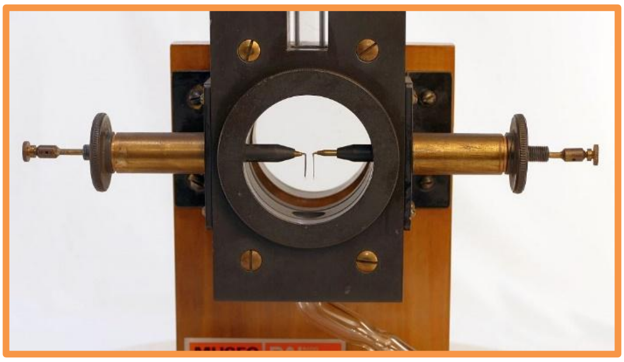
Our market research among vendors of special metal materials did not allow us to purchase what we were looking for. For this reason, we opted to construct the plates using TP 316 stainless steel, obtaining two plates identical in shape and colour to the platinum ones.

The durability of these blades was exceptional and they guaranteed the functioning of the microphone for all the tests we carried out without any problems.

Now our microphone is ready to be used together with the Poulsen arc transmitter.

B and C plates in TP 316 stainless steel

The microphone reassembled



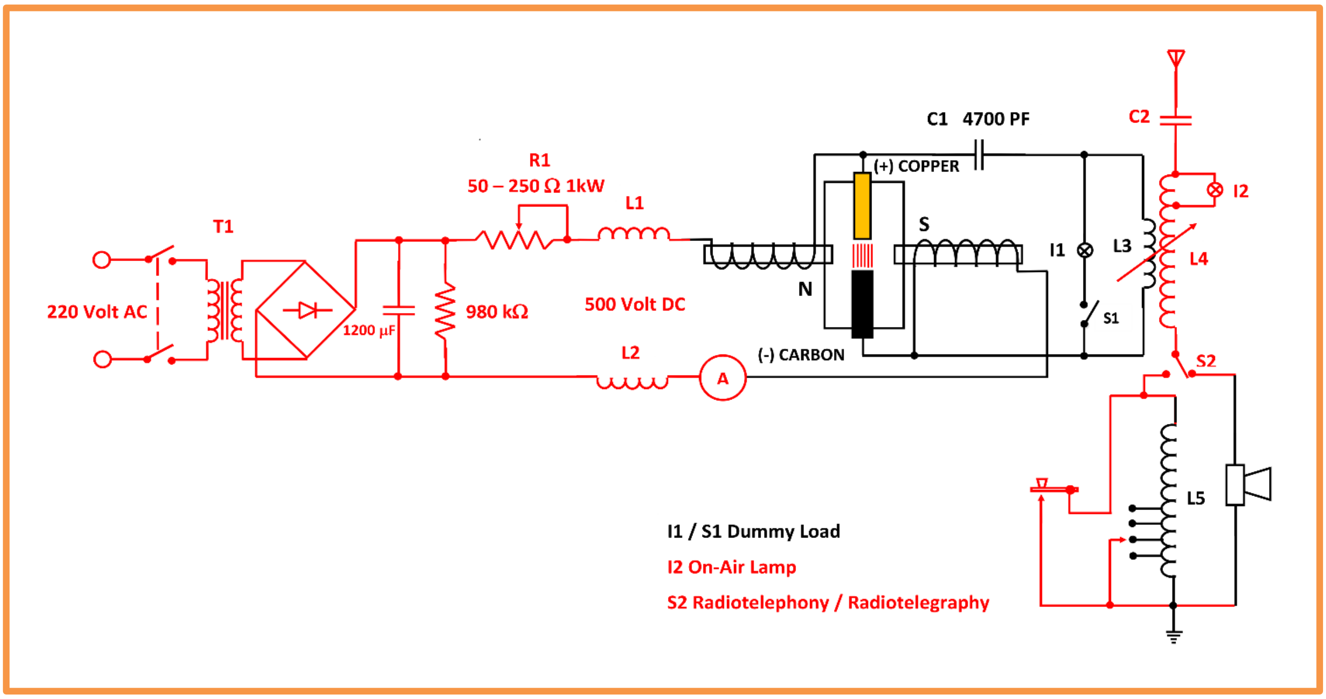
The microphone placed back on its stand

AND NOW LET'S TALK ABOUT THE RESTORATION OF THE POULSEN ARC TRANSMITTER

Below there is the complete wiring scheme of the transmitter. The parts that were present at the beginning of the restoration are in black, while the parts that were integrated because they were missing are in red.

And finally we find the two filter impedances L1 and L2 to conveniently protect the power supply from radio frequency returns.

A 40 Ampere F.S. ammeter used to measure the current supplied to the arc is the only component of the power supply belonging to the past.



The first part we built was the high-voltage power supply. We wanted to create a robust power supply capable of continuously supplying 500 Volt DC with a current of 30 Ampere using only modern and reliable components to replace the dynamo.

Let's look at the scheme above together.

The 1500 VA T1 transformer when powered at the primary with 230 Volt provides 390 Volt at the secondary.

The rectifier bridge was made with N° 4, 600 Ampere diodes cooled with a heatsink.

Next comes the 1200 µF filter capacitor and 980 Ω drain resistor.

Potentiometer R1 is made with a series of 220 Volt 1.000 Watt electrical resistors that are switched on and off via sturdy switches. This potentiometer allows the arc to be started at 150 Ω and then switched to 250 Ω with the arc lit and the hot chamber adjusting the arc current and the relative emission power.

The inside of the power supply

The ammeter used to measure the arc current

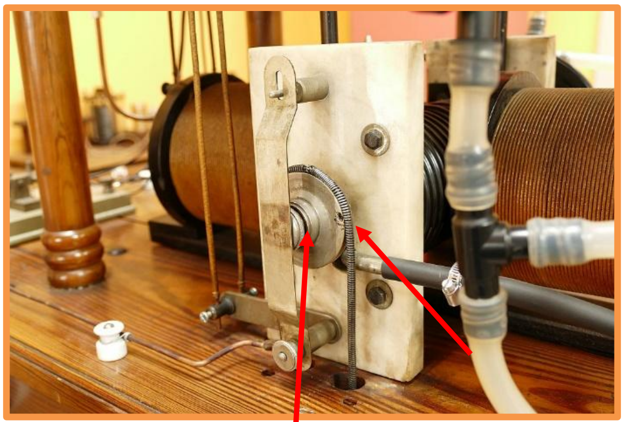
THE RESTORATION OF THE TRANSMITTER FOLLOWS

This is an arc transmitter made by **G. Campostano company, Via Cesare Cantù 2, MILAN**, at the beginning of the 1900s (see following photo)

We began the restoration with a very important component, the gear motor, positioned under the transmitter floor which, via a metal belt, rotates the carbon cathode.

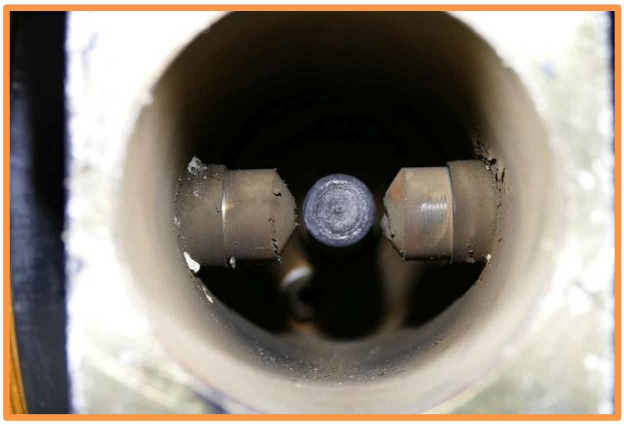
A very slow and uniform rotation (about 3 revolutions per minute) is essential to ensure uniform consumption of the cathode and consequently correct and continuous ignition of the arc.

This motor has been overhauled, oiled and greased.



The cathode end and the drive belt

Another particular object of restoration was the polar masses. One of these had a melted end due to a previous short circuit. This accident had damaged the conical part and perhaps altered its correct functioning.



The arc chamber: in the foreground the polar masses and in the center the carbon cathode

Once the two polar masses were dismantled, they were re-machined on the lathe to reproduce their initial shape and size and then placed back in their initial position.

The polar masses after the turning operation

In the photograph below we can see the two large electromagnets containing the polar masses and in a perpendicular position to them the cooling circuit of the chamber, made with a metal tube painted in black.

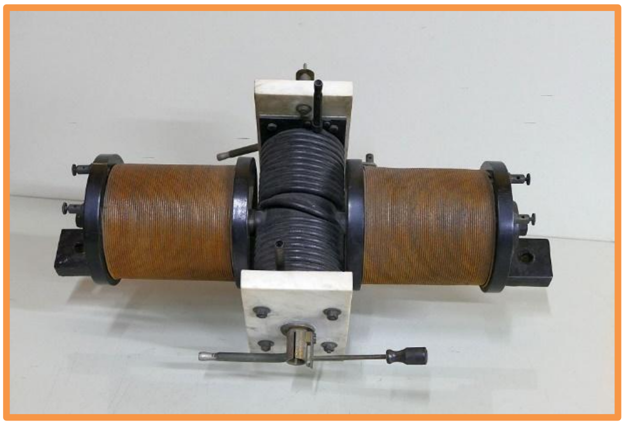
In the foreground, the electromagnets and in the perpendicular position, the chamber cooling circuit

The arc chamber cooling circuit and the copper anode cooling circuit were connected, using modern rubber tubes, to an electric pump immersed in a container of demineralized water.

Unfortunately, a corrosion phenomenon, not visible from the outside, over time, perforated the cooling metal pipe, in the point of contact with the chamber itself.

As a result, when we first started the pump, we had significant water losses.

With some trepidation, we had to completely dismantle the arc chamber. We carefully removed the 7 x 1 mm damaged lead tube, nowadays unobtainable.



Arc chamber cooling circuit

The cooling circuit was remade on a lathe using a copper tubing coil with an external diameter of 8 x 1 mm. During the winding process, each coil was soldered with tin on the arch chamber.

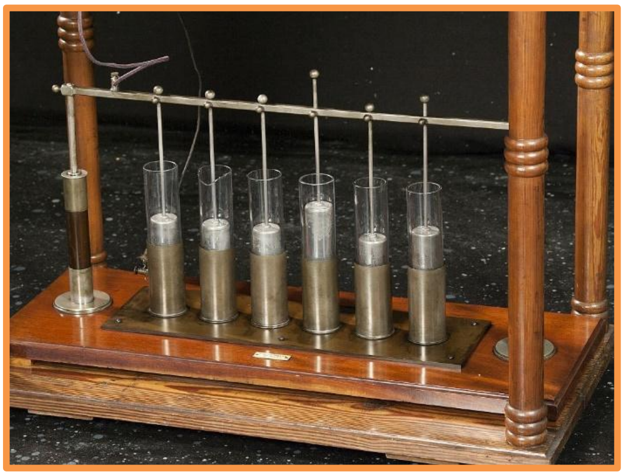
Finally the entire cooling circuit of the chamber was black repainted restoring everything exactly as it was originally.

In the previous, photo the copper tube wrapped tightly around the arc chamber

THE RESTORATION OF THE TRANSMITTER FOLLOWS

The Leyden jars positioned at the bottom of the transmitter constitute the capacitance of the oscillating circuit C1/L3.

They have undergone careful restoration, in particular they have all been dismantled by separating the glass containers from the nickel-plated brass electrodes.



Leyden jars after restoration

There was a strong oxidation on the electrodes, which had caused the glass to break and modified the total capacity.

Once the operation was completed, the parallel of Leyden jars, provided a capacitance of 380 pF, a capacitance that will be increased to determine the oscillation frequency in medium waves, as we will see later.

The label of the Leyden jars manufacturer by G. Campostano Via Ratti 2, Milan

FIRST LIGHTING OF THE ARC

Once all the previous operations have been completed, the arc now has to be lit to produce persistent oscillations.

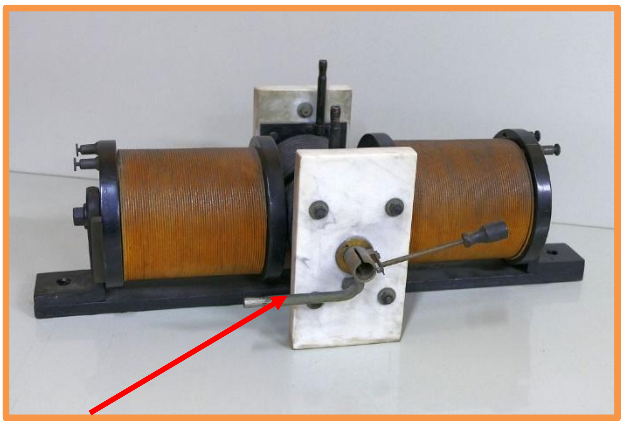
This transmitter was originally designed to operate with town gas or hydrogen. These highly energetic, but also highly explosive, gases were introduced directly into the combustion chamber through a small tube near the copper anode. The gases were then extracted through an identical tube located on the carbon cathode side.

We didn't have town gas and we also turned down the use of hydrogen from the beginning, prioritizing safety. At this point, a series of gases and fuels remained available, the results of which are described below.

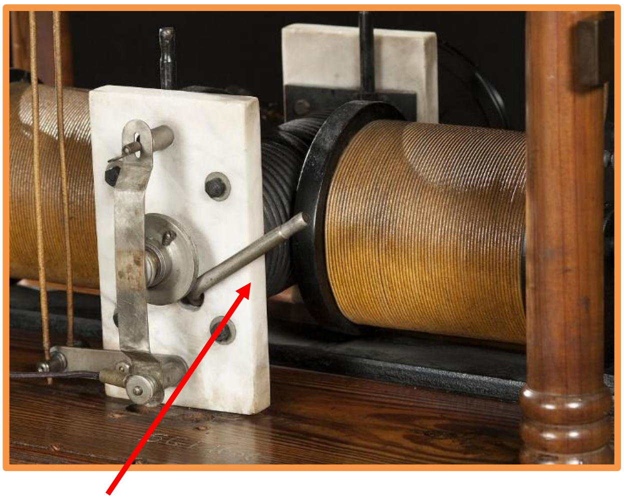
Furthermore, in order not to introduce too many variables, the following tests were performed only with the oscillating circuit composed of C1 and L3. Coils L4 and L5 will be used only after the arc has been operated correctly.

Unfortunately, all the old technical documentation in our possession is lacking in detail.

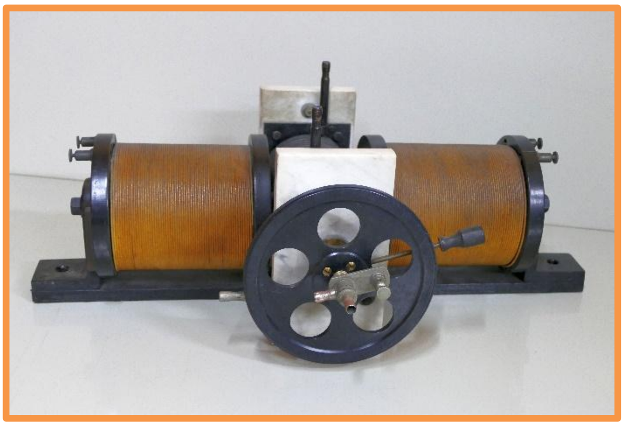
The technical articles available are all similar, errors included. Therefore, every component, every parameter, and every operating condition must be researched on the field through tries, and re-tries without losing heart. Moreover, the Poulsen system in particular was used for just a few years and then replaced by vacuum tubes, hence the lack of documentation.



Combustion chamber gas inlet pipe



Combustion chamber gas exhaust pipe



Large wheel used to vary the position of the anode relative to the position of the cathode

To produce and maintain the arc you must operate in the following way:

Fill the chamber with the gas to be tested

Turn on the DC power supply, adjust the voltage to 500 Volt

Operate on potentiometer R1, set it to 150 Ω

Rotate the large wheel counter clockwise by means of which you can vary the position of the copper anode until it comes into contact with the carbon cathode.

Once contact has occurred, remove the copper anode immediately, thus triggering the arc

Operate on potentiometer R1, set it to 250 Ω

Set the arc current to 15 Ampere

The system begins to oscillate when bulb **I1** begins to light up. Furthermore, to visualize the emission frequency and its waveform, we used a modern spectrum analyser. See the following photograph.

I1 dummy load bulb and spectrum analyser

Evidence that the system oscillates is provided by turning on the light bulb **I1** with a brightness proportional to the energy of the oscillator.

Below are the tests performed:

Test No. 1 was performed by filling the chamber with 99,9% Argon, we did not notice any ignition of the arc and no signs of oscillations.

Test No. 2 was performed by filling the chamber with a 99,9% Argon + 5%H_2 mixture. The system began to oscillate timidly, the arc was very unstable and kept turning off.

Test No. 3 was performed by filling the chamber with propane C_3H_8. The system began to oscillate slightly, the arc was very unstable and kept turning off.

Test No. 4 was performed by filling the chamber with butane C_4H_{10}. Compared to the previous tests, no substantial differences were noted.

Test No. 5 was performed by purging the chamber with 99,9% Argon + 5% H_2 and then introducing approximately 5% butane C_4H_{10}. Compared to previous tests, the system began to oscillate at 1.200 kHz, but not yet in the correct way.

Our confidence in being able to make the transmitter work diminished with each negative test; in any case, we continued the tests with perseverance without ever backing down.

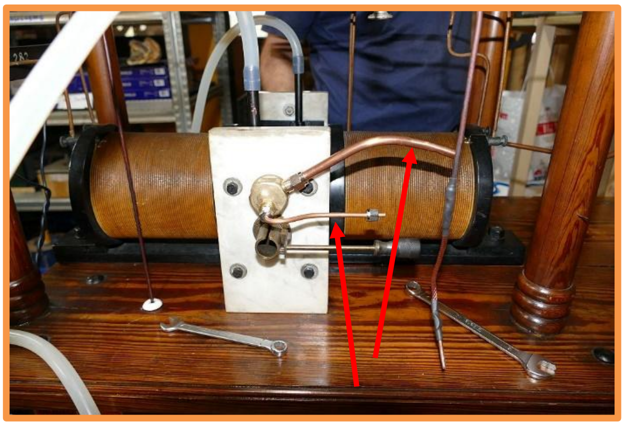
Alberto Erbea disheartened at not being able to make the system swing

Furthermore, the gases escaping from the combustion chamber were eliminated with a Bunsen burner. In the laboratory where the tests were carried out, there was always a certain amount of smelly gases that put a strain on our respiratory systems.

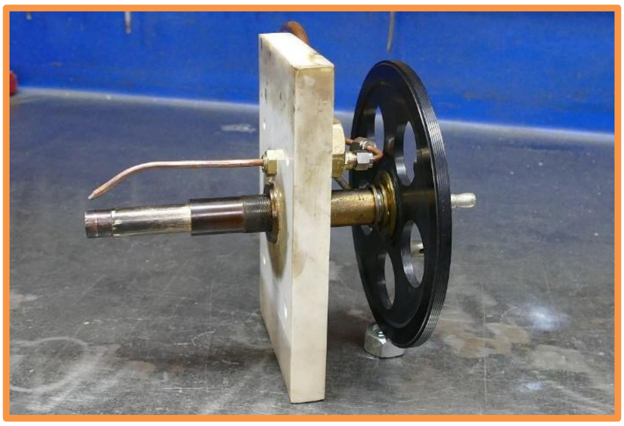
The Bunsen burner in operation

From the technical documentation we mentioned earlier, we learned that in the arc chamber, instead of gas with a high calorific value, it was possible to introduce alcohol dripped onto the hot copper anode.

System for introducing gas into the larger tube and alcohol through the smaller tube

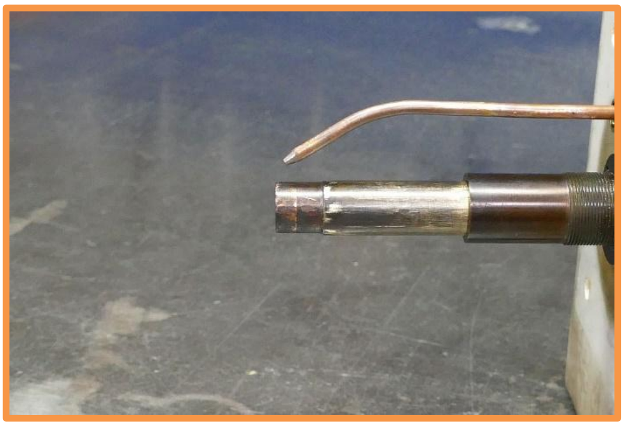


The system reassembled on the arc chamber, at the top the tube for filling the chamber with gas, at the bottom the alcohol tube



Tube for dripping alcohol

The alcohol tank equipped with a tap



As above

We checked what could be done to modify it and found a solution that allowed us to introduce the alcohol without making new holes in the arc chamber.

The walls that close the room are made of white marble, a new hole could cause a breakage of the same.

Test No. 6 began with apprehension. The arc chamber was purged with 99,9% Argon + 5% H_2.

The arc was lit with 500 Volt 30 Ampere.

After opening the tap of the 95% denatured ethyl alcohol tank, the alcohol began to drip onto the anode.

The system started to oscillate at 1.200 kHz in a fairly stable manner; had we, found the solution ?.

Several other tests followed with various types of alcohol always dripped onto the copper anode:
denatured ethyl alcohol 96,6%
denatured ethyl alcohol 99,9%
isopropyl alcohol 99,9%
Coloured alcohols are prone to fouling the arc chamber with carbon deposits that require continuous cleaning of the electrodes.
99,9% isopropyl alcohol was found to be the best

By analysing the results obtained, the confidence of succeeding in the enterprise begins to become concrete.

We ask ourselves several questions; but one in particular seems very correct.

Dropping alcohol onto the anode begins to give good results; but why drip alcohol onto a water-cooled electrode ? Wouldn't it be better to drip alcohol onto the carbon cathode, which is undoubtedly very hot ?.

Thought is immediately followed by opening of the chamber and another modification; we extend the tube until it is able to deposit the alcohol on the carbon cathode.

Furthermore, the 25 mm diameter carbon cathode is too large. We turned an adapter sleeve to accommodate a 12 mm diameter carbon rod. A smaller carbon electrode should allow for a strong arc even with a lower current and consequently a higher voltage. This produces a higher power arc.

Small diameter carbon cathode

Once all the changes have been completed, we will proceed with the **Test N° 7**

The arc chamber is always purged with Argon 99,9% + 5% H_2 at the beginning and end of transmissions.

Subsequently the arc is lit with 500 Volt and the current is stabilized at 15 Ampere.

The carbon cathode must always rotate at a constant speed to ensure uniform consumption of the cathode itself.

Uniform consumption ensures arc stability.

Next, open the tap on the 99,9% isopropyl alcohol tank. A very small amount of alcohol is sufficient, approximately 1 drop per minute. The alcohol begins to drip onto the carbon cathode and evaporate.

The system starts to oscillate at 1.200 kHz in a very stable way, constant over time and with little noise; **we finally found the way to operate.**

After about 40 minutes of operation we turn off the transmitter to view the arc chamber.

It appears misty and with some condensation on the walls; this means that the walls of the room are too cold.

The amount of cooling water circulating in the cooling coil must be reduced, see photographs on page 13.

All subsequent tests were carried out using these parameters, always obtaining good results.

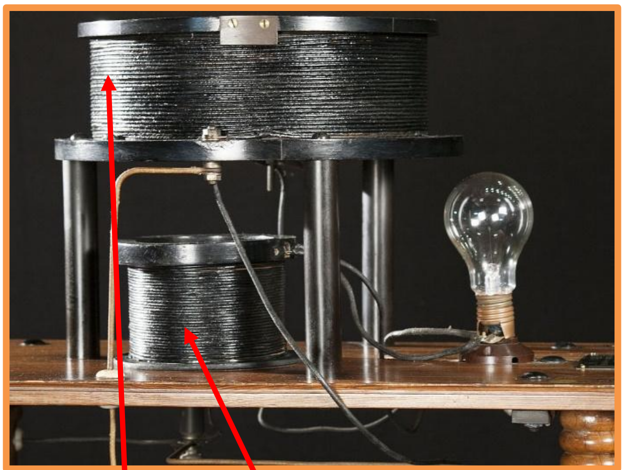
Another important parameter, confirming the optimization of the system, is the reduction in the quantity of gaseous products expelled from the system and eliminated with the Bunsen burner.

The system starts to oscillate at 1.200 kHz, the I1 bulb with dummy load function lights up vigorously

Now with the certainty that the circuit composed of C1 and L3 oscillates correctly, we must think about the coils of the antenna circuit L4 and L5.

In reality, L4 went lost over the years; if we want to continue with the tests, we must consider reproducing it. No technical documentation has been found regarding its dimensions.

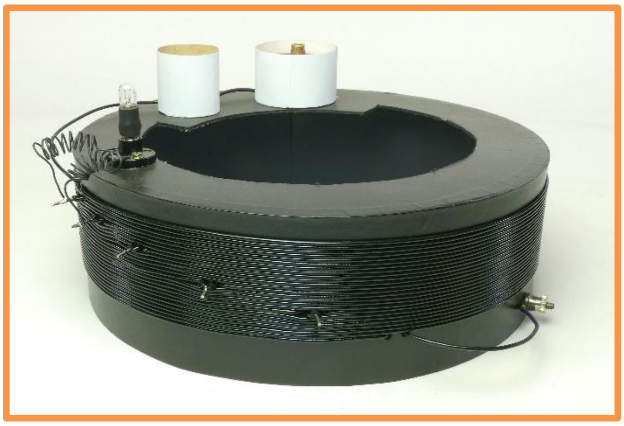
Starting from the still available L3 coil, we hypothesize the construction of L4 with a larger diameter so as to insert it above L3 to obtain a good coupling.



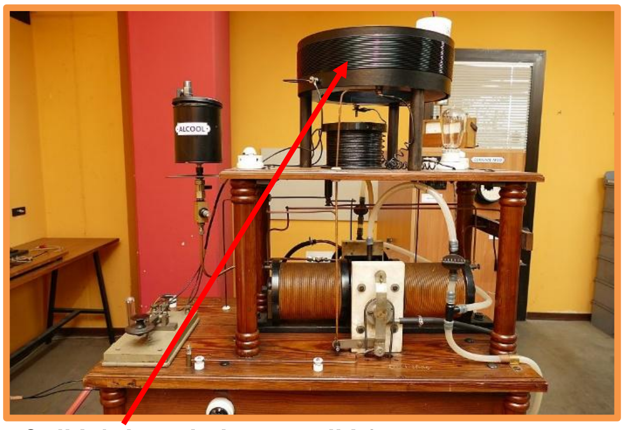
L3 coil and L5 coil

For this purpose, we produce a thick cardboard cylinder with a diameter of 320 mm, on which we wind 24 parallel turns of copper wire of 1,5 mm^2. In order to have the best inductance during the coil winding, we leave intermediate sockets.

The last two sockets are used to connect the I2 bulb which will prove to be very important to understand the correct way the arc works.



Coil L4 reproduced



Coil L4 threaded over coil L3

The L5 coil is available; you just need to decide where to place it and how to connect it. The only hole in the floor pan helps us determine its position; that hole clearly determines its location, below the slightly offset L3 coil.

The L5 coil sockets will be used to get the best results.

L5 coil from the socket side

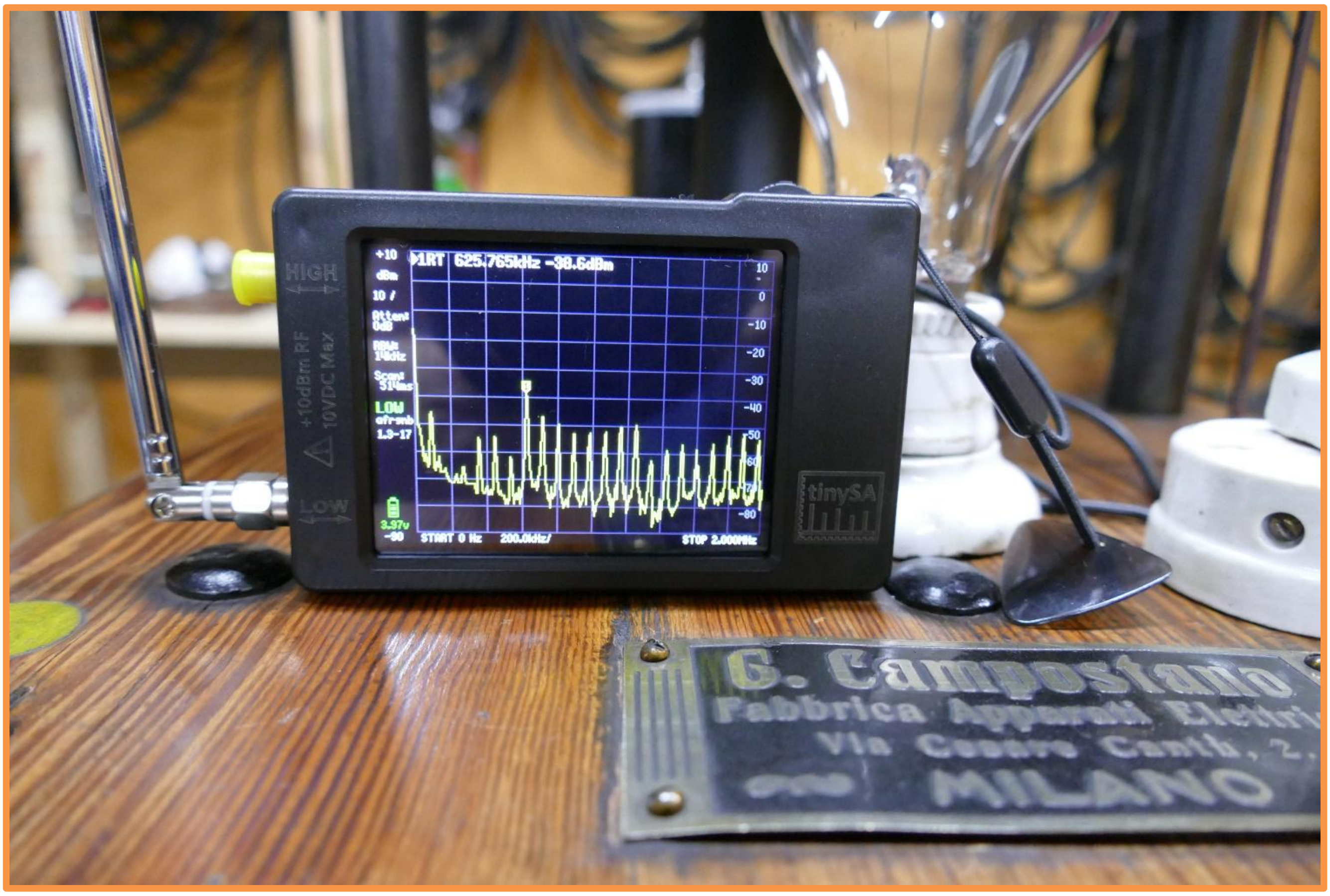
And now before we go on air we still have to think about some things.

A 25 meters long wire antenna is connected to the antenna socket.

Switch S2 is set for voice operation, and the microphone is short-circuited to avoid introducing too many variables. Antenna coil L4 is then connected directly to ground, as if the microphone's resistance, under the influence of strong vibrations, is close to 0 Ω.

We use the parameters and the method as in **Test No. 7**

Finally, after much trouble, the spectrum analyzer displays the emission spectrum, free of noise, with the fundamental frequency at 625 kHz and an innumerable quantity of harmonic; **but that's how it was in those years!!.**



Oscillogram with fundamental at 625 kHz

Now we can test the circuit in radiotelegraphic transmission.

Switch S2 is positioned for radiotelegraphy operation.

Now the antenna circuit is composed of L4 and L5 connected in series.

The telegraph key, of the very heavy type and with large contacts, is connected to the terminals.

Even for radiotelegraphic transmission, we use the parameters and the method as in **Test No 7.**

We turn on the transmitter; the frequency emitted with the key raised is equal to 535 kHz.

We press the key; the L5 coil is short-circuited and the transmission frequency is raised to 625 kHz.

It is therefore a radiotelegraphic transmission that occurs by shifting the frequency.

The transmission frequency with the key raised is called stand-by frequency and is determined by the number of turns of coil L5 inserted via the appropriate plug.

The transmission frequency with the key pressed down is called the working frequency and the receiver must be tuned to this frequency.

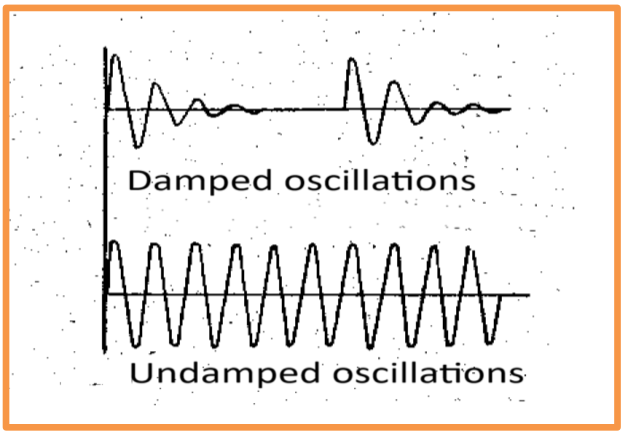
Telegraph key of the very heavy type

Essentially, in **damped-oscillations** radiotelegraph transmissions **(spark transmitters)**, a train of radio waves is produced every time the telegraph key is pressed. With the Poulsen arc, it is not possible to completely extinguish the arc and then rekindle it. This happens because the Poulsen arc has difficulty to regularly resume its normal operational regime after each interruption.

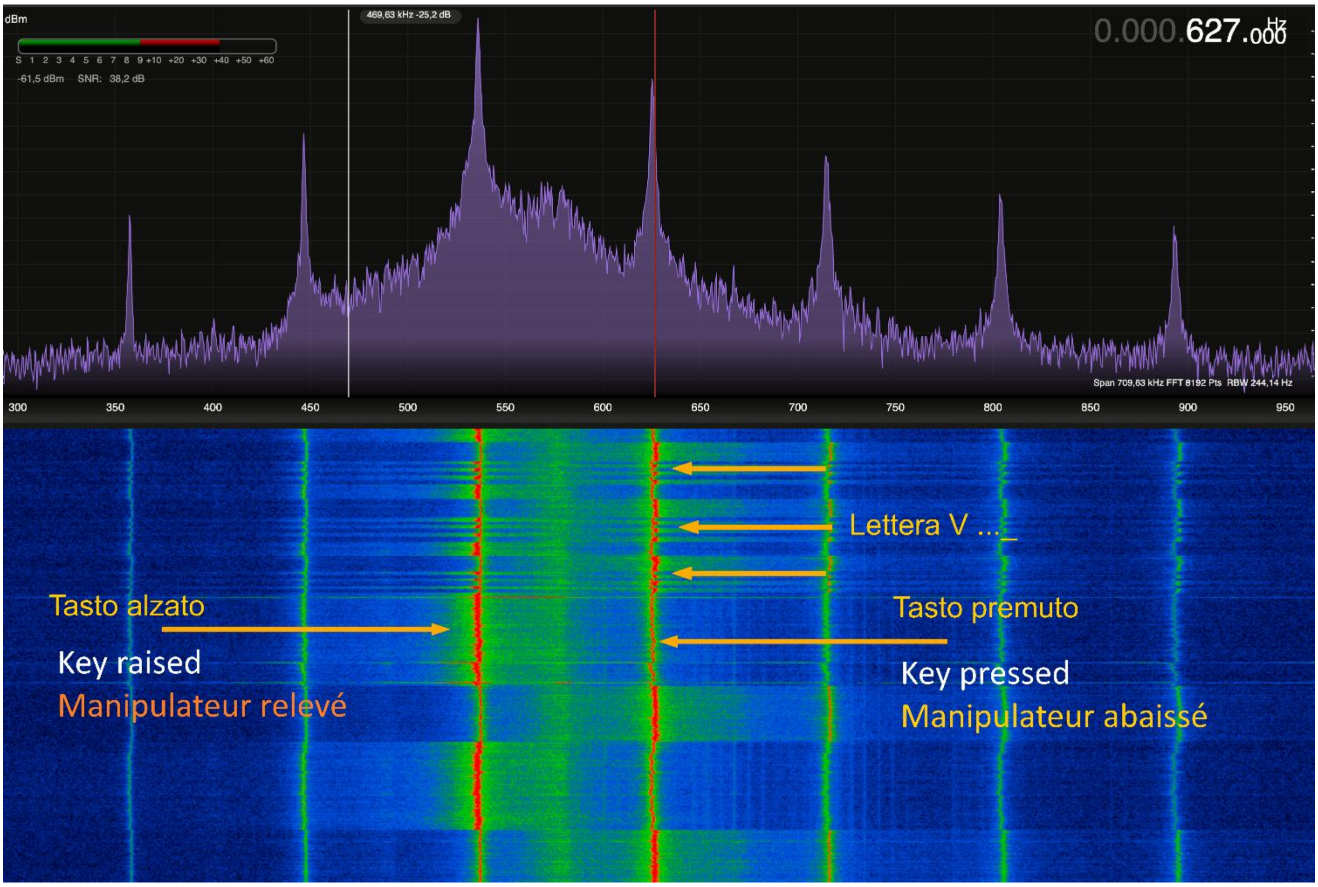
For this reason, the arc remains constantly lit, hence the name **(undamped oscillations or, more clearly, persistent oscillations).**

Telegraphic manipulation is carried out on the antenna circuit by short-circuiting some turns of the inductor itself and the transmission occurs by shifting the frequency.

We inserted a small light bulb into the antenna circuit, labelled I2 in the general scheme. This light bulb, connected to a few turns of coil L4, proved to be very useful. By interpreting the way it lit up and the light intensity produced, we could determine when the system was transmitting correctly.



Lamp I2



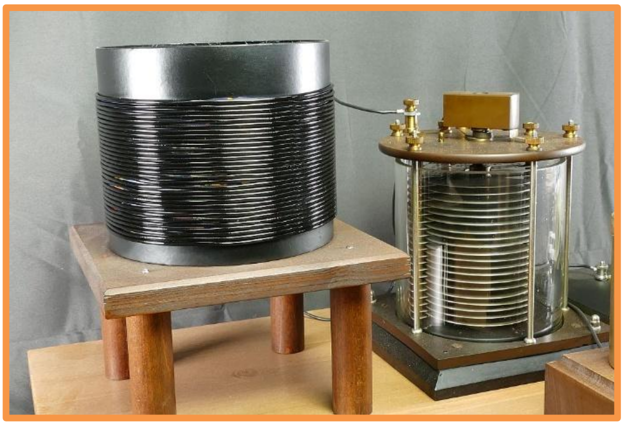
Spectrum obtained with SDR

THE RECEIVER

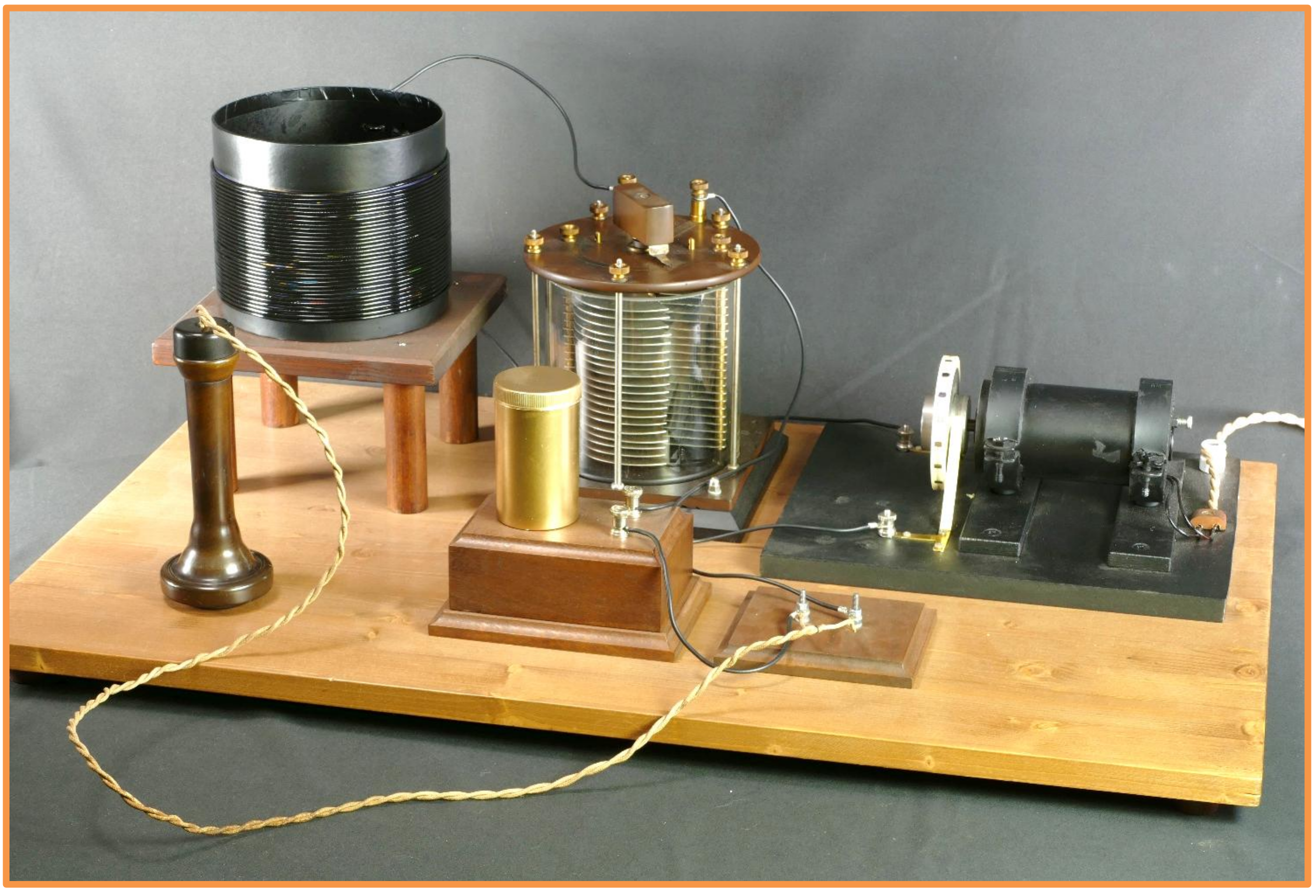
After having visualized the correct functioning of the transmitter with modern instruments, we thought of composing a receiver with which to detect and listen to the transmitted radiotelegraph signals through headphones.

We built the receiver shown below using vintage components and producing the missing ones. The component layout was chosen to reproduce the receiver used by Valdemar Poulsen in his workshop, which can be seen on page 5.

The scheme is the classic one of a receiver from the early 1900s with an electrolytic detector.



The antenna circuit inductance capacitance in parallel



The antenna circuit is of the type with inductance and capacitance in parallel.

In particular, the antenna coil was made by winding 31 turns of copper wire with a cross-section of 1,5 mm^2 onto a cardboard support with a diameter of 160 mm.

The variable capacitor is an air-filled type with a capacitance of 650 pF. The LC combination allows the receiver to be tuned to 625 kHz with the variable capacitor at half travel.

Electrolytic detector

RECEPTION TESTS OF RADIO TELEGRAPH SIGNALS

In the photo of the receiver in the previous page, on the right side, we have not provided an explanation for a mysterious electric motor. The following information will help you understand how it works.

For the proper functioning of the receiver, we have created a 50 meter long wire antenna.

After connecting the antenna and ground to the receiver described on the previous page (but without that mysterious little motor) we started listening to the radiotelegraphic signals emitted by the Poulsen arc transmitter.

Although the transmitter was functioning properly and the telegraphic keying was performed correctly, we were unable to hear any radio telegraphic signals in the earphone. In fact, we could only hear two small vibrations at the beginning and end of the telegraphic keying.

The documentation from the past that we found was of great help to us in understanding and solving this problem.

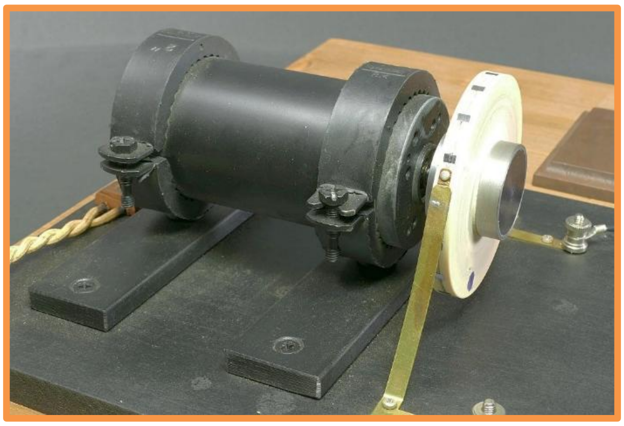
A radiotelegraph signal transmitted with a undamped wave does not produce a variable current at acoustic frequency in the crystal receiver, but rather a direct current.
For this reason, the receiver is unable to detect the telegraph signal.

In 1908, Poulsen's collaborator, a certain Pedersen, in order to solve this problem created the first device called **TIKKER**.
It is a rotary switch composed of a toothed wheel and a sliding contact, capable of interrupting the signal before its detection, at a frequency of approximately 500 interruptions per second.
The more interruptions there are, the higher the note you can achieve.

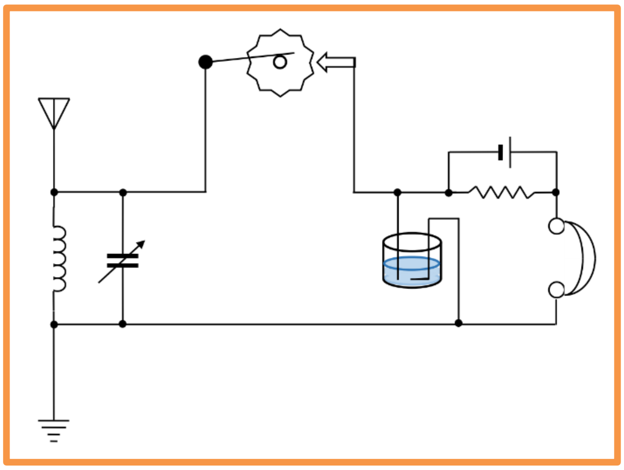
This device produced a buzzing sound in the earpiece corresponding to the lines and dots of the Morse code.

The mysterious electric motor on the previous page is a perfectly functioning reproduction of a TIKKER, **an object that is now unobtainable**.

Now with the use of the TIKKER applied to our crystal receiver, the radiotelegraph reception of the Poulsen arc transmitter occurs regularly without any difficulty.



The mysterious "TIKKER" electric motor shows the gear wheel and the sliding contact



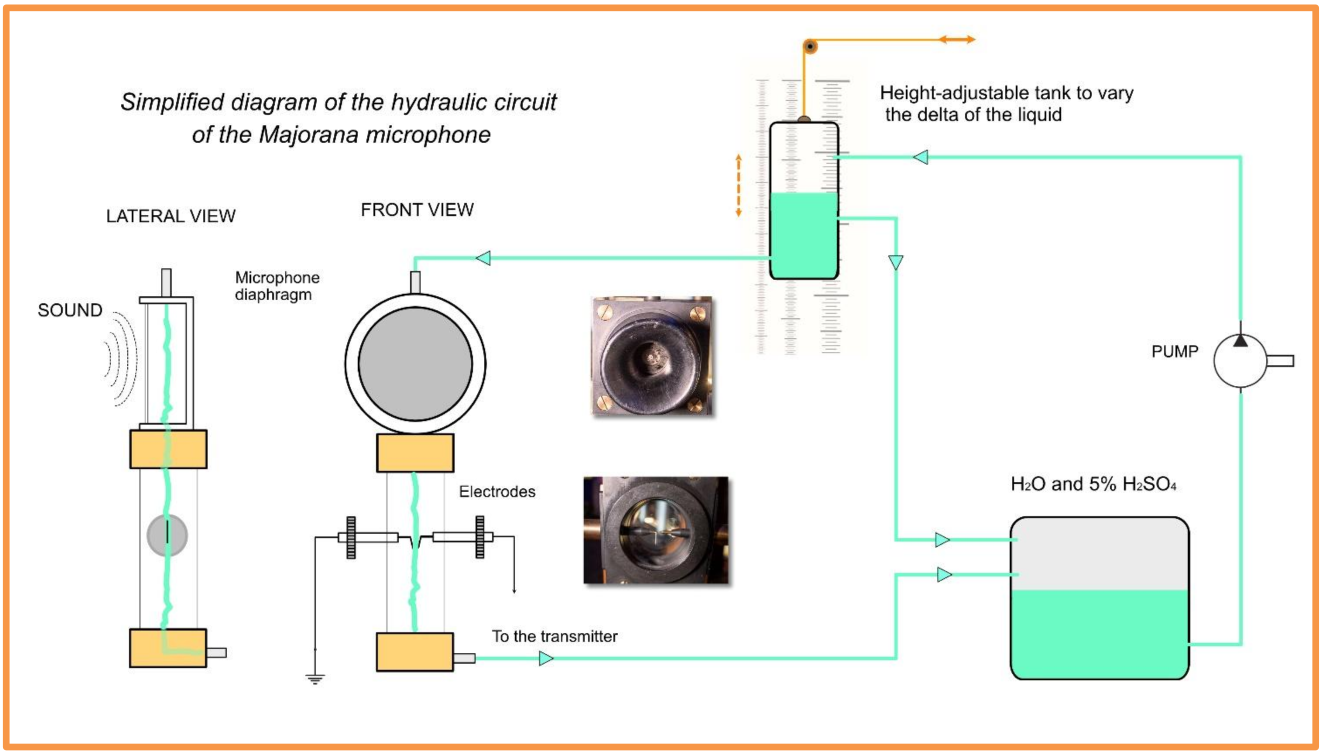
Scheme of the receiver with the TIKKER before the electrolytic detector

In current receivers the TIKKER is no longer in used.
Radiotelegraph transmissions **CW "Continuous Wave"** are received using a beat oscillator called **BFO "Beat Frequency Oscillator".**

RECEPTION TESTS OF RADIO TELEPHONIC SIGNALS, THE HYDRAULIC CIRCUIT

Quirino Majorana's water microphone has been completely repaired as described on pages 9 and pages 10.

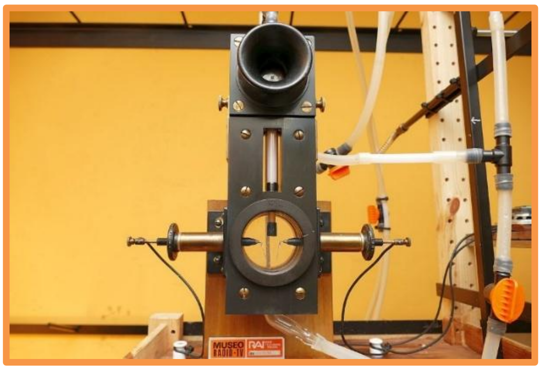
The next step was to create an hydraulic circuit, capable of circulating in the microphone, a 5% solution of sulfuric acid H_2SO_4 in water.



Hydraulic circuit scheme

The circuit was made entirely with transparent rubber tubing, joints, PVC taps and polyethylene containers.

The pump that guaranteed the recycling of the acid solution was chosen among those that had all the internal components in stainless steel and plastic material.
One container, the larger one, was filled with the acid solution, another smaller container mounted on a height-adjustable rod proved to be very useful for regulating the delta of the acid solution and ensuring a very low and constant pressure.



The microphone connected to the hydraulic circuit with all the tubes and fittings looked rather like a patient intubated for a surgical operation !.

RADIO TELEPHONE SIGNAL RECEPTION. QUIRINO MAJORANA'S WATER MICROPHONE MODULATING THE POULSEN TRANSMITTER

The hydraulic circuit is now ready and working properly.

It's very important to eliminate any air bubbles in the microphone chamber. Even the slightest trace of air will prevent the microphone from working.

It is necessary to be very careful with splashes of acidulated water, it is always sulfuric acid.

Let's put the Poulsen transmitter into operation using the parameters and the method as in **Test No 7.**

Using the switch S2 of the scheme on page 11 we insert the water microphone into the antenna circuit between the coil L4 and the ground.

The receiver we will use is always the one described on page 21, but with one exception. For signals transmitted via radiotelephony, the TIKKER must not be used; for this reason, the sliding contact will be short-circuited and the antenna signal will then be sent directly to the electrolytic detector.

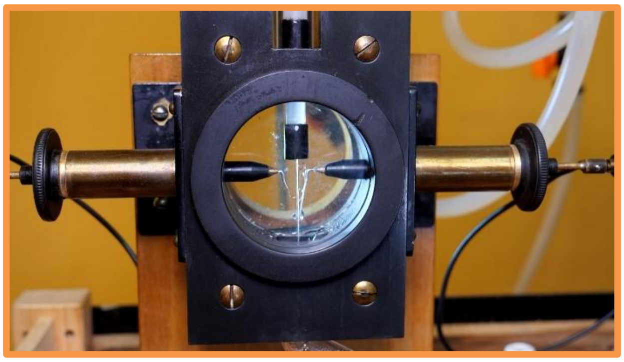
The initial operational tests were performed with a low-frequency signal generator connected to a small speaker positioned in front of the microphone.

And here the pains begins !!!.

There are several parameters to check:
- The positioning of the plates (distance and shape)
- the diameter of the nozzle hole
- the height positioning of the nozzle
- the pressure of the liquid vein entering the microphone chamber
- the choice of the operating point of the liquid vein (where the liquid vein begins to contract and break into drops)

For each variation of one of these parameters, it was necessary to start again from the beginning and re-check all the others.

Positioning of the plates in relation to the liquid vein and positioning of the nozzle



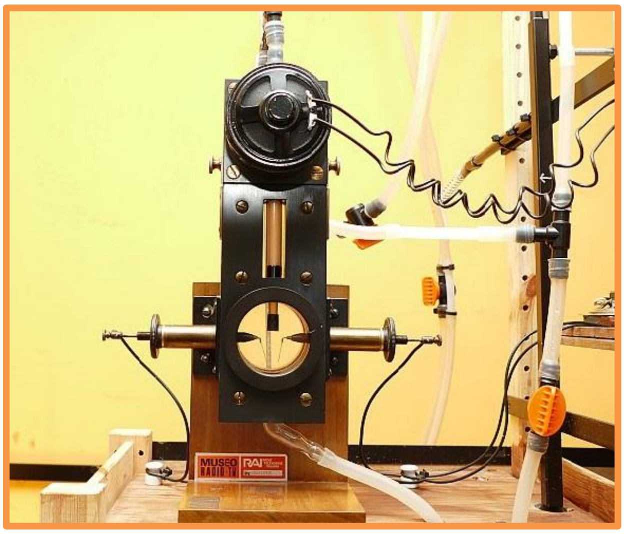
As above

Finding the correct nozzle hole diameter was particularly critical, with the best results achieved with a 0,50 mm diameter hole.
Reproducing a hole with a smooth surface free of irregularities was a challenge, as this would distort the exiting water jet.

During each test, small steps forward were made, acquiring further knowledge of the system and continuously improving the results obtained.

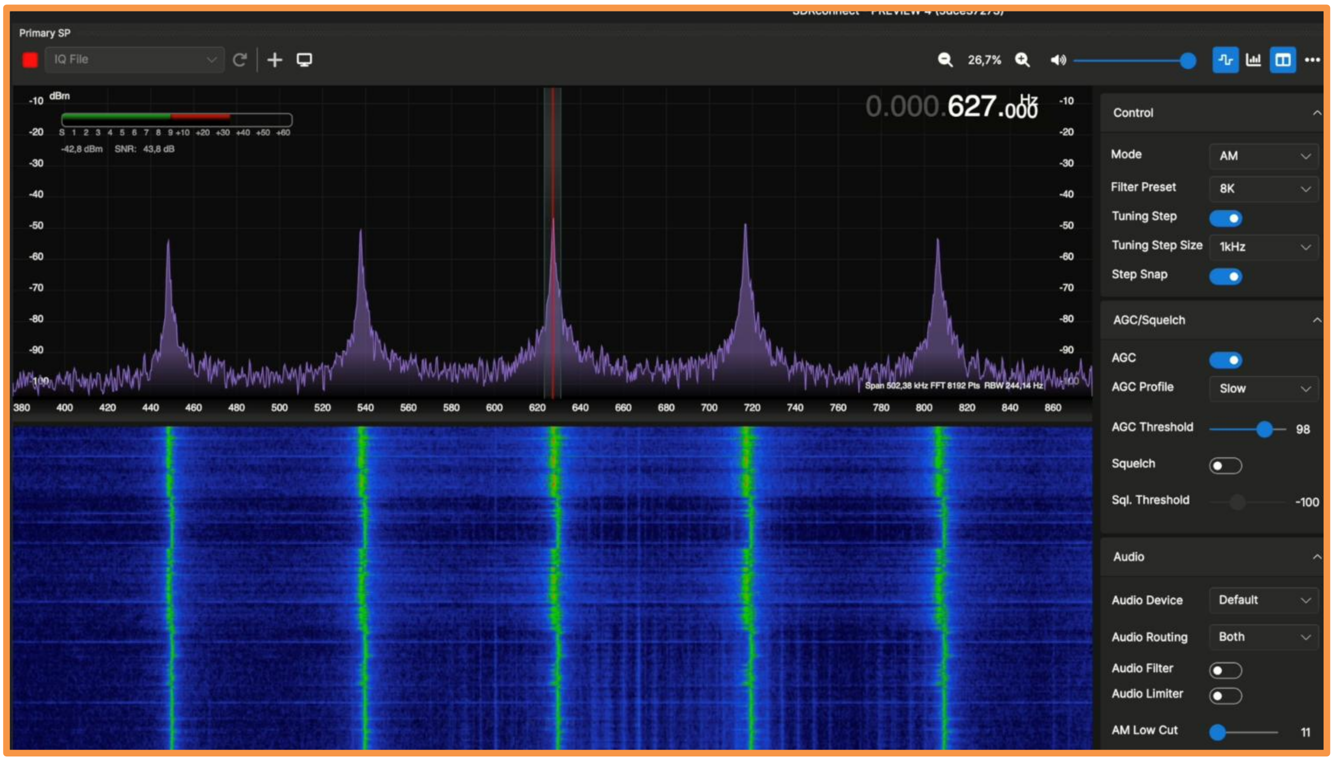
Once we were sure that the system was starting to work, we connected the small speaker, positioned in front of the microphone, to a music playback system.

Little by little, by further improving the parameters of the entire system, we were finally able to listen to the Italian anthem and opera pieces in the receiver's headphones.



The small speaker, positioned in front of the microphone

Finally, despite have gone through moments of great discouragement, after about **115** years we had managed to make the combination of **Quirino Majorana** microphone and **Valdemar Poulsen** arc transmitter work again.



Spectrum obtained with SDR

In reality the fidelity of the sound reproduction is rather lacking, especially at high frequencies.

We must however recognize that these systems were the very first instruments for the reproduction and transmission of modulated radio waves which paved the way for subsequent studies up to the present day.

Now I apologize for having bored you for so long and I will move on to the final conclusions.

CONCLUSIONS

To operate these transmitters one had to have a certain propensity for dangerous activities and the patience of a saint.

Looking at the transmitters in use today, there's no shortage of profound reflections, because of the circuit solutions employed in today's technology, but above all because of the high safety standards achieved.
The operator using these transmitters had to be extremely careful, as they lacked even the most basic safety precautions.

The operator was supposed to simply speak into the microphone, but he had to be careful and keep both hands behind his back. The terminals here and there were approximately 500 Volt DC (lethal voltage). The operator was never allowed to place his hands on the electrodes as 500 Volt DC were present here too, and not only that, the electrodes were hot and possible burns were always possible. Furthermore, the operator was not allowed to get too close to the safety valve, or he'd risk a spray of hot alcohol on his face. Refilling the alcohol tank with the transmitter in operation was also to be avoided, nor was opening the chamber before it had completely cooled, or the transmitter became a flamethrower.

Arc transmitter technology claimed a number of early martyrs. The list would undoubtedly have continued to grow if vacuum tube technology, RF oscillators and power amplifiers in the 1920s had not mature.

This historic conservation restoration meant three years of work, all in our free time. I didn't undertake this task alone, but I supported A.I.R.E member No. 2090 Alberto Erbea.
Alberto used his patience, his expertise and his perseverance to get to the end of what we had set out to do.

In July, we presented our work to interested A.I.R.E members. Approximately 30 members and supporters from Piedmont, Liguria, Lombardy, and Emilia-Romagna arrived in Valsesia to attend the scheduled day of testing and learn about these ancient means of telecommunications.

At the end of the re-enactment, the A.I.R.E members met in a local restaurant to taste the typical local products.

On this occasion, the A.I.R.E President Andrea Ferrero gave Alberto Erbea and Alberto Genova a certificate of merit, which was very welcome and for which we thank them.

The sunny day allowed the photographer to take a nice group photo.

In October 2025, once all the restoration and presentation activities to A.I.R.E members were completed, the time had come to return the Majorana microphone and the Poulsen transmitter to their rightful owner, the RAI Radio and Television Museum in Turin.

Now these two objects rest in the museum, placed in a special showcase, surrounded by curiosity and respect as a monument to the ability, perseverance and ingenuity of its inventors.

ANECDOTES

Regarding the use of alcohol in this transmission system, it seems that at the beginning of the last century, on ships equipped with Poulsen arc transmitters, alcohol systematically disappeared. To the sailors' displeasure, alcohol was replaced with kerosene!

***Thanks to*:**

- ✓ The Management of the RAI Production Centre in Turin and Dr. Alberto Allegranza, Director of the Museum, who made the equipment available to us for a conservative historical restoration
- ✓ Andrea Ferrero President of A.I.R.E for the trust shown
- ✓ Claudio Girivetto for his work as official photographer and cameraman
- ✓ All A.I.R.E. members who attended the day dedicated to this re-enactment

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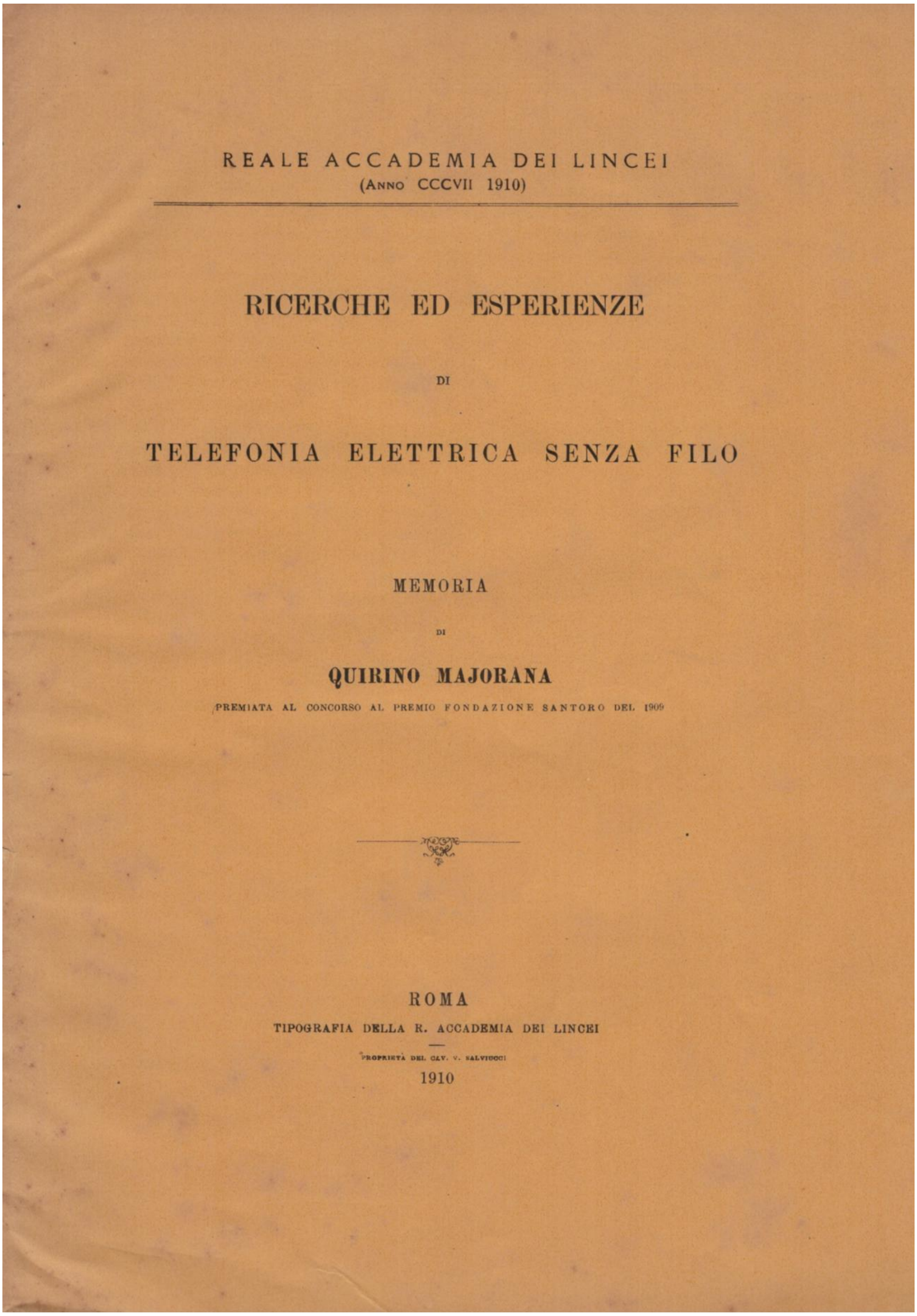
- ✓ Domenico Ravalico RADIOTELEFONIA 1920
- ✓ Harmsworth' Wireless Enciclopedia 1923
- ✓ Telegraphie Sans Fil 1917
- ✓ Ernesto Montù La Radio Per Tutti 1924
- ✓ Manuale Elementare di Radiotecnica 1927

A.I.R.E members and supporters

Alberto Genova, I1 VXA socio AIRE 0171
Alberto Erbea, socio AIRE 2090

https://piemonte.aireradio.org/rievocazione-storica-majorana.html



REALE ACCADEMIA DEI LINCEI
(ANNO CCCVII 1910)

RICERCHE ED ESPERIENZE

DI

TELEFONIA ELETTRICA SENZA FILO

MEMORIA

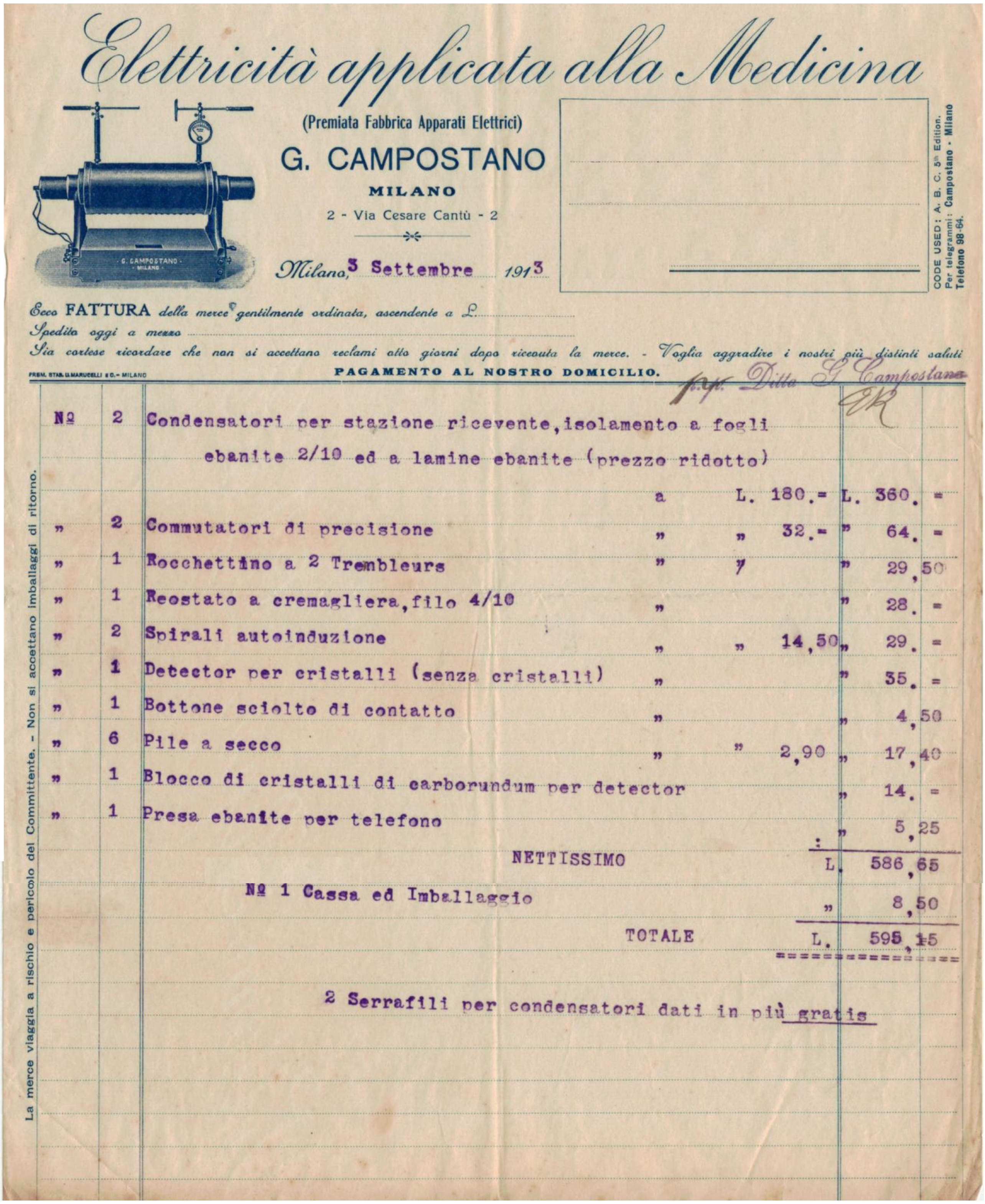
DI

QUIRINO MAJORANA

(PREMIATA AL CONCORSO AL PREMIO FONDAZIONE SANTORO DEL 1909

ROMA
TIPOGRAFIA DELLA R. ACCADEMIA DEI LINCEI
PROPRIETÀ DEL CAV. V. SALVIUCCI
1910

The Treaty of Quirino Majorana
Telefonia Elettrica senza filo ROMA 1910



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p.p. Ditta G. Campostano

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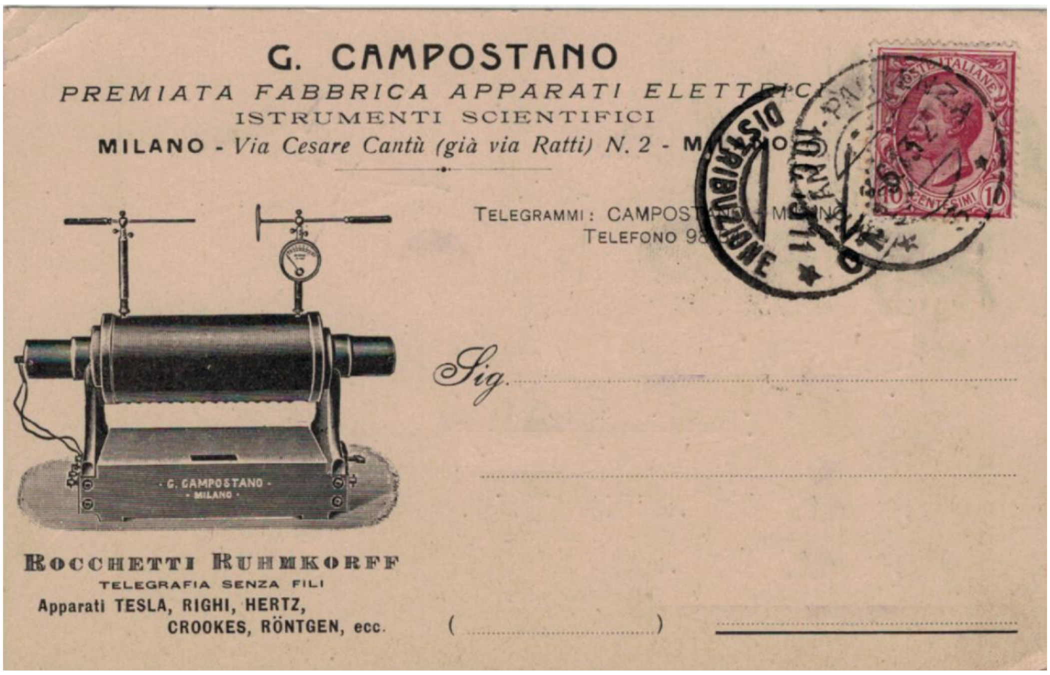

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