Ernst Lecher and His Wires

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Abstract

This paper focuses on Ernst Lecher, Austrian physicist, who studied guided electromagnetic propagation on two parallel wires, with the aim of measuring the relative wavelength. He perfected this device up to the point that "Lecher lines" become a synonym for a two-wire transmission line. His findings were used throughout all of the XXth century to tune UHF receivers, and are still used as an educational tool.

1. Life

Ernst Lecher (Vienna, Austria, June 1, 1856 -Vienna, Austria, July 19, 1926; Figure 1) was an Austrian physicist. He was the son of Zacharias Konrad Lecher (Dornbirn, Austria, December 12, 1829 – Vienna, Austria, April 28, 1905), a writer and a journalist, Chief Editor of the Wiener Zeitung Neue Freie Presse. Ernst was one of the seven children of Zacharias; among the others, the most notable were Otto and Emma.

Otto Lecher (Vienna, Austria, January 6, 1861 – Leopoldsdorf, Austria, January 20, 1939), was a lawyer, and Secretary of the Chamber of Commerce in Brno (Czech Republic). At the end of World War I, Otto Lecher was a Member of the *Provisional Nationalversammlung* (National Assembly), which established the Republic of Austria, serving from October 21, 1918 to February 16, 1919.

Emma Lecher married Adolf Lorenz (Weidenau, Czech Republic, April 21, 1854 – Altenberg, near Vienna, Austria, February 12, 1946), an orthopedic surgeon remembered for his work with bone deformities. He was known for treating patients without cutting into skin or tissue, which earned him the title of "The Bloodless Surgeon of Vienna." He was renowned for his treatment of congenital dislocation of the hip in children. He created a manipulative treatment for clubfoot and, through the use of traction and pulleys, he developed a mechanism for the treatment of scoliosis. Emma and Adolph Lorenz were parents to Konrad Lorenz (Vienna, Austria, November 7, 1903 – Vienna, Austria, February 27, 1989), the founder of modern ethology, who received the Nobel Prize for Physiology and Medicine in 1973.

Ernst Lecher (Figure 1) attended the *Akademischen Gymnasiums* (high school) in Vienna, and later studied physics at the University of Vienna. He obtained the PhD in 1879 at Innsbruck University. He married Helene von Rosthorn (Vienna, Austria, September 8, 1865 – Vienna, Austria, October 2, 1929). Helene was herself quite famous for her great services in nursing during the First World War, where she applied her knowledge of nutrition, leading the diet kitchen of the war hospital of the American Red Cross in Vienna-Meidling. Another such dietary kitchen was set up at the War-Barackenspital in Grinzing, which was headed by physiologist Arnold Durig (Innsbruck, Austria, November 12, 1872 – Schruns, Austria, October 18, 1961). This war hospital had 6,000 beds. Many of the patients suffered from dysentery. After the dissolution of the war hospital in 1919, she led two private barracks as a day care center for children at risk of poor health. She was acquainted with Hermine Wittgenstein (Teplice, Czech Republic, December 1, 1874 – Vienna, Austria, February 11, 1950), who ran a similar center for children, and who was sister to the philosopher Ludwing Wittgenstein (Vienna, Austria, April 26, 1889 – Cambridge, UK, April 29 1951), a philosopher much appreciated by one of the authors [1].

Figure 1. A photo of Ernst Lecher in 1919, by an unknown photographer (public domain).

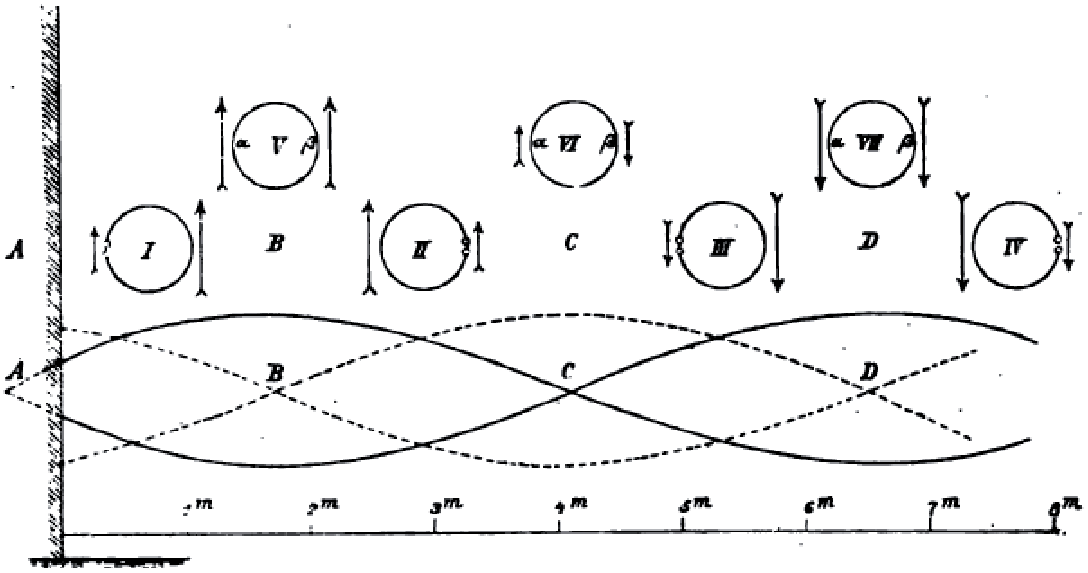

Figure 2. A figure from Hertz's 1888 paper [2], showing standing waves and the spark loop he used to find nodes (copyright expired).

Ernst Lecher become *Privatdozent* in Physics and went back to Vienna in 1882, where he become an assistant at the Department of Physics of the University, and gained the habilitation for Experimental Physics. He was back in Innsbruck as a Professor from 1891 to 1895. He then took the Chair of Experimental Physics in Prague of Ernst Mach (Brno, Czech Republic, February 18, 1838 – Munich, Germany, February 19, 1916), pioneer of supersonic fluid mechanics as well as a philosopher and physiologist. In 1892, Ernst Lecher was elected a member of the *Deutsche Akademie der Naturforscher Leopoldina – Nationale Akademie der Wissenschaften*, the German Academy of Sciences.

Lecher was back in Vienna in 1909. In recognition of his research results, the University of Lech in Vienna appointed him head of the first Physics Institute in 1909, and the Vienna Academy of Sciences accepted him in 1914 as a member.

In October 1925, a serious illness forced him to retire. Lecher died in Vienna half a year later. He rests in an honorary grave in the Döblingermonumental cemetery in Vienna. In Vienna, there is a street named after him, *Lecherweg*, parallel to the street *Marconiweg*, dedicated to Guglielmo Marconi (Bologna, Italy, April 25, 1874 - Rome, Italy, July 20, 1937). Both streets cross Oppenheimweg, dedicated to Samuel Oppenheim, astronomer (Braunsberg, Czech Republic, November 19, 1857 - Vienna, Austria, August 15, 1928).

However, we shall go back later to Lecher's connection with Marconi, writing about Lecher's wires.

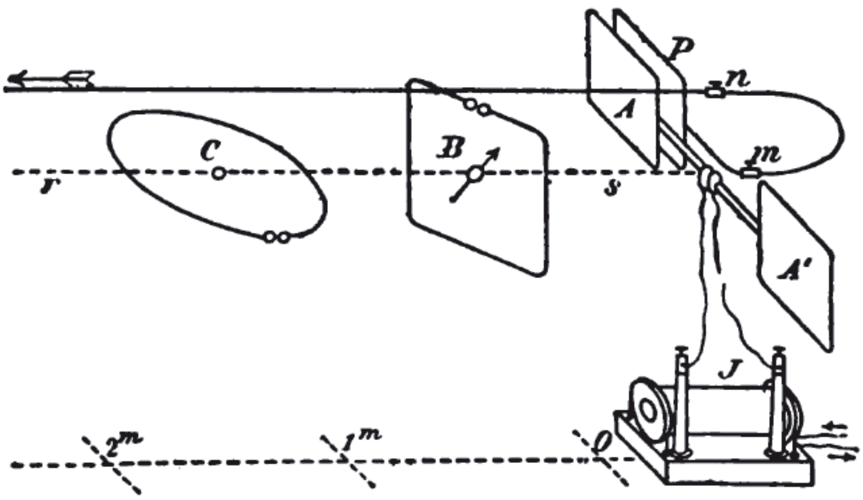

Figure 3. Hertz's 1888 apparatus [4] as it appeared in the 1893 English translation of his book [5] (copyright expired).

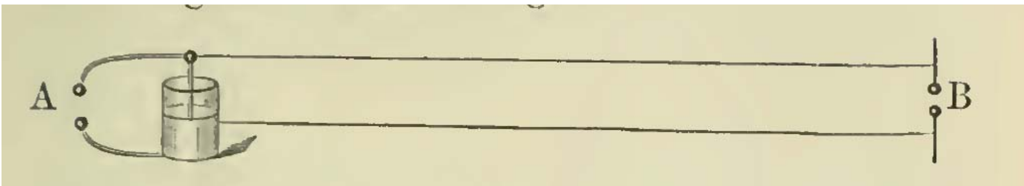

Figure 4. A figure from Lodge's 1888 paper [6] showing an apparatus for producing standing waves along a line (copyright expired).

2. Two Wires to Measure a Wave (and Its Speed)

A Lecher line is a pair of parallel wires or rods used to measure the wavelength of radio waves, mainly in the range of meters to centimeters (UHF to microwave frequencies). These are also called Lecher wires. In modern terminology, they are a resonant stub of a balanced transmission line. When connected to a source of radio-frequency power, a standing wave forms along the length of the wires.

By sliding a bar bridging the two wires along their length with some sort of voltage meter on the bar, the length of the waves can be physically measured by finding the standing wave nodes.

Heinrich Hertz was certainly the first to use standing waves to measure wavelength. Indeed, he demonstrated the existence of standing waves (Figure 2), and hence of electromagnetic waves, in his fundamental 1888 paper [2]. A recent paper in English clearly shows this experiment in modern terms [3].

Hertz also studied conducted waves [4, 5], but his apparatus was unbalanced (Figure 4) and meant to devise a difference in propagation velocity between the free-space wave and the wire-bound wave. Curiously enough, Hertz declared to have found such a difference, stating that the free-space and conducted propagation velocities were in a ratio of 45:28 [5, p. 108]. Of course, this is false, and was probably due to the very low sensitivity of Hertz's spark detectors.

Oliver Lodge (Penkhull, UK, June 12, 1851 – Wilsford, UK, August 22, 1950) was indeed probably the first to use parallel lines for this task. He published an early paper in that same 1888 (manuscript July 7, published in [6]), acknowledging in an end note to the paper (added July 24, while Lodge was in Tyrol at Cortina d'Ampezzo, now in Italy) that Hertz had made the same discovery earlier and for aether, not conducted, waves.

Figure 4 shows Lodge's apparatus. It was rather primeval: electromagnetic waves were powered by the discharge of a Leyden jar, with its capacity – thanks to a spark gap in a coil – providing an inductive behavior. The frequency was determined by their resonance. A second spark could be observed in B, much stronger if wires were a half-wavelength or multiples thereof. Of course, this was quite impractical for what concerned tuning, and poor in sensitivity

Swiss researchers Edouard Sarasin (Geneva, Switzerland, Grand-Saconnex, Switzerland, May 20, 1843 – July 22, 1917) and Lucien de la Rive (Choulex, Switzerland, April 3, 1834 – Geneva, Switzerland, May 4, 1924) also used a balanced line [7], with spark detectors similar to Hertz's (Figure 5).

Ernst Lecher made a fundamental step forward. He started from a setup similar to that used by Sarasin and de la Rive [7], providing a very detailed description of the apparatus [8] (Figure 6):

> A and A′ are square sheet metal plates with 40 cm sides; they are connected by means of a 100 cm long wire segment, which is cut in the middle and at F two brass balls of 3 cm in diameter are added (in Figure 1, only the cross-section of the square plates is drawn). The two brass balls are at a distance of 0.75 cm from each other and are connected using thin

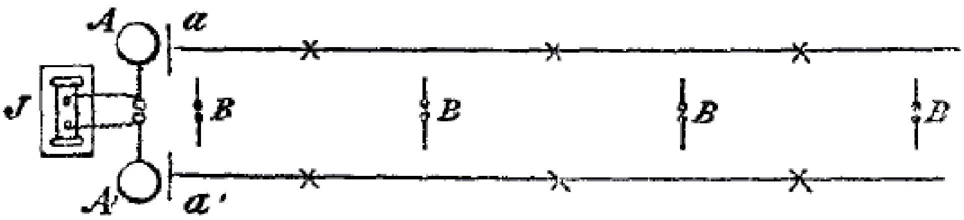

Figure 5. A figure from Sarasin's and De la Rive's 1890 paper [7], showing an apparatus for producing standing waves along a line (copyright expired).

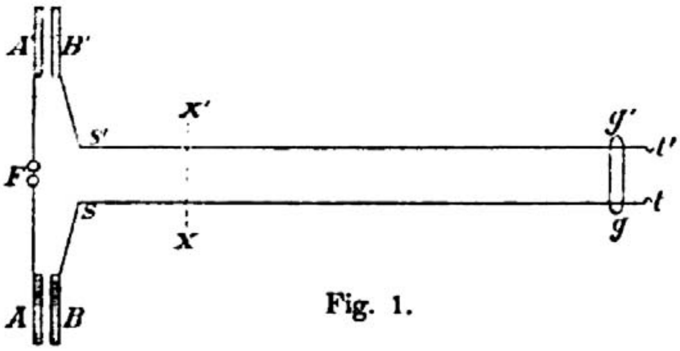

Figure 6. A figure from Lecher's 1890 paper [8] (copyright expired).

wires to the poles of a very strong inductor, whose coil has a length of 35 cm and a diameter of 18 cm; the inductor is fed by four powerful accumulators [batteries], and in some cases by a dynamo.

A Foucault mercury interrupter serves as electric break. Across from the plates A and A′ are two plates B and B′ of identical size at a distance of around 4 cm. From these plates B, B′ run two wires against s and s′ and from there parallel until t and t′. The distance between the parallel wires (s to s′) is 10-50 cm; the length st (s′t′), on the other hand, should be at least 400 cm. The diameter of these parallel wires is here and for all experiments in this publication 1 mm. For this first experiment we assume the length to be about 600 cm (drawn too short in the figure), and the distance of the parallel wires from each other 30 cm.

At the end of the parallel wires (t and t′) a cord is connected to each, which extends the length of the wires by about 100 cm, and allows for a gentle and comfortable tensioning thereof.

The paper by Lecher was dated 1890, in the last issue of the *Annalen* for that year. In its introduction, there are a few lines possibly referring to an oral presentation in April 1890 to the Academy of Science in Vienna. Lecher explicitly cited [7]. However, many references – for example [9, p. 265] – give the incorrect date of 1888 for the Lecher paper. Wikipedia [10], follows [9] in this mistake.

However, what differs from previous work is the method of detecting nodes and antinodes in the wires:

Over the wire ends t and t′ I now lay an exhausted glass tube without electrodes g g′, ideally filled with nitrogen and a trace of turpentine vapor; this glass tube starts to light up due to the electrical vibrations in the wires.

Now, while the tube is shining brightly, place a crossbar over the parallel wires, so it will connect them together metallically (the direction of the wire hanger is perpendicular to the wires and through the dotted line x x′ shown in Figure 1); then the light of the tube disappears for the moment. Now move the crossbar xx′ along the wires, until one arrives at a certain, strangely sharply defined place, where the tube suddenly lights up again. The search for these places and the circumstances surrounding their position constitute the main content of this work.

This is the key point. Previous researchers were seeking for maximums or zeros in the standing wave via a low-sensitivity spark-gap on a wire with arbitrary length, hence providing a reactive impedance to the oscillating circuit difficult to know *a priori* (at least in those early days). By placing a short in xx′, Lecher effectively created a resonator extending from ss′ to xx′. This loaded the oscillating circuit in a much more efficient manner (Lecher stated that he could hear the difference in the spark crackling [8, p. 853]). The key proof was in Figure 3 of Lecher's paper [8] (Figure 6, here).

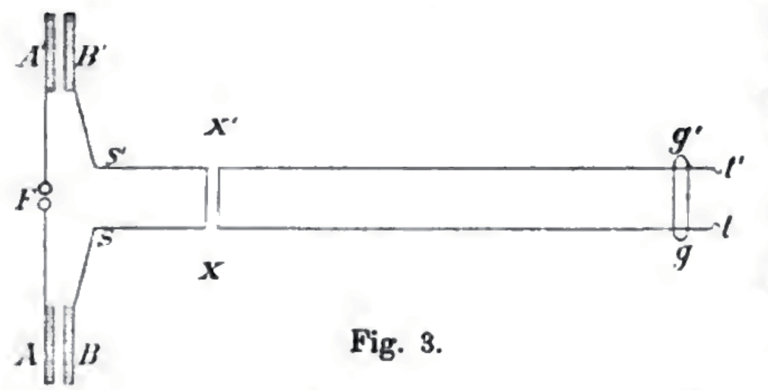

Figure 7. A figure from Lecher's 1890 paper [8], showing the apparatus with disconnected wires (copyright expired).

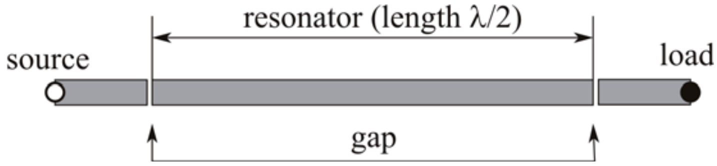

Figure 8. The simplest microstrip gap-coupled bandpass filter.

Lecher placed two isolated shorts across xx' and then cut the wires in between. This produced a short-circuit stub loading the oscillator, and a disconnected line shortened at one end and loaded by the tube at the other. The tube still shed light. If a further short was placed across the wire between xx' and the tube, then the tube turned off unless such a short was again in a very precise position. What Lecher was creating was analogous to a microstrip bandpass filter with just one resonator (Figure 8). The resonant part, a half-wavelength long, was determined by the two shorts and, at the resonance, the signal passed up to the glowing tube.

In his paper, Lecher also noted that the length of the resonant part delimited by the two shorts was also somewhat dependent on its absolute position along the line. He correctly commented that this was due to the load of the line sections on the left and the right of the resonator, which were themselves length-dependent.

In the last part of the paper, Lecher evaluated the speed of the signal along the wires. The setup was that reported in Figure 9. The left part was unchanged from the previous experiment. At the right end, a capacitor was added, and the glowing tube was placed on it. Shorts were placed in dd' and cc' so as to have a nice bright response from the tube.

Lecher measured a half wavelength of 982 cm as an average over 20 repetitions of the experiment. However, the frequency of the oscillation was determined by the *LC* circuit at the far right, comprised of an (inductive) wire loop and the capacitor. This circuit was estimated by Lecher computing the inductance via the Neumann formula [11, 12],

$$L = 2l\left[\ln\left(\frac{4l}{d}\right) - 0.75\right], \tag{1}$$

and the capacitance via its simplified formula,

$$C = \frac{R^2}{4\delta}. \tag{2}$$

The corrective term due to fringing fields was neglected; it was already known (Kirchhoff [3]) on the basis of some considerations of the dimensions of the disk and of the point where the wires were connected.

With his geometrical parameters (the length of the wire in the secondary oscillator, $l = 303.2$ cm; the wire diameter, $d = 0.1$ cm; the radius of the capacitor plates, $R = 8.96$ cm; and the distance between the plates, $\delta = 0.99$ cm, Lecher obtained

$$L = 5248 \text{ cm}, \tag{3}$$

$$C = 20 \text{ cm}.$$

Yes, inductances and capacitances are in centimeters. This is due to the odd system of units used in Lecher's times, the *electrostatic system of units*. The interested reader might refer to [14] for further details. Due to this choice, Lecher also wrote

$$T = \frac{\pi\sqrt{LC}}{c}, \tag{4}$$

with *T* being the oscillation period and *c* being the speed of light in a vacuum, a universal constant quantity that appears as a scale factor between the *electrostatic* and *electromagnetic* systems of units [14]. From Equation (4),

$$\lambda = Tc = \pi\sqrt{LC} = 1017 \text{ cm}$$

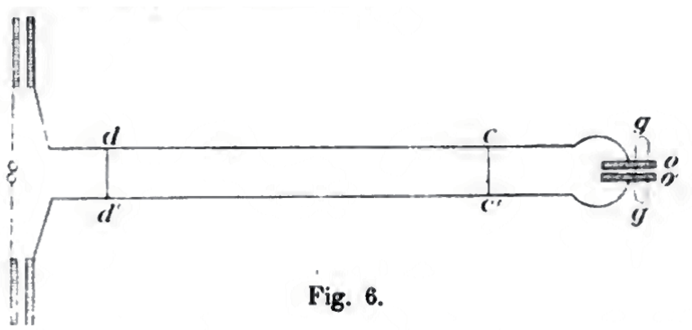

Figure 9. The Lecher apparatus modified to measure the speed of propagation, from Lecher's 1890 paper [8] (copyright expired).

Figure 10. A photo of Prosper-René Blondlot by an unknown photographer (public domain).

can immediately be obtained. The free-space wavelength and the wavelength on Lecher's wires were hence the same (within a 3.5% error that Lecher reasonably neglected and ascribed to the very delicate measurement setup). Since the period was necessarily the same and the wavelength was the same, Lecher correctly derived that also the speed of propagation was the same for both free-space and conducted waves.

Indeed, it was possible that Lecher somewhat got the result he was expecting. The formula to determine the inductance, Equation (1), is too approximate, since it is for a straight wire and not a loop. For the capacitor, he neglected fringing, and hence took a smaller value. However, the key point was the length of the wire in the rightmost part of the circuit. A subsequent investigation [15] showed that it was too long with respect to wavelength to assume that Equation (1) was valid, which was derived based on the hypothesis of a constant current along the wire. As a result, Lecher's results were obtained by chance.

Soon after Lecher, Prosper-René Blondlot (Nancy, France, July 3, 1849 – Nancy, France, November 24, 1930; Figure 10) published a more-accurate experiment [16] with several different lengths for the secondary circuit, obtaining reliable values ranging from 291400 to 304100 km/s[2]. Blondlot is actually more (in)famous for his "discovery" in 1903 of the non-existent N-rays [17]. This was a case unequalled in the number of scientists involved and the number of papers published by qualified scientists of high reputation belonging to the community of scholars. Some 120 scientists published almost 300 articles on the topic

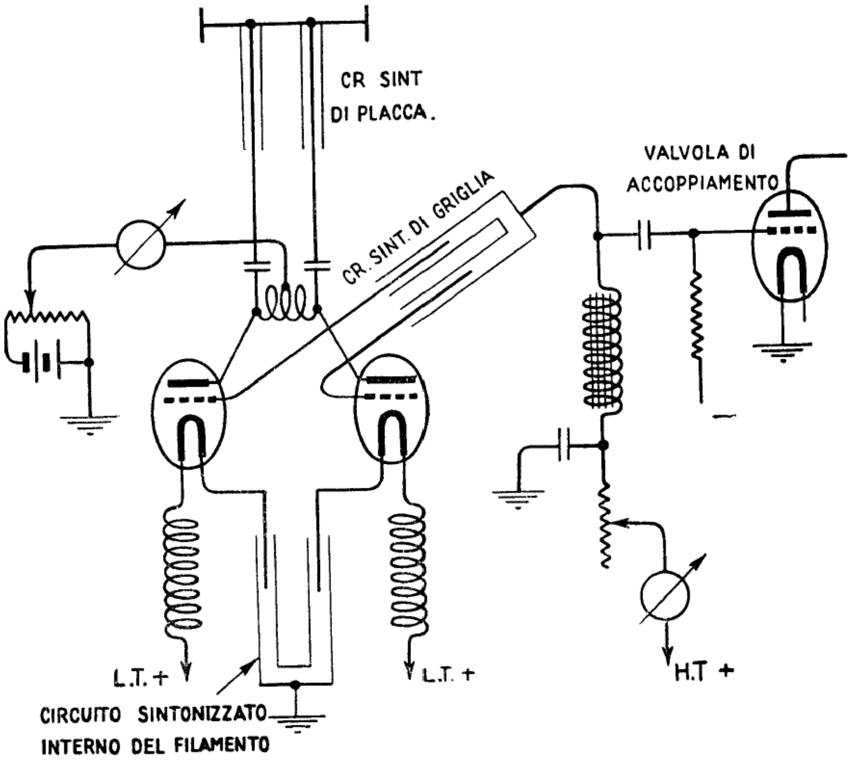

Figure 11. A receiver by G. Marconi (about 1931), with three Lecher lines of adjustable length for syntonization: on the anode (*placca*), on the grid (*griglia*), and on the cathode (*filamento*) (public domain).

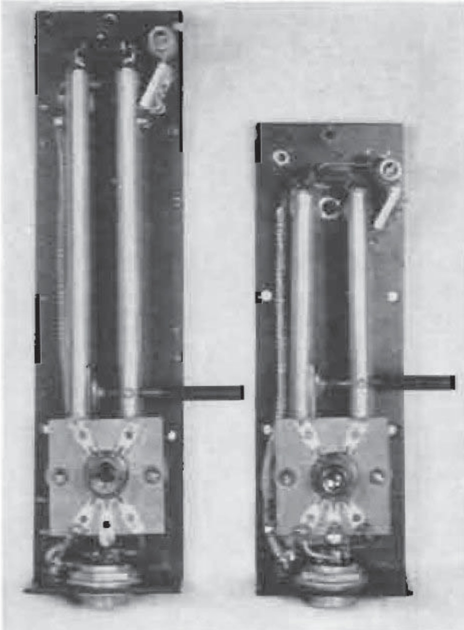

Figure 12. Lecher lines for UHF (1938). Both were one-eighth-wavelength long. (l) A 200 MHz (19 cm) line; (r) a 300 MHz (12.5 cm) line (public domain).

during the years 1903-1906. Blondlot himself published 26 articles and a book [18] before stopping, all of them on "rays" that had never been observed. Indeed, this was a paradigmatic case on the dangers of error introduced by experimenter bias [19].

3. Later, Widespread Use

Since the time described above, Lecher lines have become synonymous with two-wire transmission lines, especially if used to determine wavelength rather than as a transmission line. This remained the main instrument for determining the frequency of an oscillator up to the advent of frequency counters, just after World War II.

Indeed, when, later in his life, Guglielmo Marconi (Bologna, Italy, April 25, 1874 – Rome, Italy, July 20, 1937) started to investigate high-frequency radio communications he used Lecher lines, also in a tunable-length version, to fix the frequency of his valve oscillators [20] (Figure 11). In addition, Nello Carrara, who minted the word "Microwaves," used Lecher lines to generate them [21]. Figure 12 shows a later (1938) pair of Lecher lines used to tune a UHF receiver at 200 MHz and 300 MHz. They are used at frequencies between HF/VHF and UHF/SHF. At lower frequencies, lumped components can be used, and at higher frequencies, resonant cavities are more practical. In particular, they were used in TV tuners up to the advent of digital electronics (Figure 13).

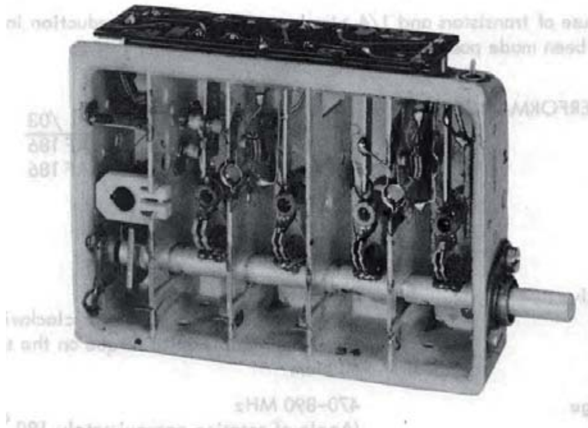

Figure 13. A 1969 UHF TV tuner (Philips Model AT6381/01). Four Lecher lines, vertically placed and loaded with variable capacitors for tuning, are visible in the four rightmost compartments (from [22]).

Lecher lines are often cited in the later literature as the easiest way to set the frequency of an oscillator, and in particular, for educational purposes [23-26].

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