RADiO MAGiC

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The Road to Radio — Part 8

Introduction

Michael Faraday **(Figure 1)** was renowned for his experimental genius despite his limited mathematical skills. He envisioned the space around magnets and electric currents as filled with invisible electric and magnetic "lines of force" that carried energy, which he believed explained electromagnetic induction.
However, classical (Newtonian) physicists found this an abstract bridge too far. William Thomson (later Lord Kelvin), while respecting Faraday's insights, sought to make them more “palatable” to Victorian physicists who viewed Newton’s analog universe as a clockwork of springs, sprockets, gears and levers.

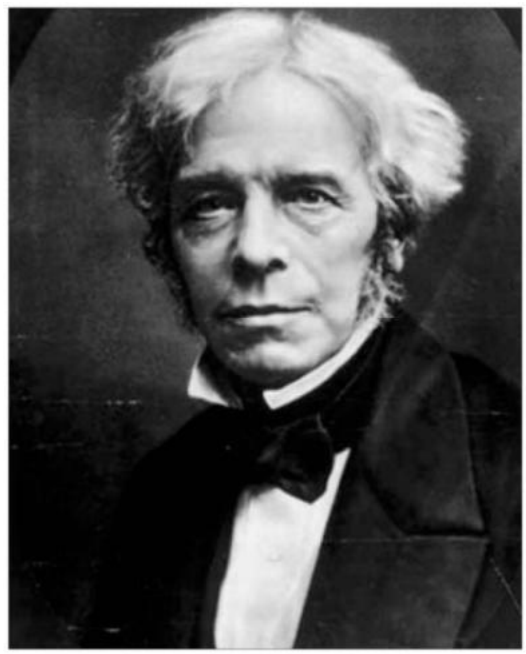


Figure 1 — Faraday, age 67, Daguerreotype. Credit: Maull and Polyblank of London, 1858.

Thomson reformulated lines of force into mechanical etheric models: tubes of tension and vortices, or rotations of strain. In his view, the ether was a tangible substance, and tensions and rotations within it produced electric, magnetic, and light phenomena. Faraday was now alone, lost deep in terra incognita.

To make matters worse, Faraday suffered from frequent bouts of “nervous exhaustion” — overwhelming mental and/or physical fatigue — and his wife, Sarah, would drag him away from London to the countryside, where, after a few weeks of rest and fresh air, he returned to his work. However, this time was different; he had not done any science for nearly two years, and was now experiencing episodes of sudden memory loss — often forgetting what he was saying or writing in mid-sentence — along with a growing difficulty in concentration. Most frustratingly, he is fully aware that it is happening to him and there is nothing anyone can do.

Note 1: Faraday’s cognitive difficulties began in his late 40s, and are consistent with long-term exposure to laboratory neurotoxins such as mercury, lead and arsenic. Chemists of his era worked without modern protective equipment or safety protocols. Chronic poisoning was an occupational hazard.

Note 2: Academic critics and jealous rivals aside, Faraday enjoyed enormous public support and admiration, including from the British Royal Family. In 1858, Queen Victoria offered the Faradays a grace-and-favour residence at Hampton Court Palace. Although he had already politely declined offers of a knighthood, a baronetcy, and even burial in Westminster Abbey near Sir Isaac Newton, Faraday accepted this practical gift for Sarah’s comfort and security. Their new home soon became known as “Faraday House.” Sarah continued to live there after Michael died in 1867 at age 75, until her death in 1879 at age 79.

On Faraday’s Lines of Force

It is now March 1857, and Mr. Faraday is back at the Royal Institution; we can resume our fly-on-the-wall observations. Sorting through his mail, he opens a thick envelope containing another unsolicited manuscript. Looking over his shoulder, we can read the title: “On Faraday’s Lines of Force.” The first paragraph begins, "The present state of electrical science seems peculiarly unfavourable to speculation."

He rolls his eyes and sighs. However, as he continues to read, he is stunned by the analogies comparing his electric and magnetic lines of force to the flow of incompressible fluids. The speed and direction of flow at any point in space are likened to the density and direction of the lines of force, although the complex mathematics bewilders him.

The accompanying letter reads,

“March 16, 1857
Dear Sir,

I have recently been devoting some time to the study of your Experimental Researches on Electricity and Magnetism, and the results at which I have arrived seem to me to confirm, to a great extent, the views which you have been led to form concerning the nature of electric and magnetic forces.

In particular, I have been endeavouring to arrive at a mathematical expression of the laws of the phenomena described in your Thirteenth and other Series of Experimental Researches. The result is that I have found that these laws admit of being represented in a very simple manner by means of certain functions which occur in the mathematical theory of the potential.

I am therefore very desirous of communicating with you on the subject, in order that I may have the benefit of your criticism, and that I may learn whether the results at which I have arrived agree with those of your own experiments.

I am, dear Sir,
Yours very faithfully,
James Clerk Maxwell”

At long last, he has found his dragon slayer. Or rather, the dragon slayer has found him **(Figure 2)**.

Figure 2 — Maxwell, age 24, Daguerreotype. Holding his famous red, green and blue (RGB) colour wheel. By spinning it, he proved that white light is an equal additive blend of RGB, and that all colours can be derived from percentage blends of RGB. Credit: The Master and Fellows of Trinity College, Cambridge, 1855.

A Dynamical Theory of the Electromagnetic Field

In 1860, Maxwell moved to London to teach at King's College, a three-kilometre stroll from the Royal Institution. He attended several of Faraday's lectures and gave one of his own in return. Others saw Maxwell as the son Faraday never had, and Faraday likely did too. However, by 1862, Maxwell's mental health made it increasingly difficult for them to continue collaborating. In 1865, Michael Faraday resigned from the Royal Institution and retired from science altogether.

While at King’s College, Maxwell determined that the speed of electromagnetic “disturbances” travelling through the ether matched that of light. Using the available experimental data, he calculated the velocity to be about 311 million metres per second, very close to the modern value of 300 million metres per second. He went on to argue that what we call “light” is actually a transverse travelling electromagnetic wave (**Figure 3**). This appeared in his landmark 1865 paper, *A Dynamical Theory of the Electromagnetic Field*, in which he also introduced the concepts of electric and magnetic fields and magnetic flux flowing through a continuous medium.

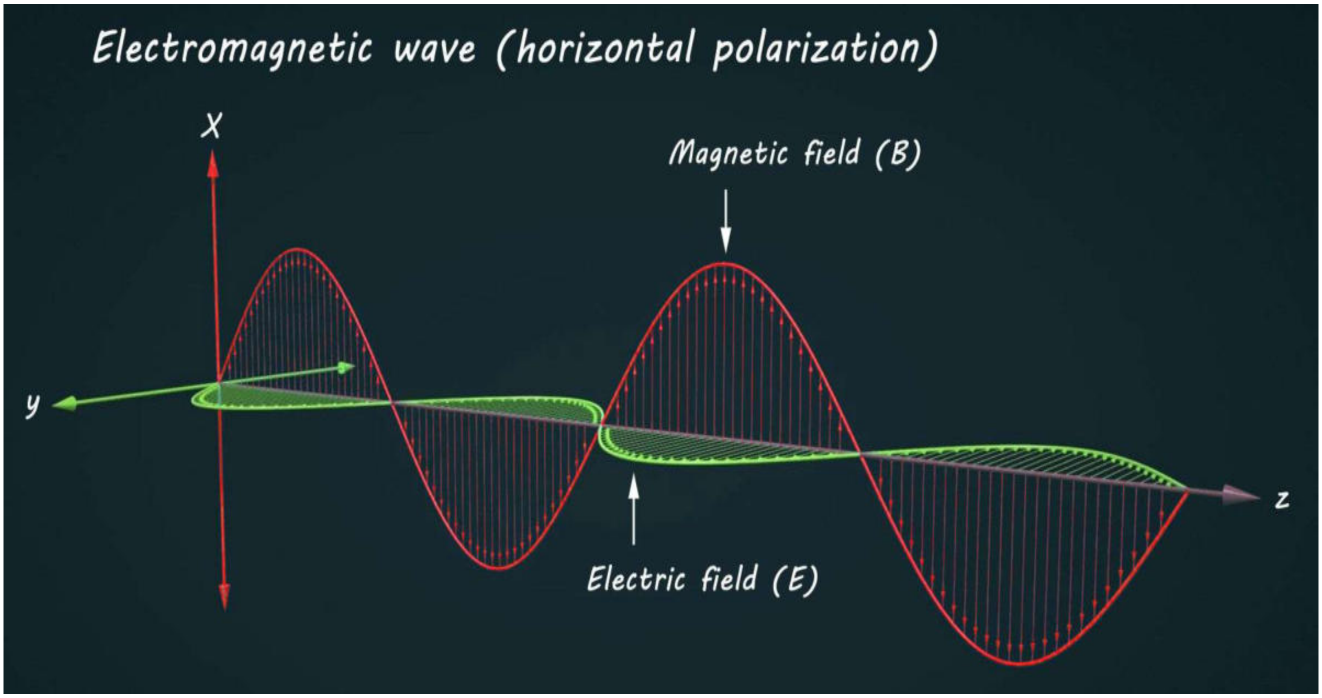


Figure 3: The Electromagnetic Wave — The polarization of electromagnetic waves is determined by the orientation of the electric field (vertical or horizontal) because ordinary matter responds primarily to it (no magnetic charges exist). Credit: https://sketchfab.com.

Maxwell believed electromagnetic waves required a propagation medium — the ether — and envisioned it as a dynamic substance capable of storing and transmitting energy. However, he used complex, rarely used quaternion and potential mathematics to explain his theory, making it extremely difficult for most physicists to understand, let alone accept.

His very dry presentation of *A Dynamical Theory*, read at a meeting of the Royal Society in 1864, introduced many strange concepts that bewildered his audience. Maxwell interwove his theory with mechanical analogies, which he did not intend to be taken literally, but they were, adding to the confusion. His mathematics (20 equations and variables) predicted the theoretical existence of waves of orthogonally entangled electric and magnetic oscillating fields travelling through the ether at the speed of light. However, he did not explain exactly how these ether waves could be generated or even detected.

William Thomson, who had directed Maxwell toward Faraday, recognized the brilliance of *A Dynamical Theory*, but he believed the convoluted mathematics was disconnected from the very real physical mechanisms required to produce electromagnetic waves. Therefore, most physicists saw Maxwell's potentials as artificial constructs designed to fit his theory rather than as physical realities. Thomson voiced the collective criticism that Maxwell, like Faraday, had "lapsed into mysticism".

Oliver Heaviside thundered that "Maxwell's potentials should be assassinated!", which he proceeded to do. What we call "Maxwell's Equations" are actually his four equations and variables. But he refused to have his name hyphenated with Maxwell's. He believed that if Maxwell had lived longer, he would have reached the same conclusion and reformulated his equations. Heaviside later coined the term "impedance," developed the mathematical framework needed to understand, design, and troubleshoot long transmission lines, and defined the "Heaviside condition" with one elegant equation still used by electrical engineers.

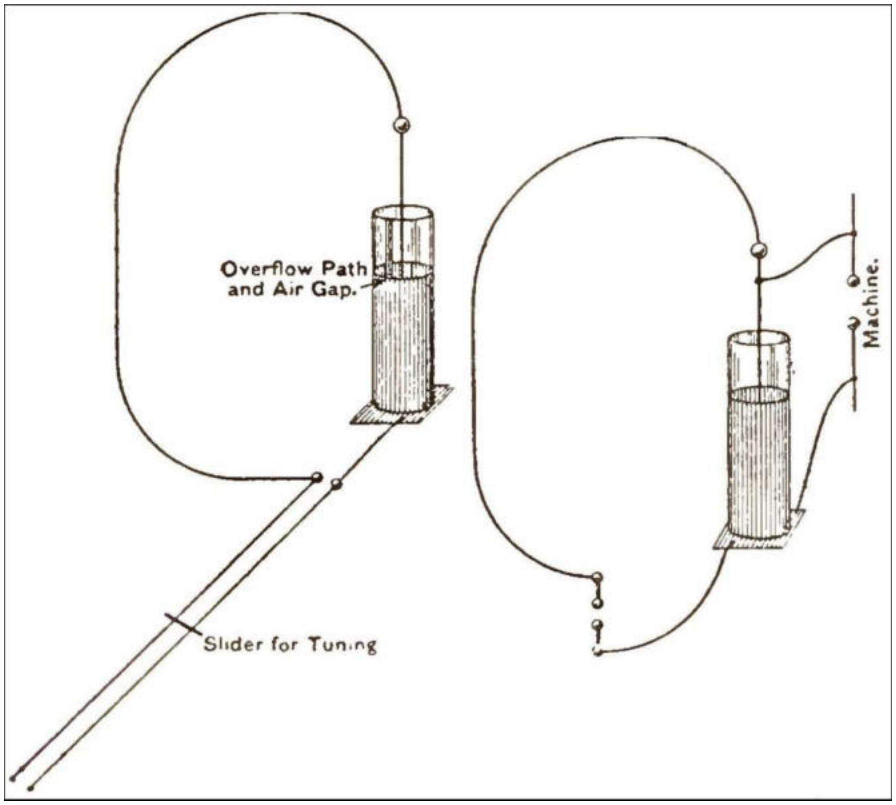
Note 4: James Clerk Maxwell died of abdominal cancer at age 48 in 1879. Eerily, his mother died of the same cancer at the same age.

The Race is On

Only a handful of men understood Maxwell's theory. One was Oliver Lodge, who, in the late 1880s, studied lightning and electrostatic discharges from Leyden jars and their disruptive effects on landline telegraph and telephone systems. He suspected they might be high-frequency alternating currents or manifestations of Maxwell's ether waves. Using Leyden jars, induction coils, and resonant circuits, he produced rapid electrical oscillations (sparks) along parallel open wires. He calculated their frequency from the inductance and capacitance of the Leyden jars and measured their wavelength from the standing waves created along the wire.

This culminated in his famous "recoil kick" experiment, in which a strong spark appeared at the far end of the line only when the line was tuned to resonance with the Leyden jar's discharges **(Figure 4)**. Strangely, he stopped there and did not attempt to transmit and detect ether waves through free space across the room.

Figure 4: Lodge's Syntonic Leyden Jar Experiments — Credit: *The Work of Hertz and Some of his Successors*, Oliver Lodge, 1894.



Because he was unaware of Heinrich Hertz's research, Lodge delayed publishing his results and took what he thought was a well-deserved break. He would read his paper at the next meeting of the British Association for the Advancement of Science (BAAS).

In Germany, unaware of Lodge's work, Heinrich Hertz was another physicist who suspected that rapid spark oscillations might generate Maxwell's electromagnetic waves. Hertz had also reworked Maxwell's equations, but later acknowledged Heaviside's priority. He chose the much harder path to discovery: transmitting and detecting Maxwell's waves through the ether.

His transmitter was a rudimentary spark-gap oscillator, and the receiver was an ingenious, simple single loop of wire with a tiny air-gap between its ends. In a darkened room, Hertz's eyes became the detector, catching faint sparks snapping across the loop's air-gap whenever the oscillator was energized **(Figure 5)**.

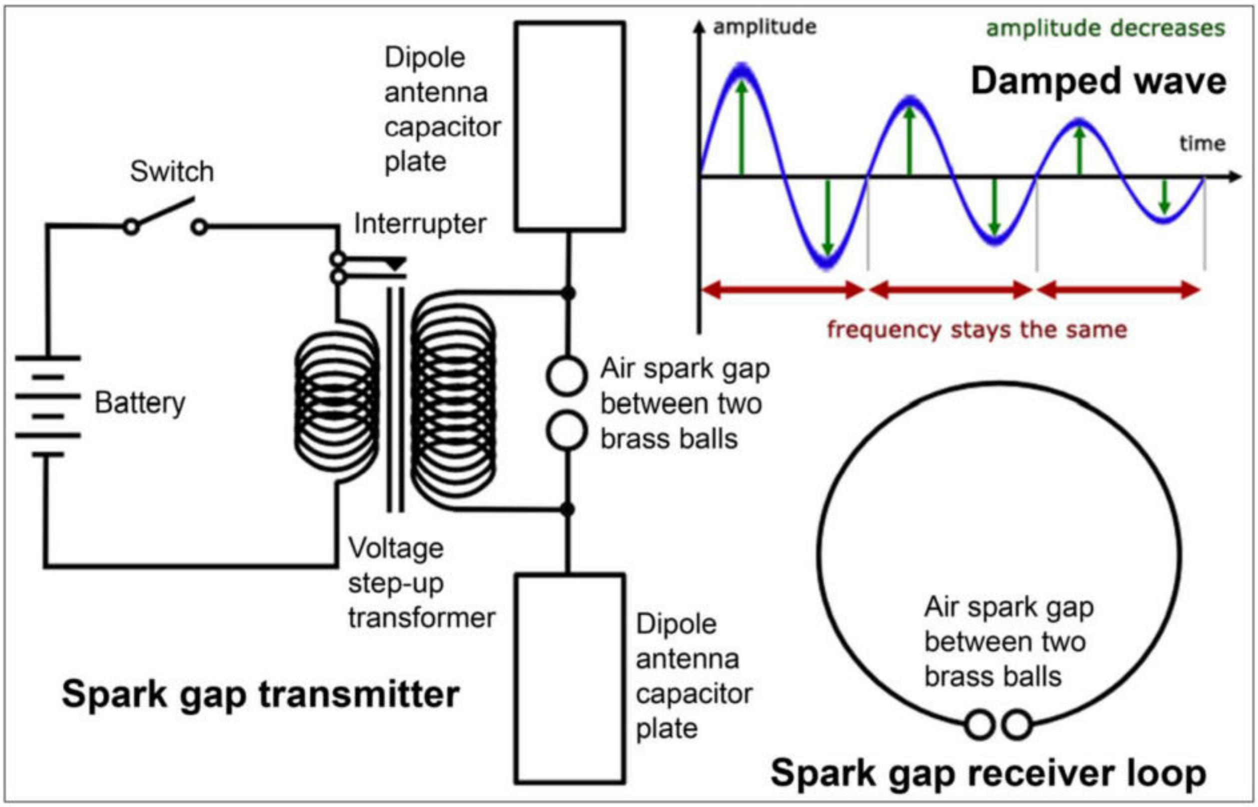


Figure 5: How Heinrich Hertz Discovered Electromagnetic Waves — High-voltage discharges emit electromagnetic (damped) waves through space (and time) and produce visible sparks that snap across a small air gap in a nearby loop. Credit: Wikipedia and The A-Level Physics Tutor https://thealevelphysicstutor.com.

To rule out Faraday's magnetic induction, Hertz conducted ingenious experiments to study and measure the characteristics of the suspected ether waves. His experiments proved they could be reflected, refracted, and polarized like light waves. But unlike light, they could also penetrate non-metallic solids — doors, walls — even his hapless laboratory assistant. Without delay, he published his results *as Über sehr schnelle elektrische Schwingungen* (On Very Rapid Electric Oscillations) in the November–December 1887 issue of *Annalen der Physik und Chemie* (Annals of Physics and Chemistry). The English translation appeared in early 1888, shortly before the BAAS meeting. Lodge, without bitterness, famously said that he had "gone on holiday and missed immortality."

Despite the international fame and honours that quickly followed, Hertz remained a pure experimentalist who wanted only to prove whether Maxwell's theoretical electromagnetic waves existed. Once he had done so, Hertz moved on, saying his work was "Of no use whatsoever." At the time, this was true because, without a device capable of automatically detecting ether waves, such waves were essentially useless outside the laboratory.

Note 5: Hertz suffered from "melancholy" — a Victorian term for deep sadness or reflective withdrawal, which may also explain his self-deprecating remark. Tragically, he died on New Year's Day, 1894, at age 36 from sepsis, weeks after minor surgery.

The Birth of "Wireless"

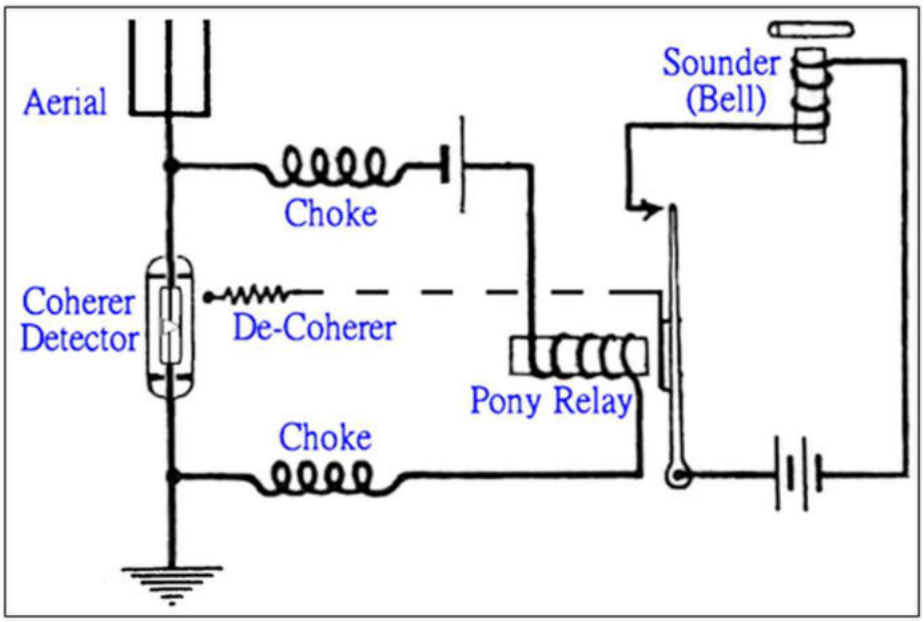
In 1890, French physicist Édouard Branly discovered that metal filings in a tube clumped together when exposed to an electrostatic discharge, thereby conducting electric current (the Branly effect). But when physically jarred, they easily broke apart and returned to their non-conductive state. No one then, or for well over a century, could explain why.

In 1893, Lodge refined "Branly's tube," increasing its sensitivity and, in the process, discovered that it also responded to ether, or, more formally, Hertzian waves **(Figure 6)**. It was the first solid-state detector. He also renamed it the "coherer" (from the Latin cohaerere, "to stick or cling together").

Figure 6: The Coherer — This design produced the most sensitive coherer. Because it had to be immediately and mechanically decohered (tapped), its maximum speed (turnaround time) was limited to about 16 words per minute using spark-gap Morse code. Credit: Navone Engineering, Inc.

On August 14, 1894, Lodge, now a professor at University College, Liverpool, England, gave the first public demonstration of "wireless" using a simple spark-gap transmitter coil located 60 metres from the lecture hall. His coherer detector, connected to an electric bell circuit in the lecture hall, rang on command, astonishing his audience **(Figure 7)**. This was nearly two years before Guglielmo Marconi's first wireless experiments in Italy.

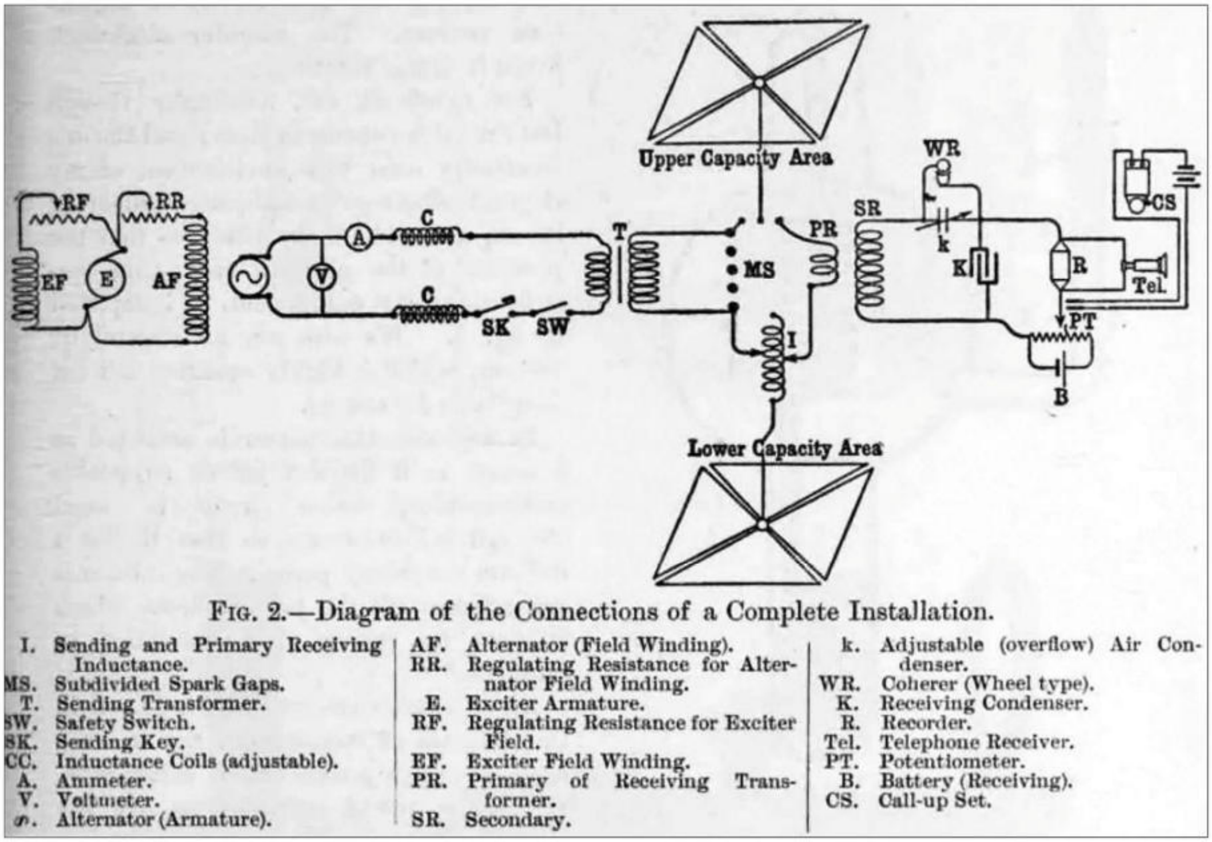
Figure 7: Lodge's 1894 Coherer Receiver — In 1895, Alexander Popov built a lightning detector using the same circuit. In 1896, Guglielmo Marconi also used it for short-range spark-gap Morse code messaging. Credit*: Elements of Radiotelegraphy*, Ellery W. Stone, 1919.



A few years later, Lodge proudly demonstrated his newly patented syntonic (tunable) wireless transmitter and receiver to a curious young Italian visitor **(Figure 8)**. In London, trying to sell his rudimentary wireless telegraphy equipment and practical applications to the British Postal Service — then in control of all landline communications — Guglielmo Marconi made a special side trip to Liverpool to meet the world's foremost wireless expert. Lodge did not realize that his intellectual property would create a wireless empire and make only one of them very rich and famous. Poor Lodge — always the bridesmaid, never the bride.

Note 6: In 1891, Nikola Tesla had already demonstrated wireless energy transmission by lighting free-standing fluorescent tubes at a distance, but he believed etheric (through-the-ether) wireless telegraphy was impractical and that the road to the future was telluric transmission — transmitting wireless electrical power and messages through the Earth. It was not.

Figure 8: Lodge's Syntonic Circuit — Syntony, or tuning, made long-distance commercial spark-gap wireless telegraphy possible. Credit: Syntonic Wireless Telegraphy, Oliver Lodge and Alexander Muirhead, 1908.



Note 7: As an all-on or all-off linear switching device, the coherer could not demodulate continuous wave (CW) or amplitude-modulated (AM) signals. In the early 20th century, electrical engineer Reginald Fessenden, known as "The Canadian Edison," developed mechanically generated CW and AM transmissions using high-speed, high-power alternators, as well as the wire barretter and electrolytic detectors. This rendered the coherer obsolete but not forgotten.

Note 8: In October 2018, Eric Falcon and Bernard Castaing of the Laboratoire de Physique, École Normale Supérieure de Lyon, revealed how it worked in *Electrical Conductivity in Granular Media and Branly's Coherer: A Simple Experiment*. They discovered that the Branly effect is caused by electro-thermal coupling due to Joule heating. In other words, "magic."

Lodge v. Marconi

The spark-gap equipment Marconi brought to London had a fatal flaw that prevented its commercial success: spark-gap (damped-wave) wireless signals were extremely broadband and interfered with nearby stations, producing a cacophony of raspy signals that made it difficult for wireless operators, or "sparks," to copy the specific signal they wanted. To solve this problem, Marconi began using Lodge's patented tuning technology without paying him royalties. When Lodge attempted to negotiate a deal, the reply was essentially, "So sue me." Unlike Marconi, Lodge did not have the finances to fight a long, drawn-out court battle, so he waited for the right moment to strike when it would cost him nothing to win or lose.

It came in the spring of 1911, when the now Sir Oliver Lodge slyly petitioned the British High Court to extend his 1897 British tuning-technology patent, set to expire, arguing he had not been fairly compensated. The High Court agreed with Lodge, extended his British patent to 1918, and ruled that he must be fairly compensated. Marconi was ordered to either negotiate a deal or shut down his British wireless operations (land and sea).

Fortunately for Marconi, Lodge did not care about the money and sold his patent outright to Marconi for only £18,000 (about $2.7 million USD today). In return, Lodge was appointed a "scientific advisor" to the Marconi Wireless Company and received an annual no-show salary of £1,000 (about $150,000 USD today) for the duration of the patent extension. By doing so, Lodge knowingly transferred to Marconi the headaches and expenses of defending the patent in court for years on end against other wireless competitors.

My Final

My last three articles that complete this journey were written in 2020: *Myth, Magic and Marconi* (Parts 1-3), in the Jan-Feb, Mar-Apr, and May-Jun issues of *TCA*. You may be wondering how I knew back then that I would write a related series of articles years later, leading back to them, but I gave up trying to understand temporal mechanics and quantum field entanglement a long time from now. — 73

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