



Timeline of radio frequency engineering ... from pre-Maxwell era to 20th century



The dawn to pinnacle of classical electrodynamics

- The story kickoffs back in **1678**, when **Christiaan Huygens**, a Dutch scientist, postulated the wave theory of light, explaining linear and spherical wave propagation, and derived the laws of reflection and refraction.
- Hans Christian Ørsted**, a Danish physicist, on **April 21, 1820**, during a lecture conducted the famous experiment showing that electricity and magnetism are linked.



Furthering Ørsted's experimental work, **André-Marie Ampère**, a Frenchman, showed that two parallel wires carrying electric currents attract or repel each other, depending on whether the currents flow in the same or opposite directions, respectively. In **1827**, Ampère published his magnum opus, *Mémoire sur la théorie mathématique des phénomènes électrodynamiques uniquement déduite de l'expérience* (Memoir on the Mathematical Theory of Electrodynamical Phenomena, Uniquely Deduced from Experience), the work that coined the name of his new science, **electrodynamics**.



Ørsted holds a wire above a magnetic needle supported on a pivot. The needle is deflected when electric current flows through the wire.

- George Simon Ohm**, a German physicist, in **1827** formulated the famous Ohm's law. Ohm's Law applies at DC, where he measured it, and just as well at microwave frequencies. Semiconductors have been known to bend Ohm's law, but it took more than 100 years after Ohm, for this to happen.
- Johann Carl Friedrich Gauss**, a German, regarded as one of the most prominent mathematician to have ever lived; in **1835** formulated the Gauss's flux theorem (although first proposed by Joseph-Louis Lagrange in **1773**).
- Michael Faraday**, an Englishman by birth, and a Chemistry Professor by profession, in **August 1831** discovered and demonstrated the principles of electromagnetic induction.
- Joseph Henry**, an American scientist, famously known for creating strong electromagnets, in **1831** created one of the first machines to use electromagnetism for motion, the earliest ancestors of the modern DC motor.



The crude electrical generator instruments used by Michael Faraday for his experimental demonstration (on display in Faraday museum, London)



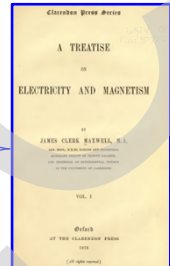
Siemens built the Indo-European Telegraph Line, "Indoline" and started operation in April 1870. Instead of 30 days, it now took only 28 minutes to transmit messages from London to Calcutta – a sensation at the time !!

- Christian Andreas Doppler**, an Austrian by birth, in **1842** published the principle of Doppler shift, which is the key ingredient of modern-day Doppler RADAR.
- Gustav Robert Kirchhoff**, a German physicist, in **1845** formulated the famous Kirchhoff's current and voltage rules as a part of his seminar exercise, which later became his doctoral research work.
- Werner von Siemens**, the German electrical engineer, in **1847** founded the company that bears his name, SIEMENS, and which later went on to make the world's first dynamo (generator) based on Faraday's law.

The Maxwell's Equations

- James Clerk Maxwell**, an Englishman, publishes the mathematical model of electromagnetism in **1865**, which united electricity and magnetism into one field of study and introduced the concept of electromagnetic waves.
- Maxwell's formulation was cast in its **modern form** by **Oliver Heaviside** during the period from **1885 to 1887**. Heaviside was a reclusive genius whose efforts removed many of the mathematical complexities of Maxwell's theory, introduced vector notation, and provided a foundation for practical applications of guided waves and transmission lines.

$$\begin{aligned}\vec{\nabla} \cdot \vec{E} &= \frac{\rho_v}{\epsilon_0} \\ \vec{\nabla} \cdot \vec{H} &= 0 \\ \vec{\nabla} \times \vec{E} &= -\mu_0 \frac{\partial \vec{H}}{\partial t} \\ \vec{\nabla} \times \vec{H} &= \vec{J}_c + \vec{J}_a = \sigma \vec{E} + \epsilon_0 \frac{\partial \vec{E}}{\partial t}\end{aligned}$$



"From a long view of the history of mankind - seen from, say, ten thousand years from now - there can be little doubt that the most significant event of the 19th century will be judged as Maxwell's discovery of the laws of electrodynamics" **Richard P Feynman**

"Since Maxwell's time, physical reality has been thought of as represented by continuous fields, and not capable of any mechanical interpretation. This change in the conception of reality is the most profound and the most fruitful that physics has experienced since the time of Newton" **Albert Einstein**

The golden era of electromagnetics engineering

- John William Strutt**, 3rd Baron Rayleigh, a British mathematician in **1871**, published electromagnetic solutions explaining blue color of the sky.
- Gustav Mie**, a German physicist, in **1908** published a paper entitled, *Beiträge zur Optik trüber Medien, speziell kolloidaler Metallösungen*, outlining what is today famously known as **Mie Theory**, which also explains the red color of the sky by solving Maxwell's equations.
- John Henry Poynting**, an English physicist, in **1884** published the concept of Poynting vector.
- In **1875**, **Thomas Alva Edison** discovered principle of radiation, and in **1885** he patented a communication system using vertical, top-loaded, grounded antennas ... first instance of recorded antenna.
- The discovery of microwaves (in particular, experimental proof of Maxwell's Equations) occurred in **1886** from the experiments of **Heinrich Hertz**, a German physicist, while he was a professor in Karlsruhe Polytechnic, which for the first time demonstrated the transmission and reflection of radio waves from various objects.

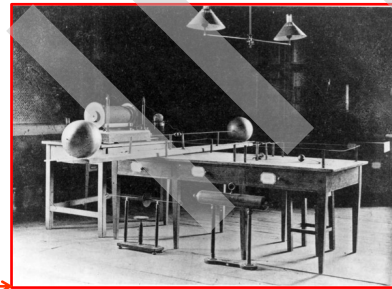
UNITED STATES PATENT OFFICE.

THOMAS A. EDISON, OF NEW YORK, NEW JERSEY.
MEANS FOR TRANSMITTING SIGNALS ELECTRICALLY.

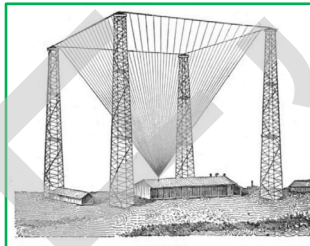
REPRODUCTION drawing part of Letters Patent No. 400,971, dated December 20, 1889.
Application filed May 15, 1878. Serial No. 194,626. (10 claims.)

To all whom it may concern:
Be it known that I, THOMAS A. EDISON, of New York, New Jersey, have discovered a new and useful improvement in means for transmitting signals electrically, (Case No. 400,971) of which the following is a specification.

And this invention would be one of great importance in telegraphy. It consists in the use of a series of vertical, top-loaded, grounded antennas ... first instance of recorded antenna.



Experimental Setup by Heinrich Hertz in Karlsruhe, Germany (Photo taken by Heinrich Hertz)



Drawing of Guglielmo Marconi's wireless telegraphy transmitting station in Poldhu, Cornwall, England, erected **October 1901**, with which he transmitted the first transatlantic radio message to St. John's Bay, Newfoundland, Canada, on **12 December 1901**, a distance of 2300 miles (3700 km)

In this context, it should be reminded that **Sir Oliver George** experimentally demonstrated the concept of metal waveguide transmission in **1894**, and, not to forget by any means, Serbian-American genius **Nikola Tesla** patented radio communications in **1897**.

Experimental work on millimeter wavelengths by an Indian

- A man whose great discoveries proved to be ahead of their time **Sir Jagadish Chandra Bose** was a visionary, biologist, botanist, physicist, and an author whose ideas led to such achievements as "crystal" radio sets.
- In a demonstration in **1895**, he used electromagnetic waves at 60 GHz to ignite gunpowder and ring a bell from a distance, reported to be nearly a mile ... IEEE (Institute of Electrical and Electronics Engineers) named him "**Father of Radio Science**"



Bose's 60-GHz apparatus at the Bose Institute in Kolkata, India



Sir J. C. Bose with his research scholars at Bose Institute, Calcutta in 1928.

The 20th century revolutions in microwave engineering



On **17 May 1904**, a 22-year-old German by the name of **Christian Hülsmeyer**, took his apparatus to the banks of the Rhine river, next to the Hohenzollern Bridge, in Köln in northern Germany, to demonstrate the detection of a ship at a range of several hundred meters.

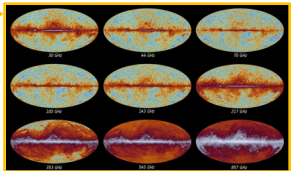
Hohenzollern Bridge, Köln, Germany birthplace of modern-day Radar

- Like many of today's great inventions, the **microwave oven** was a by-product of another technology. It was during a radar-related research project around **1946** that **Dr. Percy Spencer**, a self-taught engineer with the Raytheon Corporation, noticed that while he was testing powered radar set the candy bar in his pocket had melted. This intrigued Dr. Spencer, so he placed some popcorn kernels near the power source and, he watched with an inventive sparkle in his eye as the popcorn sputtered, cracked and popped all over his lab rest is history!

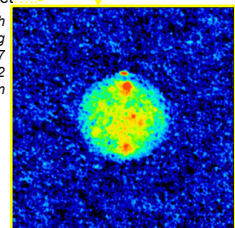


Advertisement image of microwave oven on page 15 of the October 14, 1946, publication of the Press and Sun-Bulletin

- The existence of the **Cosmic Microwave Background** was first theorized by Ukrainian-American physicist **George Gamow**, along with his students, **Ralph Alpher** and **Robert Herman**, in **1948**.
- Due to the expansion and eventual cooling of the Universe after the Big bang, the background radiation has a low temperature of **5 K (- 268 °C)** – just five degrees above absolute zero – which corresponds to microwave wavelengths ($P = kT\Delta f$)
- The **VLA** (Very Large Array in Socorro, New Mexico) project was approved in **August 1972** (then 78 million USD) and was fully operational around **1980s** go to **34.04°N, -107.37°W** in Google maps and zoom-in !!
- In **1991**, planetary scientists studied **planet Mercury** using a radar system consisting of NASA's 70-meter (230-foot) dish antenna at Goldstone, California, equipped with 500000 W transmitter. The beam of 8.5-GHz microwaves sent from Goldstone bounced off Mercury and was collected at the VLA to produce a radar image of the planet



The VLA consists of 28 mobile antenna dishes, each 82-foot diameter and height 90-foot, each weighing 230 tons, each fitted with 10 receivers at 74 MHz, 327 MHz, 1.4 GHz, 3 GHz, 5 GHz, 8.4 GHz, 15 GHz, 22 GHz, 33 GHz, 43 GHz and can be manually placed in a Y-configuration with each arm measuring 21 kms.



This image of Mercury was the result of the radar experiment in 1991. The north pole is the brightest region, an indication of the presence of significant amounts of water-ice.