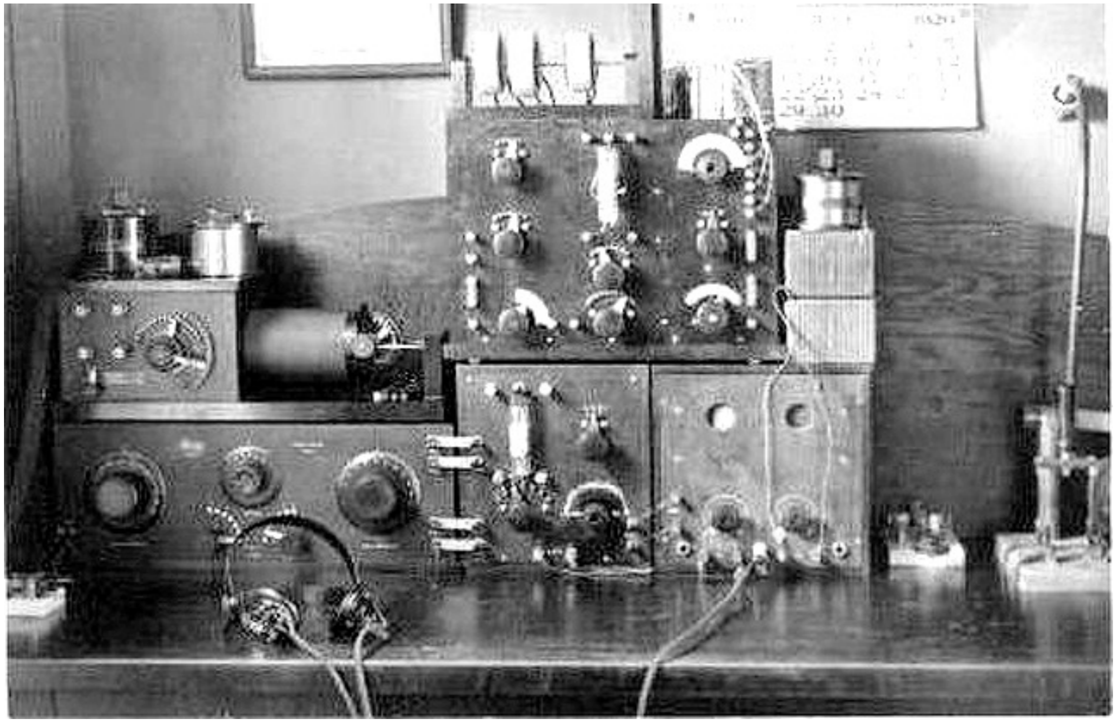
Early Days of Amateur Radio



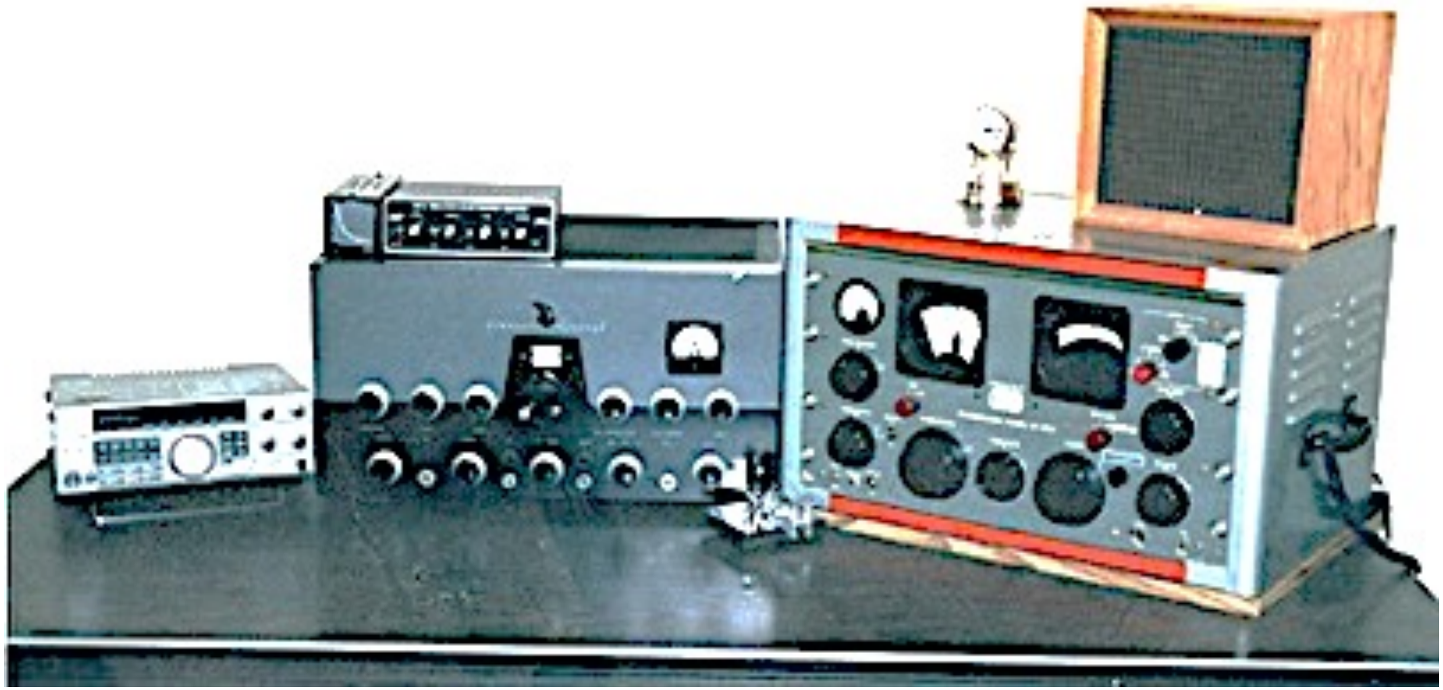
Museum of Yesterday

Ken Larson KJ6RZ

January 2024

www.skywave-radio.org

In Perspective



- The 1960s were the dividing line between the early days of amateur radio and amateur radio technology today
- Center: 1950s amateur radio 100 W Viking II CW / AM transmitter
- Right: 1950s Hammarlund SP-600 CW / AM receiver
- Left: 1990 100 W Kenwood 440 CW / Single Side Band Transceiver

Single Side Band a Whole New Architecture

- The Viking II was a very good amateur radio CW and Amplitude Modulated (AM) voice transmitter BUT incapable of single side band (SSB) operation
- Hammarlund was an excellent CW & AM receiver BUT a poor SSB receiver
- SSB is not just a another operating mode, it is a whole new radio architecture
- SSB modulation is performed at low levels (maybe 50 mv) and amplified by highly linear amplifiers to 100 W or so. Efficiency around 50%
- Viking II was not linear at all, but its efficiency > 80%
- Like all transmitters before it, the Viking was a pulse transmitter outputting a pulse that was filtered into a modulated sine wave by its tuned output circuit
- High level AM modulation performed at the transmitter’s output stage

Radical Drop in Cost of Radio Equipment

- Together, a new Viking II and Hammarlund cost as much as a new Chevy car
- They were very expensive to build, all hand assembled and wired, wire by wire
- Semiconductor technology replaced vacuum tubes in the new SSB radios
- Semiconductor radios are small allowing the transmitter and receiver functions to be combined into a single transceiver unit, dramatically reducing cost
- Manufacturing of SSB semiconductor radios all done by automated machines
- Today a high quality transceiver costs about 1/10 the cost of a new Chevy

Software Defined Radios

- Software Defined Radio (SDR) is the latest paradigm shift in radio technology
- The transition to SDR began in 1972 with the advent of embedded microprocessor (μP) technology
- Since then the μPs embedded in radios have been taking over more and more of the radio’s functions as the μPs become faster
- Today there is little analog circuitry left in SDR transceivers
- Shortly, even entry level amateur radio transceivers will be SDR
- Doing it in silicon and software is simply less expensive

A Colossal Change in Amateur Radio Technology

>>>>

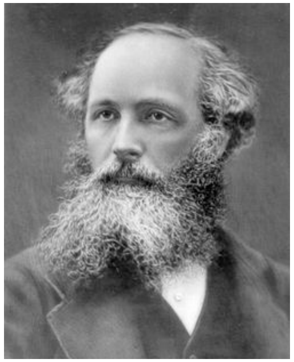
In 60 years

Elecraft K4 today

Elecraft K4 in 1960 >>>>>

- If implemented using vacuum tubes, the Elecraft K4 SDR would occupying racks and racks of equipment in a very large room

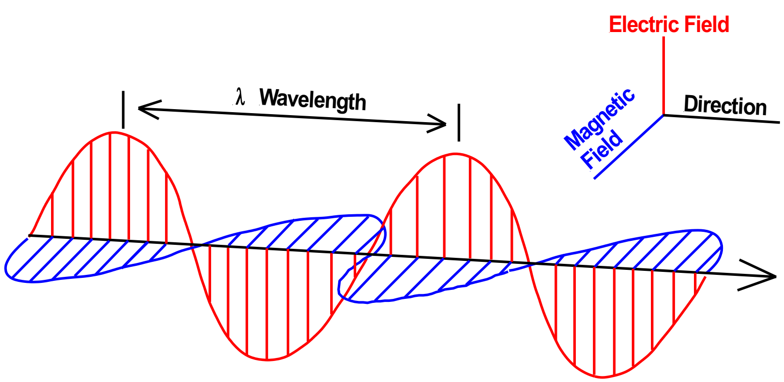
Maxwell's Equations



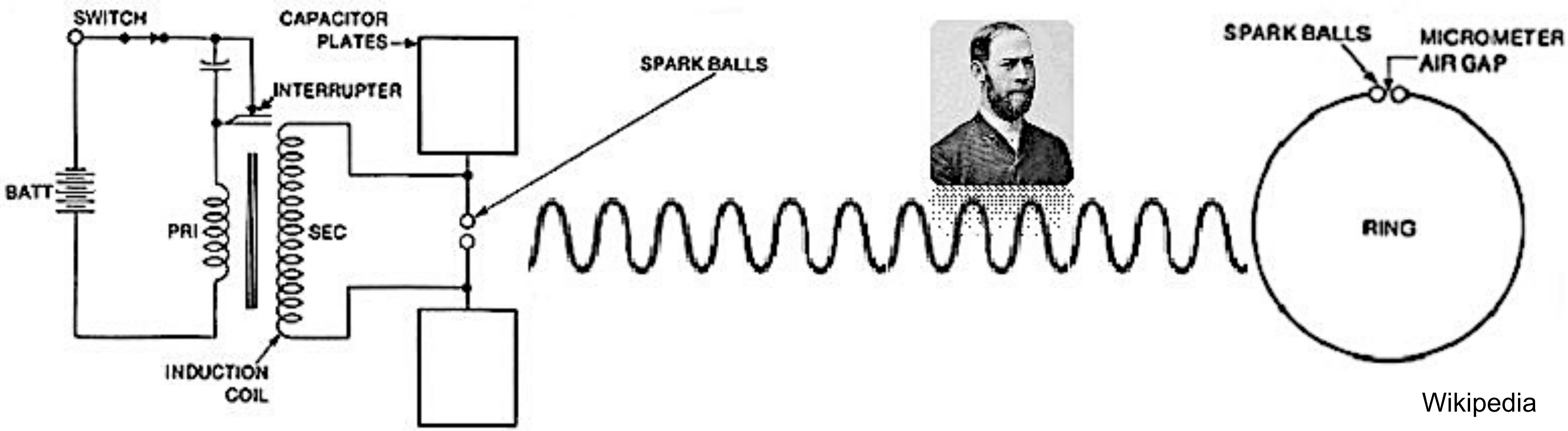
Physical Principle	*Differential (Local) Form*
Gauss's Law: inverse-square field of monopole	$\vec{\nabla}\cdot\vec{E}=\frac{\rho}{\varepsilon_o}$
Gauss's Law: magnetic monopoles do not exist	$\vec{\nabla}\cdot\vec{B}=0$
Faraday's Law: changing magnetic field induces electric field	$\vec{\nabla}\times\vec{E}=-\frac{d\vec{B}}{dt}$
Ampére & Maxwell: magnetic field caused by current or changing E-field	$\vec{\nabla}\times\vec{B}=\mu_o\vec{J}+\mu_o\varepsilon_o\frac{d\vec{E}}{dt}$

Displacement Current

- **In 1865** James Maxwell developed a unified theory of electromagnetics based on equations of others
- Maxwell corrected Ampere's equation by adding displacement current
- In the vacuum of empty space the 1st & 2nd equations disappear as does current density J
- What remains is the equation for an electromagnetic wave traveling at the speed of light



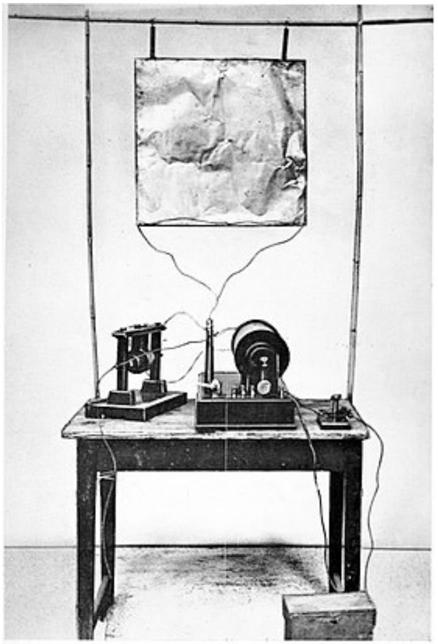
Discovering Radio Waves



Wikipedia

- 20 years later in 1888 physicist Heinrich Hertz decided to test Maxwell's equations to see if electromagnetic waves really existed
- Hertz performed extensive experiments in what we consider the 2 meter to 70 cm frequency bands proving conclusively that electromagnetic waves did in fact exist
- It is unlikely that the commercial ramifications of his experiments ever occurred to him
- His experiments completed, he went on to other things

Guglielmo Marconi Understood the Potential



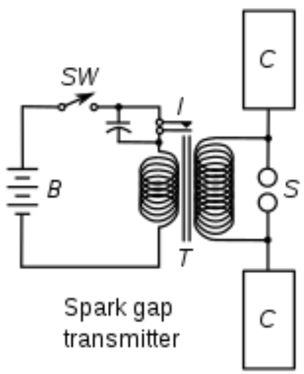
Marconi's First Spark gap

Marconi's "Lab" at Villa Griffone

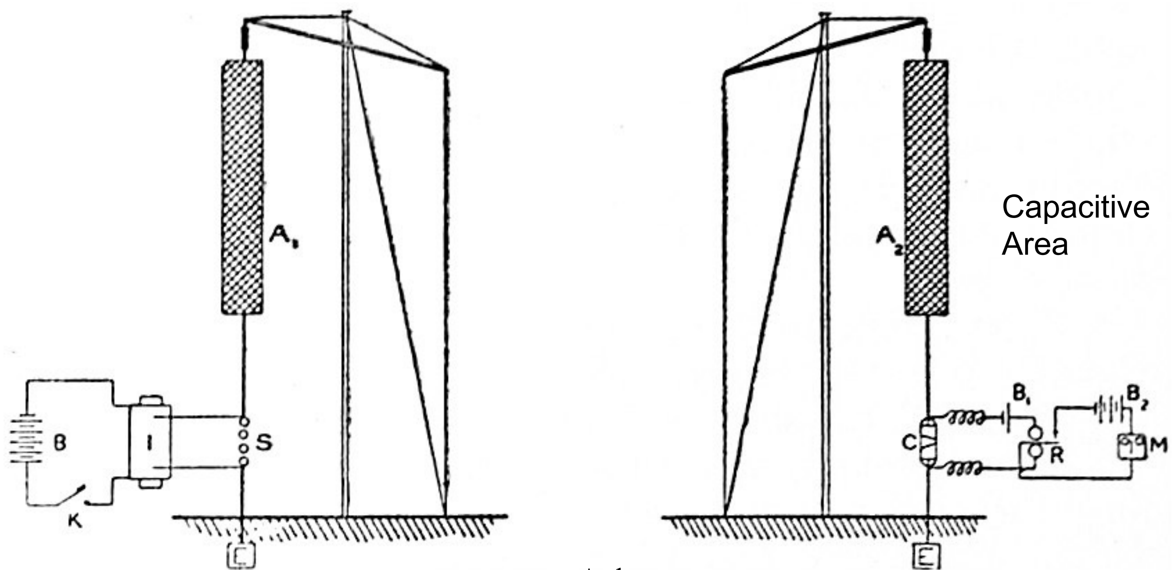
(source: Wikipedia)

- **In 1894**, when Marconi was 20 years old, he read an obituary on Heinrich Hertz describing the work that Hertz had done
- Marconi realized the commercial ramifications of the electromagnetic experiments performed by Hertz and began repeating the experiments at his father's estate (Villa Griffone) near Bologna, Italy
- What drove Marconi personally, and in obtaining money from his father and others for his experiments, was transmitting long distances
- At first a couple hundred feet, then progressively further 1.5 miles, 5 miles, 20 miles, etc.

Ground Plane Vertical Antenna



Marconi's 1st spark gap transmitter

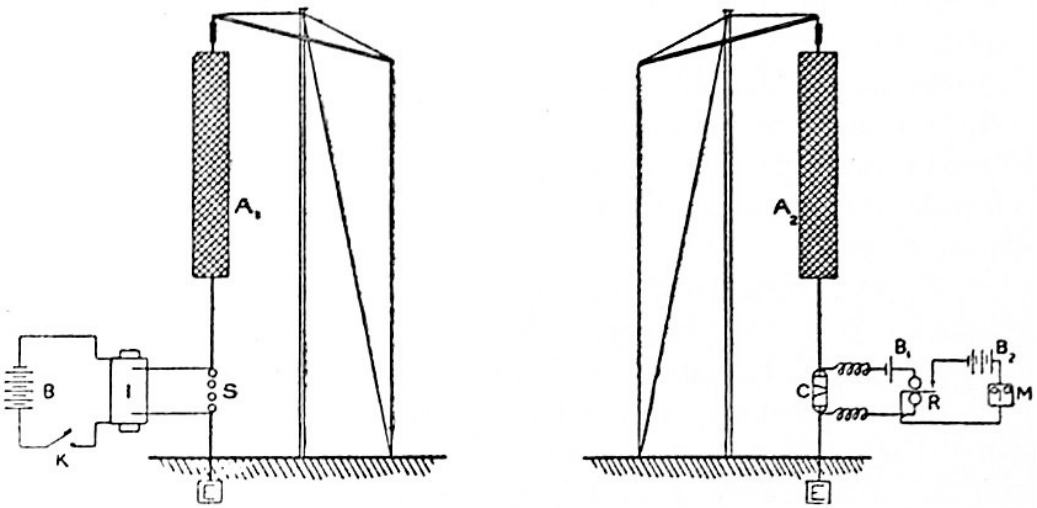


Capacitive Area

source: Attken

- To Marconi, transmitting longer distances meant using longer antennas
- As the result of "cut and try" experimentation Marconi invented the ground mounted vertical antenna
- Although he didn't understand it at the time, what he was doing was using the ground as the lower half of a vertical half wavelength dipole
- Using the vertical antenna transmission distances considerably increased
- Today's vertical antennas date back to Marconi's 1st vertical In 1896

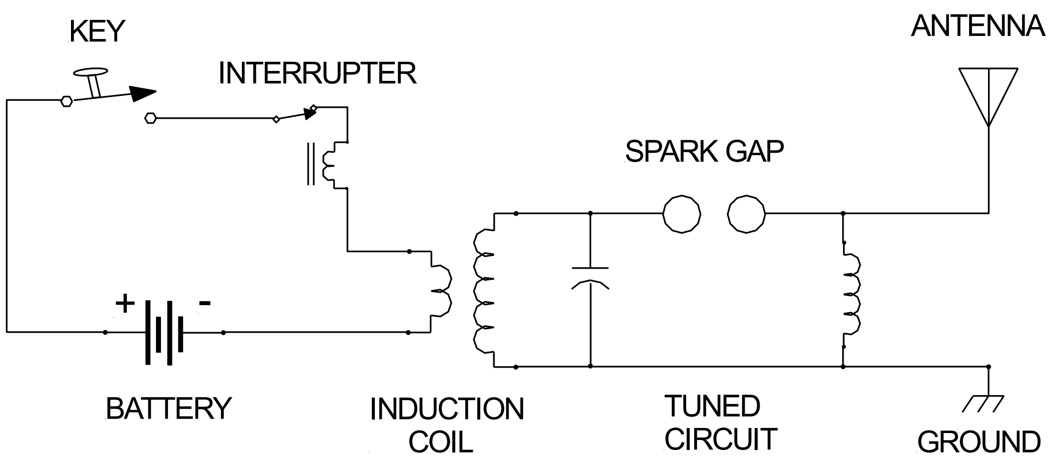
Lower Frequencies Meant Longer Distance



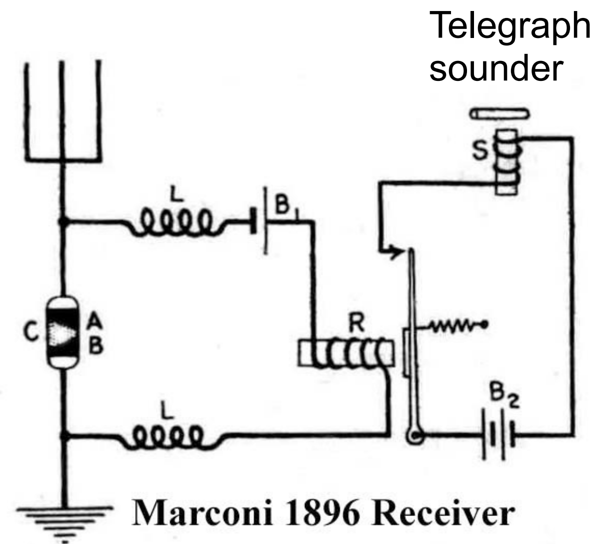
- Increasing the length of the vertical wire lowered the operating frequency
- Lower frequency meant longer ground wave propagation distance
- Eventually Marconi wireless systems operated at frequencies from **1 MHz down to 300 KHz** requiring very large antennas
- The ionosphere at the time was of course unknown

Marconi's Early Spark Gap System

Damped sinusoid signal

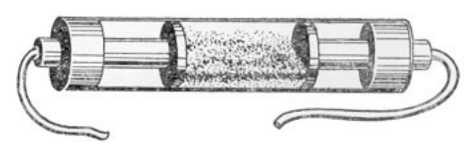


Spark Gap Transmitter



Marconi 1896 Receiver

Wikipedia



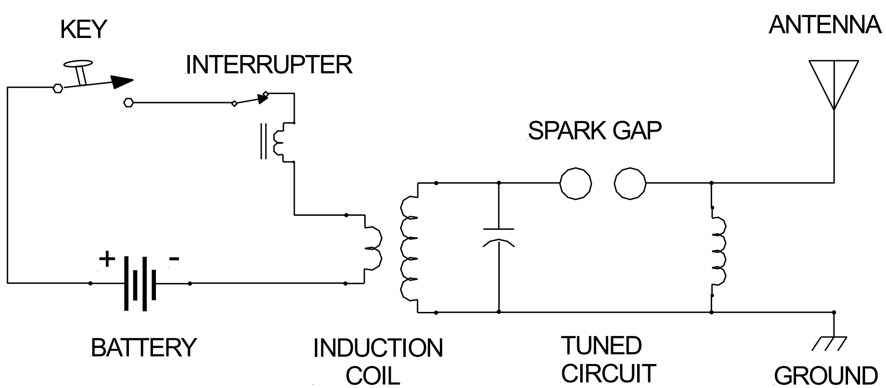
electronics.stackexchange.com

Coherer invented in 1890 by Edouard Branly, Improved by Oliver Lodge, & Marconi

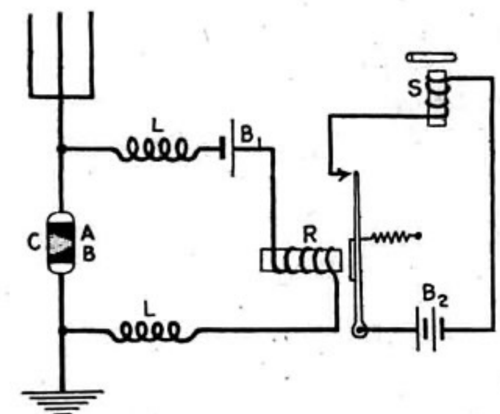
- The analogy of hitting a bell with a hammer was fundament to the design of transmitters for the first 60 years of radio
- Spark gap great for morse code but could not transmit voice

Spark-Gap Equipment

(source: Wikipedia)



Spark-gap Transmitter



Receiver

A Family Business

- At his Father's insistence, Marconi offered his wireless system to the Italian Navy but they were not interested
- Marconi's father was not only rich, but his English born mother was part of a well to do well connected family back in England
- In the spring of 1896 Marconi and his mother travel to England
- With access to the right people, the English Post Office (by law responsible for all electrical communications in England i.e. the telegraph) became very interested in Marconi's wireless
- Others including Oliver Lodge were also experimenting with wireless
- But to William Preece (chief engineer at the post office) young Marconi seemed very promising and provided Marconi with considerable support
- Marconi's cousin, a very capable business man, strongly suggested that Marconi start a wireless communications company which Marconi did
- It was a wholly own family business financed by his extended English family (Marconi had opportunities that no one else involved in wireless had)

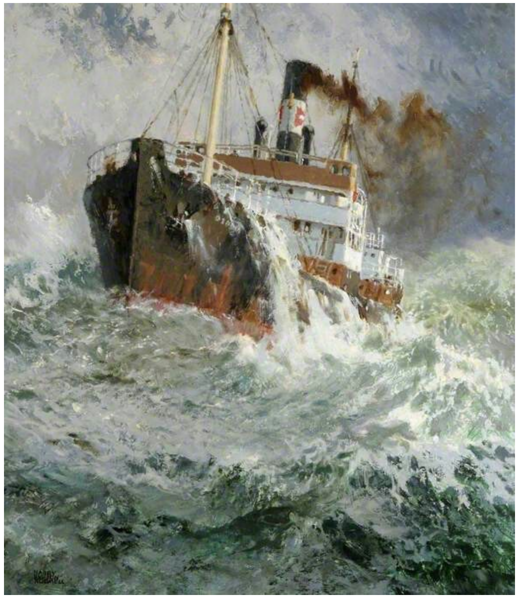
What Was The Market For Wireless?

Wikipedia

- Marconi could not compete with the wired telegraph
  - Telegraph was well established well funded big business, not a tiny start-up
  - The telegraph had extensive world wide connectivity
  - The wired telegraph was far more dependable than the wireless
  - **Morse code speed very fast over wired telegraph, slow on the wireless**

A Golden Opportunity

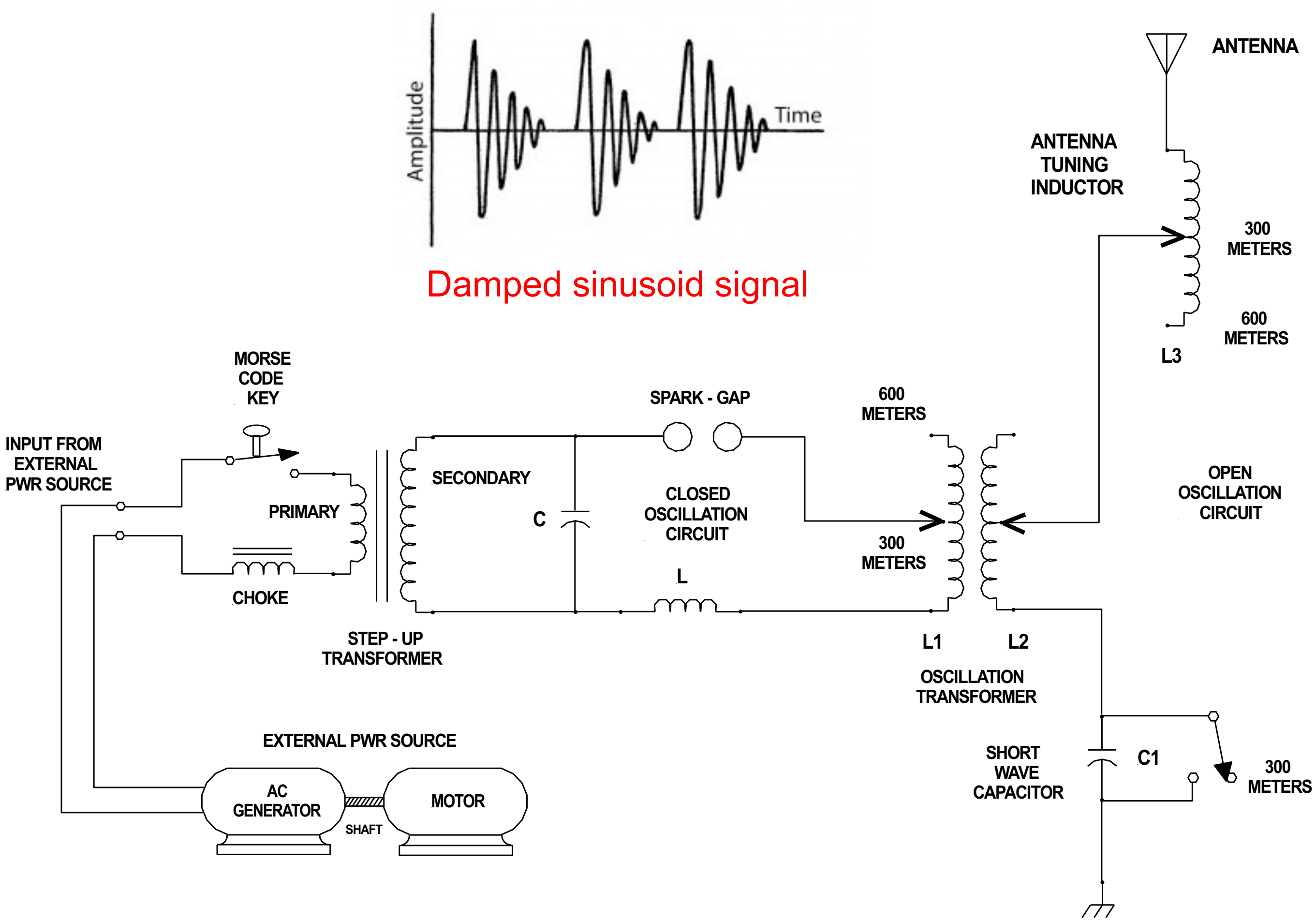
- Throughout most of history, all knowledge a ship was lost from the time it left port until, hopefully, it arrived at its destination port
- Once at sea, its location and its situation were completely unknown
- Ship-to-Shore and Ship-to-Ship communications offered Marconi a golden opportunity which the telegraph business could not compete with
- Ship owners were wildly interested in the wireless
- But they did not want to buy hardware from Marconi
- They wanted Marconi to provide the complete system:
  - Shore based radio stations plus
  - Marconi build, installed, and operated radio equipment aboard ship



(source: transpress nz)

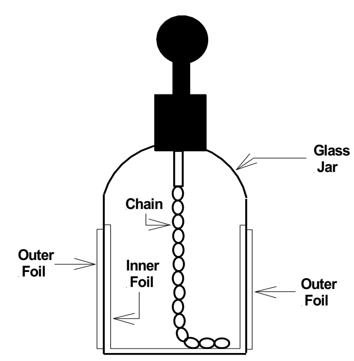
For awhile in early 1900s Marconi achieved nearly a complete monopoly in maritime communication

Commercial Wireless Transmitter



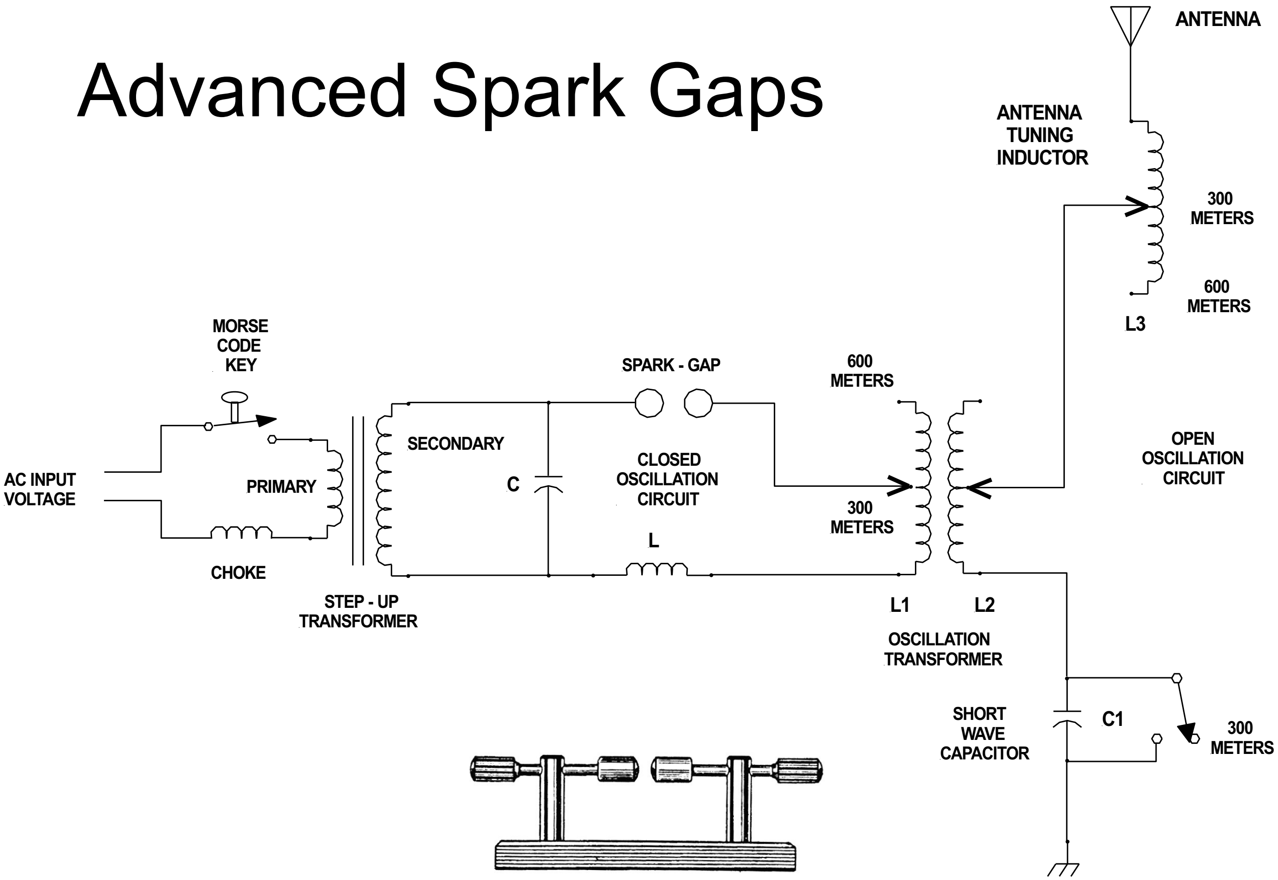
Damped sinusoid signal

Leyden Jar Capacitor



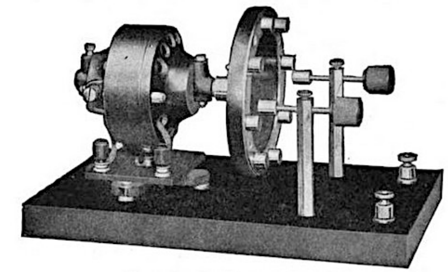
From static electric era 150 years earlier

Advanced Spark Gaps



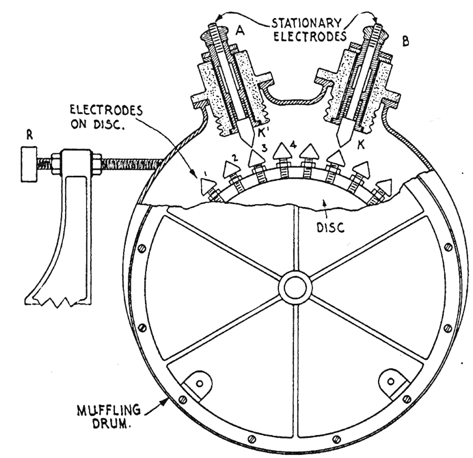
Plain spark gap

(source: E. Bucher)



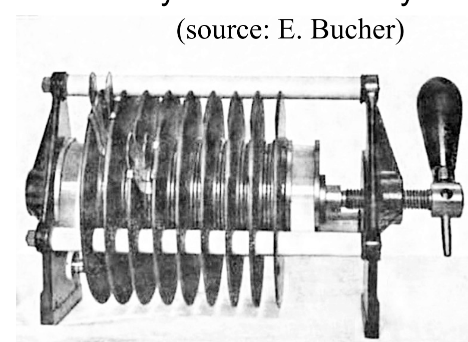
Nonsynchronous rotary

(Wikipedia)



Synchronous rotary

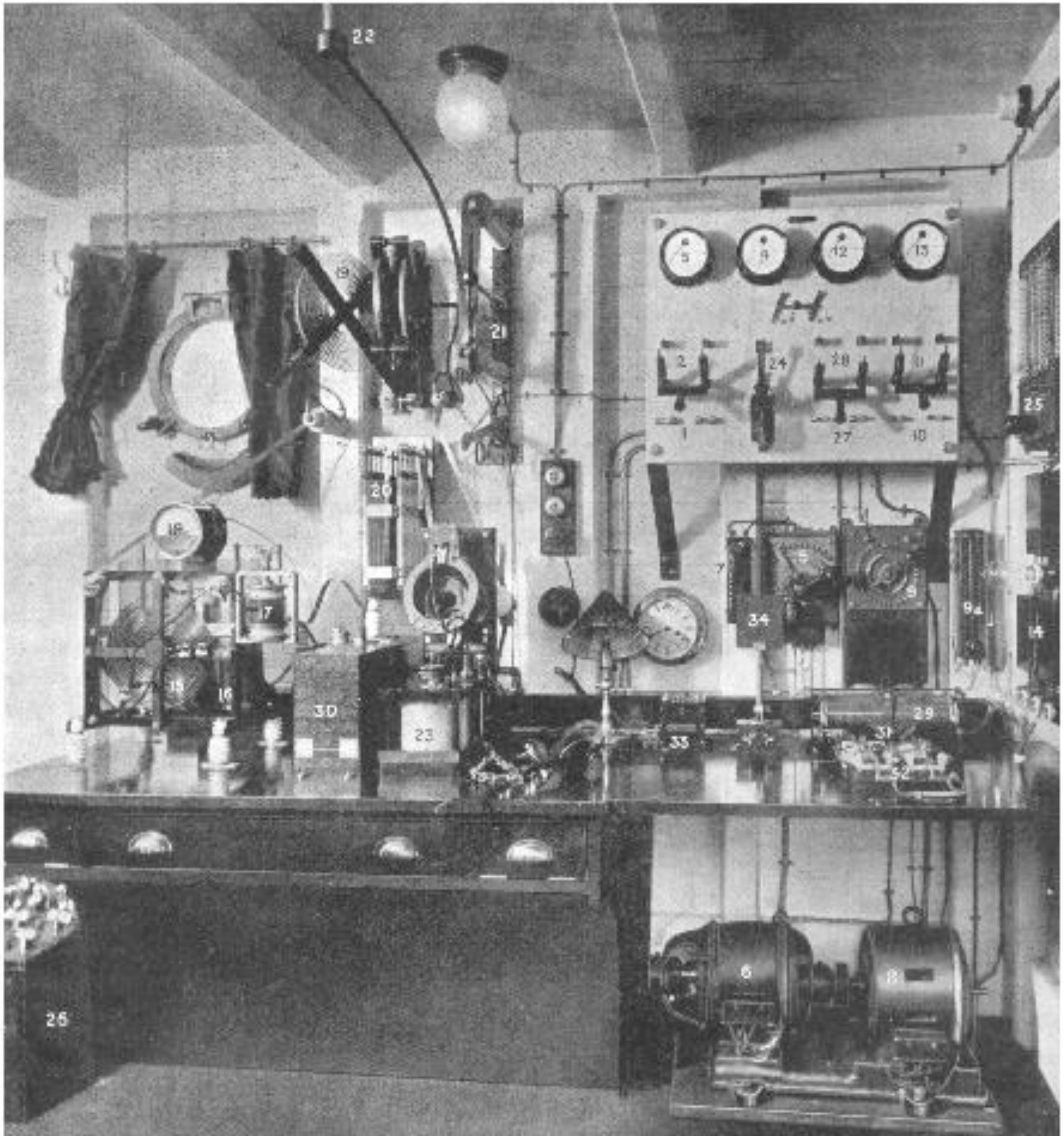
(source: E. Bucher)



Squelched Spark

(Wikipedia)

- Delivered more output power
- Produced higher frequency tones at the receiver, and
- Less interference with other radio stations



(source: Brown's Signaling)

Shipboard Radio Shack

Motor: 6

Alternator: 8

Step-up transformer: 30

Closed oscillation circuit with squelched spark discharger: 15, 16,17

Oscillation transformer: 19

Shorting capacitor: 20

Lightning switch: 21

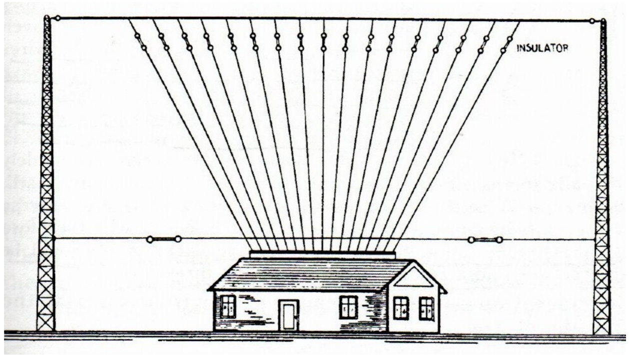
Antenna lead-in: 22

Wireless receiver 23

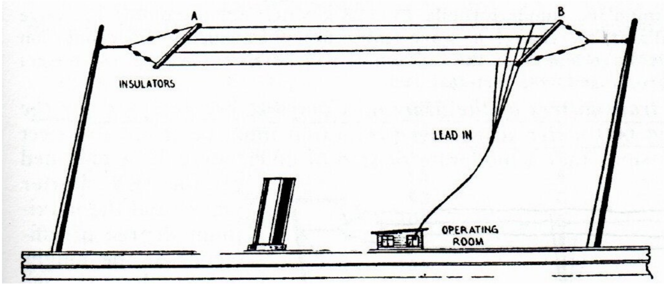
Operating freq 200 – 2000 meters (1.5 MHz to 150 KHz)

With a 115 feet high mast, the range was 250 miles by day and 375 miles by night

Antenna's



Vertical Antenna

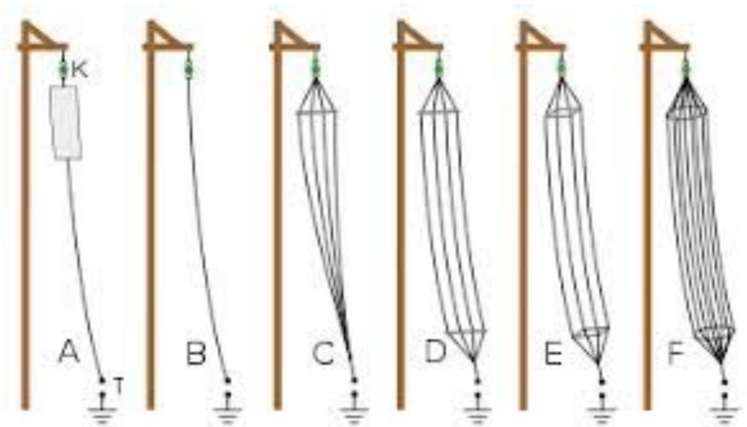


Inverted L Antenna

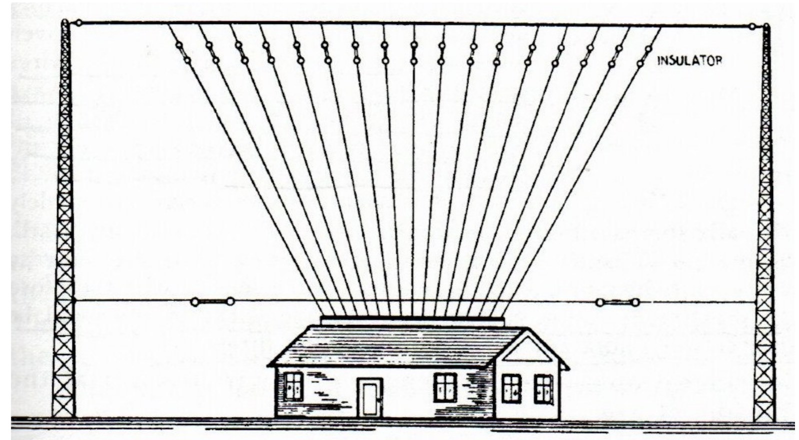
T Antenna (source: Hilomast)

- Vertical antennas the best long distance antennas, extensively used on shore but not practical for ship board operation
- The Inverted L and the T antennas were the most popular ship antennas
- The Vertical, Inverted L & T antennas are all ¼ λ radiating elements requiring an extensive ground to completed the antenna
- Aboard ship the steel hull provided the needed ground, on shore extensive radial systems were installed
- Inverted L and T antennas are still used today by amateur radio operators on 160 and 80 meters

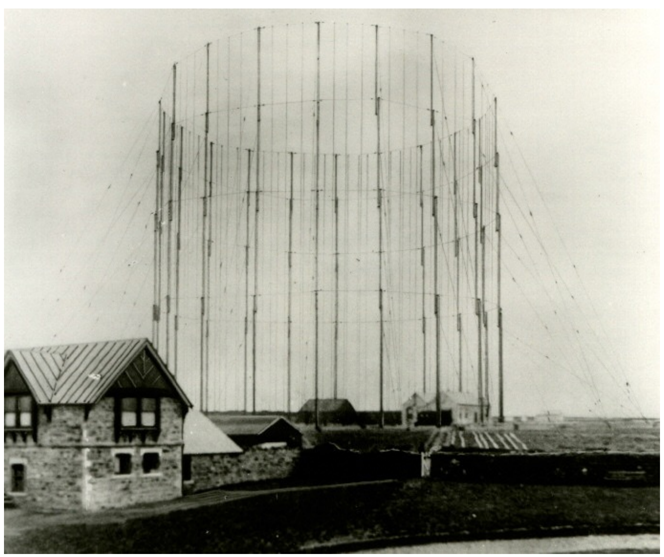
Some Early Vertical Antenna's



(source: Wikipedia)

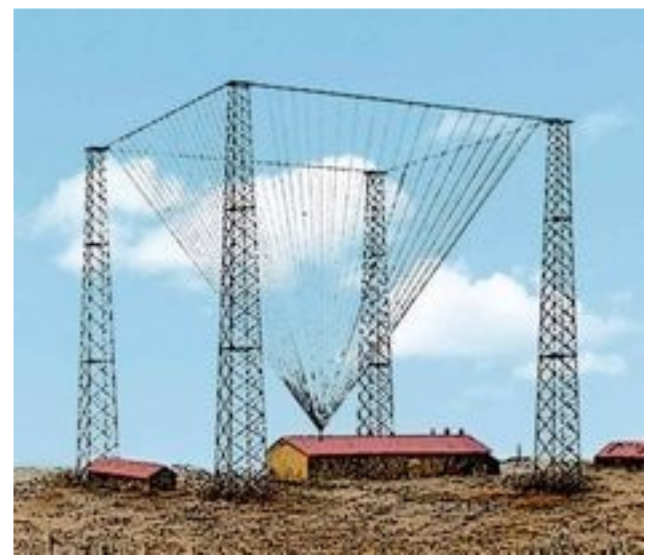


(source: Hilomast)



Marconi 1st Cornwall Antenna 1901

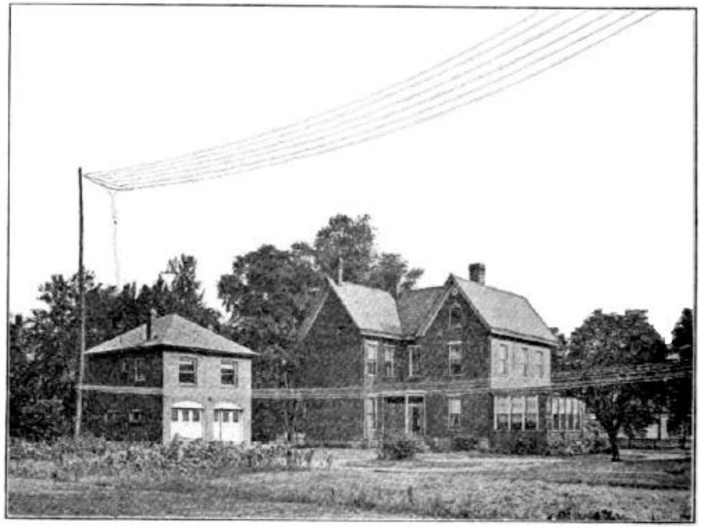
(source: Wikipedia)

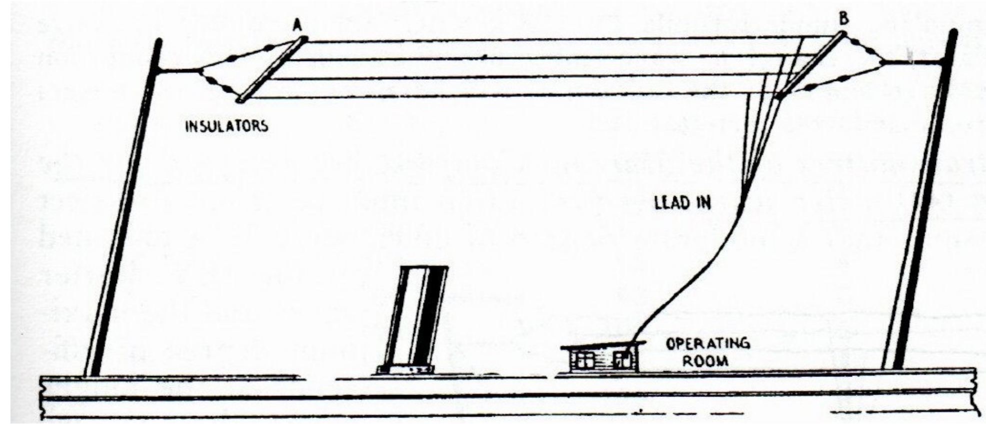


Marconi 2nd Cornwall Antenna 1901

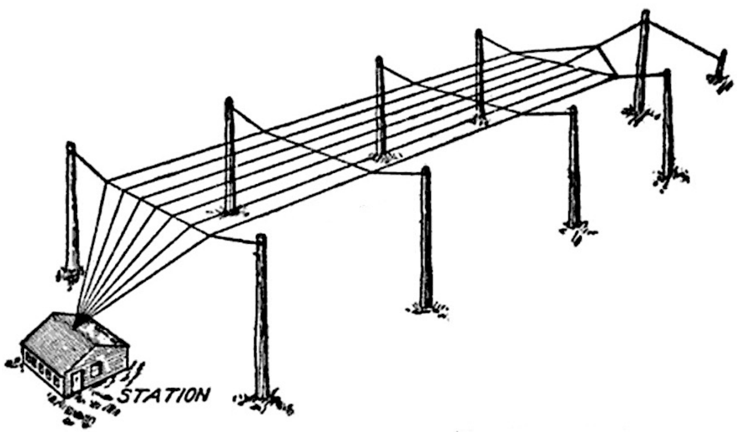
(source: Pinterest)

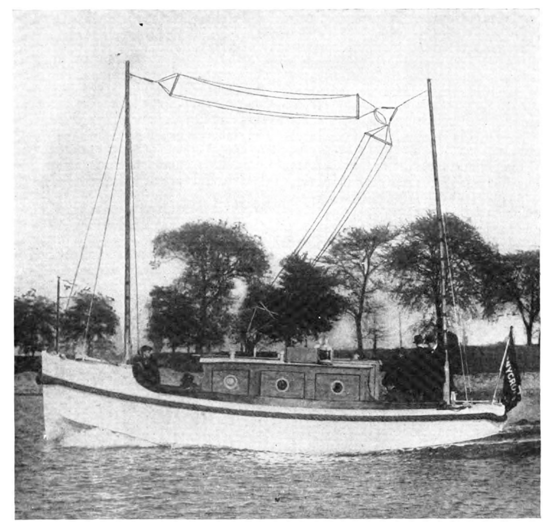
Some Early Inverted L Antenna's





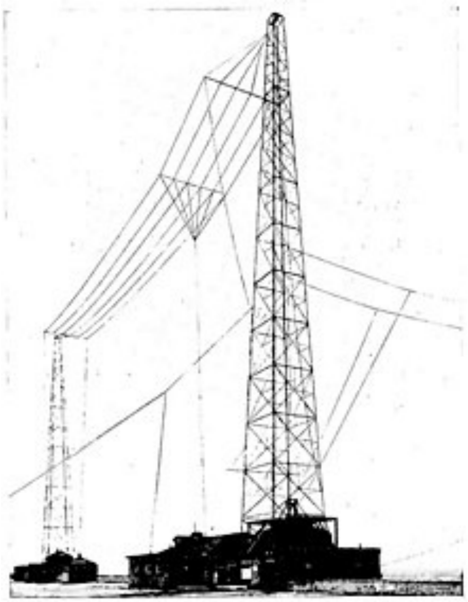
(source: Hilomast)



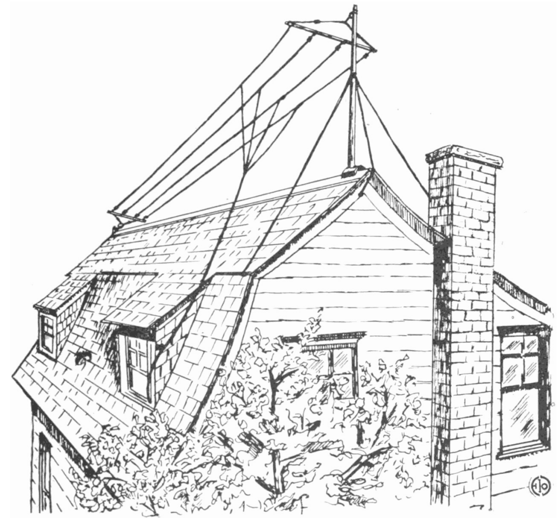


Multiple parallel wires were believed to increase the antenna's capacitance with ground and radiating surface

Some Early T Antenna's

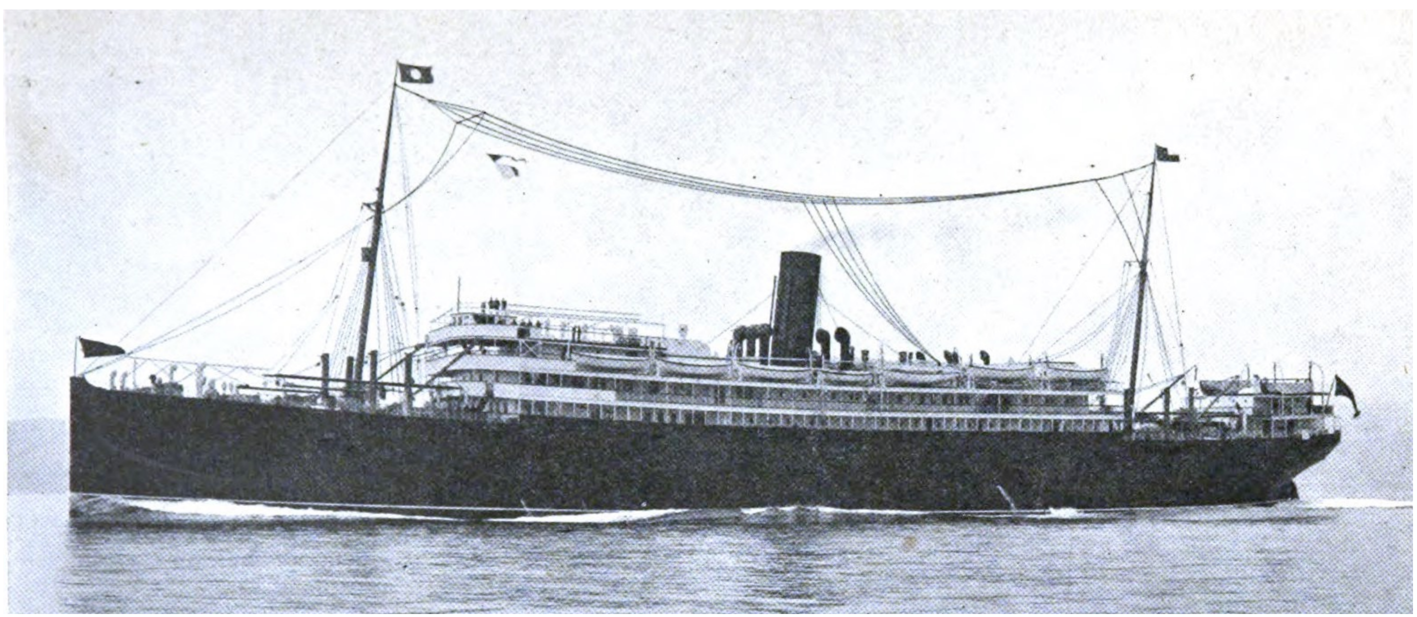


(source: Ham Signal)



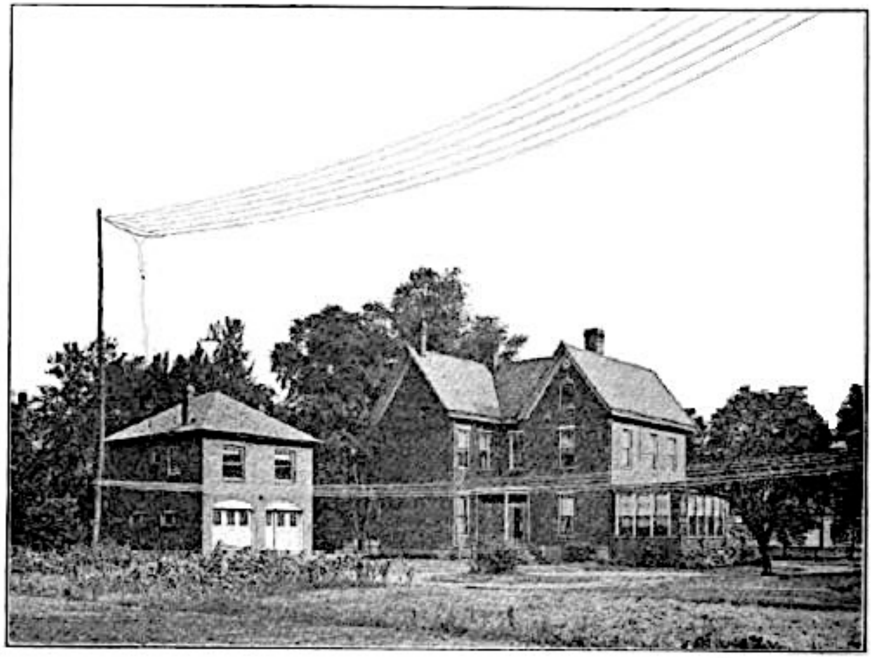
An amateur radio station T antenna

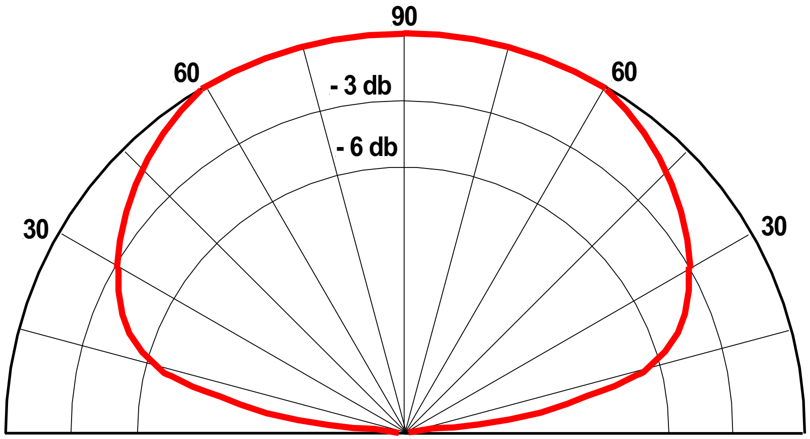
Wikipedia



Wikipedia

Radiation Pattern of Low Horizontal Antennas

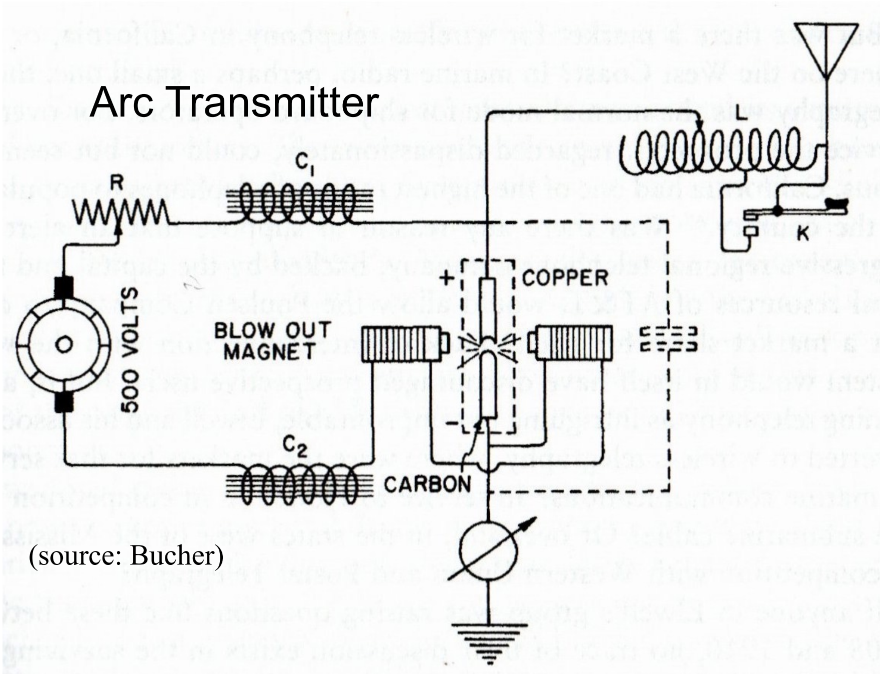




- Long horizontal antennas (300 to 1,000 meters in length) installed close to the ground had a high, near vertical, radiation pattern
- We tend to think of Near Vertical Incident Skywave (NVIS) propagation as a relatively new propagation mode that is very useful for emergency communications
- In fact, NVIS is one of the oldest propagation modes

Transmitters Evolve

Arc Transmitter

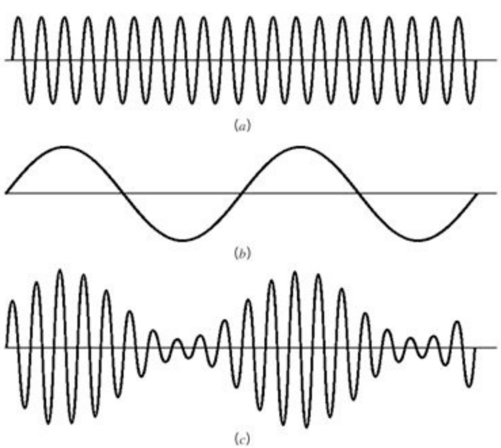


(source: Bucher)

CW

Voice

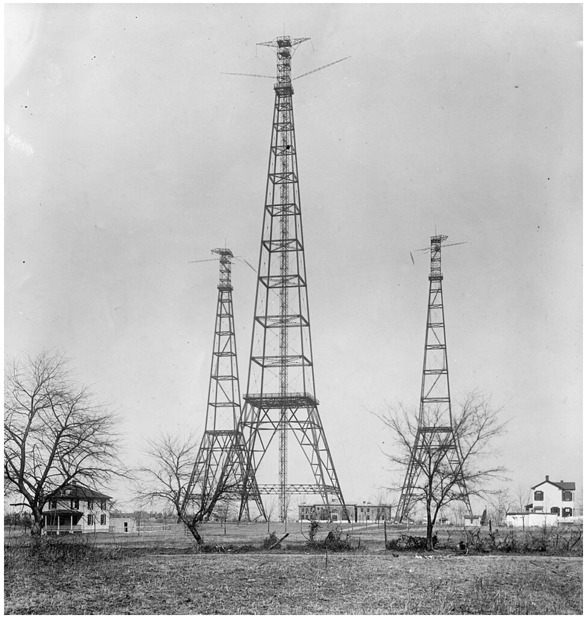
Modulated Wave



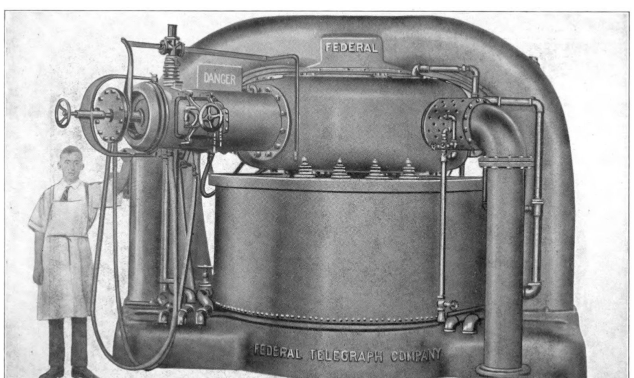
Same waveforms as produced by Viking II

- Spark gap technology improved from 1900 through 1915
- Other electro-mechanical transmitters also evolved
- Arc transmitters were the most important alternate technology
- Unlike the spark gap, an arc transmitter transmitted a continuous wave (CW)
- Spark gap excellent for wireless telegraph, but could not transmit voice
- Arc transmitters with their continuous wave could, and by 1910, were transmitting voice as well as wireless telegraph
- But until the 1920s no market for wireless telephone

U.S. Navy's Extensive Wireless Telegraph Network



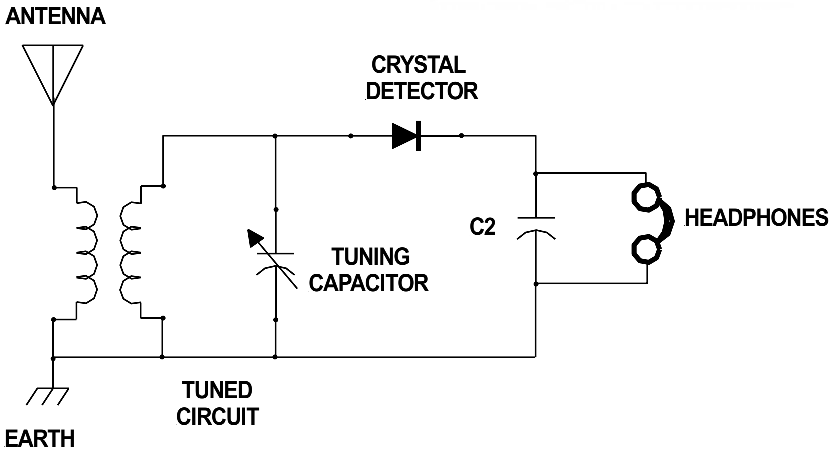
Navy's Arlington, VA Station
Pinterest

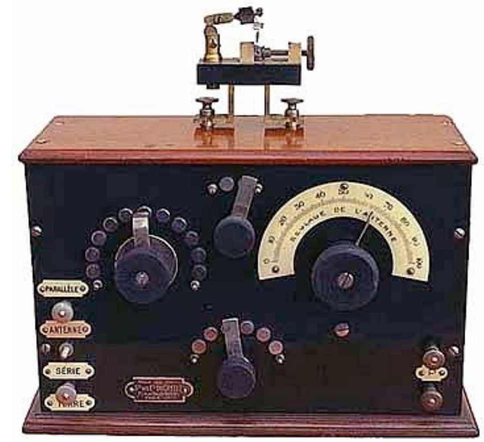


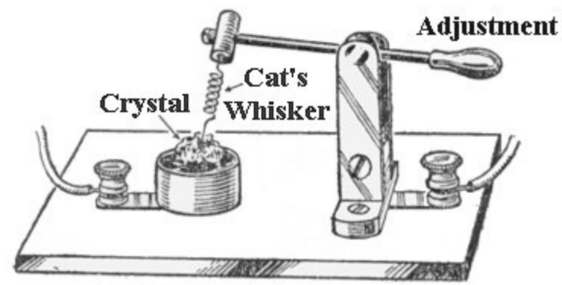
Arc Transmitter Weight = 60 Tons
SlideShare

- By 1915 arc transmitters were the most powerful transmitters in the world
- Built under contract to the Navy, the Federal Company in Palo Alto, CA built arc transmitters ranging in power from 100 to 1,000 KW and operating, like all transmitters of the day at 300 to 1,000 meters (1,000 KHz down to 300 KHz)
- Arlington, VA was the hub of the Navy's network
- Arlington could contact Panama and San Francisco at night and sometimes during the day
- Hawaii reached by San Francisco and sometimes directly by Arlington
- Guam and Hawaii talked regularly, all before amateur radio operators discovered short wave radio

Crystal Radio Receiver



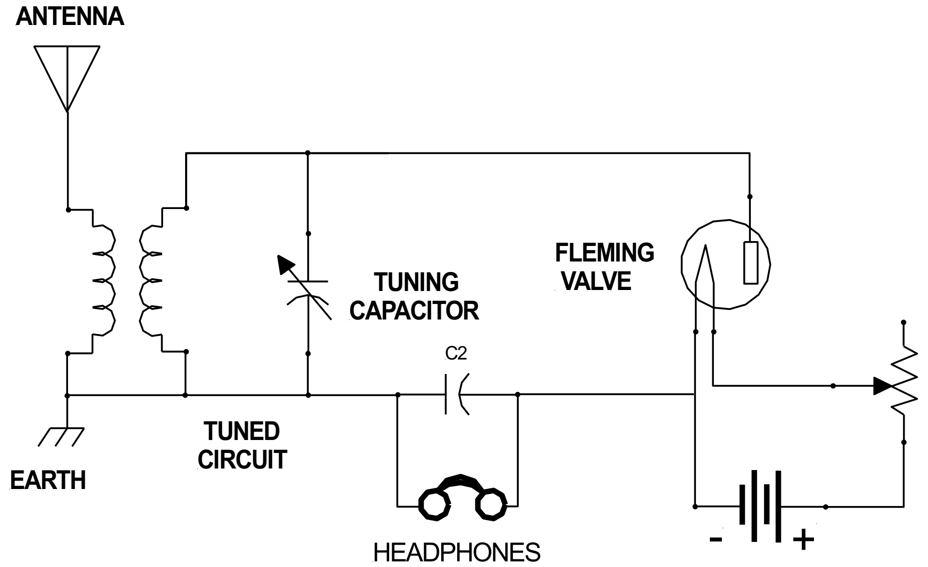


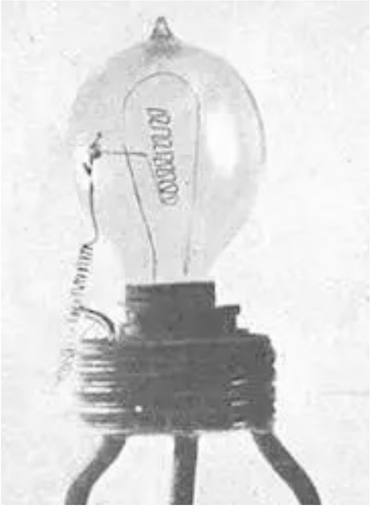


Wikipedia

- The coherer was a miserable detector, but for a long time no one could come up with a better device
- Many different designs were tried including an electrolytic detector
- **By 1906** the coherer had been replaced by the carborundum crystal detector which was simple, low cost, and very effective
- The crystal detector extensively used by spark gap amateur radio operators

Fleming's Valve Detector

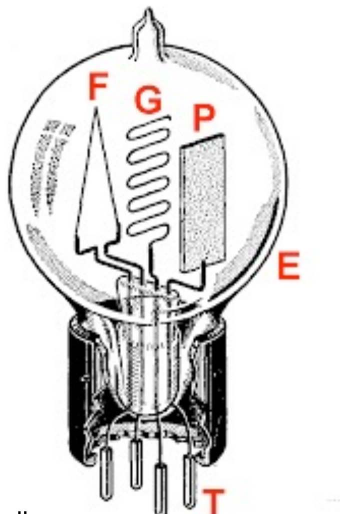




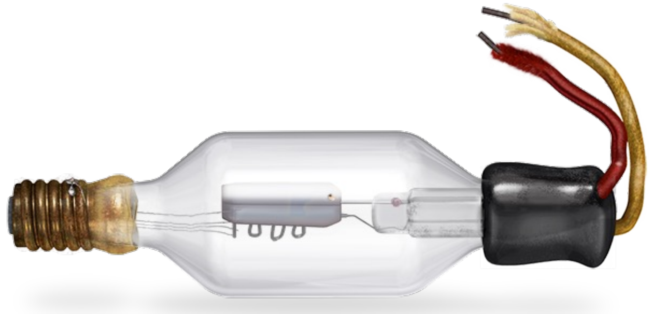
EDN Magazine

- **In 1904** John Fleming invented the vacuum tube diode while working on various detectors at the Marconi Company
- The invention was based in part on work he had done on light bulbs in the 1880s at the Edison Company
- The vacuum tube diode worked well as a detector
- But the crystal detector worked as well and was much less expensive

The DeForest Audion



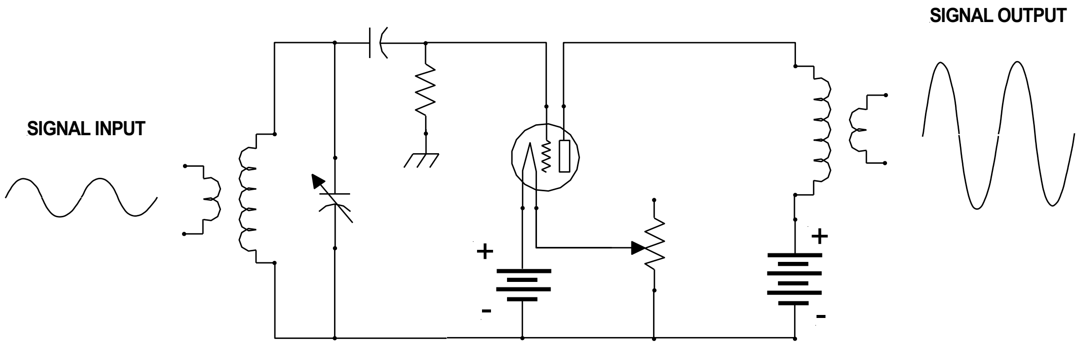
Wikipedia



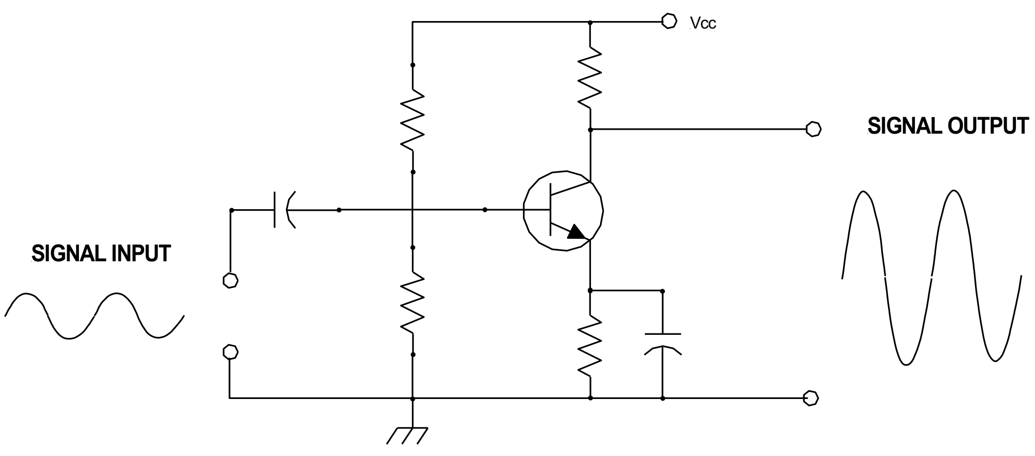
MagLab

- **In 1906** Lee DeForest invented the triode vacuum tube which he called the Audion
- Many claimed that he had simply added a 3rd element to Fleming's diode
- The courts finally concluded that DeForest's work was original
- Fleming stated several years later that the idea of adding a third element to his diode had never occurred to him

Beginning of the Electronic Age



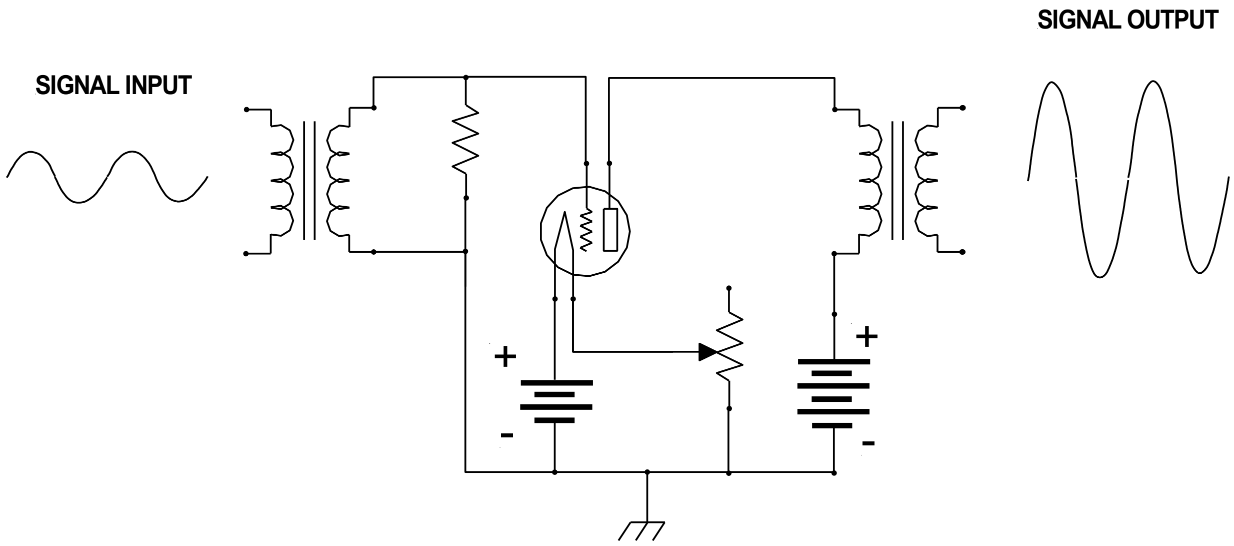
Audion Triode Amplifier



Transistor Amplifier

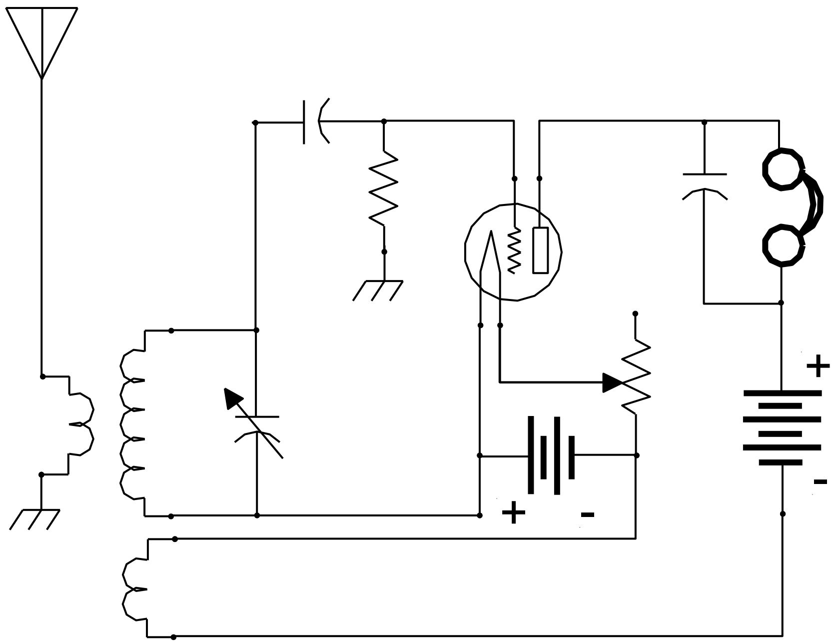
- The Electronic Age as we know it today began On October 26, 1906 when DeForest applied for a patent on "a device for amplifying feeble electrical currents"
- However, despite its enormous importance, the audion was basically ignored for the 1st five years or so
- We don't use vacuum tubes much anymore, but transistors are fundamentally the same 3 element architecture

AT&T Audion Audio Amplifier



- Initially, no one, not evening DeForest, appreciated the importance of the audion as an amplifier
- In 1914 AT&T was committed to providing transcontinental telephone service and needed some type of audio amplifier
- An audion modified for telephone operation was the answer

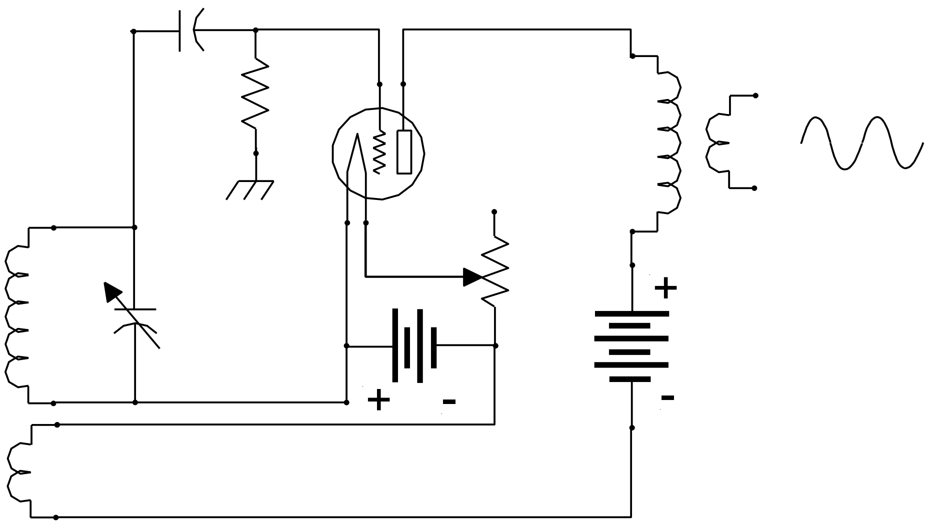
The Regenerative Receiver



(source: Wikipedia)

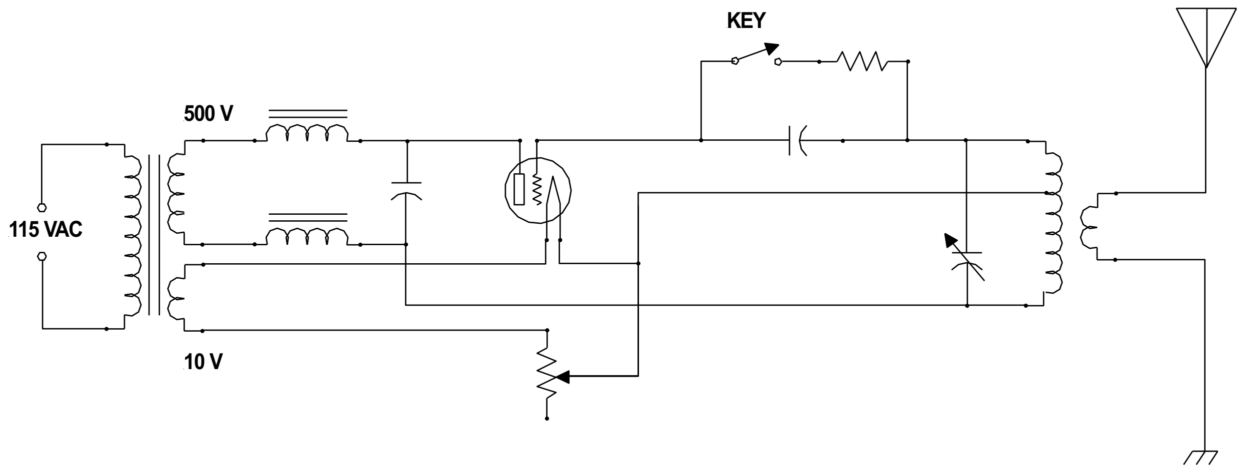
- Edwin Armstrong realized that considerable amplification could be achieved by feeding part of the amplified output signal back to the audion's input causing the signal to be amplified over and over again
- Armstrong patented the regenerative receiver in 1914
- The regenerative receiver was extensively used by Hams for many years
- If not carefully adjust, it would go into oscillation becoming a transmitter

Audion As An Oscillator



- One of the problems with the audion amplifier was that it often broke into oscillation – not good
- Turning bad into good
- However, it was quickly realized that with appropriate circuitry an audion could intentionally be made to operate as an RF oscillator capable of generating continuous radio waves

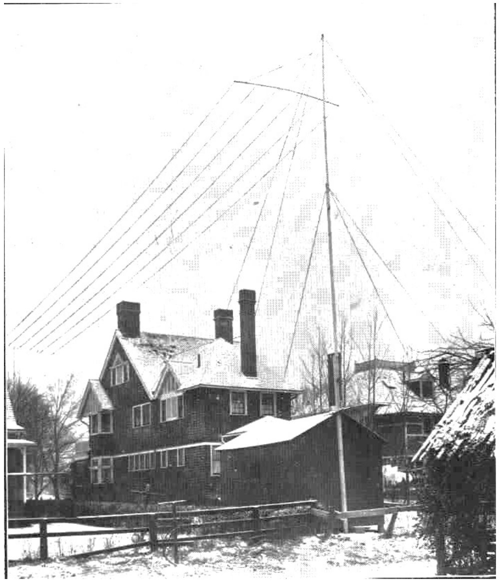
5 Watt 100 Mile CW Transmitter



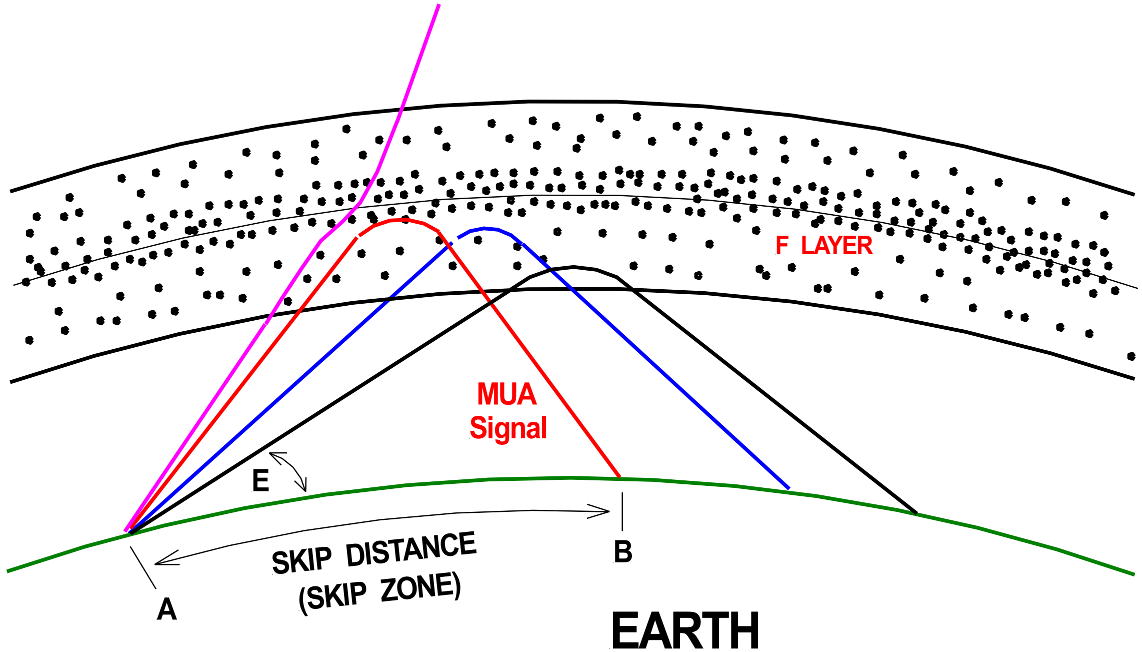
- Diagram of a 5 watt 100 mile CW transmitter as it appeared in the first Radio Amateur's Hand Book in 1922
- Hams primarily operated late at night relaying messages cross country
- In general hams were operating NVIS, but didn't know it
- At the time no one knew that the ionosphere existed
- Most hams in 1922 were operating at low frequencies generally at 200 meters (around 1.5 MHz)

200 Meters & Down

- **From 1912** on amateur radio operators were exiled to the worthless frequencies of 200 meters and down
- Better know to day as 160, 80, 40, 20, and 10 meters
- Amateurs were a pain
  - There were so many of them
  - Their home-brew equipment was often better than that commercially available
- With no other place to go, amateurs did the best they could with what they were given
- In the process **in 1924** amateur radio operators discovered the long distance capabilities of “short wave” radio

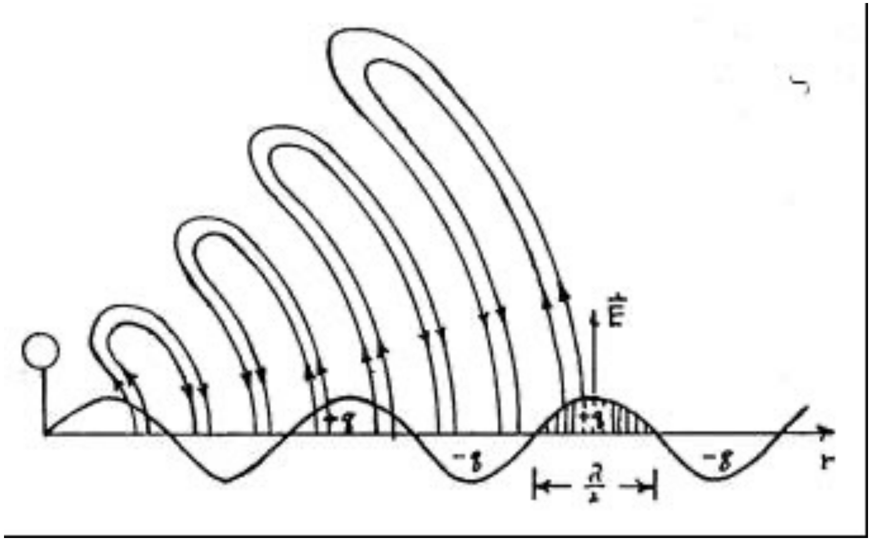


Skip Zone Discovered



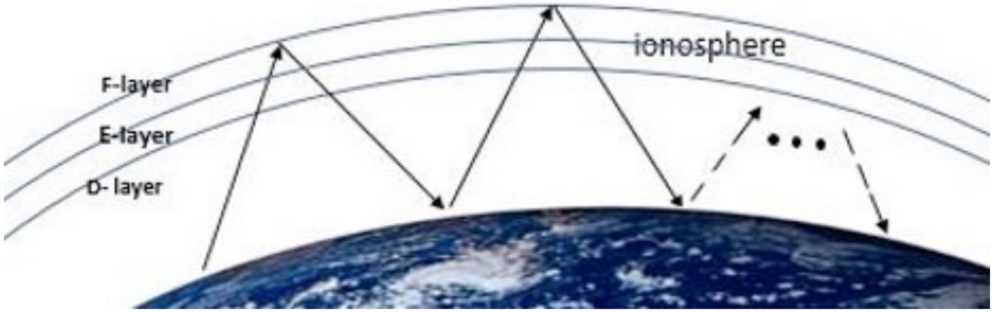
- As the amateur radio operators demonstrated, short wave radio disobeyed the accepted theories of radio propagation
  - Short wave radio propagation, unlike long wave, seemed to involve only the atmosphere
- The skip zone was an interesting phenomena of short wave radio that was discovery by amateur radio operators in 1924
  - Radio signals disappeared a certain distance from the transmitter but then reemerged farther away

Theory Did Not Match Data



- The leading scientists from the mid 1990s through 1920 believed that radio waves traveled along the ground, or along the ocean surface
- But the theories, most of them consisting of very complex mathematics, did not match the results of carefully conducted experiments

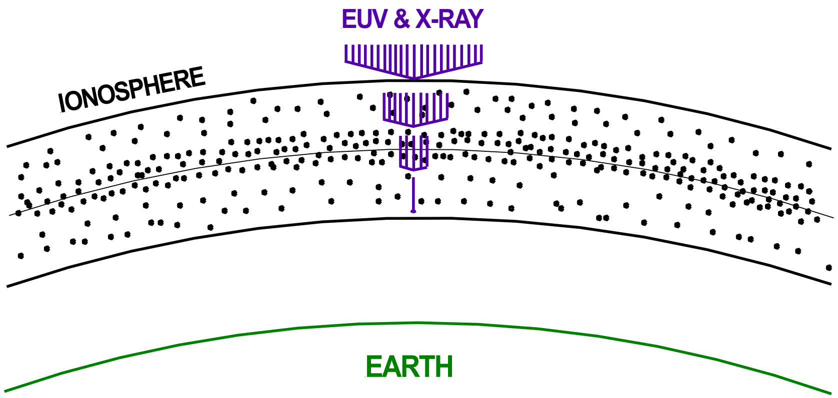
Talk of an Ionosphere

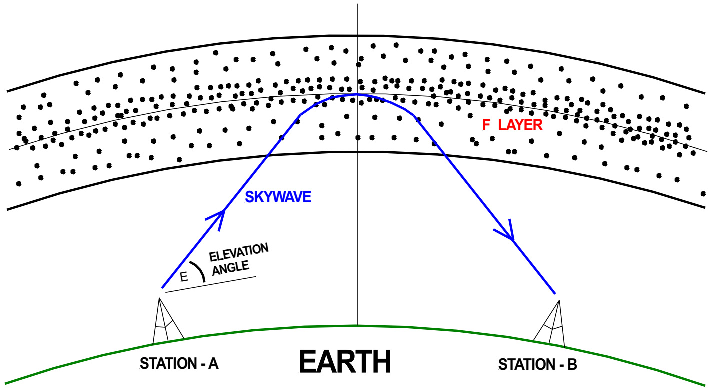


ResearchGate

- **In 1902** Heaviside (English) and Kennelly (United States) independently theorized that a conducting layer in the upper atmosphere could account for long range wireless transmissions
- They theorized that wireless signals traveled back & forth between the ground and the conducing layer
- But they had not actual proof

Theory of Ionospheric Refraction

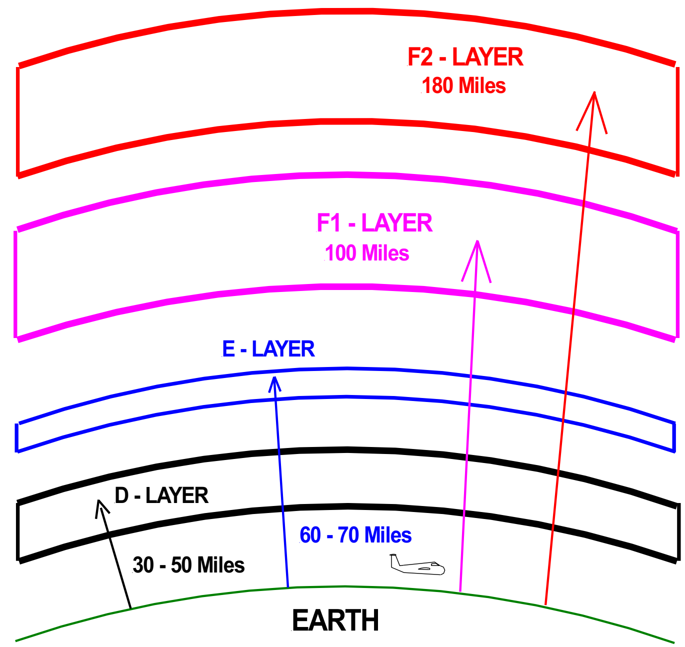




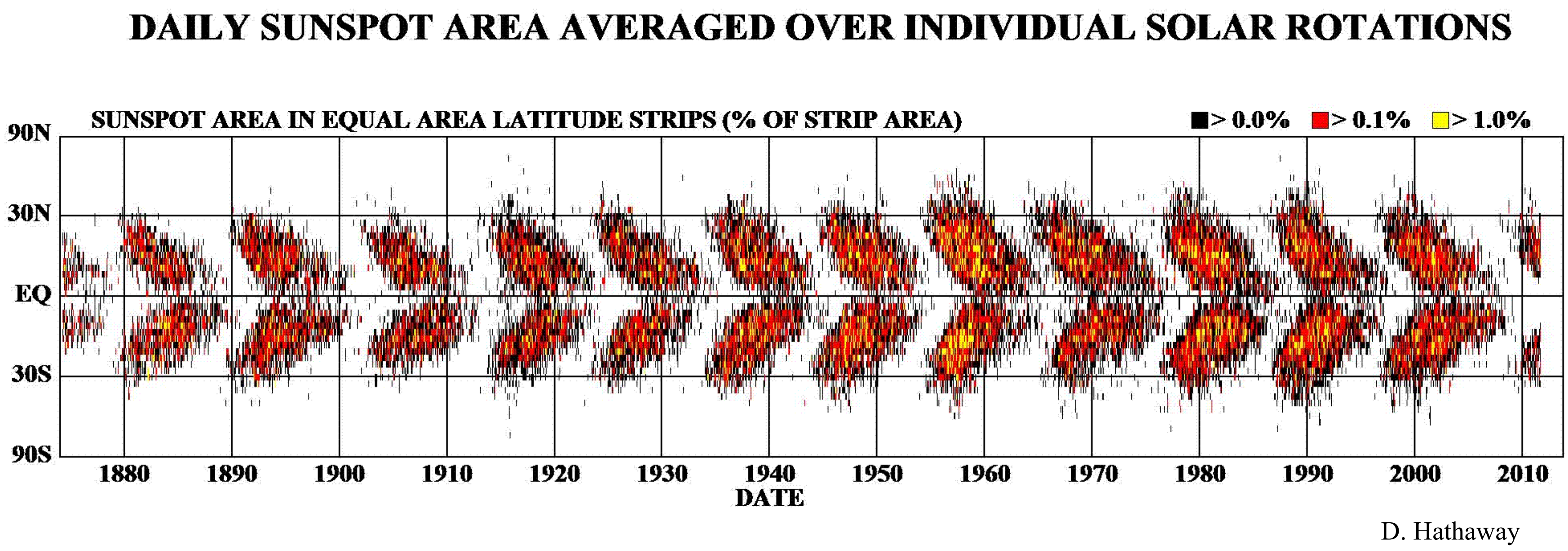
- **In 1910** English engineer/scientist William Eccles <u>theorized</u> that:
  - A body of electrons and positive ions existed in the upper atmosphere resulting from sunlight decomposing the air
  - Radio waves were not reflected in the upper atmosphere as suggested by Heaviside & Kennelly
  - Instead radio waves refracted in the upper atmosphere (bending back to Earth) as the electron density gradually increased with altitude
- Again, there was no actual proof that this was so

Edward Appleton Discovers The Ionosphere

- **In April 1924** Appleton studied the strength of radio signals received at Kings Collage from a London BBC radio station
- He discovered signal strength was constant during the day but varied at night
- He theorized that at night he was receiving two signals, one traveled along the ground the other reflected from the upper atmosphere
- Further investigations showed that the radio waves were reflecting from atmospheric ionization about 60 miles above the Earth > from what he called the electrified E-layer
- He later discovered that short wave radio signals passed through the E-layer and were reflected in what he called the F-layer about 100 to 200 miles above the Earth

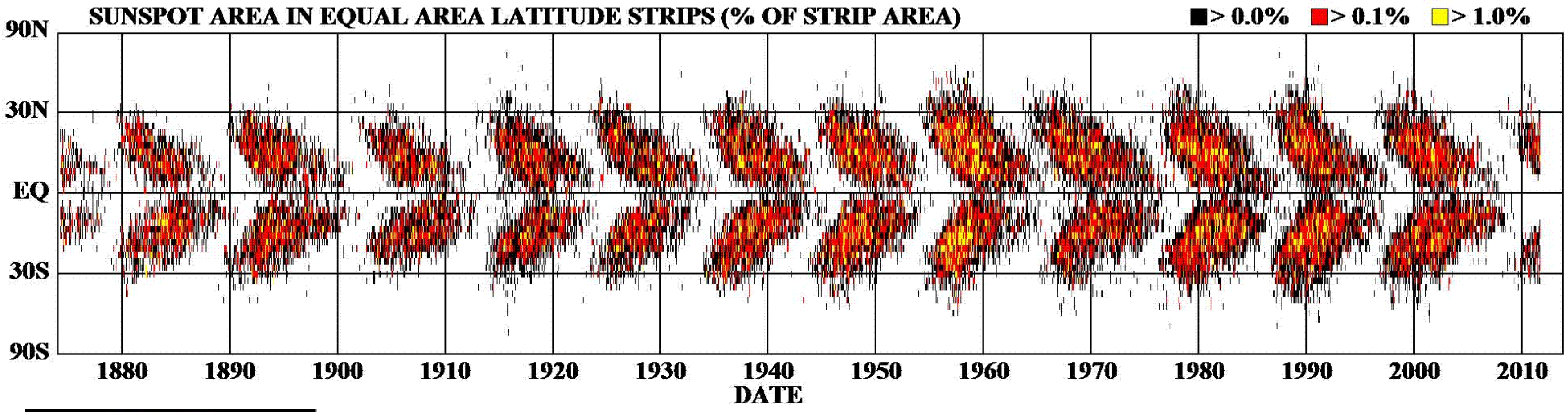


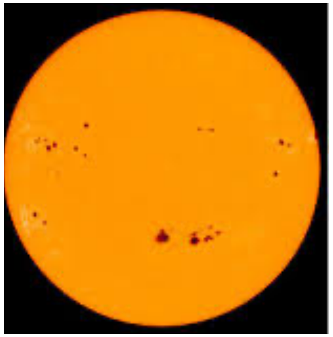
A Disturbing Situation



- Around the world short wave communications had been excellent and exciting since its discovery in the mid 1920s until around 1932
- Then for some unexplained reason, it all went away
- It was difficult to make any long distance short wave contacts
- But then in the late 1930s it all came back again

Short Wave Radio and The Sunspot Cycle





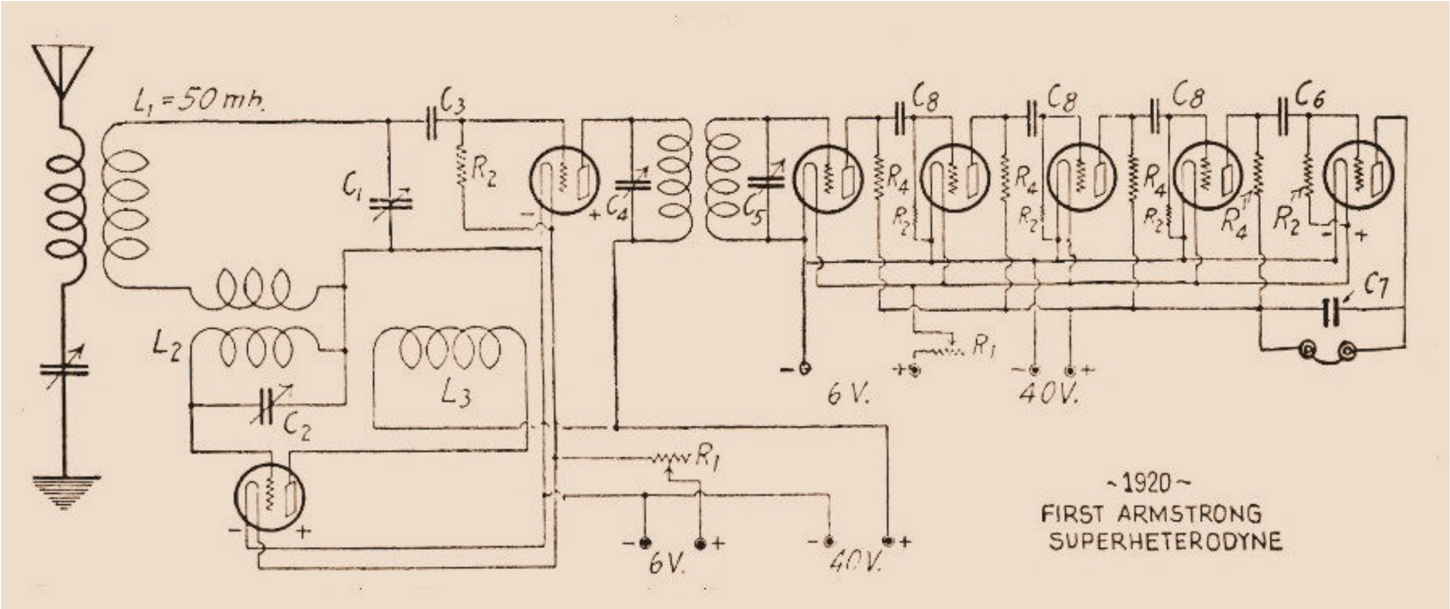
Solar Max

(credit: springer.com)

Solar Min

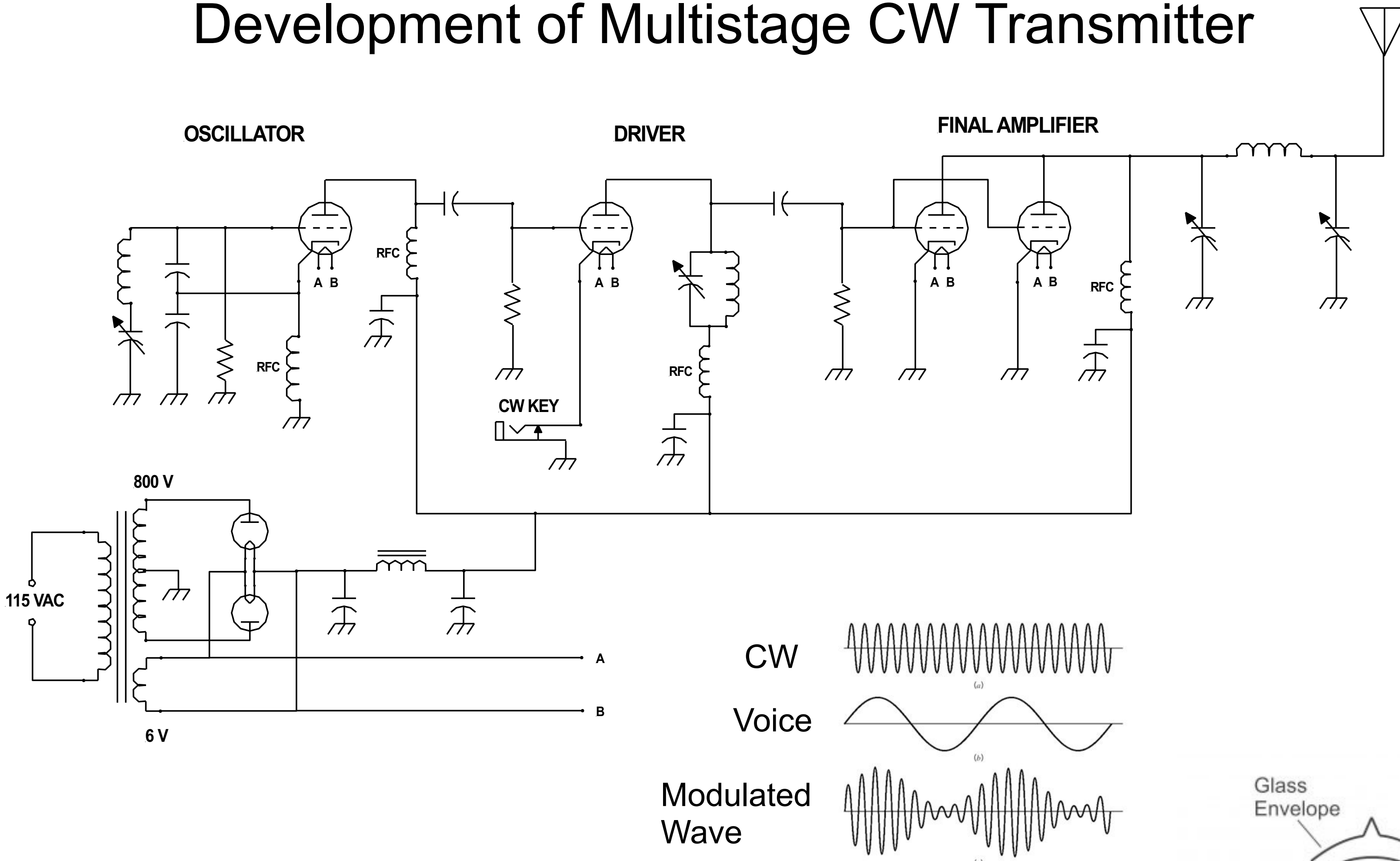
- Amateur radio operators and others had discovered the effect of the solar cycle on short wave communications
- Early on it was known that signal strength and quality varied:
  - Throughout the day, and
  - Seasonally
- It was now apparent that signal strength and quality also varied with the 11 year solar cycle

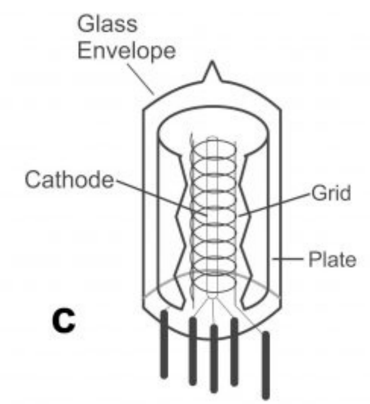
Invention of the Superheterodyne Receiver



- **In 1919** Edwin Armstrong developed a superheterodyne receiver that was considerably more sensitive and selective than previous receivers
- The key feature of a superheterodyne receiver is mixing of the incoming radio signal with a locally generated signal that is at a different frequency
- Mixing produces a fixed, unchanging intermediate frequency (IF) that is easily amplified and detected by following stages
- From 1925 on the superheterodyne design dominated the receiver market

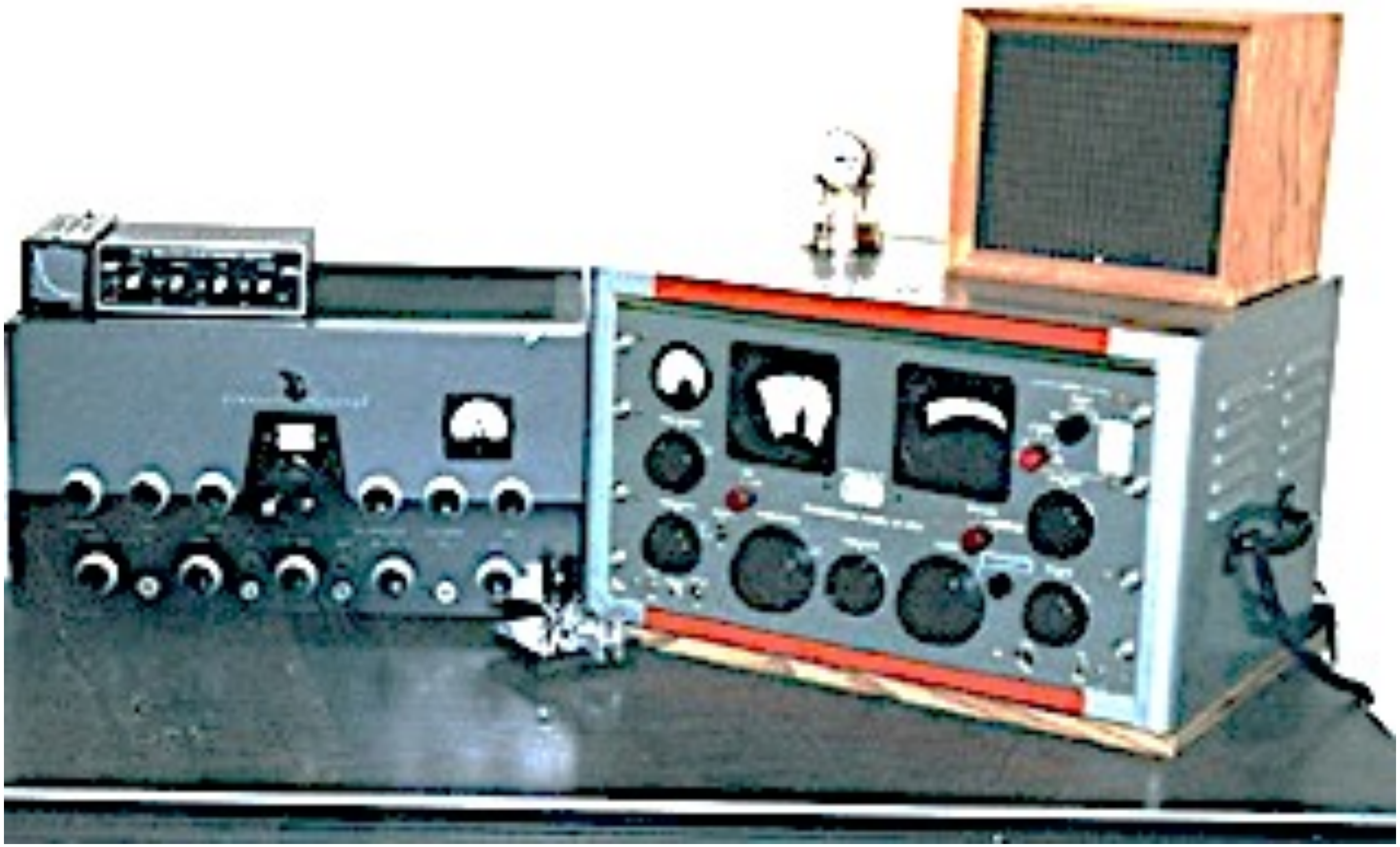
Development of Multistage CW Transmitter



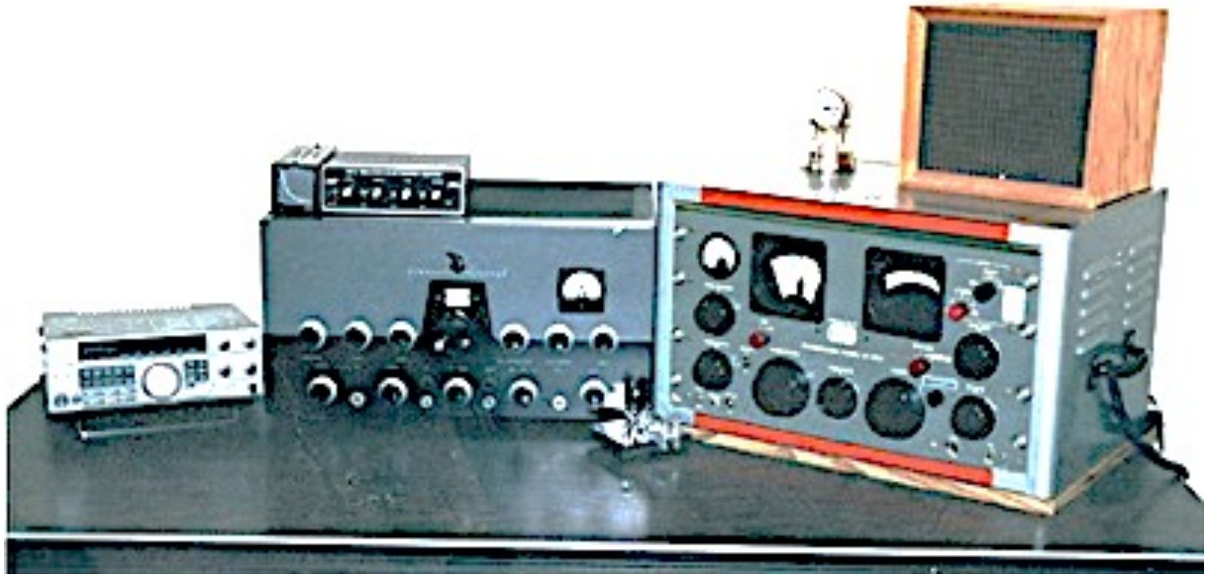


- Transmitter technology developed rapidly during the 1920s with the availability of new and improved vacuum tubes

Leading eventually to the radio equipment of the 1950s



But In The 1960s It All Changed



- The 1960s were the dividing line between the early days of amateur radio and amateur radio technology today
- Semiconductor technology introduced in the 1960s drastically reducing the size of radio equipment and giving birth to transceivers
- Single Side Band replaced Amplitude Modulation for voice communications reducing bandwidth while also reducing interference and fading problems
- And so it is today