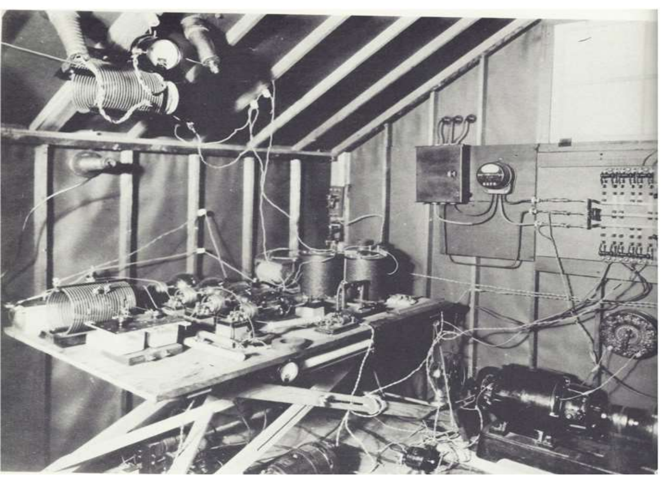
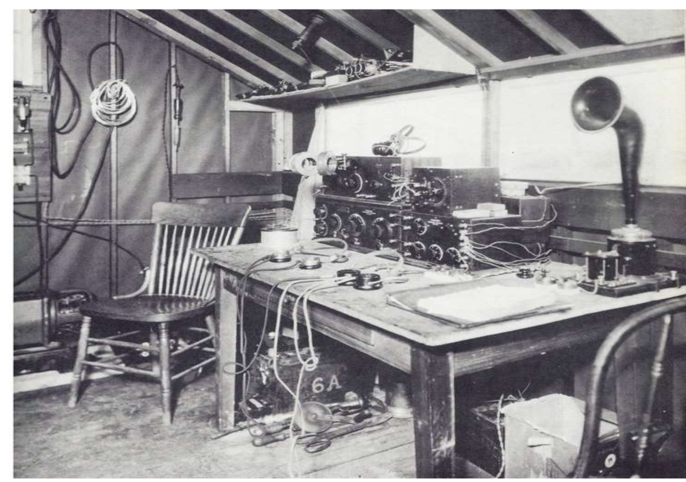
History of Amateur Radio

(1895-1925)





Tino Zottola, VE2GCE

August 16, 2021

Agenda

- Introduction
- Radio physics era
  - James Clerk Maxwell
  - Heinrich Hertz
  - Guglielmo Marconi
- Rise and fall of spark gap
  - Spark gap evolution
  - Titanic radio room
  - Ernst Alexanderson
  - Reginald Fessenden
- Electronic age
  - John Ambrose Fleming
  - Lee De Forest
  - Edwin Howard Armstrong
- Amateur radio evolution
  - 1910s Amateur Radio Station
  - 1920s Amateur Radio Station
  - 1921 Transatlantic Challenge
- Conclusion

Introduction

Modern radio is possible by incremental contributions of many scientists and experimenters (proto-radio amateurs)

Radio physics era (1864 - 1904):

- Maxwell took work of Gauss, Faraday and Ampère and formulated the 4 x fundamental equations of electromagnetic waves
- Hertz proved Maxwell's equations experimentally by creating and sending electromagnetic waves across his laboratory

> "*It's of no use whatsoever*[...] *this is just an experiment that proves Maestro Maxwell was right—*
> *we just have these mysterious electromagnetic waves that we cannot see with the naked eye. But they are there.*"
> — Heinrich Hertz

- Marconi takes Hertz's experiment and improves distance by orders of magnitude

> I could scarcely conceive it possible that [radio's] application to useful purposes could have escaped the notice of such eminent scientists.
> *— Guglielmo Marconi*

Electronic age (1904 - present):

- Fleming takes Edison effect and creates highly improved detector (first vacuum tube)
- De Forest takes Fleming valve and creates triode tube (first electronic amplifying device)
- Armstrong takes De Forest triode and creates subsystems of modern radio: oscillator, regen detector and superheterodyne.

Transatlantic challenge:

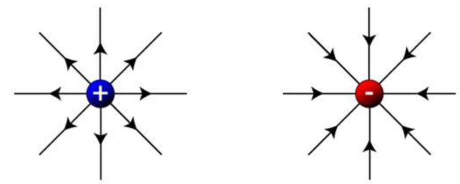
- Only commercial stations were capable of spanning oceans between 1901-1921
- How did hams finally accomplish this feat in 1921 ?

James Clerk Maxwell

James Clerk Maxwell in 1864 formulated fundamentals *four equations of electromagnetic waves:

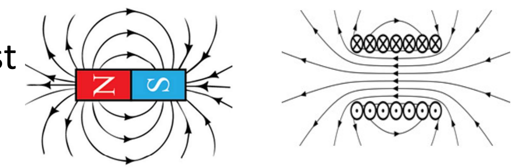
$$\nabla \cdot D = \rho \qquad \nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \cdot B = 0 \qquad \nabla \times H = J + \frac{\partial D}{\partial t}$$



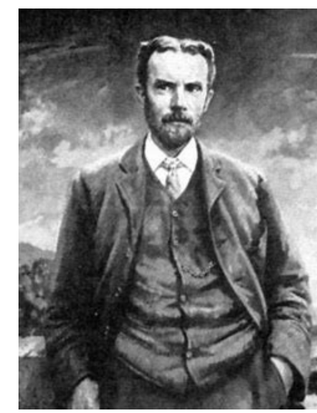
1) Gauss's law for static electric fields. Electric monopoles exist.

Electric field through a closed surface equals the enclosed charge



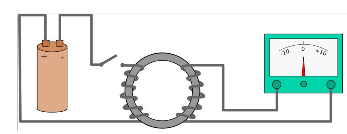
2) Gauss's law for static magnetic fields. Magnetic monopoles do not exist

Magnetic field through a closed surface equals zero



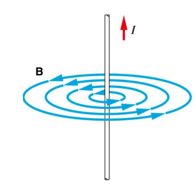
3) Faraday's law of induction: varying magnetic field induces a varying current in nearby conductor

➔ Maxwell-Faraday's law: **a varying magnetic field produces a varying electric field** (displacement current)



4) Ampère's law: a current through a conductor produces a magnetic field.

➔Ampère-Maxwell's law: **a varying electric field** (displacement current) **produces a varying magnetic field**



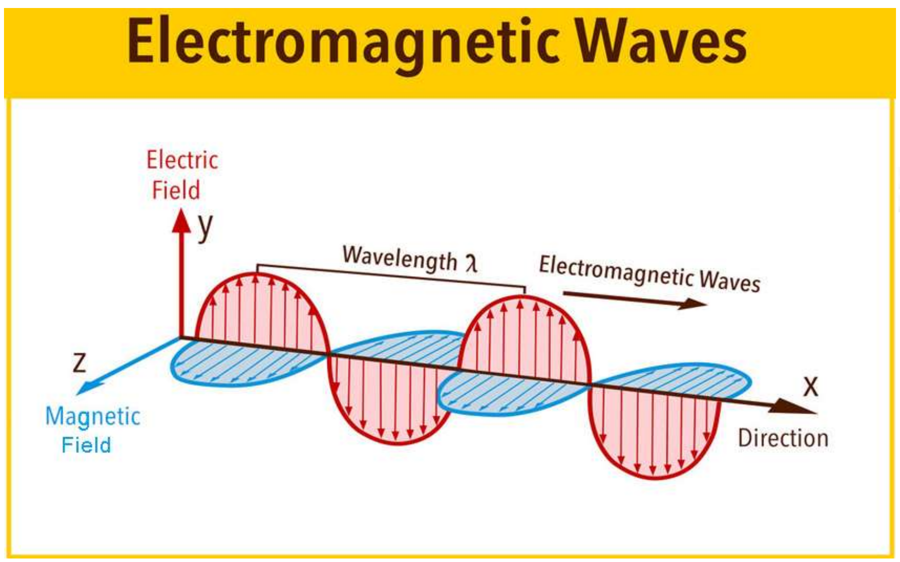
*Oliver Heaviside "simplified" Maxwell's original 20 equations to 4 equations.

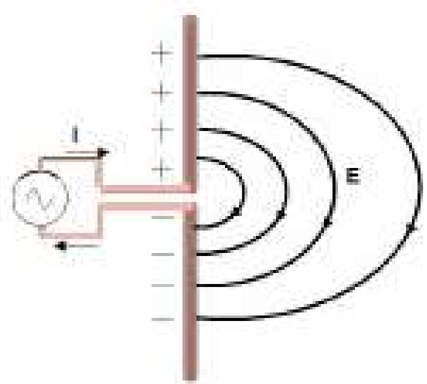
James Clerk Maxwell

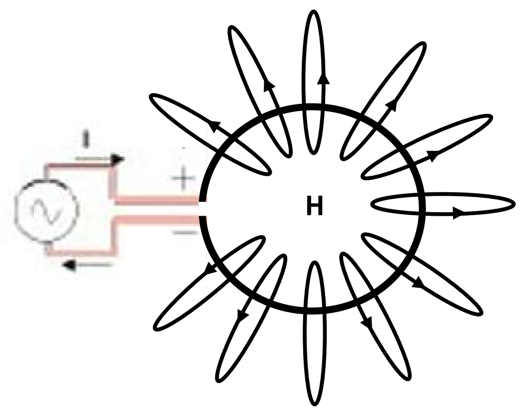
➔ Equations 3 and 4 explain how electromagnetic wave can propagate on their own

Electric and magnetic fields create each other independent of charges, current or materials

- A changing electric field produces a changing magnetic field
- A changing magnetic field produces a changing electric field
- Cycle continues and a self propagating electromagnetic wave travels through the space







E-Field Antennas

- Hertzian dipole
- Marconi vertical
- Yagi (beam)

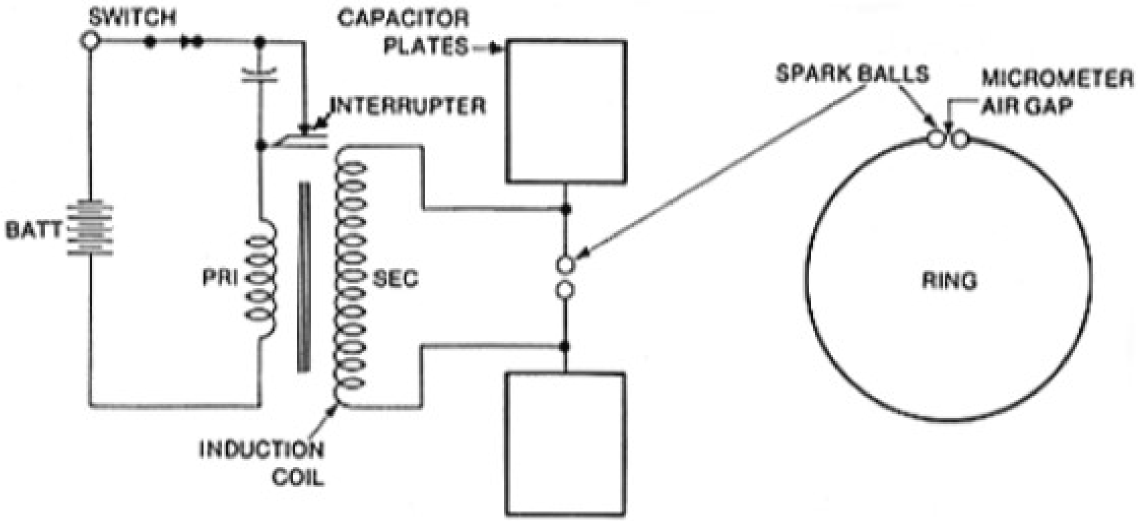
M-Field Antennas

- UHF analog TV loop
- Delta and quad antennas
- AM tube radio rear panel loop

Heinrich Hertz

In 1888, Heinrich Hertz experimentally proved existence Maxwell's electromagnetic waves.

- HV transformer (30 KV) + interrupter creates spark across gap ➔ wide spectrum of RF energy
- RF signal applied to antenna cut for 50 MHz* which radiates electromagnetic (radio) waves
- Hertz used E-Field antenna on Tx side and M-field antenna on Rx side
- Rx ring intercepts radio waves: Spark is visible across air gap with microscope in dark room



*Using 50 MHz as the experimental frequency was a double-edge sword:

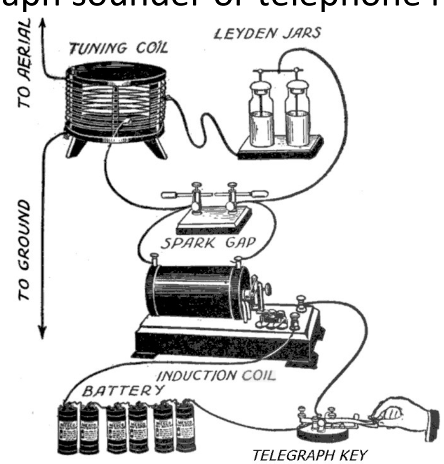
- Positive aspect is short wavelength results in compact setup (i.e. small antennas)
- Negative aspect is spark gap harmonics are very weak at higher frequencies

Guglielmo Marconi

Marconi studied work of many scientists. Only Nobel prize winner (1909) without university degree.

He invented and improved components of the radio system as follows:

- Realized antenna and ground system was most critical part of radio.
- Invented quarter wave, inverted “L” and “T” vertical antennas
- Found increased antenna height improved range (Marconi’s law)
- Used LF and MF frequencies (with ground waves) as opposed to line-of-sight VHF used by Hertz
- Much easier to build powerful transmitters at LF and MF frequencies
- Branly ➔ Powdered iron coherer to detect damped waves.
- Lodge ➔ LC circuit on transmitter and receiver to tune damped waves to specific frequency
- Used telegraph key to send message on TX side
- Telegraph sounder or telephone headset for reception



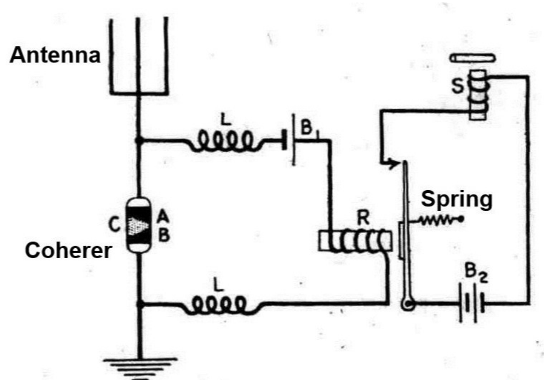
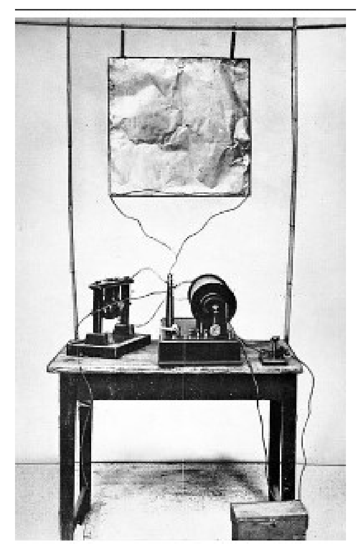


Fig. 101. Marconi 1896 Receiver.



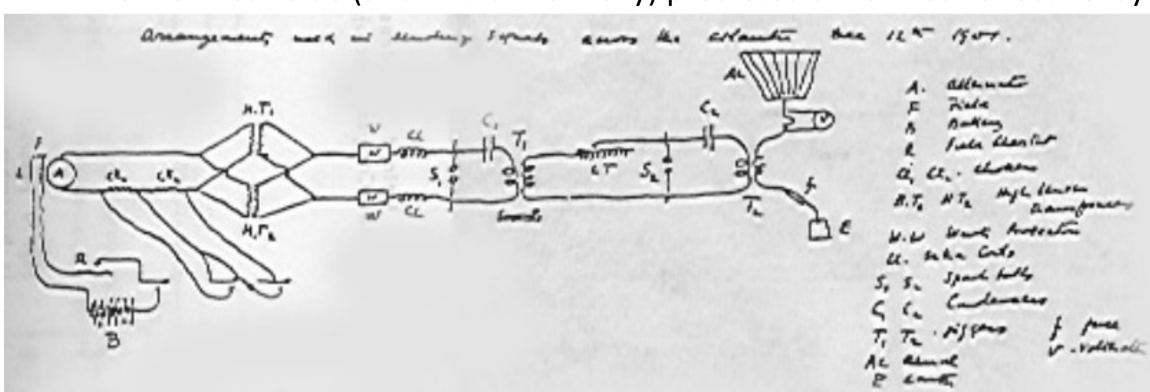
Guglielmo Marconi

- Late 1895: Guglielmo Marconi transmitted 1.5 miles (2.4 km)
- Mar 27, 1899, transmits across the English channel 46 km (28 miles)
- Dec 12, 1901 @ 11:30 AM (NST), Marconi spanned the Atlantic ocean 2000 miles (3200 km) becoming first DX'er.

➔ Poldhu, Cornwall 35 KW transmitter with two stage spark gap @ 820 kHz (366 metres) designed by John A. Fleming
➔ Received repeated 'S' at St. John's, Newfoundland using <u>untuned coherer receiver</u> with 400 ft antenna on kite

- Midday spanning of Atlantic on 820 KHz seems improbable and was disputed by many.
- Marconi's reception of three 'S' at scheduled times was confirmed by witnesses on site.
- Henry Bradford theorizes he received SW harmonics (near 40 meters) in NFLD on untuned coherer.

Marconi demonstrated two key things:
1) Greater distances beyond Hertz's initial experiment are possible.
   - Oliver Lodge predicted ½ mile as maximum distance in 1894 based on Hertz's apparatus
2) Propagation of radio waves beyond horizon is possible.
   - Oliver Heaviside (and Arthur Kennelly) predicted an ionized reflective layer (i.e. E-region in ionosphere) in 1902

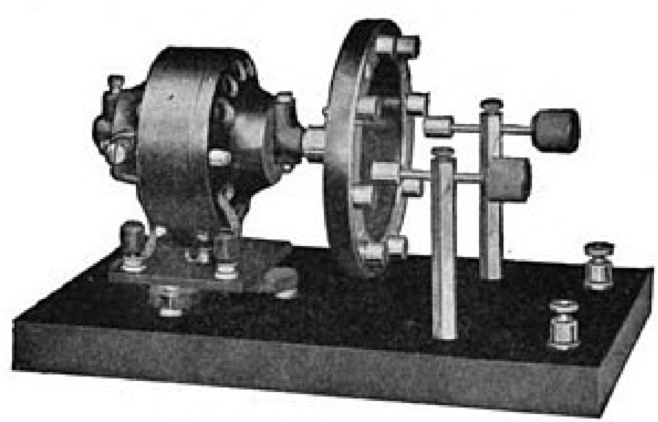


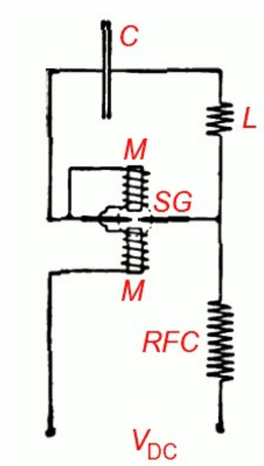
Transmitter Spark Gap Technology

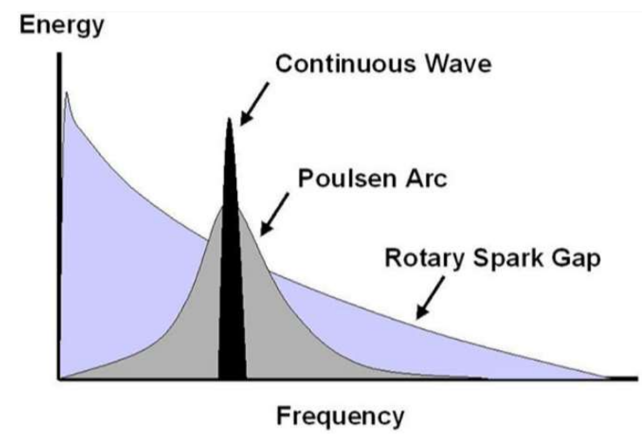
Refinement to spark gap during its history were made

- Rotary spark gap: Stable spark not affected by temperature and has controlled quenching
- Poulsen arc: DC arc with tuned circuit across created a focused bandlimited RF signal

- Spark gap equipment would be displaced by more effective CW equipment by early 1920’s
- Spark gap outlawed in 1938, because of its disturbance to other stations
- Used for emergencies on older ships from 1920’s to 1938







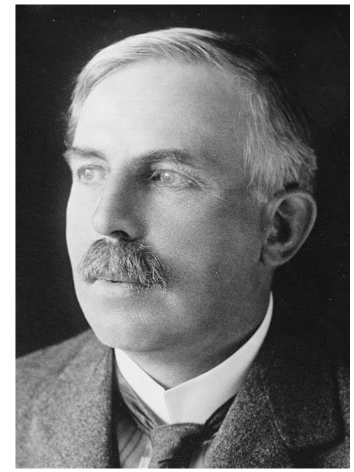
Receiver Spark Gap Technology

1) Coherer, a primitive RF detector, was invented by physicist Edouard Branly in 1890

- Applied RF signal causes powdered iron in sealed glass tube to stick (i.e. micro-weld) and pass a current to sounder
- It remains stuck after RF signal is gone and needed to be shaken loose by external tapper
- Limited to 12-15 WPM, most commercial operators could send 50 WPM

2) In 1896, Ernest Rutherford discovered that RF energy demagnetizes a magnetized steel wire

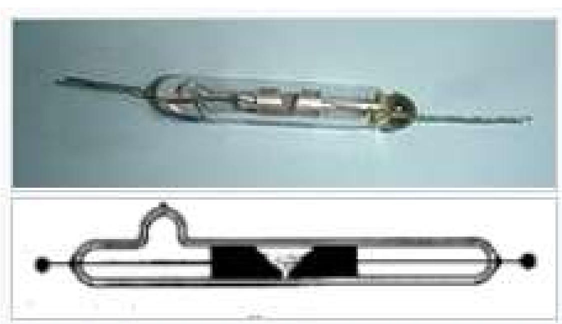
- McGill physicist (1898-1907). Discoverer of radioactive decay; α, β, γ radiation; and structure of atom



Marconi added wire loop + clock spring mechanism to Rutherford’s phenomenon to create demodulator

- Magnetized steel wire passes through 1st coil. RF instance (dot or dash) on coil demagnetizes steel wire
- Partially demagnetized wire passes through 2nd coil where demodulated signal sent to headset
- Main RX on Titanic consisted of Marconi Multi-tuner and Marconi Magnetic Detector (“Maggie”)

Mechanical detectors eventually replaced by Fleming valve and mineral detectors.

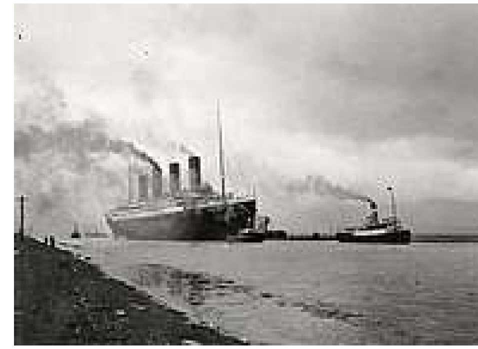


Marconi Coherer

Marconi Multi-Tuner

Marconi Magnetic Detector

The Titanic

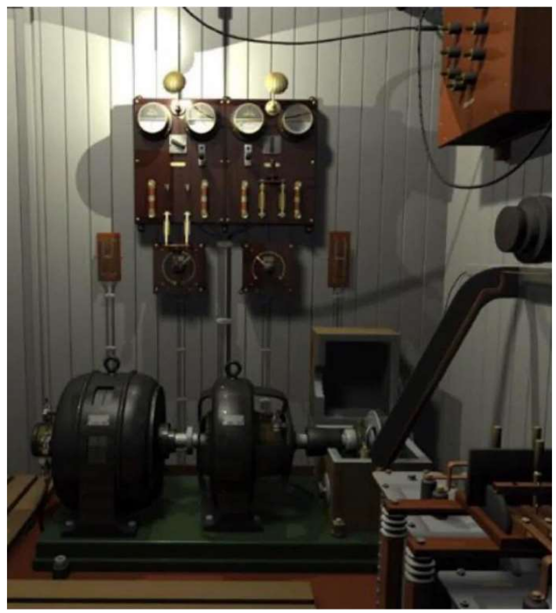


1912 was the high water mark for spark gap technology

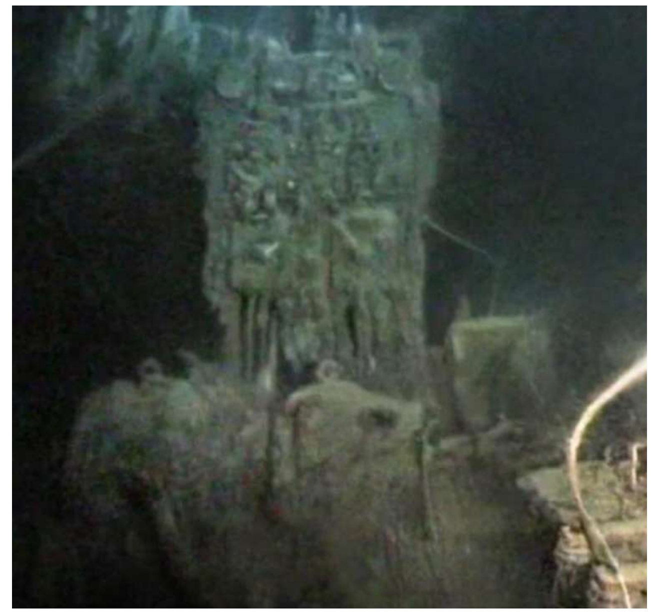
- Radio primarily used for telegram traffic for 1st and 2nd passengers
    - Cost was prohibitive. $62.00 for first ten words and $3.00 for each additional word in 2021 dollars.
- Titanic's Marconi radio saved 705 lives and radio became mandatory afterwards on all ships

Operator's room with receivers + Aux Tx

"Silent Room" with Main Tx



James Cameron photo of "Silent Room"



Titanic - Marconi Trivia:

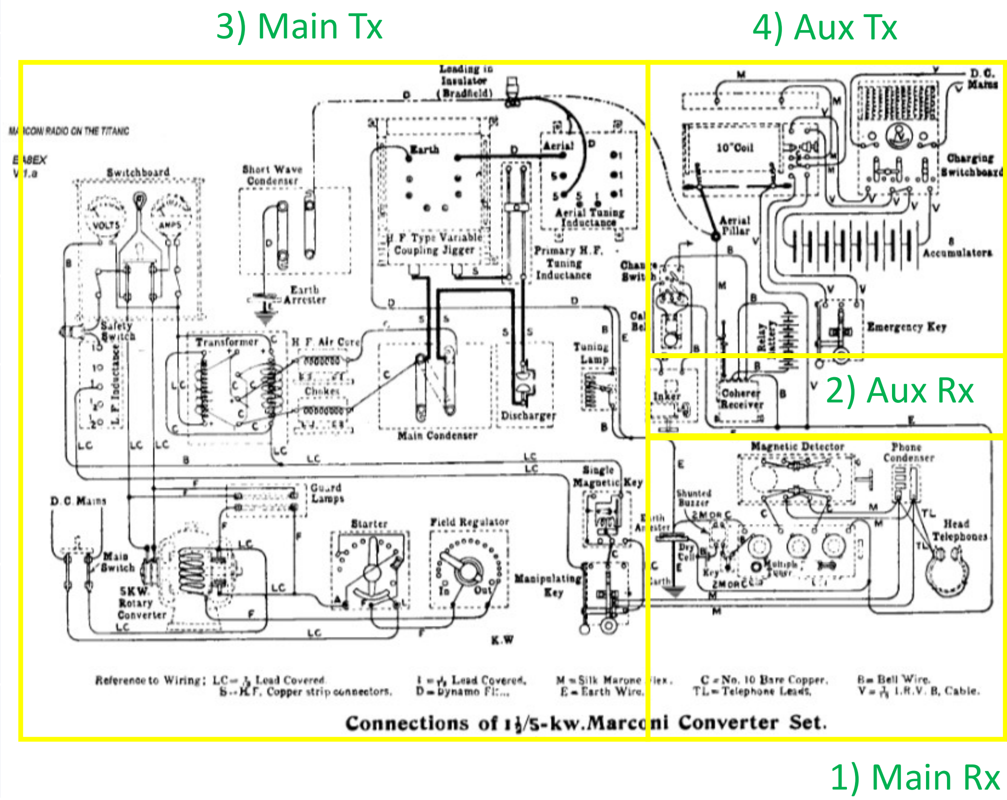
- Marconi offered free ticket on Titanic maiden voyage on April 10, 1912
- He had business in New York and left 3 days earlier on the Lusitania (which would be sunk 3 years later in WWI) instead
- Marconi's wife and two children were scheduled to board the Titanic, but fate intervened when his son developed a sudden fever

The Titanic Radio Set

Titanic had two radio setups:

- Main radio used relatively new technology
- Auxiliary radio (for emergencies) used older technology

TITANIC's RADIO EQUIPMENT - CALL SIGN **MGY**		
Receivers	(1)	Main receiver: • Marconi Multi Tuner: 2600 to 100m (115 kHz to 3 MHz) • a) Marconi magnetic detector • b) Marconi valve tuner: 2 x Fleming valve detectors • Standard telephones (headphones)
	(2)	Auxiliary receiver: No tuner • Coherer with Inker/printer.
Transmitters	(3)	Main Transmitter : 5 kW disk discharger set • Input power: 100-110 VDC @ 60 amps • Bands: 600 m “longwave” and 325m “shortwave” • Set produced a CW note of 840 Hz. • Range: Day: 250 mi; Night: 2000+ mi, (not guaranteed)
	(4)	Auxiliary Transmitter: 1.5 kW plain spark set 10” coil • Powered by batteries. • Range: Day: approx. 40 mi
Antenna		Twin T balanced type. 450 feet long • Two pairs of wires and two feed lines to radio



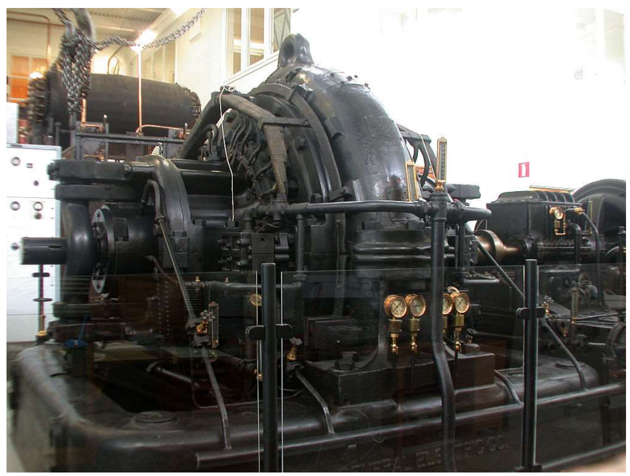
Ernst Alexanderson

Spark gap was primary mode of communication until World One.

- Despite many enhancements, spark gap transmitters were inherently inefficient
- Spark gap transmitters operate over wide spectrum and RF power is dispersed.

1906: Ernst Alexanderson built the first high frequency high power alternators to create CW

- First alternator transmitter built for Fessenden @ 50 Khz 500 watts
- Power levels from 250 watts to 500 KW
- Operated between 12 KHz and 100 KHz
- Obsoleted by high power transmitter tubes in the 1930’s
- Used well into 1940’s by US Navy for submarine communication

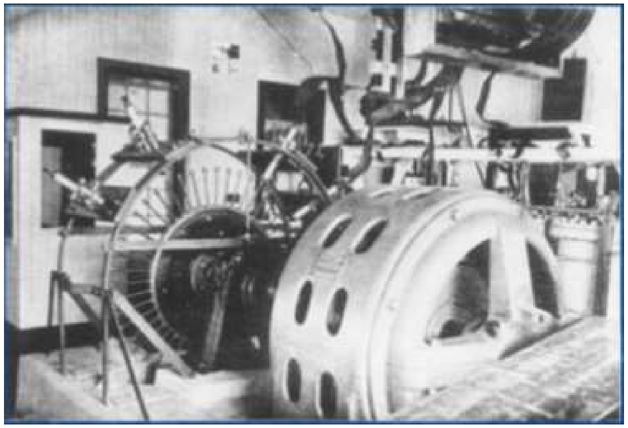


Reginald Fessenden

Reginald Fessenden (born in East Bolton, Quebec) was first to send voice / music over radio

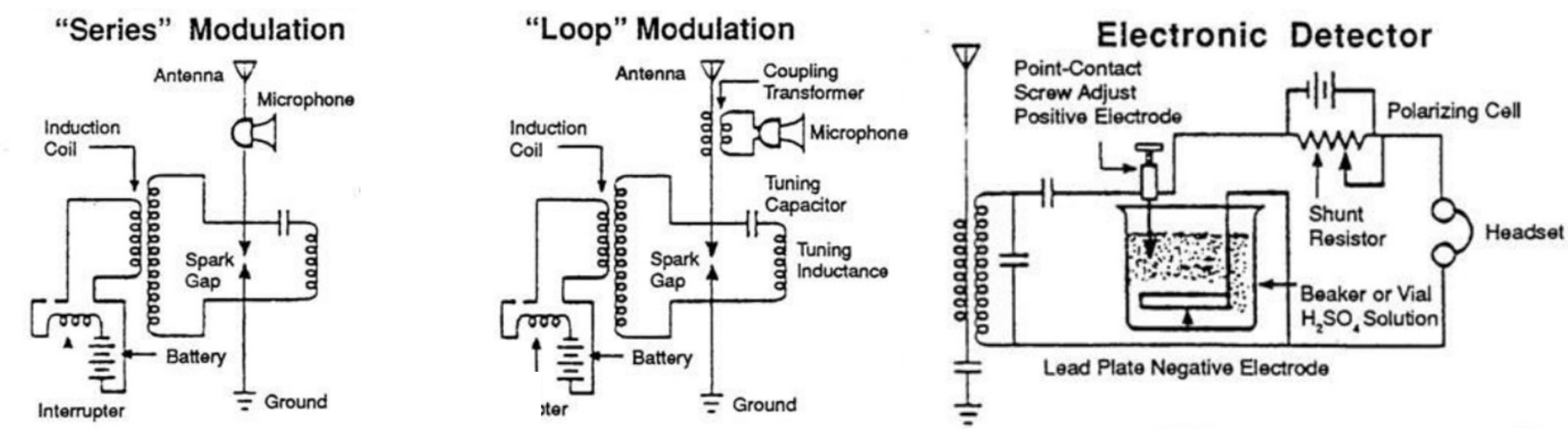
First two broadcasts of voice / music using alternator-transmitter from Brant Rock, Mass

- Audience was primarily shipboard radio operators along the Atlantic seaboard
- 1906: First Christmas Eve broadcast had been heard as far as Norfolk, Virginia
- 1907: Second New Year Eve's broadcast had reached listeners in the West Indies



Reginald Fessenden

- Fessenden fitted existing telegraph transmitter with carbon microphone in series with antenna
- High power transmitter used an Alexanderson alternator instead of interrupter + battery (shown below)
- Conventional receiver with coherer cannot receive voice/music broadcast
- Detector used sulfuric acid with two electrodes to make voice/music reception possible
- Receiver operation similar to radio using mineral crystal or Fleming valve based detector



John Ambrose Fleming

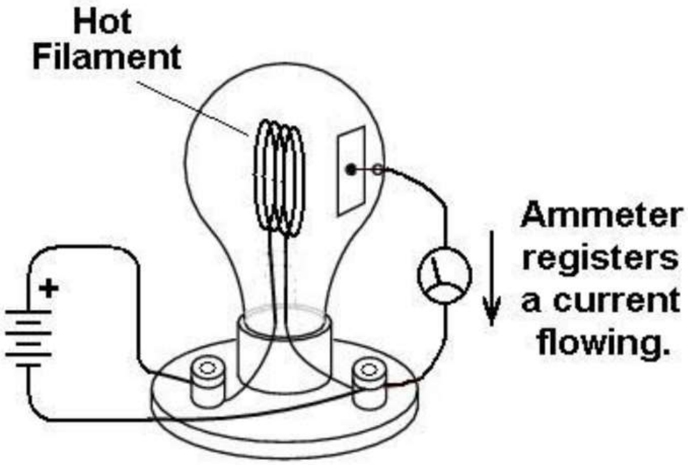
1884: Thomas Edison experiments to reduce light bulb “blackening”

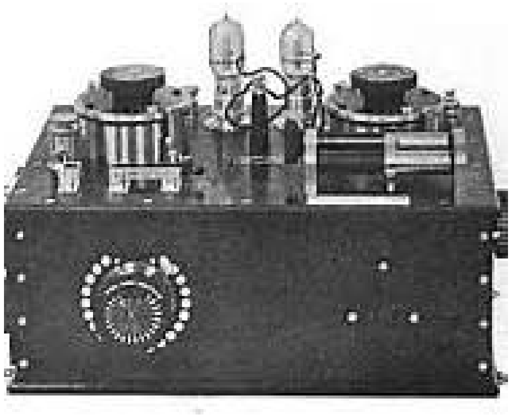
He noted the following, after adding a plate inside the light bulb

- Plate conducted current when it was positive
- Plate did not conduct current when it was negative

Edison saw no commercial use for it at the time

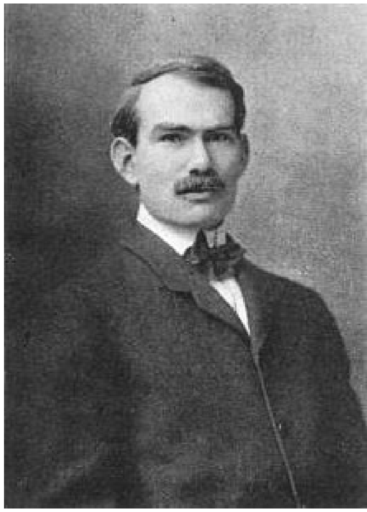
1904: Fleming (key member of Marconi’s team) found phenomena useful for detecting radio waves, great improvement over mechanical coherer.





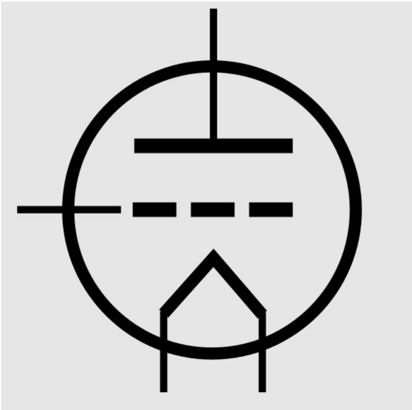
Marconi Valve Tuner

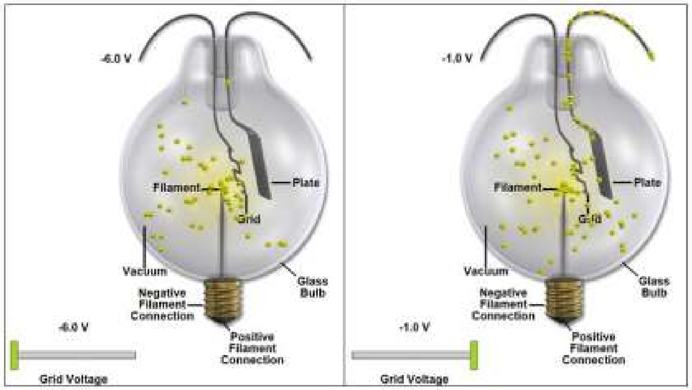
Lee De Forest

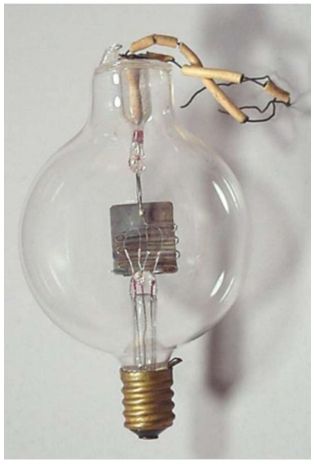


1908: Lee De Forest invents Audion
- Added third element “grid” between filament and plate
- Small voltage on grid controls large current between filament and plate
- De Forest had a limited understanding of how it worked at the time

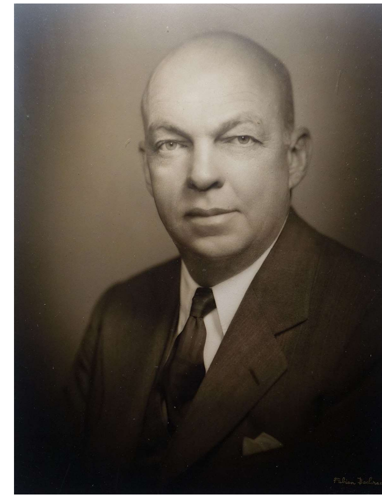
Audion had three revolutionary characteristics
- As a grid leak detector, it was a marked improvement over Fleming valve.
- Audion had a high input impedance that did not load antenna + tuned circuit
- In 1911, Edwin Armstrong recognized that triode could operate as an amplifier







Edwin H. Armstrong



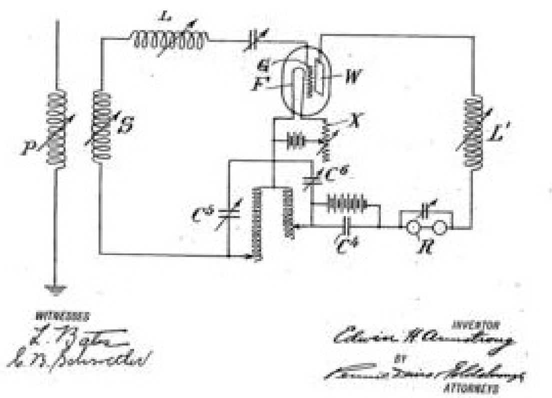
Armstrong is the “Edison of Radio” having invented numerous radio sub-systems, still in use today.

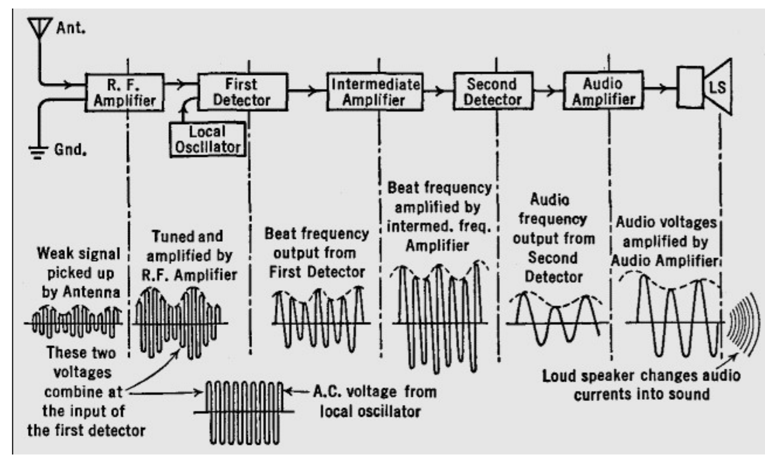
1913: Took De Forest’s Audion and invented two key radio building blocks

- Uses positive feedback “Regeneration” to achieve high amplification and high “Q”
- When feedback is increased further, triode became an oscillator, a CW source

1918: Armstrong's most significant accomplishment was the “supersonic heterodyne”, more commonly known as the “superheterodyne” radio receiver circuit

- Most of amplification is done at lower IF “Intermediate Frequency” resulting in stable, sensitive and selective Rx
- TRF receivers did most of the amplification at higher RF frequencies and were unstable after a few cascaded stages



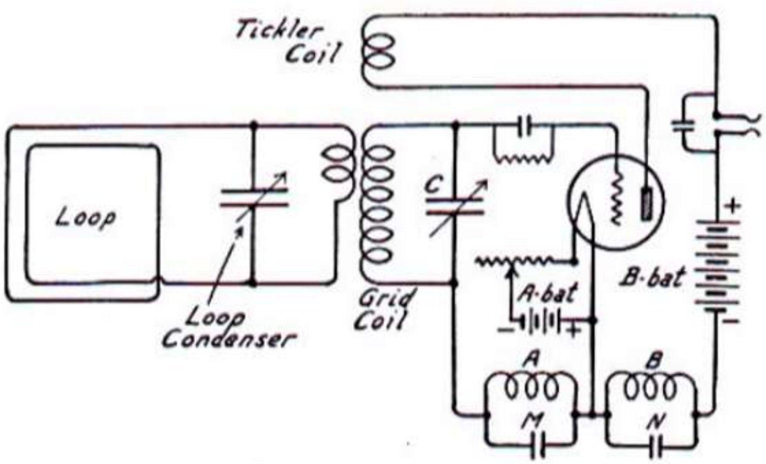


Edwin Armstrong

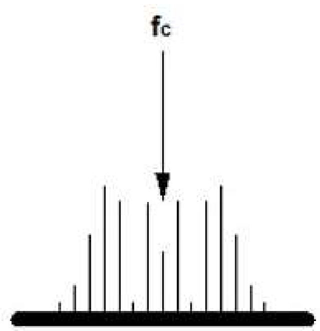
1922: While counteracting a claim made by a patent attorney, Armstrong discovered super-regeneration
- "Quenching" the detector oscillations above audible range achieves even higher amplification.
- No adjustment needed, tends to favor strong signals, often used on VHF / UHF receivers

1922: John Renshaw Carson of AT&T, inventor of Single-sideband modulation (SSB),
- Published detailed mathematical analysis ➔ FM transmissions did not provide any improvement over AM
- Result was limited because he analyzed only what is now known as "narrow-band" FM.

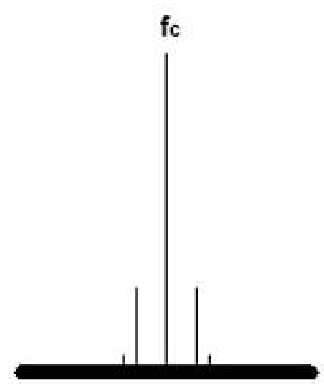
1933: Armstrong's demonstrated wideband FM was clearly superior to AM



Circuits of Super-Regenerative Single Tube Receiver.



Wide-Band FM



Narrow-Band FM

Amateur Radio: 1910s

1909: One first radio clubs in US formed, RCA (Radio Club of America).

- Predates ARRL by 5 years and still in existence today.

Pre-1912: Radio landscape was the 'Wild West' with no "policing"

1912: RMS Titanic sinks, US Congress passed the Radio Act of 1912

- Amateur radio licensing mandated
- Restricted to 200 meters or shorter (1500 kHz or higher)
- Short wave frequencies were considered useless at the time
- Amateur radio operator population dropped by 88%
- First licensed ham in US was Irving Vernilya, 1ZE

1914: ARRL was formed.

- Typical ham station had range of no more than 50 miles
- ARRL goal: Create network of ham stations to relay messages across USA

1915: First licensed women ham in US was Emma Chandler, 8NH

1917-1919: Amateur Radio operation suspended due to World War I.

- 6000 hams go off the air

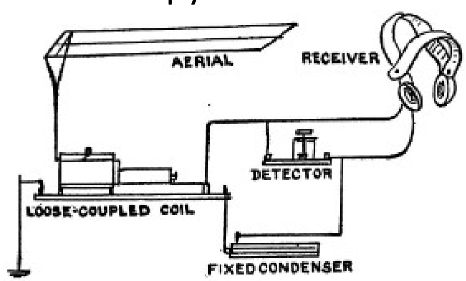
Radio frequencies used by spark transmitters during the wireless telegraphy era			
Uses	**Frequency (kilohertz)**	**Wavelength (meters)**	**Typical power range (kW)**
Amateur	> 1500	< 200	0.25 - 0.5
Ships	500, 660, 1000	600, 450, 300	1 - 10
Navy	187.5 - 500	1600 - 600	5 - 20
Moderate size land stations	187.5 - 333	1600 - 900	5 - 20
Transoceanic stations	15 - 187.5	20,000 - 1600	20 - 500

Amateur Radio: 1910s

Equipment was homebrew, including most individual components

Typical Receiver (circa 1912):

- Variable input tuning coil + fixed capacitor
- Carborundum, silicon, galena or iron pyrite based detector
- High impedance headset



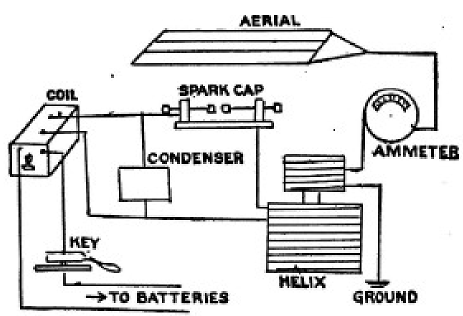
Helix coil

Rx tuning coil

HV coil

Typical Transmitter (circa 1912):

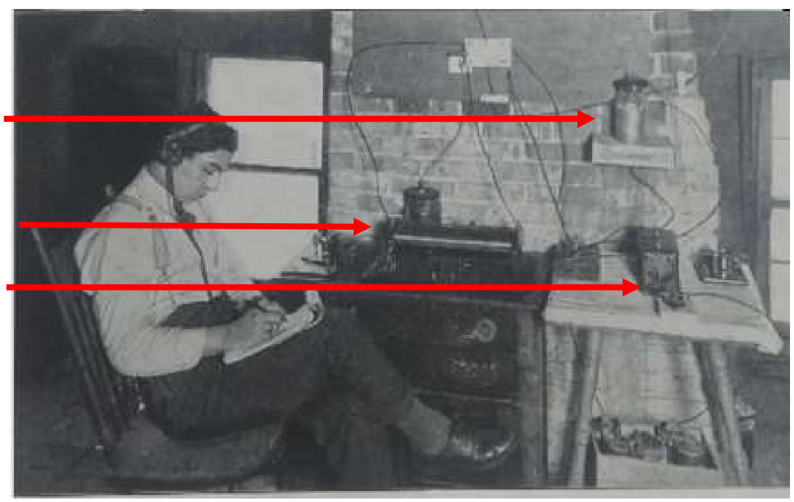
- HV coil (e.g. Ford Model "T" ignition coil) + spark gap
- Output tuning circuit consisting of Helix and Leyden jars
- Standard telegraph key



Leyden jar

Rx tuning coil

HV coil



Amateur Radio: 1920s

Most equipment was still homebrew, but many individual components could be store bought

Vacuum tubes and individual components were available at reasonable costs.

Commercially manufactured receivers started to appear on the market.

Receiver Architecture:

1) Tuned Radio Frequency (TRF)

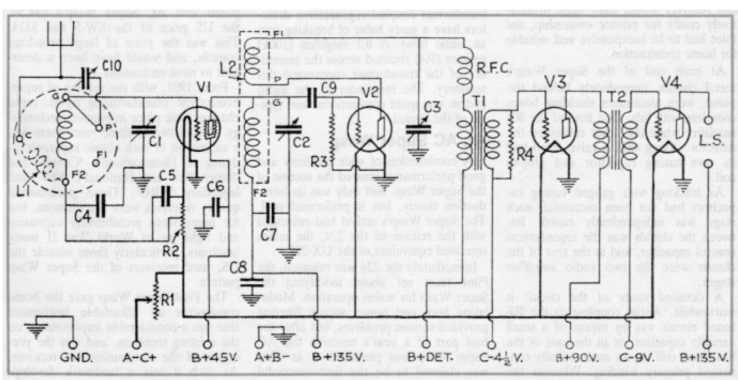
- Cascaded RF stages, progressively unstable as frequency goes up

2) Super-heterodyne (Superhet)

- Superior receiver, complex and expensive because of RCA patent royalties

3) Regenerative (favorite among hams)

- Regenerative detector with RF and audio stages



Amateur Radio: 1920s

1924: Amateurs get assigned fixed bands on 80, 40, 20 and 5 meters and keep existing 150-200 meter band

- Spark gap prohibited on new bands (80, 40, 20, 5 meters)

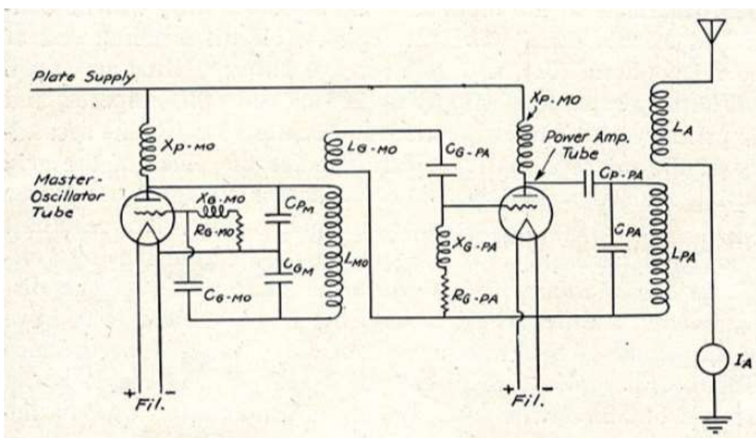
1926: Spark gap is banned on 150-200 meter band

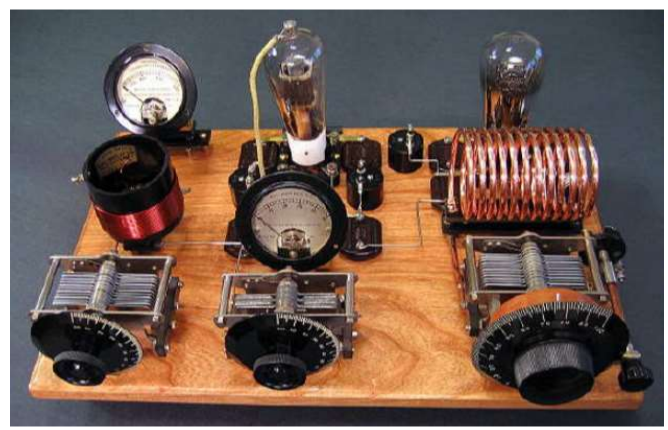
1927: Radio Act of 1927 creates the Federal Radio Commission

- 10 meter band is added
- 1.5 to 2.0 Mhz band is narrowed to 1.75 to 2.0 MHz (160 meters)
- International callsign prefixes are assigned

Transmitter Architecture:

- MOPA (Master Oscillator Power Amplifier) CW transmitter using low power audio tubes
- More affluent hams could afford high power transmitting tubes (e.g. $2000 for 250 watt tube, 2021 dollars)
- Frequency determined by LC in oscillator. Not very stable, drifting of several kHz was common
- Oscillator crystals introduced in 1925 @ $50.00. Would take 10 yrs for widespread use when prices dropped





1921 Transatlantic Challenge

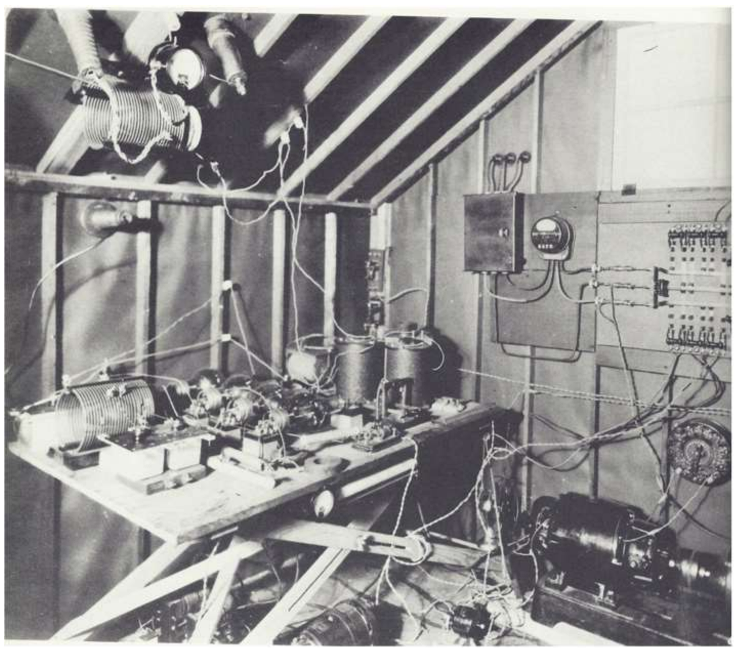
1921 American hams challenge UK counterparts to receive radio contacts across the Atlantic.

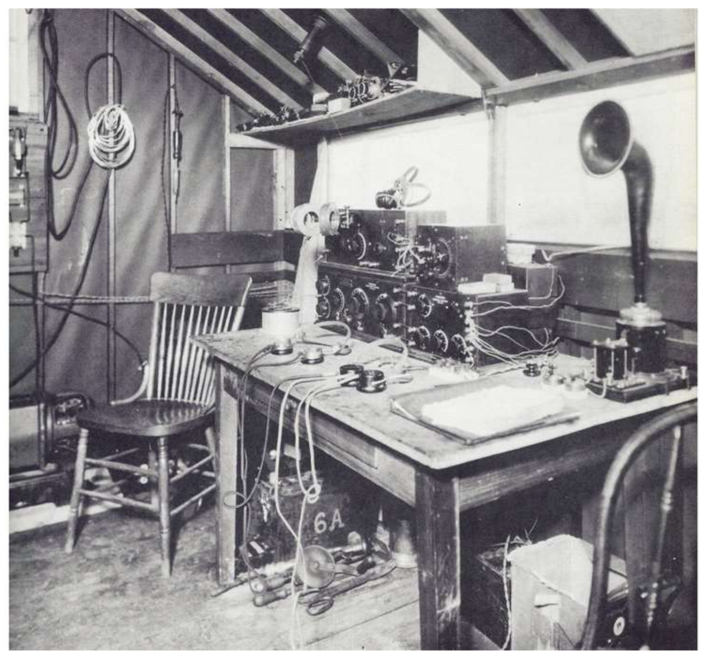
- Big news at the time, featured in leading numerous magazines: QST, Scientific American, Everyday Engineering, etc.
- Goal was to repeat Marconi’s feat of Dec 12, 1901 ➔ with lower power, CW and higher frequency (200 meters)

Tests held on February 2, 4 and 6 1921 ended in disappointment, no US amateurs heard in UK

Next series of tests commenced on December 8 through 17, 1921.

- Prominent station was built by six RCA (Radio Club of America) members which included Major Edwin Armstrong
- Station owner: Milton Cronkite, 1BCG and station operator: John Grinan, 2PM, NJ2PZ in Greenwich, Connecticut

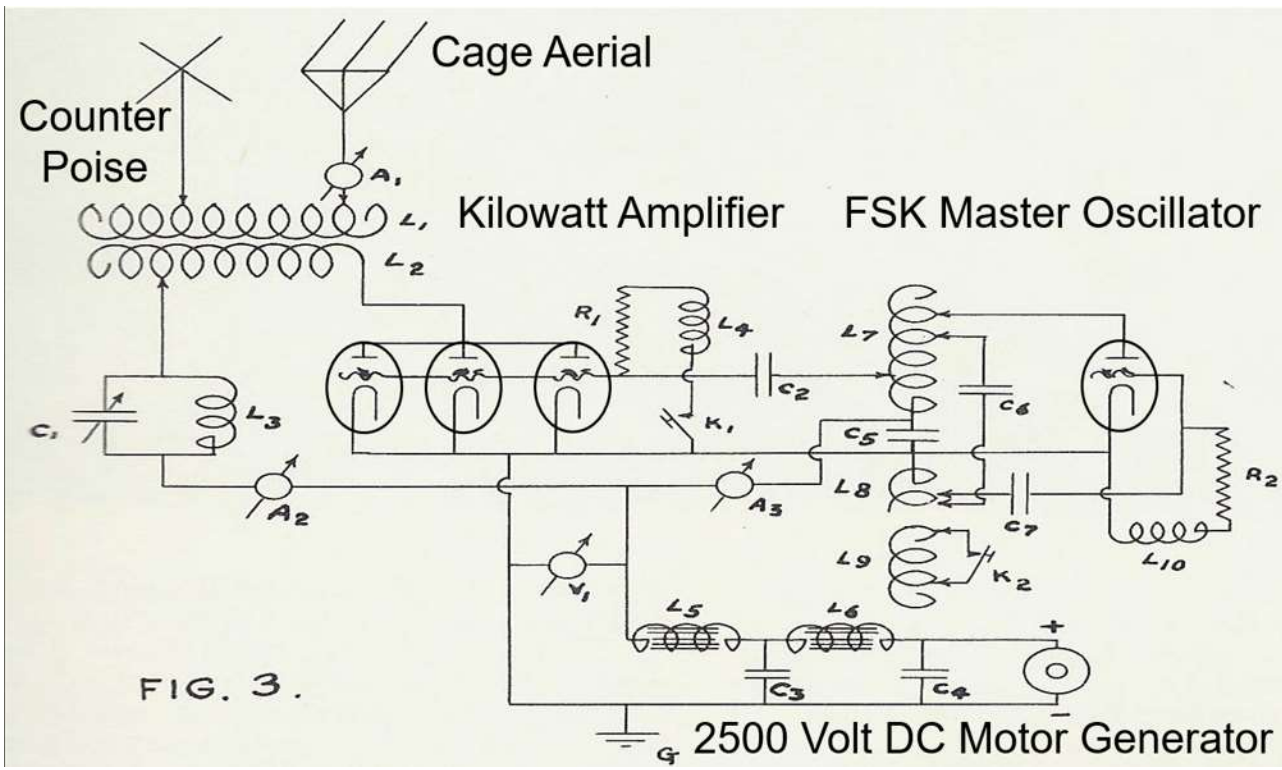




Transatlantic Challenge

1 KW Transmitter used a MOPA architecture:

- UV204 oscillator
- 3 x UV204 PA stage
- Powered by 2.5 KV motor-generator (i.e. Dynamotor)



Their station was heard in Scotland

Here are the men who sent the message that was heard in Scotland. Behind them is their RCA equipped station. From left to right they are Amy, Grinan, Burghard, Armstrong and Cronkhite. Their call and a complete message were the first to be received in Scotland. *How did they do it?*

With four General Electric Company's Radiotrons UV-204—the most powerful of radiotrons—using one as a master oscillator and three as amplifiers.

Then, too, the majority of the stations heard in Scotland, during the great historic contest, used the 50-watt Radiotron UV-203. Letters sent by the owners of these stations to the Radio Corporation of America prove this conclusively.

Send 25 cents for the RCA Catalogue containing full information on CW operation, then consult your nearest dealer

Radiotron UV-203 50-Watts *Price, $30*

Radiotron UV-204 250-Watts *Price, $110*

The famous Radiotron UV-204

RADIOTRON

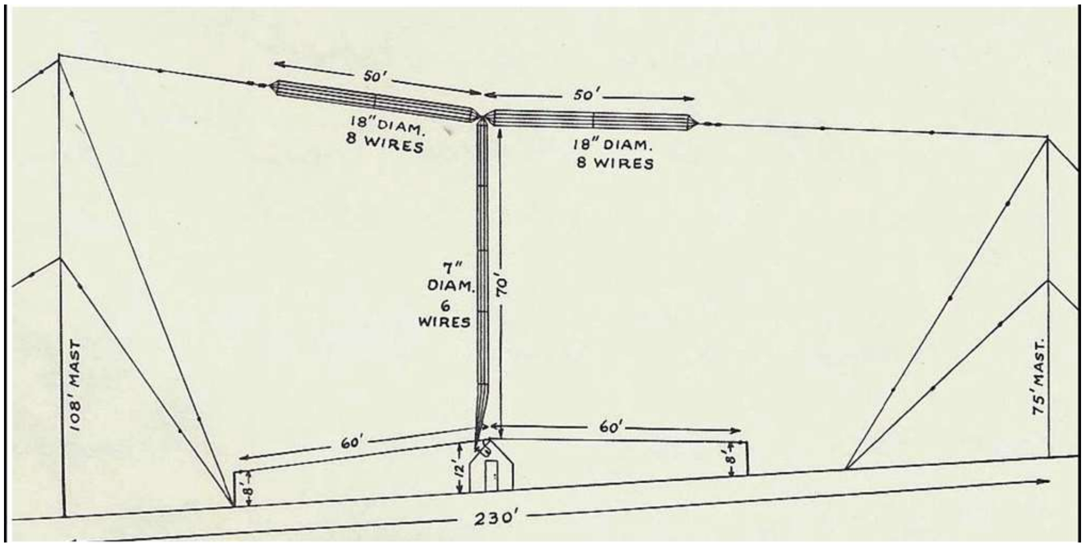
Radio Corporation of America

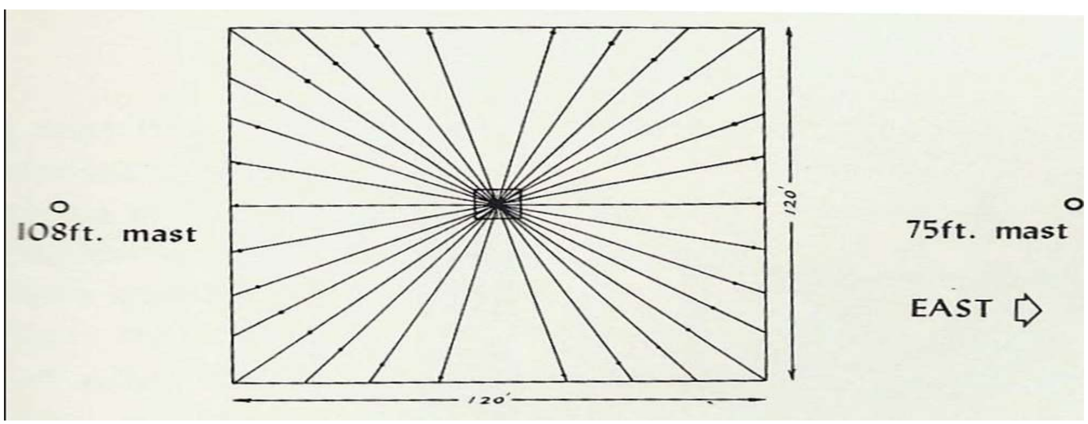
WORLD WIDE WIRELESS

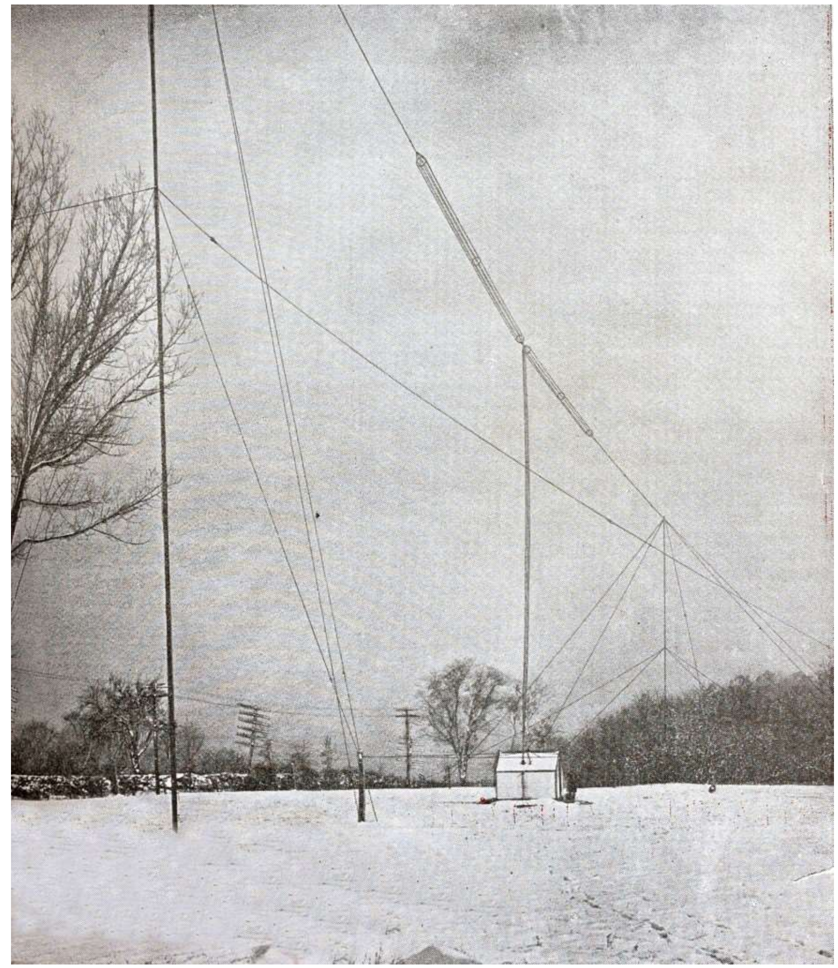
Sales Division, Suite 1801
233 Broadway, New York City

Transatlantic Challenge

- 1BCG, used a cage antenna with counterpoise system (grounding network)



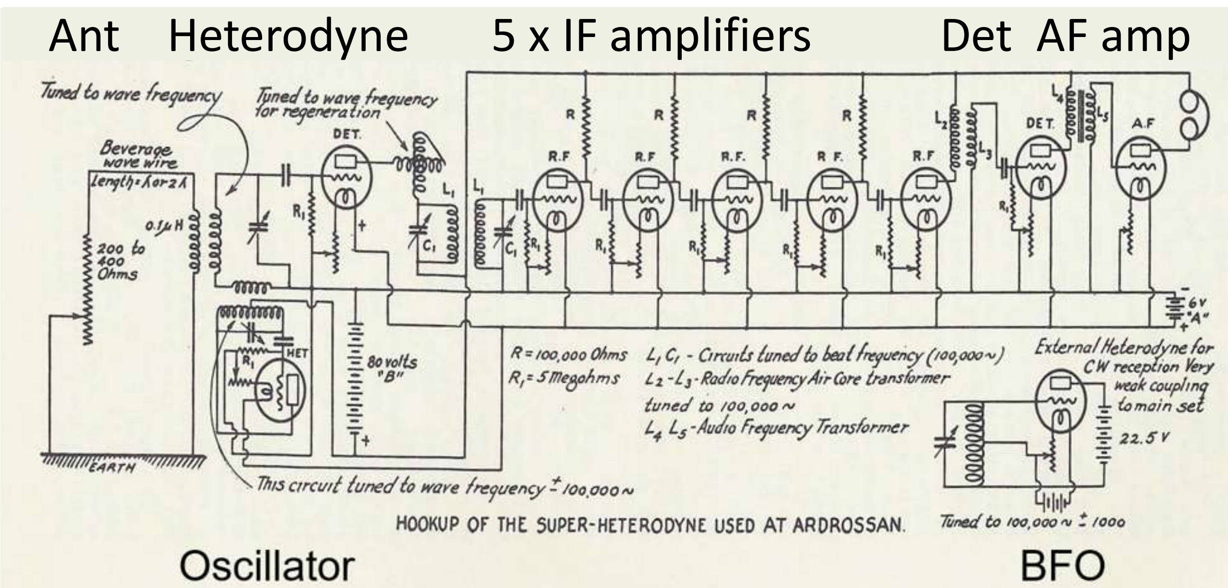


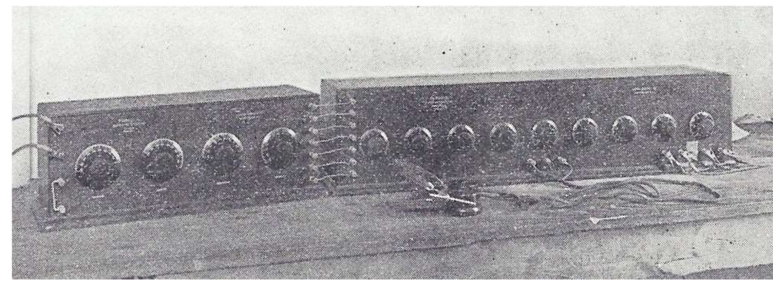


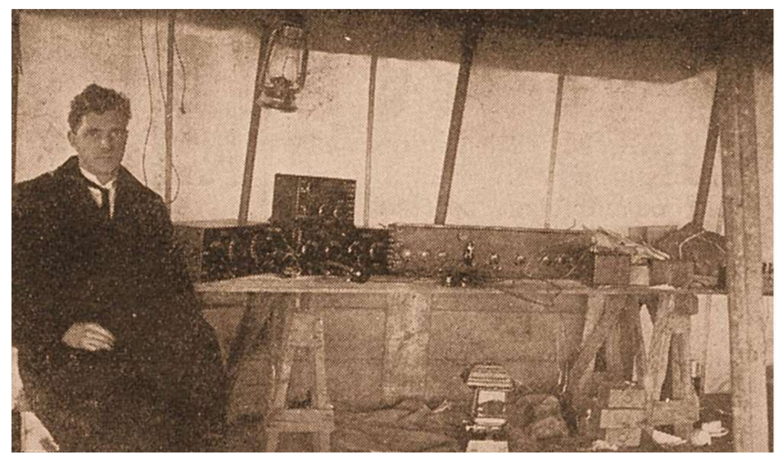
Transatlantic Challenge

- Best receiving equipment available sent along with Paul Godley, 2ZE to the UK
  - Armstrong superheterodyne and Paragon regenerative receiver
  - Receiving antenna was a 1300 foot beverage
- Godley established a listening post in a field just outside Ardossan, Scotland

➔ Dec 9, 1921 0050 UTC, 2ZE received 1BCG transmission



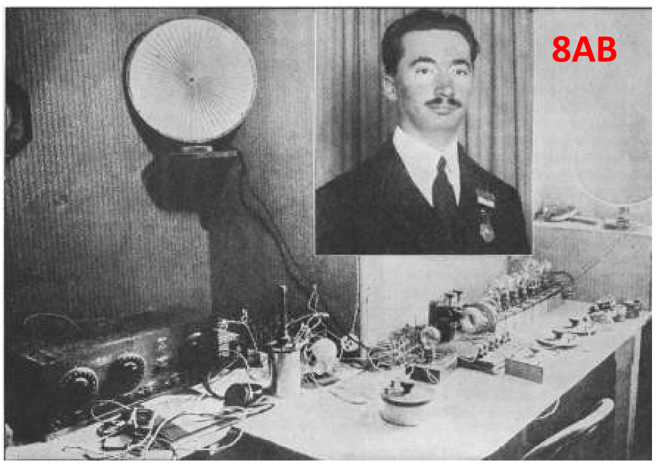


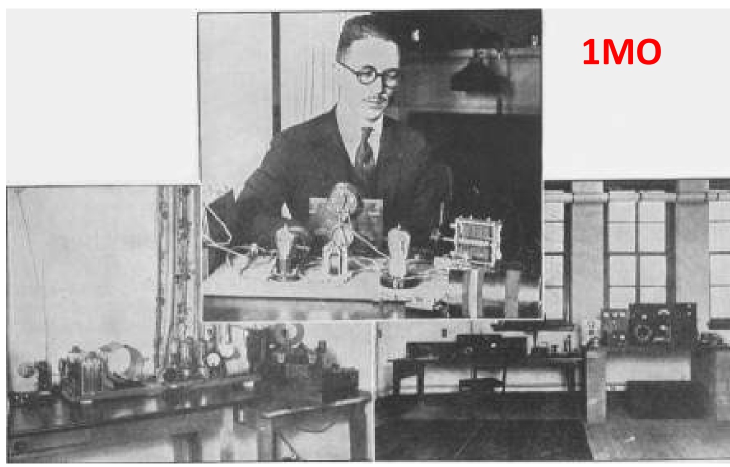


Tino Zottola, VE2GCE, Aug 16, 2021

Transatlantic Challenge

- Jan 1922: QST reports 26 stations heard by 2ZE
- Dec 1922: UK amateur 5WS heard in the US
- Nov 27, 1923: First two-way between Leon Deloy, 8AB, in Nice, France and Fred Schnell, 1MO, West Hartford CT on 100 meters
- Dec 8, 1923: First UK two-way contact between Jack Partridge G2KF and Fred Schnell, 1MO
- 1924: Communications achieved between North and South America; South America and NZ; North America and NZ
- Oct 16, 1924: UK to NZ between Cecil Goyder G2SZ and Frank Bell ZL4AAA





The January 1922 QST cover announcing the success of the transatlantic listening tests in 1921.

CLOSE ✕

Conclusion

Continuous one-upmanship throughout the history of radio responsible for its rapid evolution.

1) In the short span of 37 years, electromagnetic waves go from theory to spanning the Atlantic ocean.

- 1864: James Maxwell formulates electromagnetic waves
  Maxwell died in 1879 and would not live to see his theory proved
- 1888: Heinrich Hertz proves the existence of electromagnetic waves experimentally
  Hertz died in 1894 and would not live to see the commercial value of what he proved
- 1895-1901: Guglielmo Marconi makes worldwide radio communication possible after many refinements to Hertz's apparatus
  Marconi died in 1937 and lived to see over 40 years of advancements in radio technology

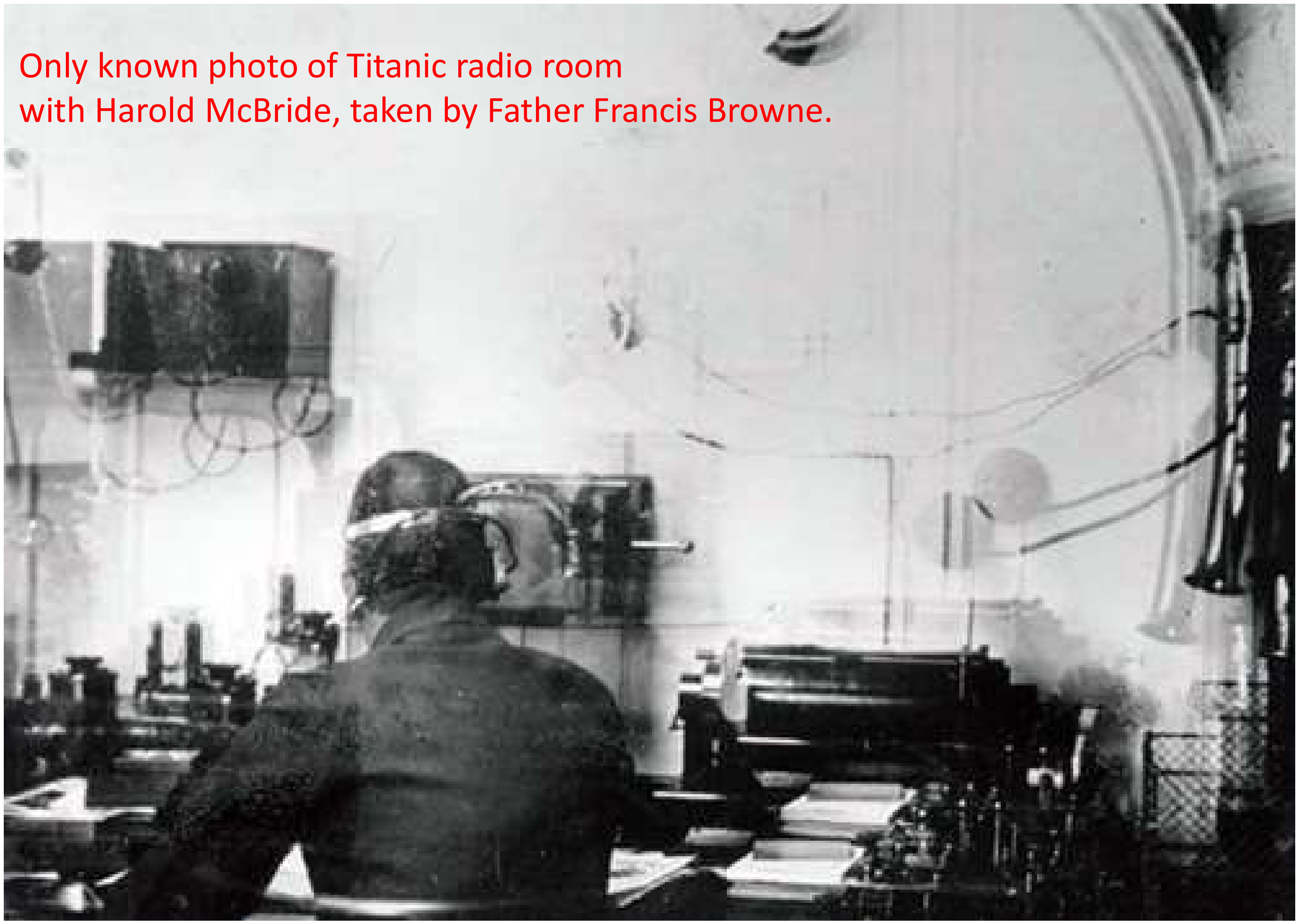
2) In the short span of 14 years, radio electronics advances in leaps and bounds

- 1904: John Fleming takes Edison effect and creates highly improved detector (first vacuum tube)
- 1908: Lee De Forest takes Fleming valve and creates triode tube (first electronic amplifying device)
- 1913, 1918: Edwin Armstrong takes De Forest triode and creates subsystems of modern radio: oscillator and superheterodyne.

3) Technology used in amateur radio stations advances rapidly as radio technology spearheaded forward

- 1910s: Amateur stations were homebrewed with mainly homebrew parts and range was no more than 50 miles
- 1920s: Amateur stations were homebrewed with store bought parts and much greater ranges were achievable.
- Modern amateur radio era begins Dec 9, 1921 when amateurs succeed in repeating Marconi's transatlantic feat.
  - Continuous wave, instead of spark gap, on 200 meters
  - Using much less power (1 KW vs 35 KW)
  - Ultra sensitive and selective superheterodyne receiver
- Establishment of modern ham bands: 160, 80, 40, 20, 10 and 5 meters (6 meters after WW2)

Questions ?



Only known photo of Titanic radio room
with Harold McBride, taken by Father Francis Browne.