Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

European

Married on December 1, 1923, Howard and Marion Armstrong went to Palm Beach for their honeymoon. Here on the beach Howard tunes in the world's first "portable" radio, a wedding gift to his bride.

Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

Presentation Outline

- Before Radio
  Standing on the Shoulders of Greatness:
- 1st Generation
  Spark Gap Receiver Technology, circa WWI
- 2nd Generation
  Regeneration & TRF Receiver Technology
- 3rd Generation
  Superhetrodyne, FM
- 4th Generation and Future Direction
  SDR and IoT

Evolution of Wireless Communications Architecture;

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James Clerk Maxwell

1861-1873: James Clerk Maxwell ***models*** electromagnetic waves mathematically and writes the classic ***"A Treatise on Electricity and Magnetism"*** & Proved by Heinrich Hertz (1857 – 1894)

$$\nabla \cdot \mathbf{E} = \rho/\varepsilon_0$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \mu_0 \boldsymbol{j}_c$$

where

$$\nabla = \hat{\mathbf{i}} \frac{\partial}{\partial x} + \hat{\mathbf{j}} \frac{\partial}{\partial y} + \hat{\mathbf{k}} \frac{\partial}{\partial z}$$

Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

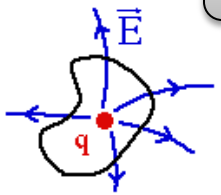
James Clerk Maxwell

Maxwell's equations are differential equations for the electric (€) and magnetic (H) field vectors because these fields, at every point in space , for every instance of time, can be related to the fields at nearby points in space and time. They are **partial differential equations** because there are multiple independent variables, i.e., time, and at least one space variable.

Maxwell's Equations

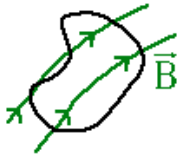
$$\oiint \vec{E} \bullet \hat{n}\, dS = \frac{q}{\varepsilon_o}$$

Gauss's Law

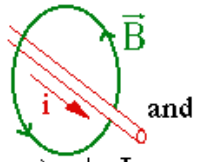


$$\oiint \vec{B} \bullet \hat{n}\, dS = 0$$

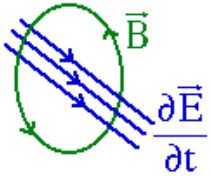
(no monopoles)



$$\oint \vec{B} \bullet d\vec{l} = \mu_o\left(i + \varepsilon_o \frac{d}{dt}\Phi_E\right)$$



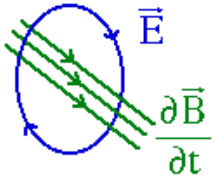
and



Ampère's Law

$$\oint \vec{E} \bullet d\vec{l} = -\frac{d}{dt}\Phi_B$$

Faraday's Law



$$\vec{\nabla} \bullet \vec{E} = \frac{\rho}{\varepsilon_o} \qquad \vec{\nabla} \times \vec{B} = \mu_o\left(\vec{j} + \varepsilon_o \frac{\partial \vec{E}}{\partial t}\right)$$

$$\vec{\nabla} \bullet \vec{B} = 0 \qquad \vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

(Differential Forms)

James Clerk Maxwell

Maxwell's equations are differential equations for the electric (€) and magnetic (H) field vectors because these fields, at every point in space , for every instance of time, can be related to the fields at nearby points in space and time. They are **partial differential equations** because there are multiple independent variables, i.e., time, and at least one space variable.

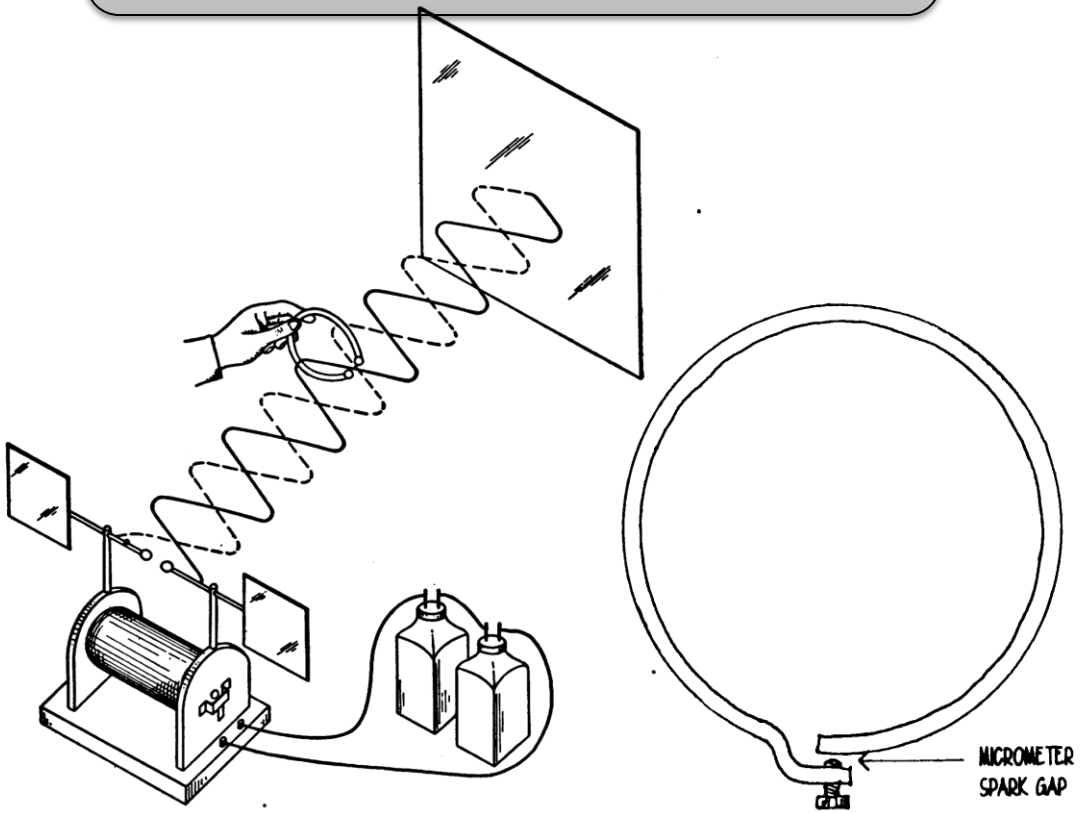
Faraday was a great Experimenter but James Maxwell built the Comprehensive Electromagnetic Models which explained the Observed Experimental Data

Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

Heinrich Hertz

Hertzian Experiment



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Guglielmo Marconi

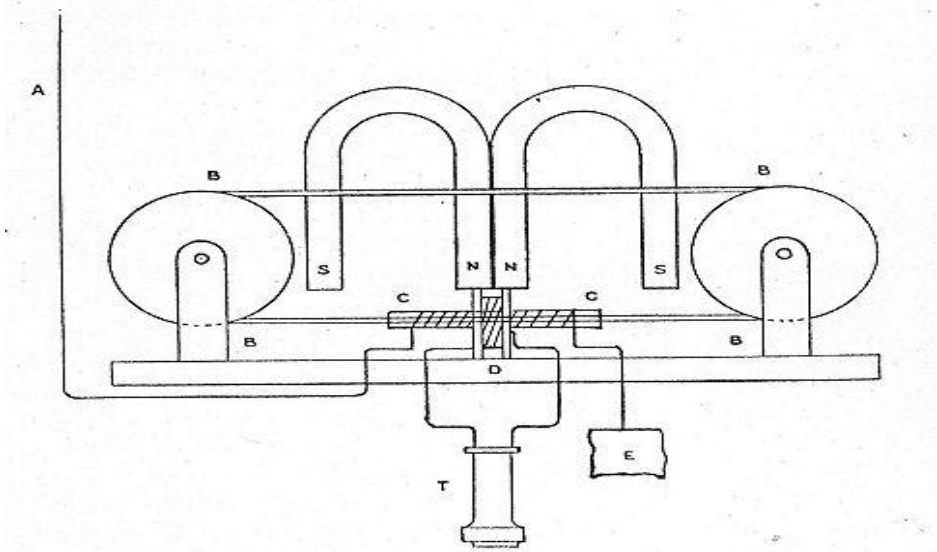
1874-1937: Italian Guglielmo Marconi used a pulsating electric spark to generate radio waves & shared the 1909 Nobel Prize in physics with German Karl Ferdinand Braun. A typical Ship's Comm Rm

Inspired by Hertz's Obituary in 1894

Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

Guglielmo Marconi



Marconi magnetic detector, Guglielmo Marconi's favorite Detector was Invented in 1895 by British physicist Ernest Rutherford and improved experimentally in 1902 by Guglielmo Marconi. It was used in Marconi wireless stations until around 1912, when it was superseded by the Fleming vacuum tube

Because the output was an audio alternating current and not a direct current, the detector could only be used with earphones and not with the common recording instrument used in coherer radiotelegraphy receivers, the siphon paper tape recorder

Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

Coherer Receivers

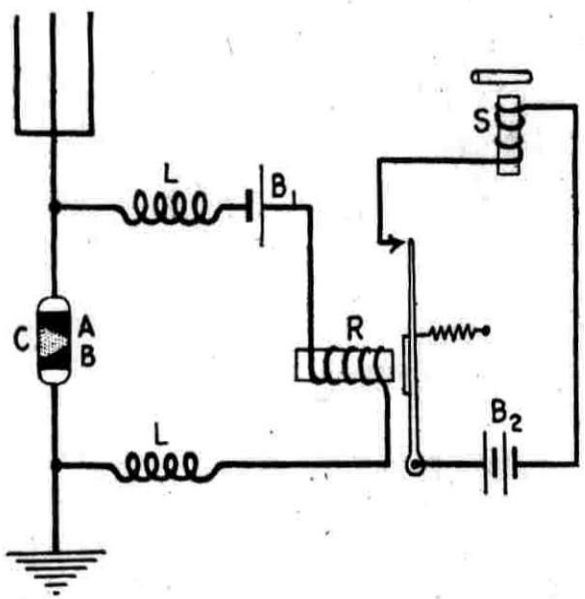


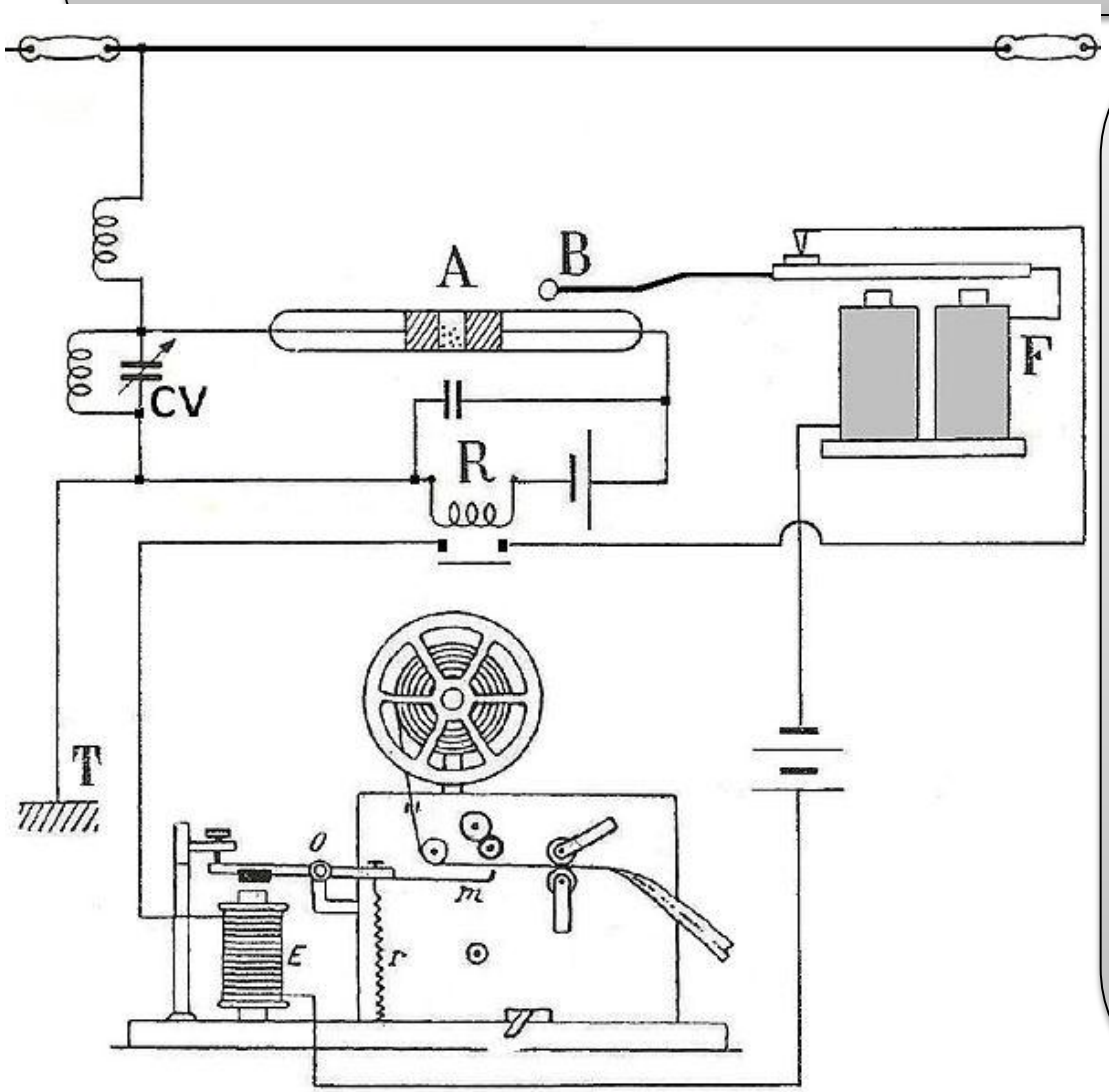
Fig. 101. Marconi 1896 Receiver.

Massie Coherer

Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

Coherer Receivers



The coherer was Invented around 1890 by French scientist Édouard Branly, it consists of a tube or capsule containing two electrodes spaced a small distance apart, with metal filings in the space between them. When a radio frequency signal is applied to the device, the initial high resistance of the filings reduces, allowing an electric current to flow through it. The coherer was a key enabling technology for radio, and was the first device used to detect radio signals in practical spark gap transmitter wireless telegraphy

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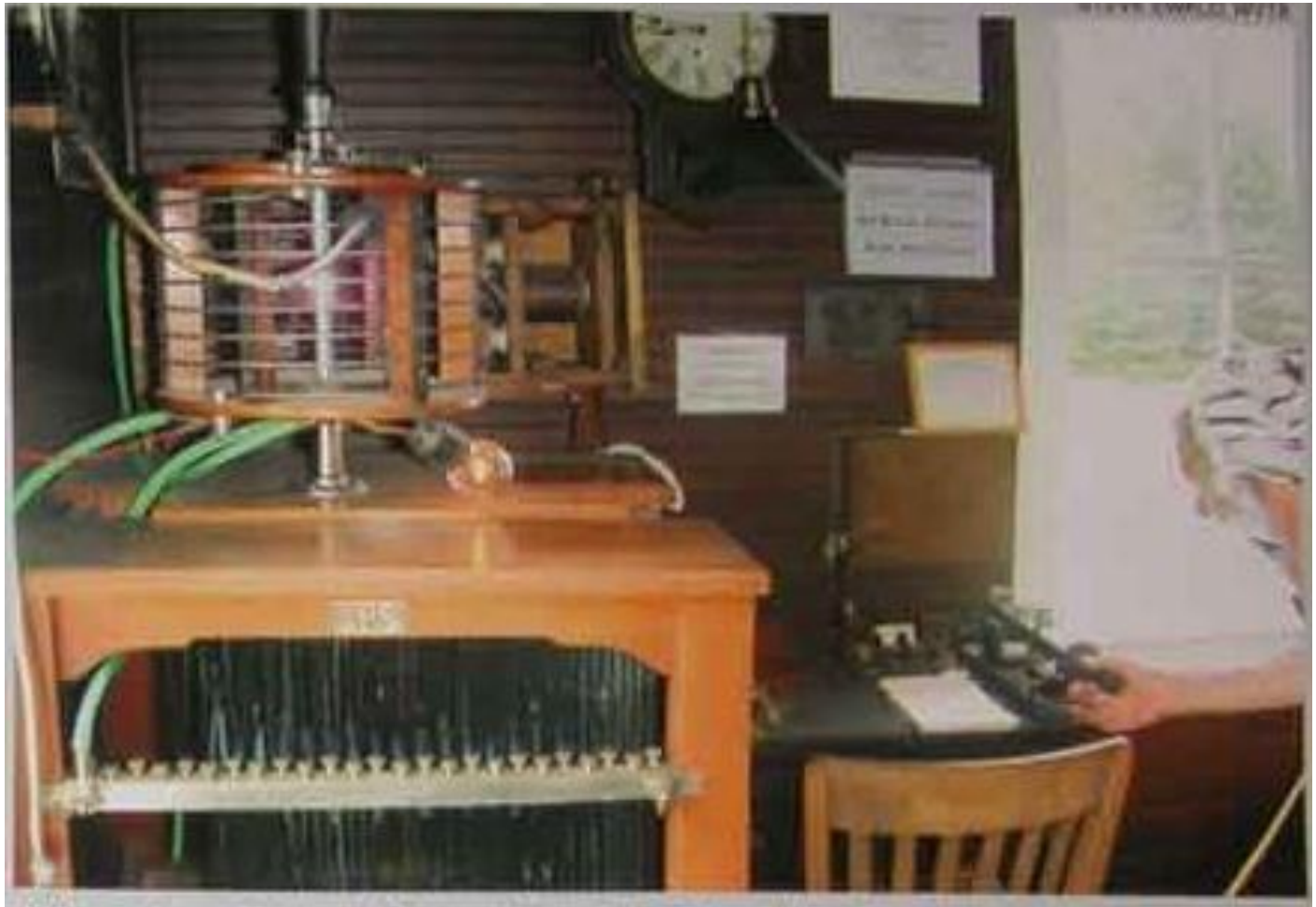
from Spark Gap to Software-Defined Radio

Massie Spark Gap Transmitter

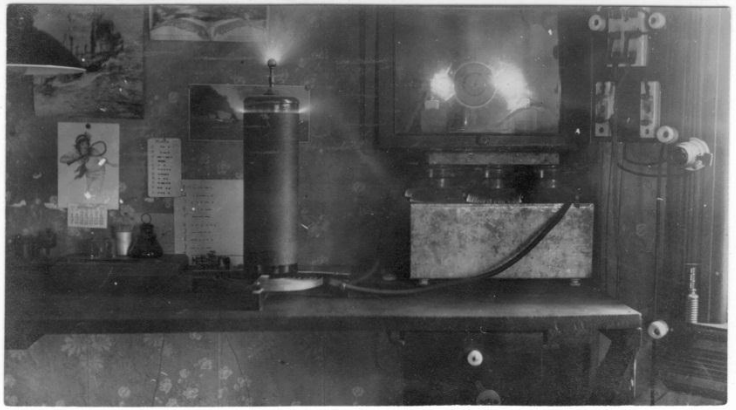


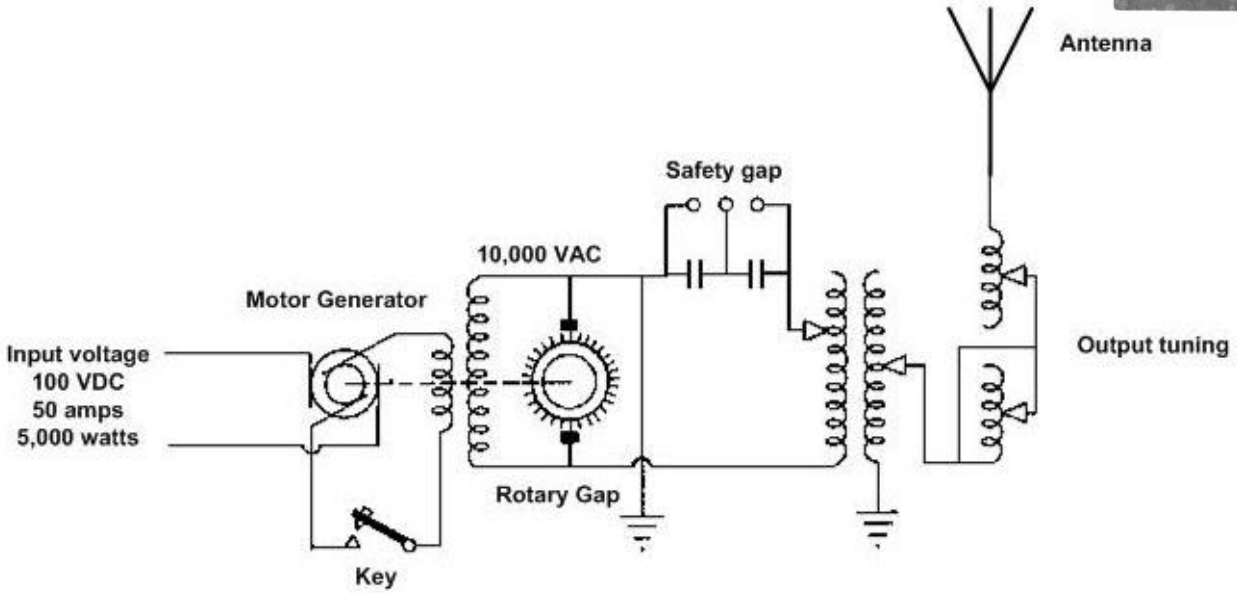
Still sparking: The spark transmitter at the Massie Wireless Station in Rhode Island still operates. A straight spark is inside the helix, and the hot wire ammeter is on the wall.

Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

Other Spark Gap Transmitters





Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

Marconi Patent 7777, Syntonic Transmitter and Rcvr

Application filed 12 April 1900

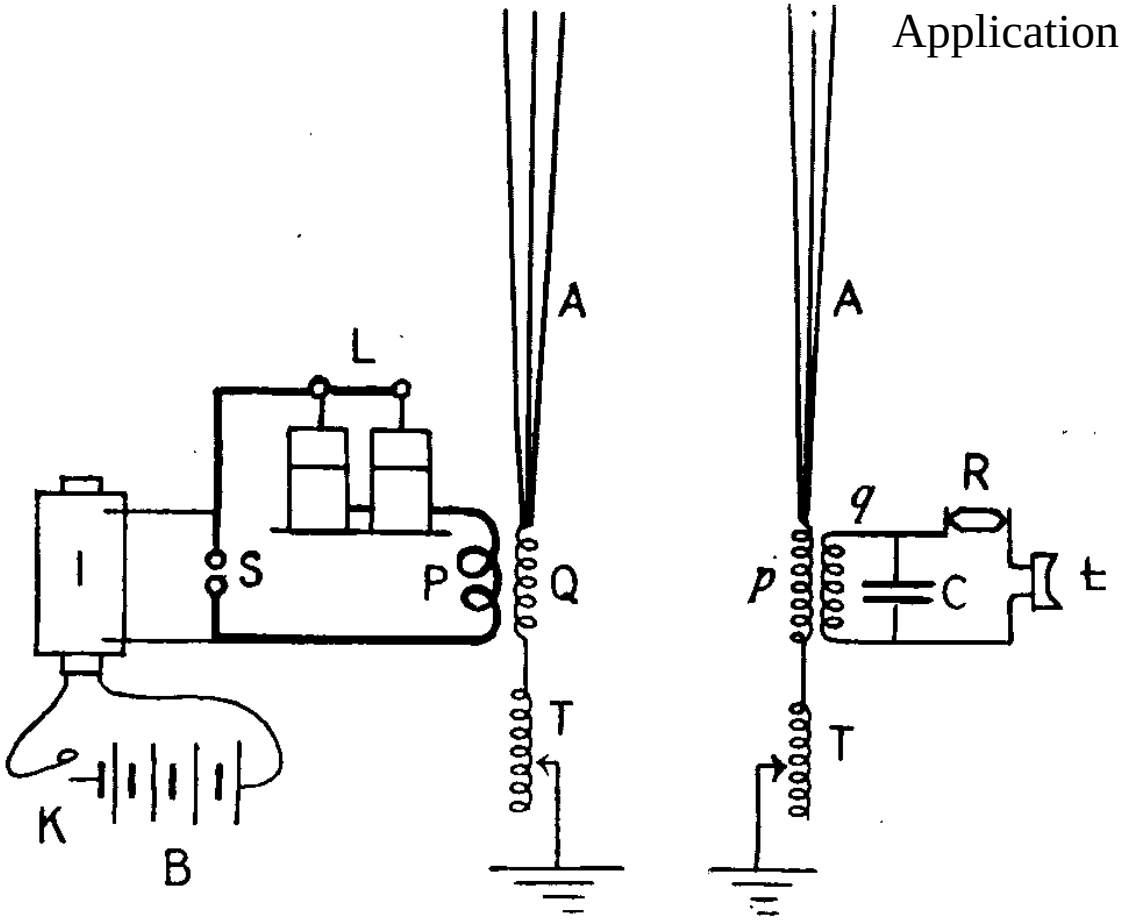
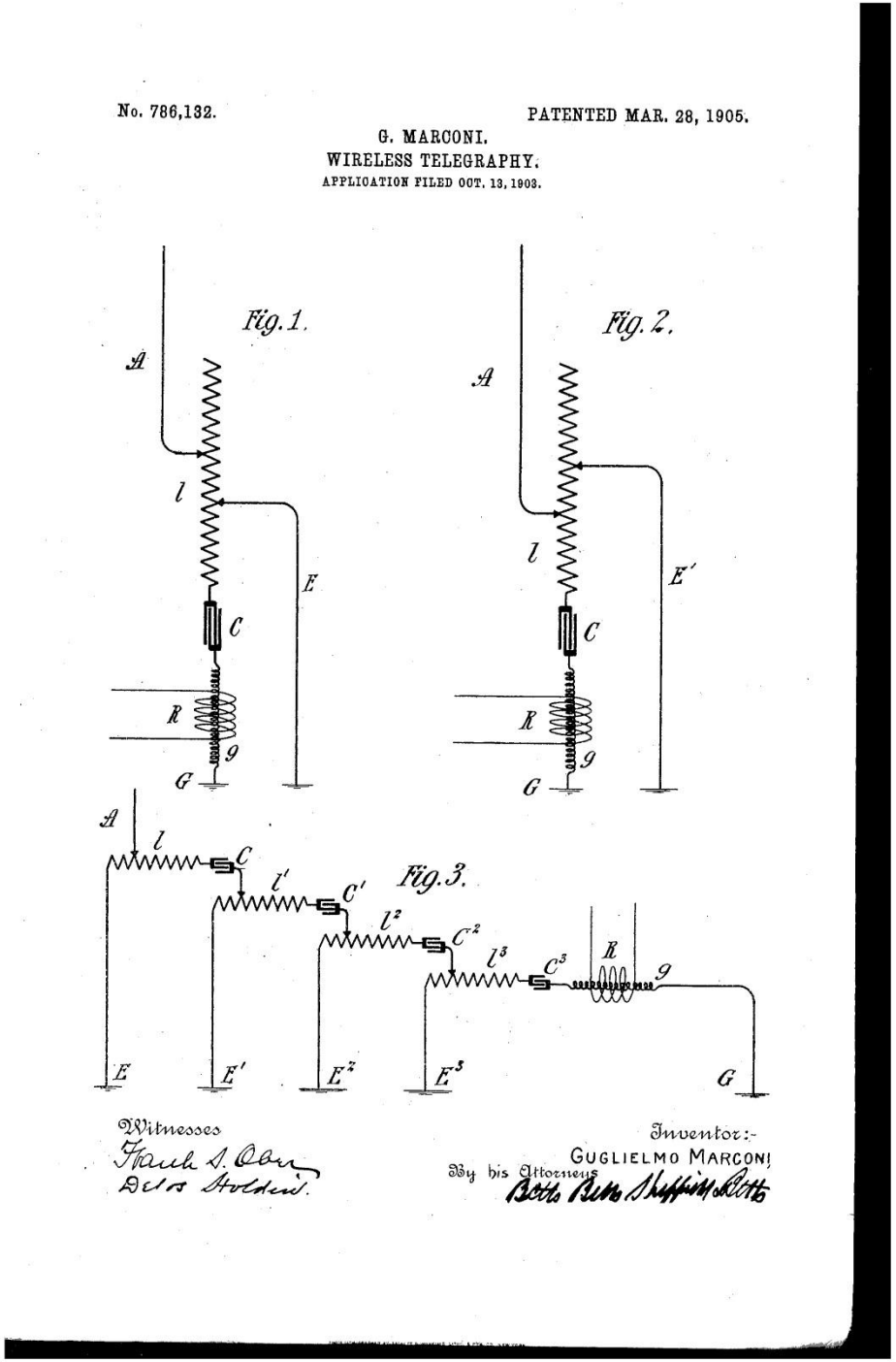


FIG. 45.—Marconi syntonic transmitter and receiver.

Marconi Patent



The most simple form of my invention is shown in Fig. 1, in which A represents the receiving-aerial adjustably connected to the inductance-coil Z; O, a condenser connected to the inductance-coil; R, a suitable receiver or detector such as the magnetic detector of my inventions

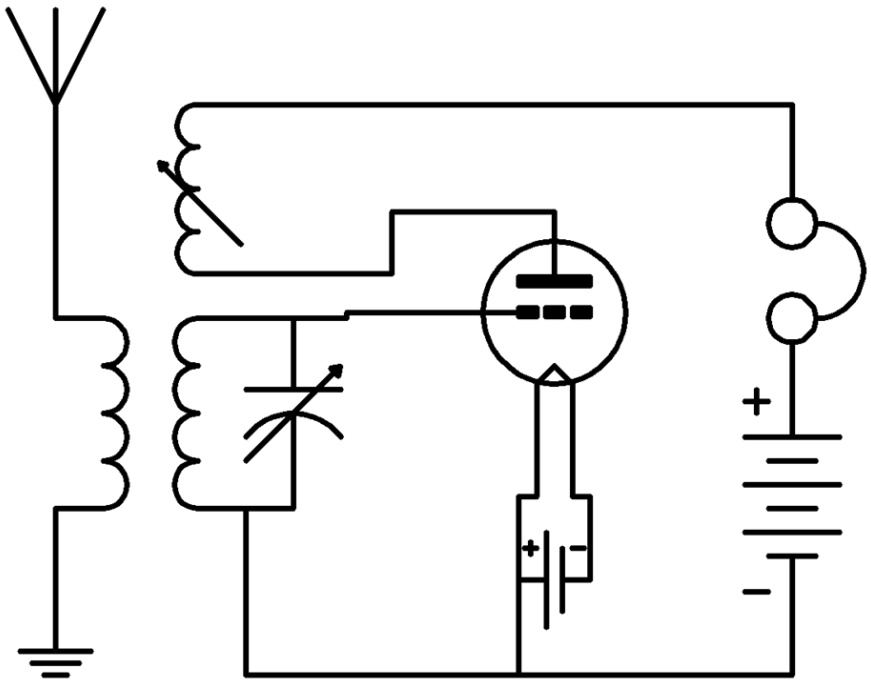
One terminal, 9, of the detector is grounded at G, and another ground connection, E, which is preferably flexible or adjustable, is joined to the inductance Z at a certain point, the position of which is dependent upon the period of the electric wave radiated from the distant transmitting-station. This receiving system is syntonized or attuned to one particular frequency of electrical waves radiated from any one of a number of differently-attuned distant electric radiators in the following manner:

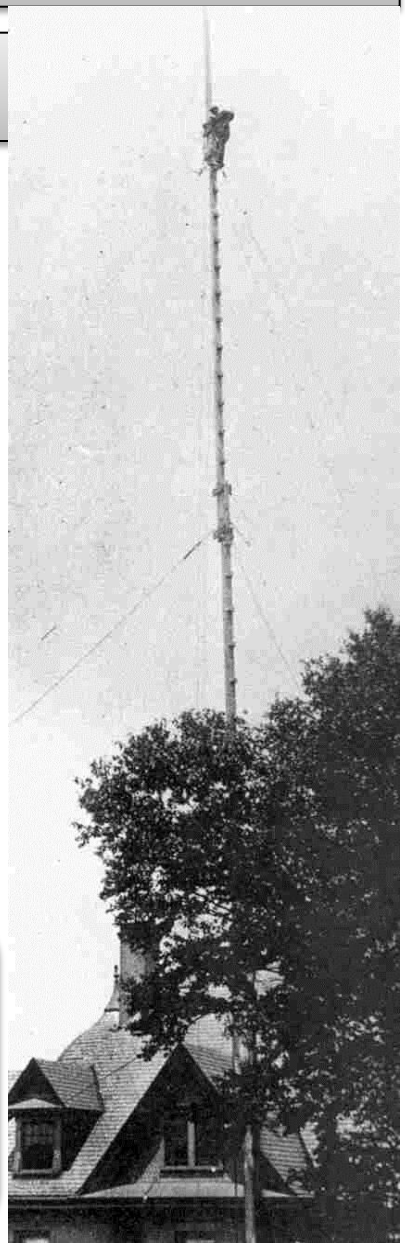
The size of the condenser O is fixed, and the I inductance Z is varied by adjusting its connection with the aerial until signals are received on the responder or detector R. Then by sliding the flexible or adjustable ground connection E along the inductance Z, waves of the particular frequency radiated from a given distant transmitting-station from which it is desired to receive signals will be received and detected to the exclusion of signals transmitted from other stations radiating waves of different frequencies. By means of this present invention a very sharp selectivity of signals is obtained and the troublesome effects of atmospheric electricity are largely or wholly eliminated.

Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

E. H. Armstrong



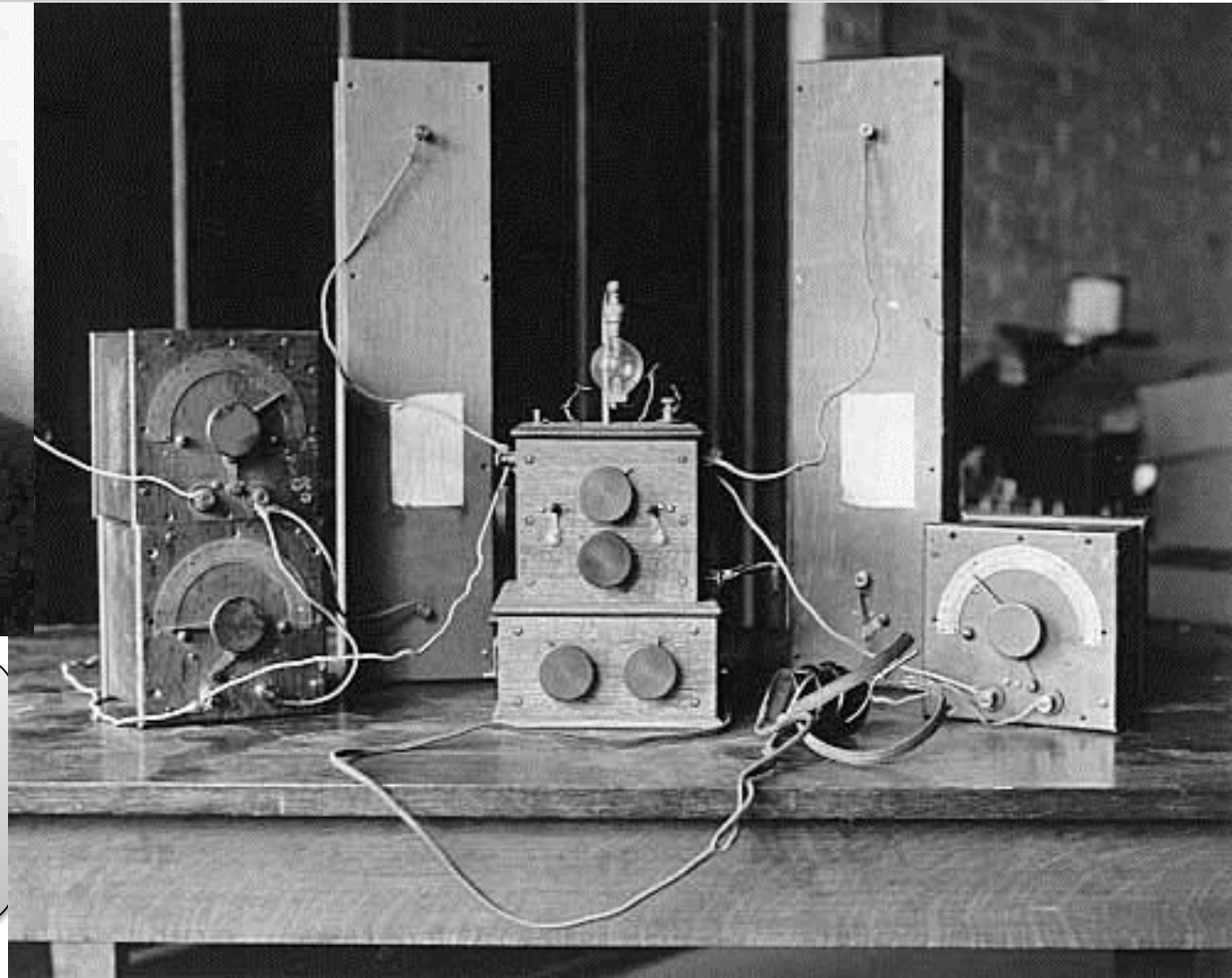


Edwin Howard Armstrong (December 18, 1890 – January 31, 1954) He invented the regenerative circuit and patented it in 1914, followed by the super-regenerative circuit in 1922, the superheterodyne receiver in 1918. Armstrong was also the inventor of modern frequency modulation (FM) radio transmission in 1933.

Evolution of Wireless Communications Architecture;

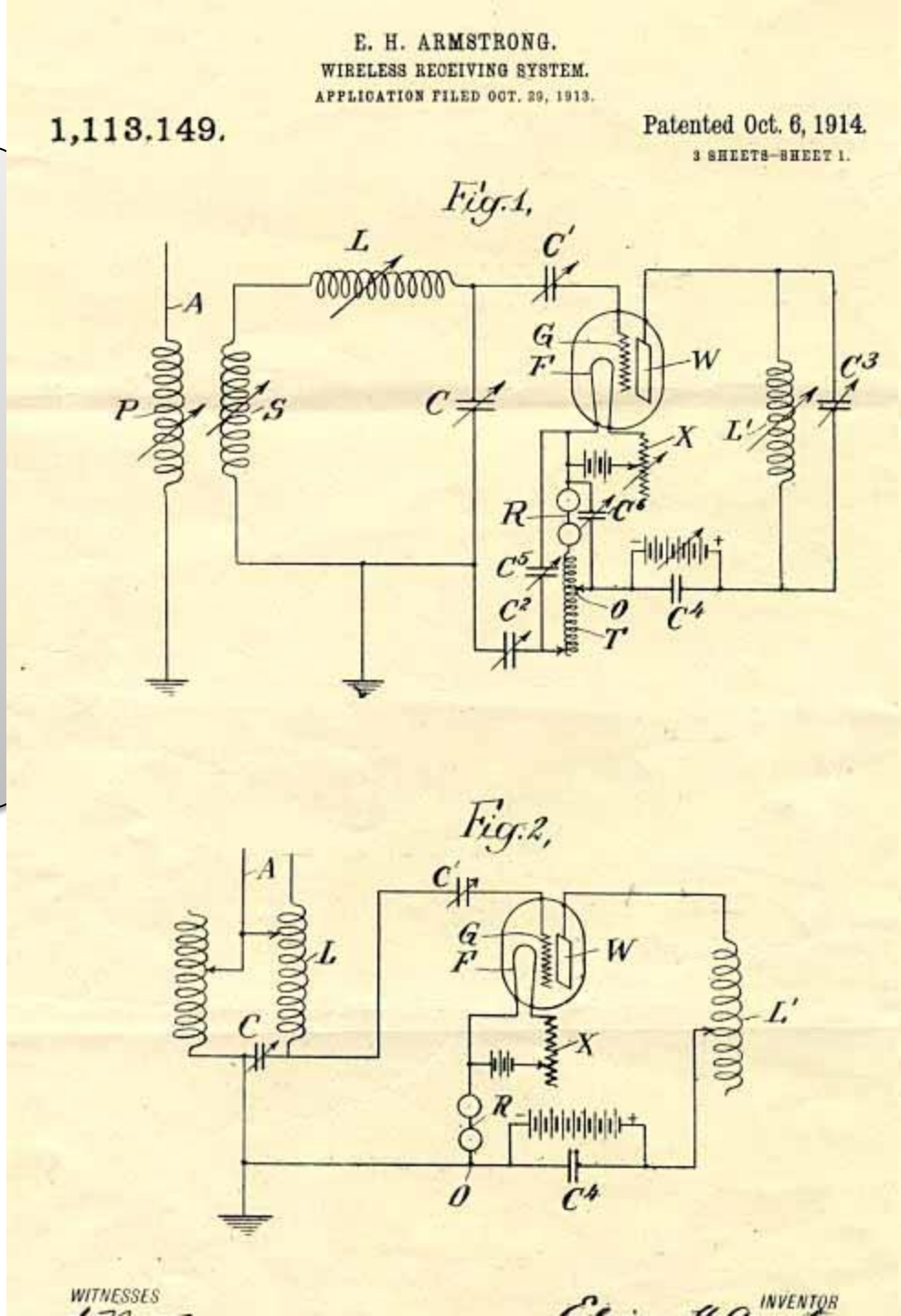
from Spark Gap to Software-Defined Radio

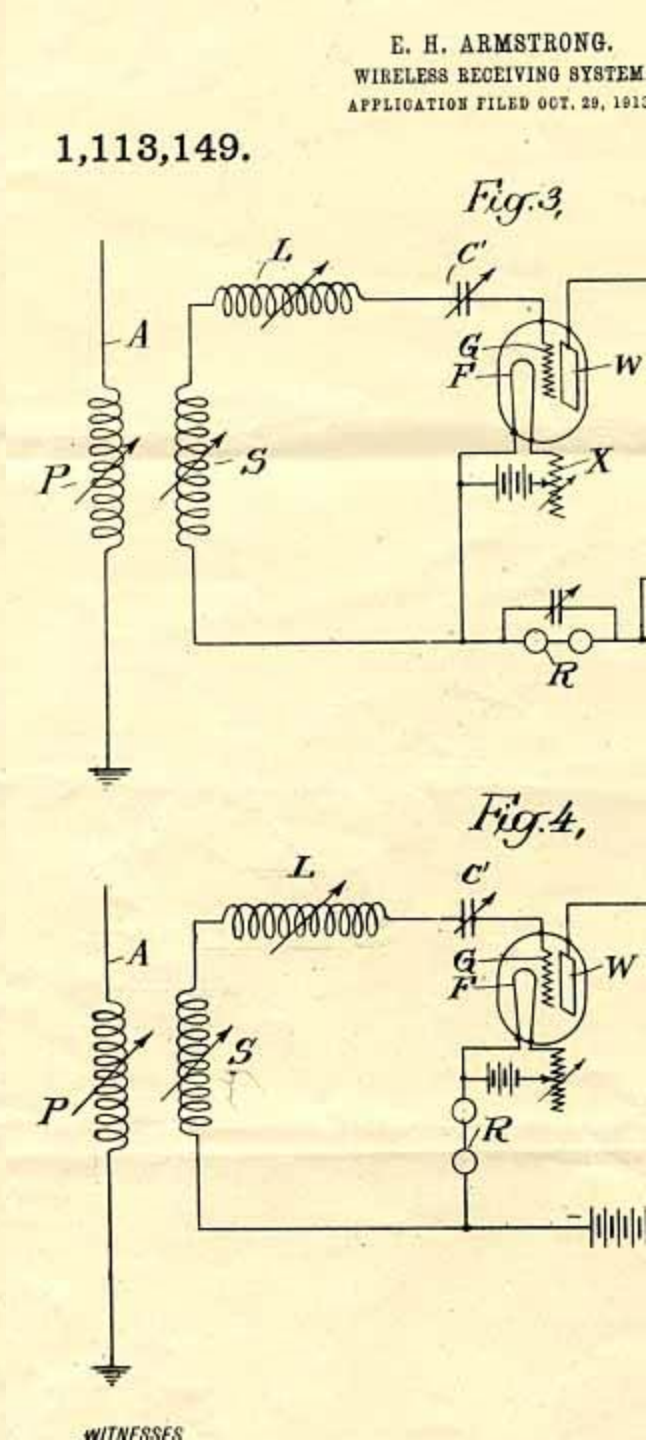
E. H. Armstrong



1912: First Regenerative Receiver Prototype, demoed to Sarnoff at the Marconi station in NJ at Belmar

1914: E. H. Armstrongs Regeneration Patent Schematics. One-Tube Improved Performance through multiplying Q Factor





1914: Additional Patent Schematic - Regeneration Patent Schematics. One-Tube Improved Performance through multiplying Q Factor

E. H. ARMSTRONG.
WIRELESS RECEIVING SYSTEM.
APPLICATION FILED OCT. 29, 1913.

1,113,149.

Patented Oct. 6, 1914.
3 SHEETS—SHEET 3.

Fig. 5,

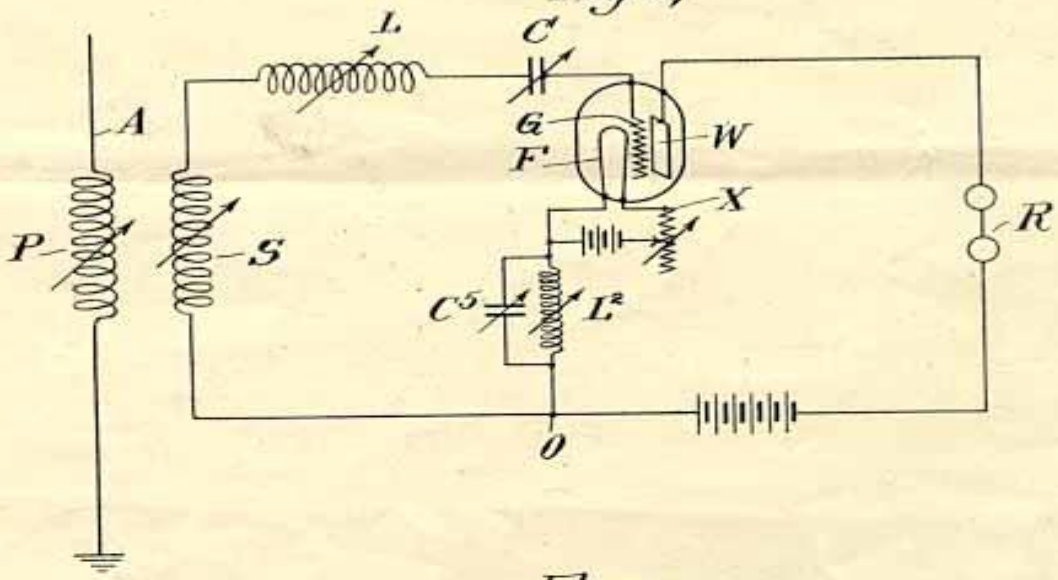
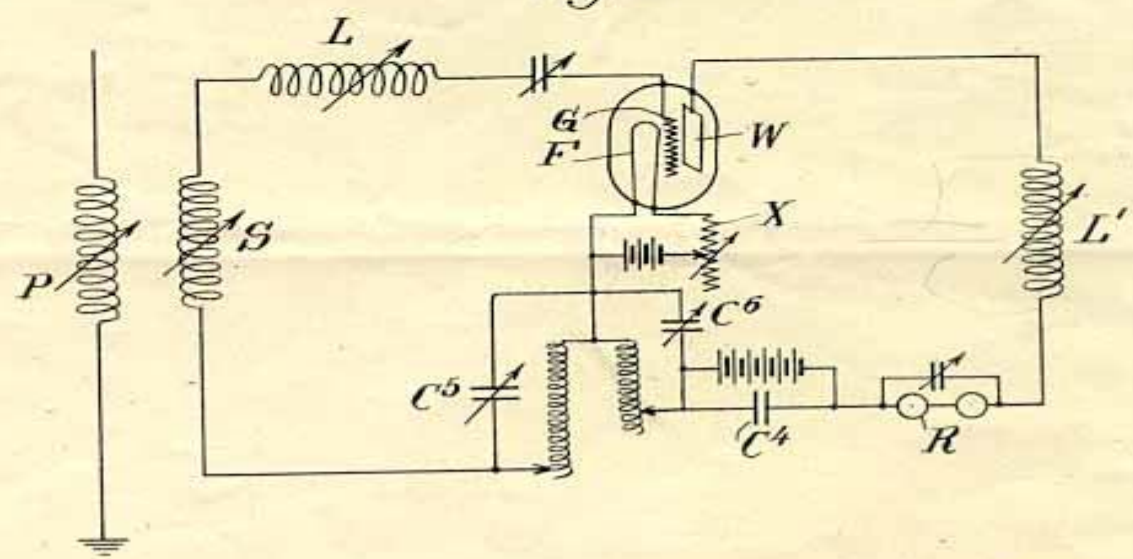


Fig. 6



INVENTOR

Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

E. H. Armstrong

November 25, 1906, Lee de Forest produced the first modified Fleming valve with a grid placed between the filament and plate. The triode, dubbed the "Audion" by de Forest, was born. Armstrong discovered the de Forest description of how this worked was incorrect – that a vacuum was required for this to function instead of de Forest claims that a gas was necessary (which E. H. Armstrong debunked in Dec 12, 1914 in Electrical World).

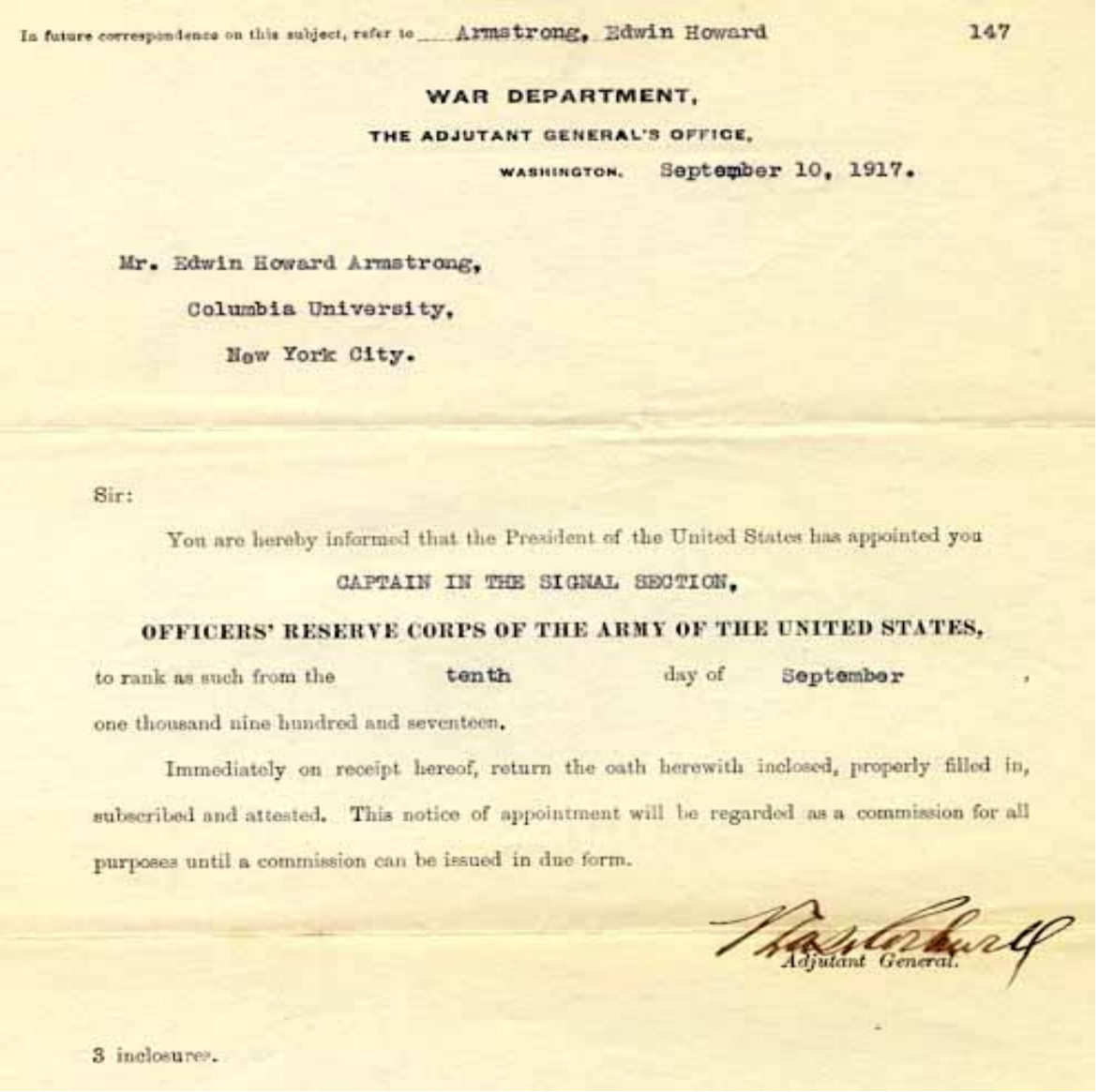
Right: One of Armstrong's de Forest Audions, ca. 1912

http://users.erols.com/oldradio/eha1a.htm

Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

1917: Armstrong Applied to join the Army Signal Corp and was accepted. He now liked to be called "Major"



In future correspondence on this subject, refer to Armstrong, Edwin Howard 147

WAR DEPARTMENT,

THE ADJUTANT GENERAL'S OFFICE,

WASHINGTON. September 10, 1917.

Mr. Edwin Howard Armstrong,

Columbia University,

New York City.

Sir:

You are hereby informed that the President of the United States has appointed you

CAPTAIN IN THE SIGNAL SECTION,

OFFICERS' RESERVE CORPS OF THE ARMY OF THE UNITED STATES,

to rank as such from the tenth day of September, one thousand nine hundred and seventeen.

Immediately on receipt hereof, return the oath herewith inclosed, properly filled in, subscribed and attested. This notice of appointment will be regarded as a commission for all purposes until a commission can be issued in due form.

Adjutant General.

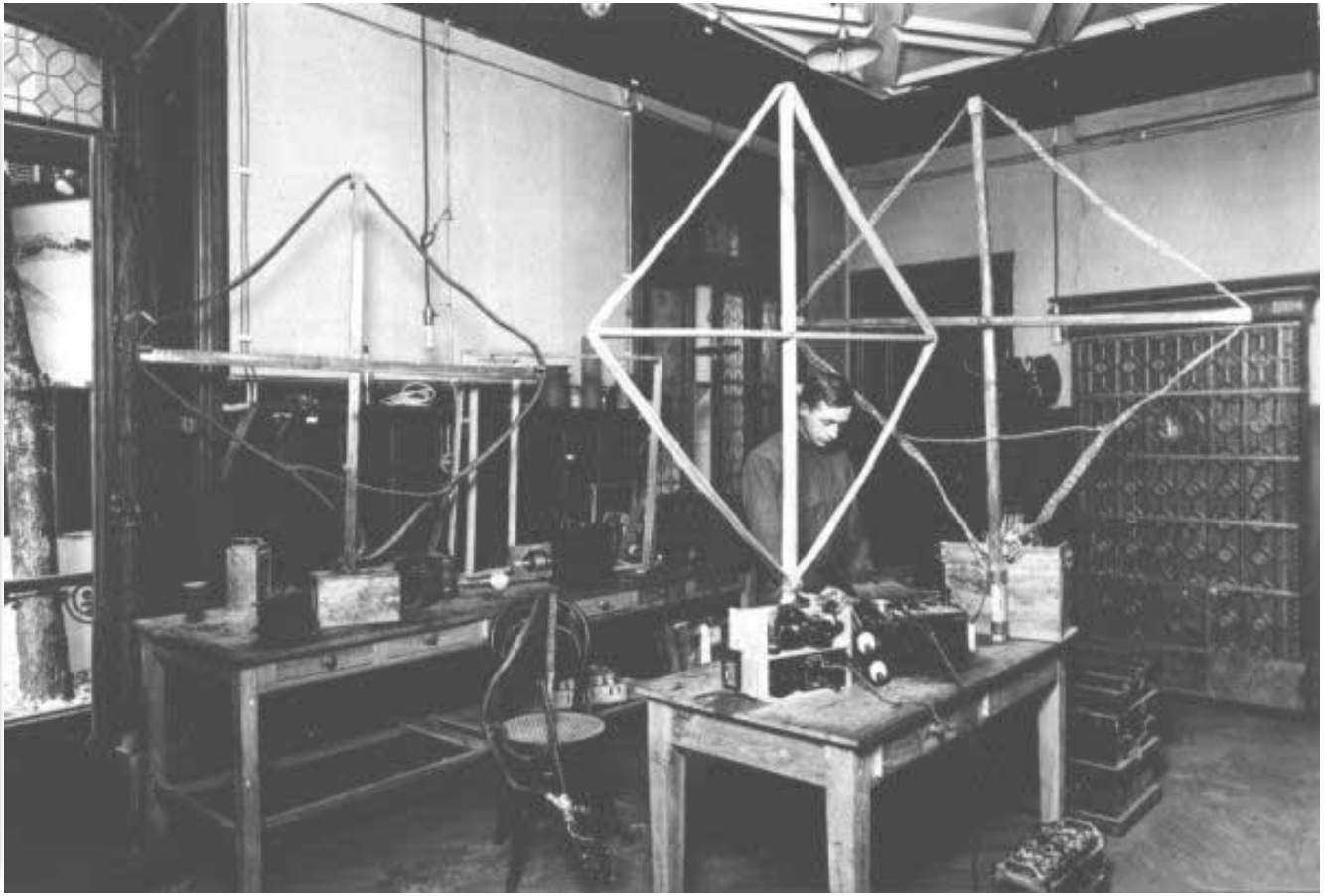
3 inclosures.

Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

E. H. Armstrong

Armstrong, in his Paris Lab worked on a solution to solve the poor high-frequency performance of the existing valve technology. His goal was to detect the enemy aircraft ignition signals and this leads to the Superheterodyne patent.



Armstrong's Paris Laboratory (U.S. Army Signal Corps photos)

E. H. Armstrong, 1923 Superheterodyne Wedding Gift

European

Married on December 1, 1923, Howard and Marion Armstrong went to Palm Beach for their honeymoon. Here on the beach Howard tunes in the world's first "portable" radio, a wedding gift to his bride.

Evolution of Wireless Communications Architecture;

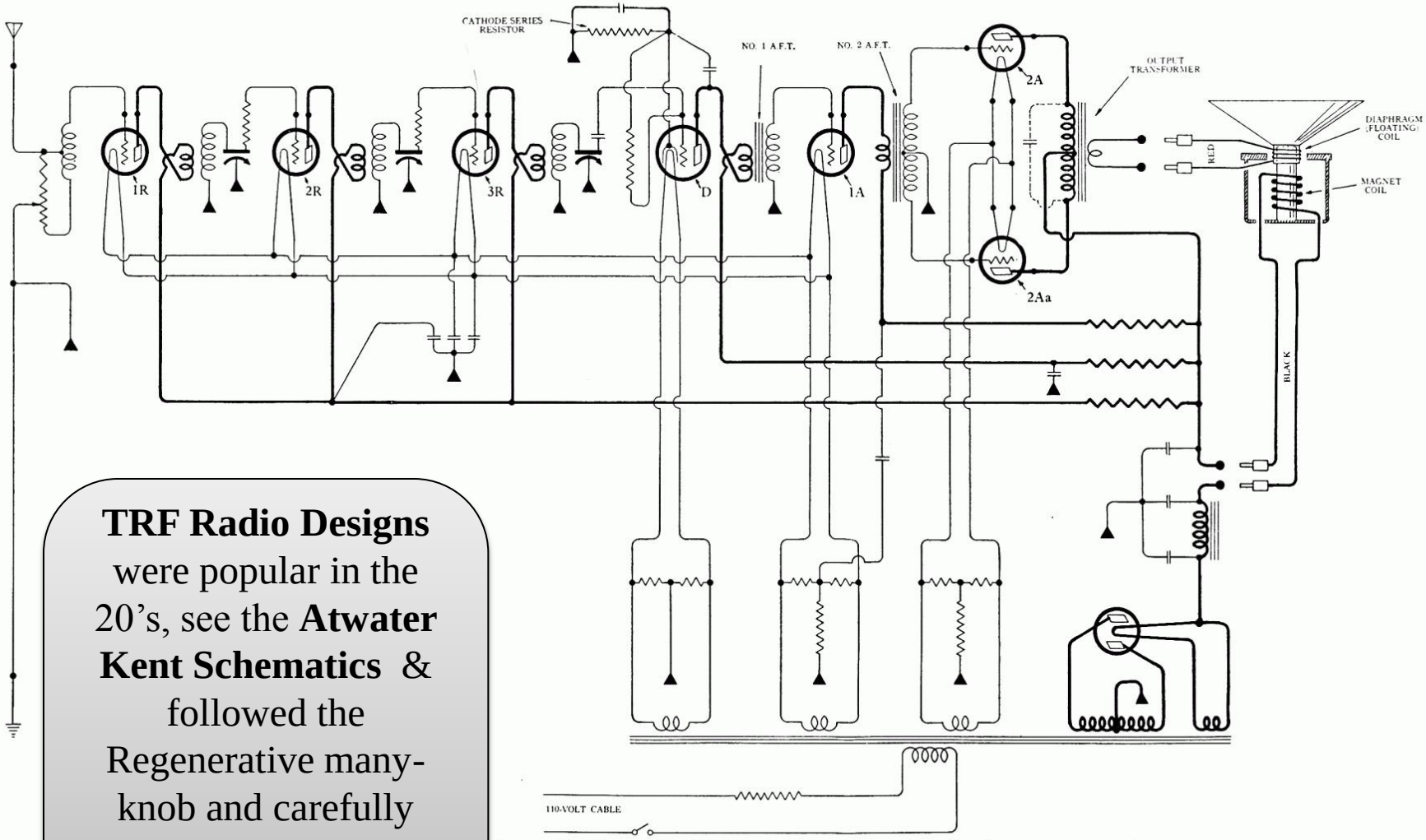
from Spark Gap to Software-Defined Radio

Superheterodyne vs. Tuned Radio Frequency (TRF)

TRF Radio Designs were popular in the 20's, see the Atwater Kent Schematics & followed the Regenerative many-knob and carefully tuning requirements.

May 1930, Image provided by John Dilks, K2TQN

Superheterodyne vs. Tuned Radio Frequency (TRF)



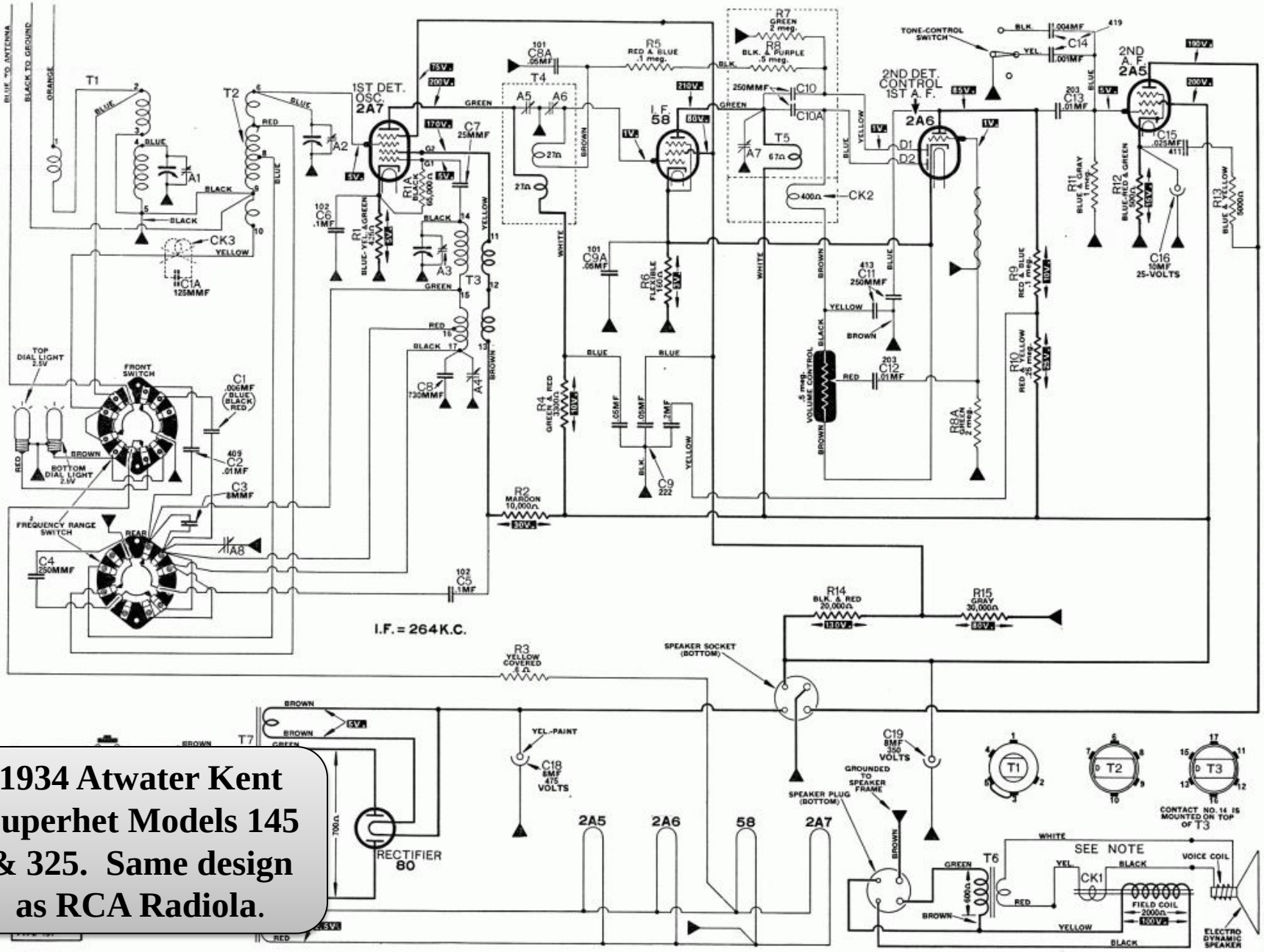
MODEL 43, 46 AND 53. (The output transformer is sealed in the power unit.)
s one extra stage of R. F. amplification and a local-distance switch similar to that in Model 44.

ATWATER KENT RADIO

MODEL 43, 46, 47 AND 53

TRF Radio Designs were popular in the 20's, see the **Atwater Kent Schematics** & followed the Regenerative many-knob and carefully tuning requirements at the cost of more tubes.

ATWATER KENT RADIO
MODELS 145 AND 325



1934 Atwater Kent Superhet Models 145 & 325. Same design as RCA Radiola.

In Model 325 the field coil is 1200 Ω and the voltages throughout are slightly higher than shown in diagram. In later sets C4 is not used, the diode circuit is changed and there are some minor changes in the frequency-switch circuit.

1920:
E. H. Armstrong's foundational FM Patent – "Method of Receiving High Frequency Oscillations

E. H. ARMSTRONG.
METHOD OF RECEIVING HIGH FREQUENCY OSCILLATIONS.
APPLICATION FILED FEB. 8, 1919.

1,342,885. Patented June 8, 1920.

Fig. 1,

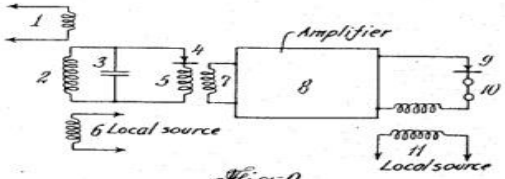


Fig. 2,

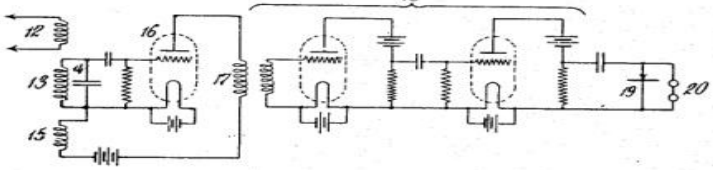


Fig. 3,

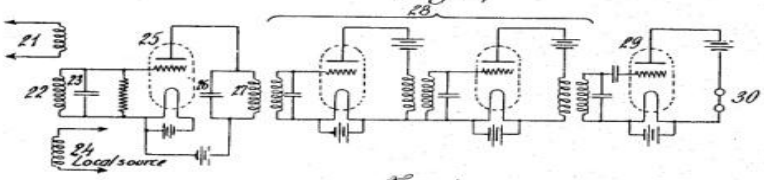
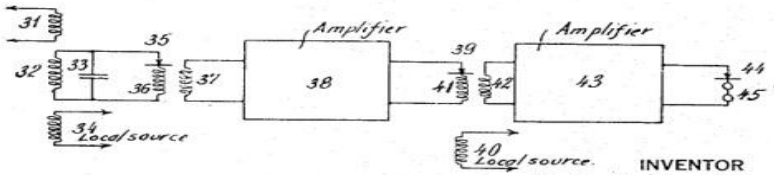


Fig. 4,



INVENTOR
Edwin H. Armstrong
BY
Pennie, Davis, Marvin & Edmonds
ATTORNEYS

The Armstrong Patent Situation as Described in this "Proceedings of the Radio Club of America, Nov 1990, which ultimately cost Armstrong his life, is obviously broken1920: E. H. Armstrong's foundational FM Patent – "Method of Receiving High Frequency Oscillations

Who Invented the Superheterodyne?

By Alan Douglas

Originally published in the Proceedings of the Radio Club of America, Nov. 1990, Vol.64 no.3
"The Legacies of Edwin Howard Armstrong."

Of E.H. Armstrong's four principal inventions—regeneration, superregeneration, the superheterodyne, and frequency modulation—the superheterodyne has always seemed one of the least controversial. "Everyone" knows that Armstrong invented it. He devised it during World War I, patented it shortly afterward, sold his patent to Westinghouse who cross-licensed RCA and the radio industry, and that was that. Some Frenchman named Lévy claimed he was first, but whoever heard of him?

All of Armstrong's inventions were involved in controversies. Lee de Forest got legal credit for regeneration (and others might have, with better counsel, notably Robert Goddard [1]). John Bolitho had discovered much of the superregeneration principle before Armstrong, who prudently bought Bolitho's patent before negotiating with RCA. FM had been gathering dust on theoreticians' shelves for decades before Armstrong took it up, but as soon as he had made it worth fighting over, he was beset from all sides. So, if the superheterodyne was his most valuable invention—and it is fundamental to essentially every radio and television made since 1930—it would be surprising if Armstrong had not had his priority disputed.

The dispute ended in defeat. In 1928 Armstrong lost his superheterodyne patent in an interference proceeding within the Patent Office, when most of its claims were transferred to a Lévy patent owned by AT&T. Since AT&T was in the same patent pool as Westinghouse and RCA, this transfer had no effect on the industry and attracted little notice [2]. Lévy did not publicly press his claims outside of France, and even there, Armstrong was often credited with the invention.

Interception Favorite Radio – the National HRO-60

National HRO-60:

Architecture:

- Single Conversion below 7MHz
- 50 – 35000 kHz, 50 – 54 MHz, 16 Tubes
- Uses Plug-In Coil Racks
- 1st IF Frequency , 2010 kHz
- Dual Conversion, 2nd IF, 455 kHz
- 2 x 6BA6 RF Amplifiers
- 6C4 Local Oscillator
- 6BE6 Mixer
- 2 x 6SG7 IF Amplifier
- 6V6GT Audio Amplifier
- OB2 Voltage Regulator
- 4H4C Current Regulator

Mfg: US 1952 – 1964

Cost New: $483-$745

Cost Used: $300 – $400

National HRO-500, my Collection Favorite

National HRO-500:

Architecture:

FIRST Commercial All-Transistor Communications receiver in 1964

5 – 30000 kHz Continuous Synthesized LO

60 500 kHz bands

Mechanical Display 500kHz

Analog 1 kHz Gradations

37 Transistors, 21 Diodes

1st IF Frequency , 2.75 -3.25 MHz

2nd IF Frequency, 230 kHz

<100 Hz Stability

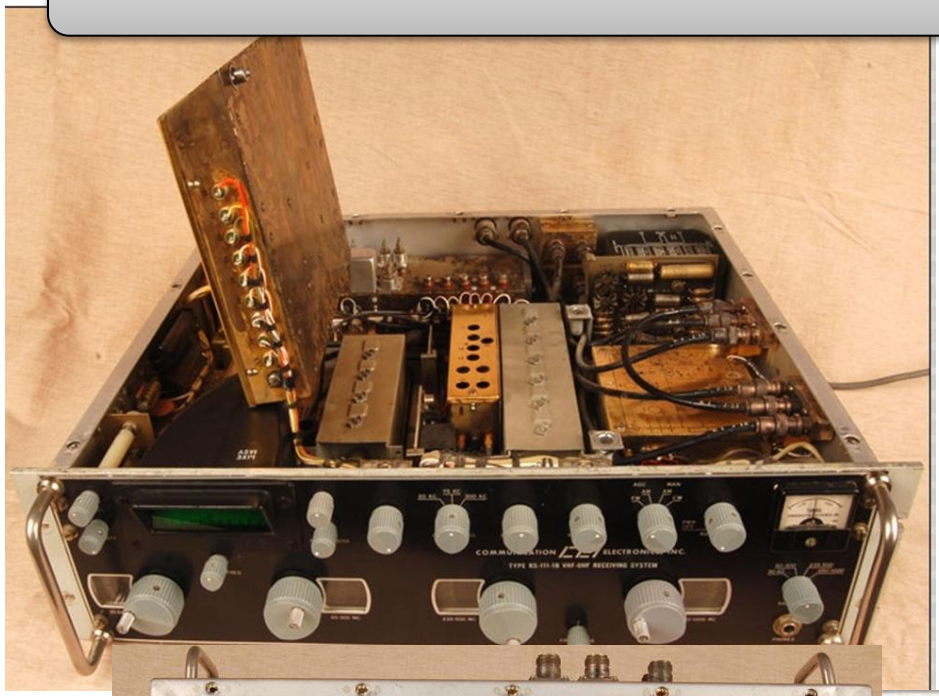
<1 uV Sensitivity

Mfg: US 1964 – 1973

Cost New: $1300-$1995 (!)

Cost Used: $600 – $4000

Collection of Cold War CEI/Watkins-Johnson Surveillance Receivers



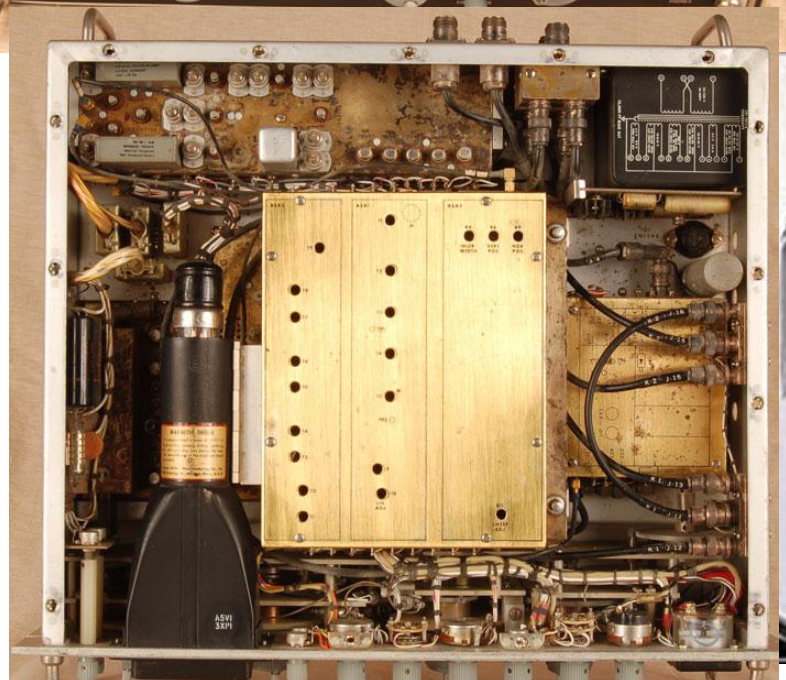
CEI RS-111 (Mfg 1968):

Architecture:

Surveillance Receiver used in WATERGATE bugging
30 MHz – 1,000 MHz Continuous Coverage
<=1uV Sensitivity, 20kHz AM
21.4 MHz IF Frequency
Panoramic Spectrum Display Built-in
Transistor + Tube Design

Mfg: US 1968

Cost New: $6, 250

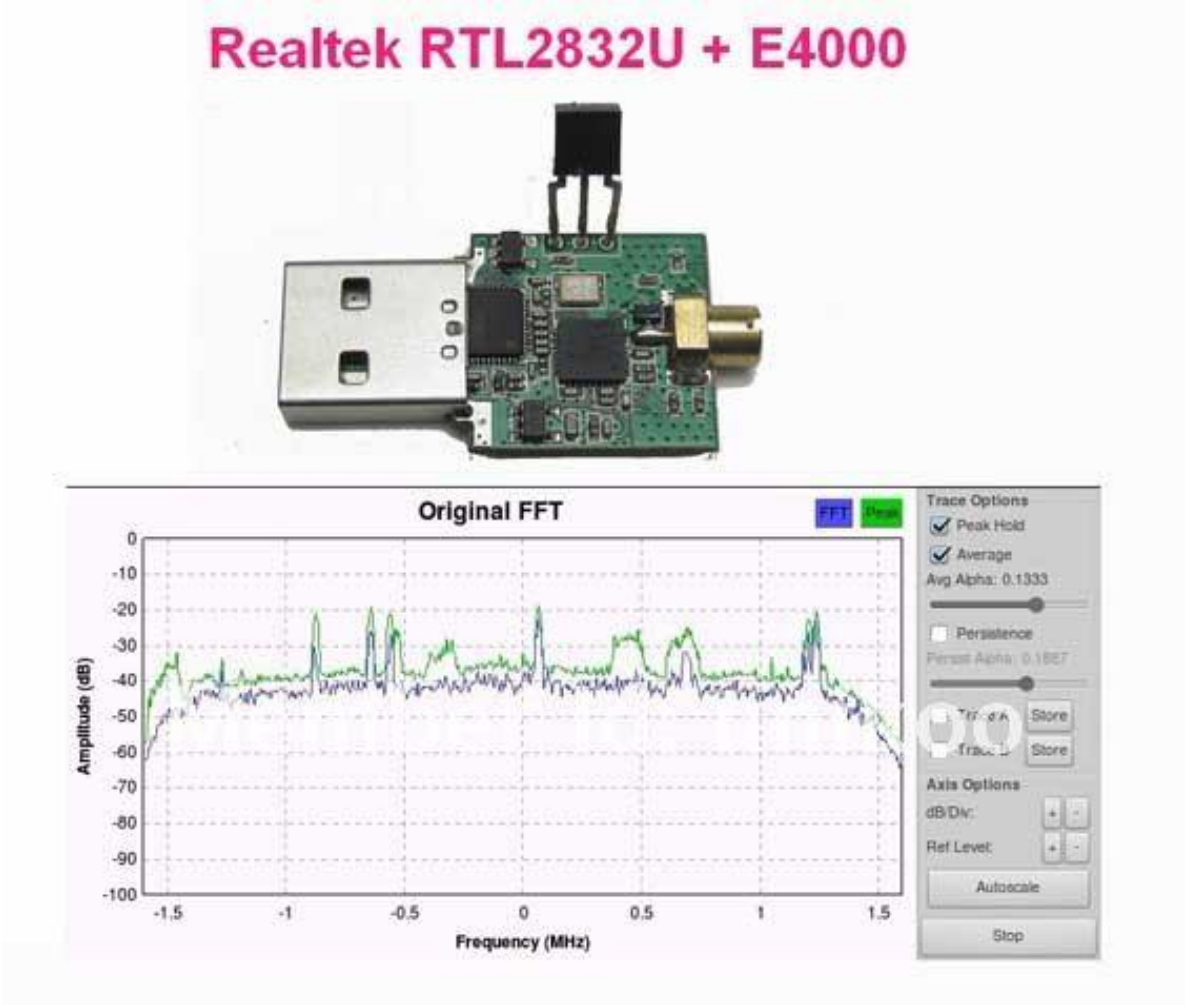


Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

Software Definable Radio

A European Digital TV USB (~$8.00) has been hacked into a complete Spectrum Receiver

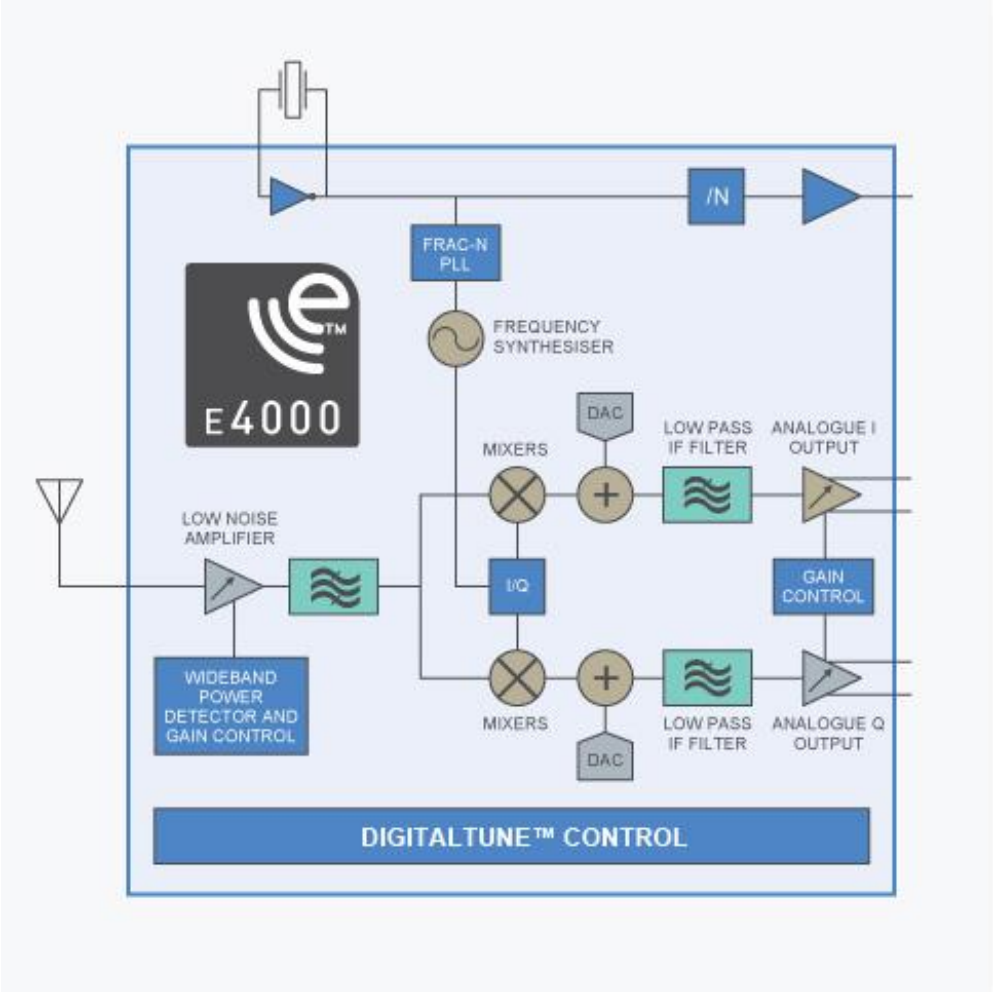


Evolution of Wireless Communications Architecture;

from Spark Gap to Software-Defined Radio

Software Definable Radio

A European Digital TV USB (~$8.00) Block Diagram Showing I/Q Demodulator. This follows a Fast 10-bit A/D Converter



Evolution of Wireless Communications Architecture;

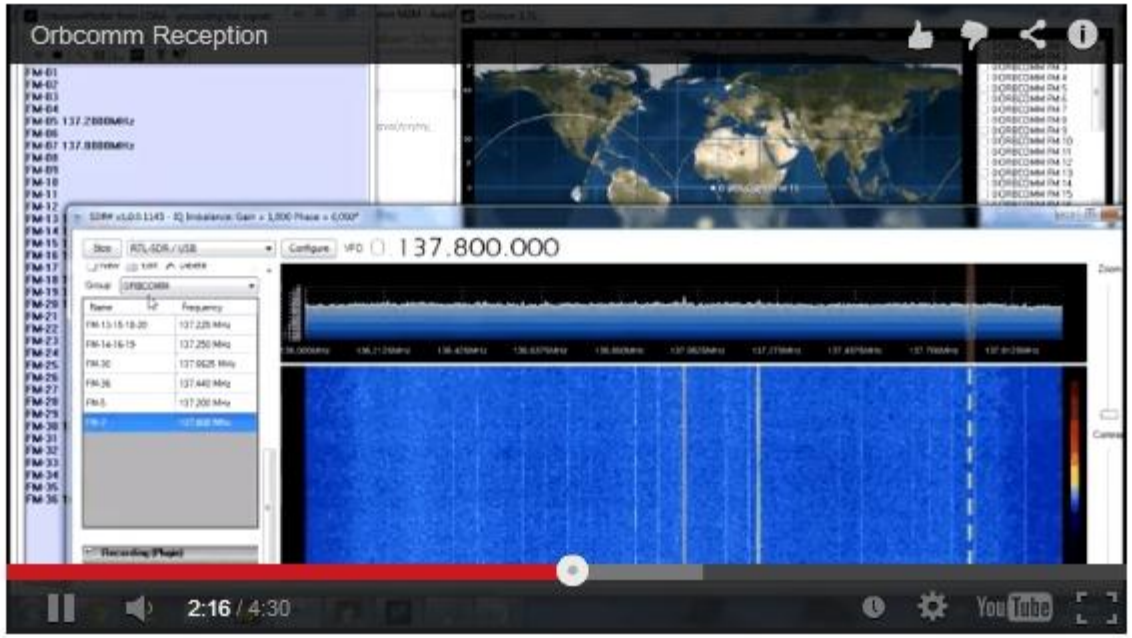
from Spark Gap to Software-Defined Radio

Software Definable Radio

COAA describes Orbcomm satellites as

> a satellite communication system (www.orbcomm.com) providing two-way data and positioning service to small, portable user terminals in the VHF frequency bands. You can use a simple VHF radio receiver (scanner) tuned to the band between 137 and 138 MHz to pick up the strong signals from these satellites. With OrbcommPlotter you can decode the telemetry and find out the positions of the satellites, their operational status and their uplink and downlink channels. Unlike most satellite signals, there are so many Orbcomm satellites that there is likely to be one within range of almost any spot on Earth at any time of the day or night.

A European Digital TV USB (~$8.00) As the heart of the SDR Orbcomm Receiver and PC Demodulator!



Les Allen, W2CCO

Les Allen showing Bill Falcy, County Disaster Control Coordinator (and Commissioner) Operation of D.V.R.A Club Transmitter W2ZQ - June 1954

Les Allen.,June,1954, Image provided by John Dilks, K2TQN

Les Allen.,June,1954, Image provided by John Dilks, K2TQN

Les Allen.,June,1954, Image provided by John Dilks, K2TQN

Messenger, Thursday, March 17, 1977

RADIO PIONEER — "BB" Wentzel [right], Mercer County CDDC Communications Coordinator, shows William H. Falcey, County CDDC Coordinator, the new Civil Defense Walkie Talkie with telephone dialing capability to anywhere in the Continental United States, developed by Amateur Radio Technicians.

"B.B."Wentzel,W2HX

SK//W2HX//WENTZEL/JR,/AMANDUS/G//LastCall=W2HX/"Spark/Op"/1stCall=3HW//1st2Way=1919/LastKnownAddress=318/GARDNER/AVE,/TRENTON,/NJ/,/08618`2516,/Born=1/2/1904/SK=08/28/1995/ Member#0253/

B.B. Wentzel was a regular in my 60's Civil Defense meetings at the Broad Street (fire house) and I remember him speaking about telemetry and its use in the military… which is now my consulting focus and expertise.

Example:

60's Troop Movement UHF Sensor and Transmitter placed along the Ho Chi Minh Trail

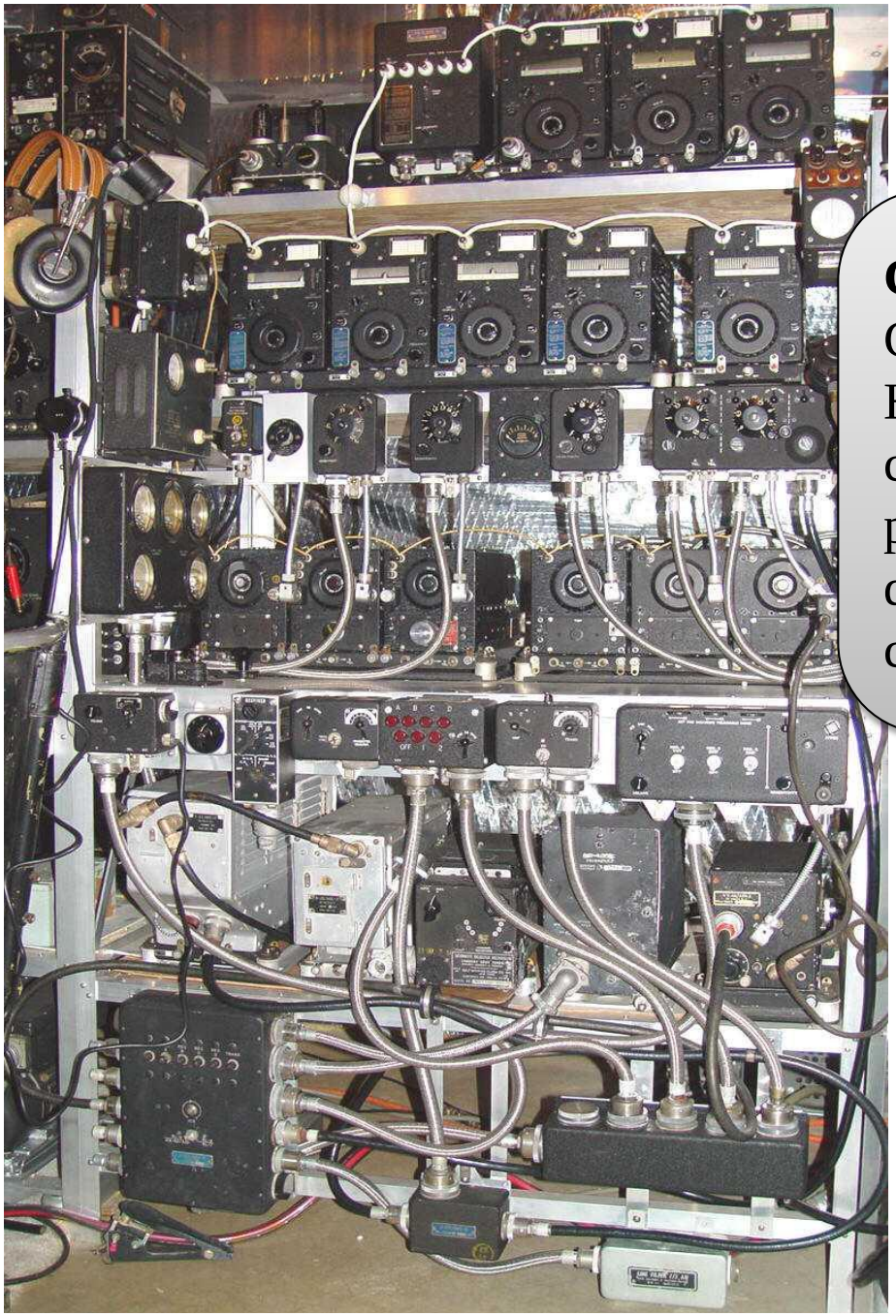
behe -Talky" was n ary trans hoto. I woul son," but I am p ly ask that a mo ho is able to properly identify that radio come forward and rescue me." by Tom Glover

Image provided by Tom Glover

WHITLEY, J RAYMOND, W2RLY, #0790,
1st Wireless=1909, 1st Call=NS-1909, Born=4/25/1895
W2RLY WHITLEY, J RAYMOND LastCall=W2RLY "Spark Op"
1stCall=NS 1st2Way=1909. LastKnownAddress=31 WILFORD AVE, TRENTON, NY , 08610

Ray Whitley:

Described how a tactical nuclear strike is not only survivable, but how to continue communication during a strike. His tube-based Collins gear could survive an EMP as a result of a nuclear strike. Also, Ray taught me how Regeneration Radios really worked (WWI Signal Core Experience) in amazing details which helped me years later, how to improve RFID performance.



Carlton E. Polhemus, W2RMJ

Carl was a pilot and active in not only Civil Defense, but also the Civil Air Patrol. He was a great resource when I needed to convert the surplus ARC-5 and BC-348 power supply requirements (originally a dynamotor supply) to a standard 115v 60 cycle power supply.

RASER, EDWARD G - W2ZI - "Spark Op" 3NG-1910 TRENTON NJ

Ed was born April 1, 1899. He was first licensed in April, 1914 as 3NG

May 1930, Image provided by John Dilks, K2TQN

May 1930, Image provided by John Dilks, K2TQN

Ed G. Raser, W2ZI

Ed G. Raser

OCTOBER 1970 "TRENTON" Magazine By Bill Garry

Further details about the history of broadcasting in the Greater Trenton Area, and the industry itself, are readily available at the unique W2ZI Historical Wireless Museum at the home of Ed G. Raser, 19 Blackwood Drive, Trenton. A bonefide wireless pioneer (he received a commercial license in 1916) Raser has what has been described as the finest private collection of early wireless and radio equipment in the world. There also is a large historical library on the art of wireless with magazines, books and biographies of many wireless pioneers from Marconi on.

While the collection is highly technical in nature, anyone with an interest in broadcasting would enjoy the museum's founder, Mr. Raser. His intimate knowledge of the early radio days in the Greater Trenton Area, and of the people who owned and ran the stations is a library in itself. He put one Trenton station on the air, and built numerous pieces of equipment for others. The call letters W2ZI are for his amateur license which is among the oldest in the country. He is still on the air regularly and has radio friends around the world.

Mr. Raser retired in 1963 as radio communications superintendent for the N.J. State Police, and since has devoted most of his time to his museum and library. He is truly one of Trenton's most valuable resources.

Demise of the Last Communications Shop in Trenton

What Happened to Trenton's Electronic Businesses?

- Major Loss of Manufacturing Businesses & Associated Jobs in the 1960's
- Loss of Industry and Entrepreneurs due to Losses in Economic Freedom
- Opportunity with Les Allen would be lost if Minimum Wages were Enforced
- Manufacturers Left Trenton, Jobs are Now Mostly Government-related
- Newark 1967 Riots (Newark fires could be Seen at Night in Trenton)
- NJ-based Universities and Colleges Failed to Collaborate with Businesses

Thanks to Les Allen and the Spark Guys for their Knowledge!

JJ Receiving the Edison Award in 2007 from GE's Chairman Jeff Immelt