On the Roots of Wireless Communications

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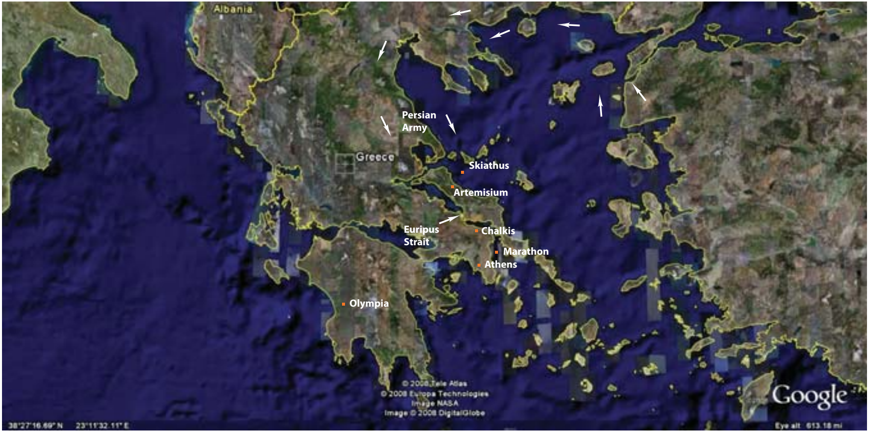
- In another part of his histories, describing the advance of the Persian army towards Athens in 480 BC, Herodotus recounts that "When the Greeks stationed at Artemisium learned what had happened by *fire signals* from Skiathus, they were terrified and retreated to Chalcis so that they could guard the Euripus strait". (See [Waterfield, 1998].)

Introduction *Cont'd*



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- This presentation will deal with some of the highlights of the key discoveries and inventions as well as the key players involved that led to what we call today *wireless communications*.
- Two groups of people played a key role in the emergence of wireless communications, *the discoverers and the innovators.*

The Discoverers

The key scientific discoveries were made by

- Michael Faraday (1791-1867)
- William Thomson (Lord Kelvin) (1824-1907)
- James Clerk Maxwell (1831-1879)
- Heinrich Rudolf Hertz (1857-1894)

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- His break in life came about when a very famous chemist of the 1800s by the name of Humphry Davy appointed him as his assistant.

  Davy discovered chlorine, iodine, the miner's safety lamp, and many other things.

Faraday *Cont'd*

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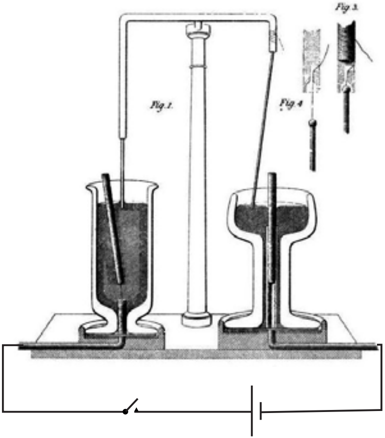
- Early in his career, he meticulously explored many phenomena pertaining to chemistry but later on he began to study the properties of electricity and magnetism for the Royal Institution where he worked.

- In 1821, Faraday demonstrated the relationship between electric current and magnetism, i.e., *Faraday's law*, by constructing a so-called *rotator* which was essentially the first induction motor.



- In 1831, he showed that a changing current in a coil of wire would induce a current in a nearby coil of wire, which is the basis of the *transformer* (See [Hirshfeld, 2006]).

Faraday's *induction ring*.

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- Many years later, Thomson was knighted by queen Victoria as *Lord Kelvin* for his work on the first transatlantic cable.

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- He showed that the behavior of electric and magnetic fields and their interactions can be characterized very precisely by mathematical equations.
- In 1862, he showed that the speed of propagation of an electromagnetic field is approximately the same as the speed of light and predicted that a relation must exist between light on the one hand and electric and magnetic phenomena on the other.

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- Soon after, Maxwell's equations caught the imagination of the scientific community. Einstein described Maxwell's work as *the most profound and the most fruitful that physics has experienced since the time of Newton*.

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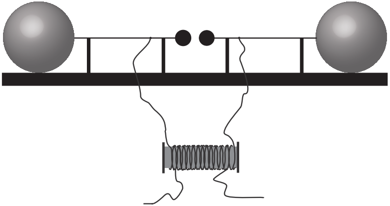
- In 1887, he showed by experiment that electricity can be transmitted by electromagnetic waves which travel at the speed of light and which possess many of the properties of light, e.g., reflection and refraction, *as predicted by Maxwell*.

Hertz

- To demonstrate the properties of electromagnetic waves, Hertz constructed a *transmitter* comprising an induction coil, two large metal spheres which served as a capacitor, and a spark-gap mechanism made from two brass knobs.

  He also constructed a *receiver* using a loop of copper wire and a spark-gap mechanism similar to that of the transmitter.

Experiment of Hertz



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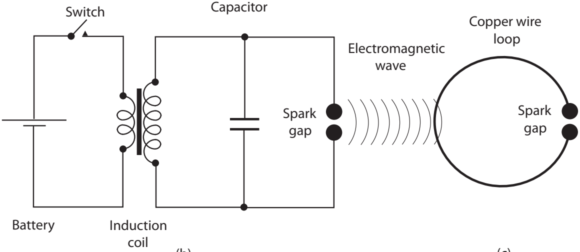

(b)

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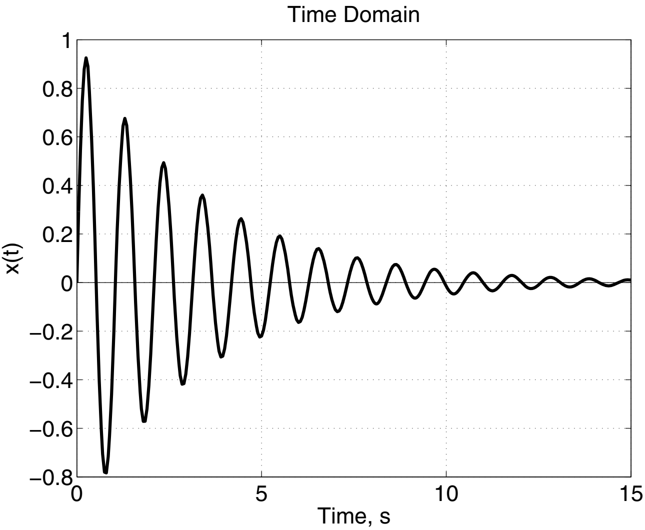
- It helped, of course, to perform the experiment in a dark room and also use a magnifying glass to check for the fleeting spark!

Experiment of Hertz *Cont'd*



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- "So, what next?" asked one of his students.
- Hertz shrugged. A modest man of no pretensions and, apparently, little ambition, he replied: "Nothing, I guess." [Hertz, Heinrich Rudolf].

The Innovators

With the verification of Maxwell's prediction, a group of illustrious innovators appeared on the scene determined to exploit the properties of electromagnetic waves.

There were many such individuals but four of them left a substantial legacy:

- Tesla (1856-1943)
- Marconi (1874-1937)
- Fessenden (1866-1932)
- De Forest (1873-1961)

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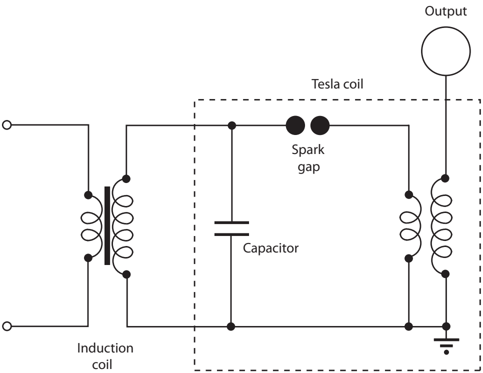
  (See [Cheney, M., 1981].)

Tesla's Coil



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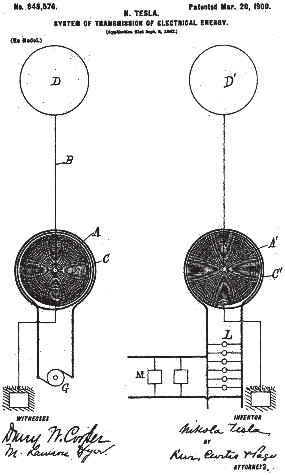
- The system comprised a transmitter, basically a step-up transformer driven by a generator, and a receiver, basically a step-down transformer loaded by a series of lights and motors connected in parallel.

Tesla's Transmission System



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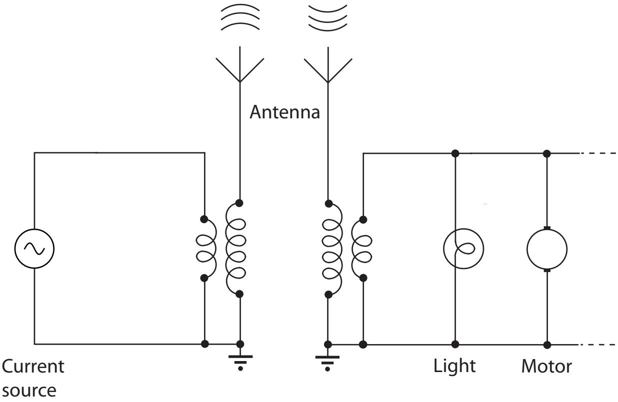

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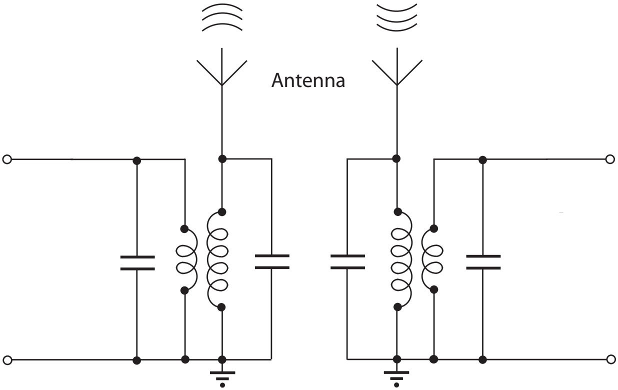
- The transmitter and receiver were, in effect, *bandpass filters*, the first equipped with a transmitting antenna and the second equipped with a receiving antenna.

Tesla's Transmission System *Cont'd*



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- He explored ingenious innovations to the state-of-the art that would increase the distance over which effective transmission could be achieved.
- Soon he was able to transmit signals over an impressive distance of about 1.5 km.

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- Through a series of experiments, Marconi was later able to transmit Morse signals first over a distance of 6 km and after that over a distance of 16 km.

  In due course, he was able to send Morse signals over the Atlantic. (See [Weightman, 2003]).

Marconi *Cont'd*

- Marconi was a smart system designer and a clever entrepreneur who readily borrowed ideas from his peers.

  He used a so-called Righi oscillator, a device known as a coherer invented by Branly and improved by Lodge, an aerial system of Dolbear, and Tesla's coil. [see History of Wireless by Sarkar et al.].

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- Like today's wireless systems, it comprised a *transmitter* and a *receiver*.

Early Wireless System – Transmitter

- Basically, the transmitter consisted of
  - an induction coil in series with a relay,
  - a parallel resonant circuit, and
  - a spark gap constructed from two metal balls just like the one used by Hertz.

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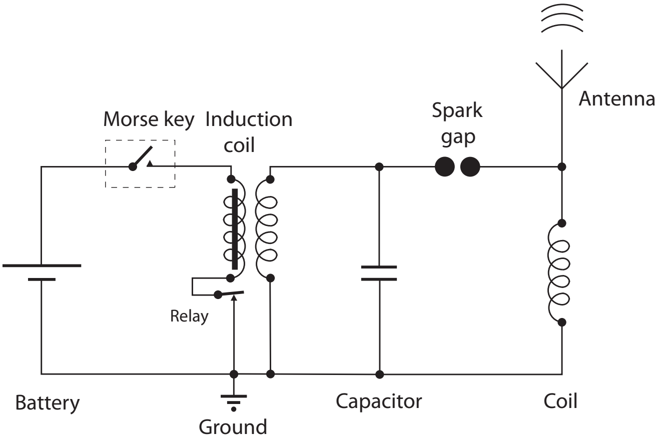

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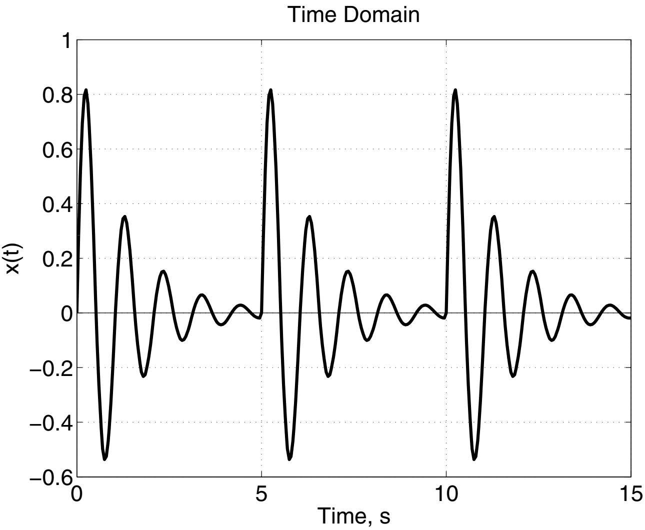
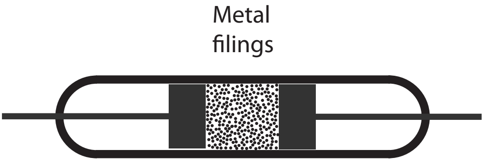
- Thus as long as the Morse key was kept depressed, a series of dumped oscillations was generated in the loop of the secondary thereby sustaining a continuous oscillation at the resonant frequency.

Early Wireless System – Transmitter *Cont'd*



Early Wireless System – Receiver

- The early receivers comprised two circuits, the antenna circuit and the Morse sounder circuit.
- The antenna circuit comprised a coil, a battery, a relay, and a *coherer* which was a glass tube with metal filings sandwiched between two small metal pistons.



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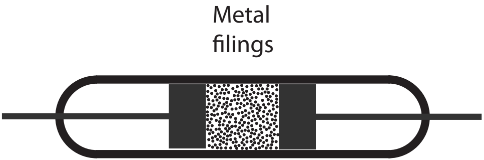
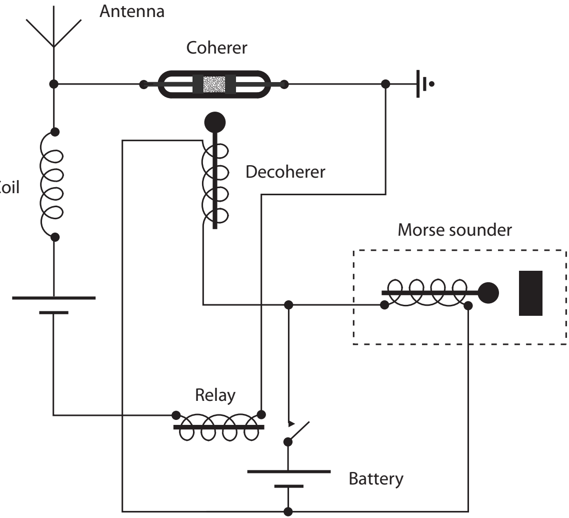


- The Morse sounder circuit comprised a Morse sounder, a battery, and a *decoherer* which was essentially an electrically activated knocker.

Early Wireless System – Receiver *Cont'd*



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- To reset the coherer, a decoherer was activated by the Morse sounder circuit which essentially tapped the coherer.

Evolution of Wireless Systems

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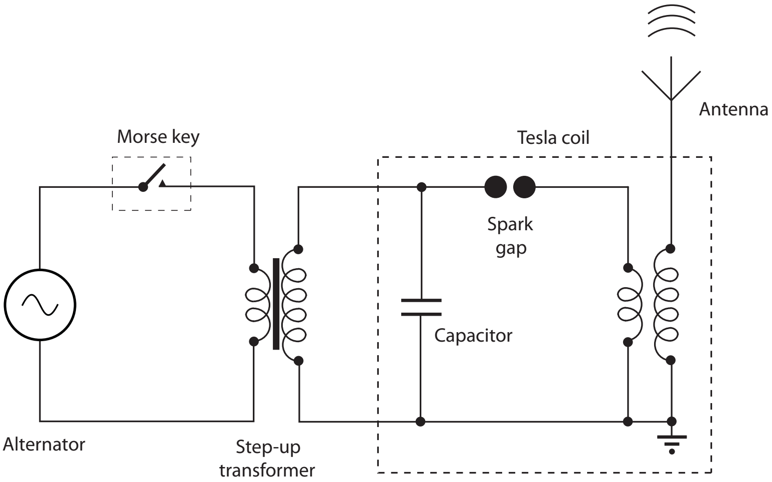
  In this way, two sparks could be generated for every cycle of the supply voltage.
- And almost always, a Tesla coil was used to feed the generated signal to the antenna.

  The capacitor and the induction coil formed a *parallel resonant circuit* and the induction coil essentially served as a *step-up radio-frequency transformer*.

Evolution of Wireless Systems *Cont'd*



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- This problem was solved by using *spark-gap rotators*.

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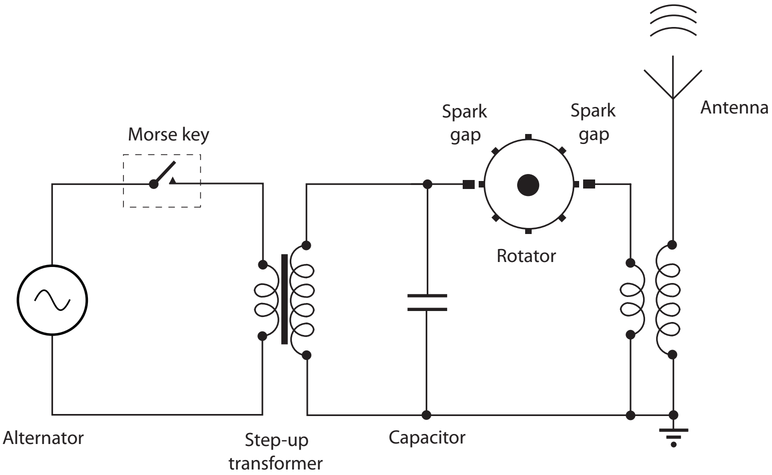

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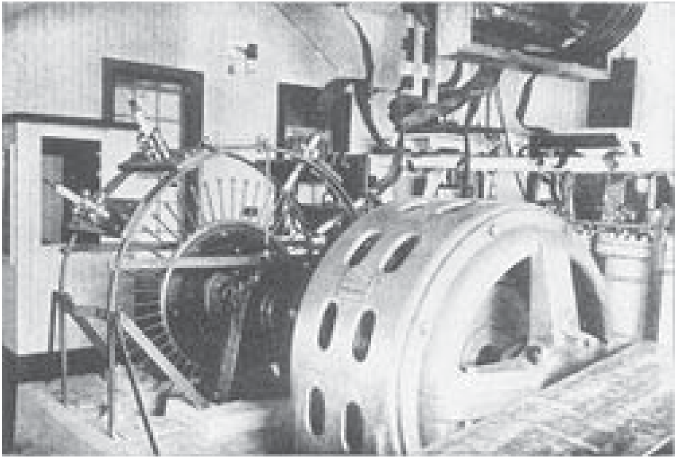
  This caused the firing of the sparks to be erratic, which reduced the amount of radiated energy.
- To maximize the amount of radiated energy, a *Canadian by the name of Fessenden* had the alternator and the spark-gap rotator mounted on one and the same shaft in order to synchronize the sparks generated with the instants of maximum positive or negative voltage.

- Fessenden also used multi-phase alternators of the type invented by Tesla to increase the spark rate even more.

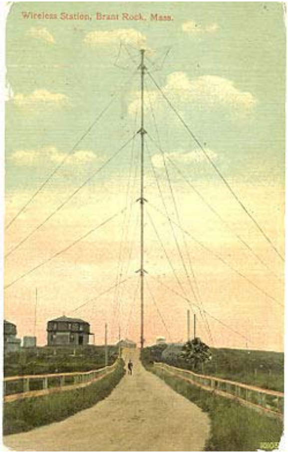
Evolution of Wireless Systems *Cont'd*

- Fessenden also used multi-phase alternators of the type invented by Tesla to increase the spark rate even more.
- By using a 125-Hz, 3-phase alternator, he was able to achieve a spark rate of 750 sparks/s.

  In this way, a vibration in the audio range was heard at the Morse receiver which sounded like a musical note.



(See [Reginald Fessenden].)



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- In due course, both Marconi and Fessenden considered that no further improvements were possible in the coherer and both spent considerable effort exploring alternative devices for their receivers.
- In fact, Fessenden considered that the invention of the coherer was a *misfortune* that retarded the development of practical detectors.
- Borrowing certain ideas of Rutherford, Marconi patented a magnetic decoder that relied on the demagnetizing effect of a dumped oscillation.

Fessenden's Hot-Wire Barretter

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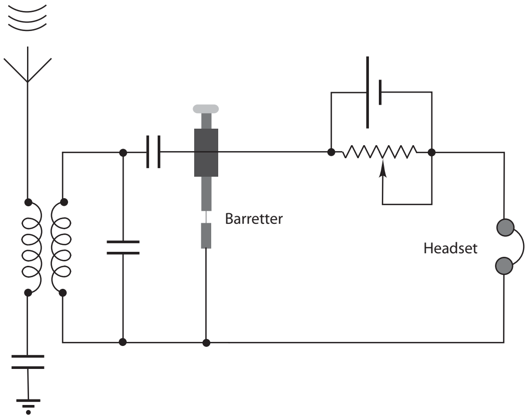
- The operation of the hot-wire barretter relied on the heating of the platinum wire caused by the detected signal.

Fessenden's Barretter Hot-Wire Barretter *Cont'd*



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- Actually, the device could in theory be used to detect *amplitude-modulated signals* although the practical difficulties would be many.

Fessenden's Electrolytic Barretter

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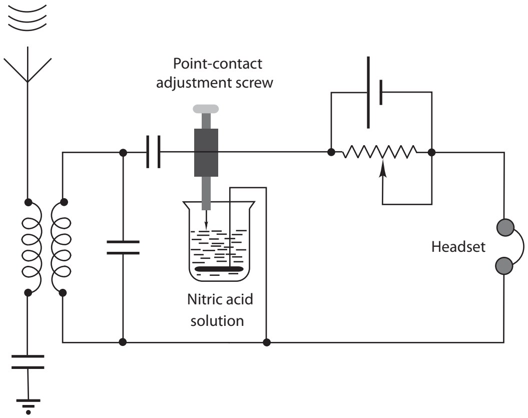
- On close examination, he found out that the platinum wire in the most efficient hot-wire barretter was *broken*!

  And thus the *electrolytic receiver* was invented.



Point-contact
adjustment screw
Headset
Nitric acid
solution

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- The electrolytic barretter remained the detector of choice over several years.

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- He also proposed the *heterdyne detector* ten year's before it could be implemented.
- The use of continuous waves eventually led to voice wireless communications.

Vacuum-Tube Technology

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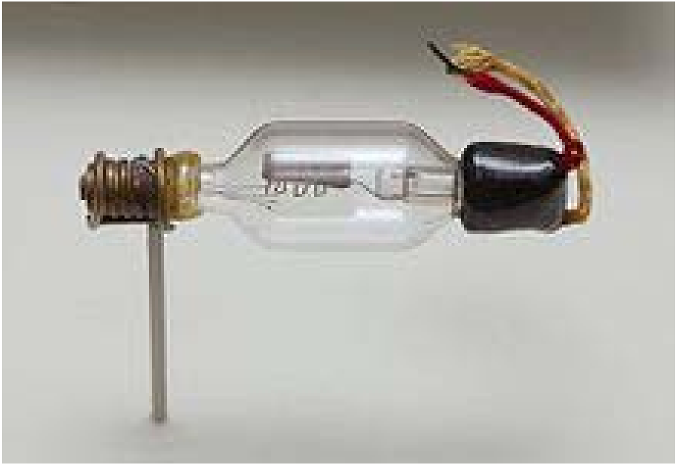
- Before too long, in 1906, an American inventor by the name of Lee De Forrest added another electrode to Fleming's vacuum-tube diode to invent the so-called *audion* as an amplifying device [De Forest, Lee, 1908].

De Forest's Audion



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- Unlike the audion, the vacuum-tube triode could achieve linear amplification.
- Soon after, the triode became the workhorse of wireless communication systems.

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- He continued to be involved with the evolution of radio during the next decade.

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- The circumstances associated with this process as well as De Forest's other inventions are both dramatic and controversial and would make a good story for a Hollywood feature movie.
- Although the Phonofilm process did not make as a mainstream technology, De Forest received in 1959 an Oscar *for his pioneering inventions which brought sound to the motion pictures.*

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- And the rest is history.

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- Hertz verified by experiment that Maxwell was correct in his assessment.
- Tesla, Marconi, Fessenden, De Forest, and many others were able to design electrical circuits that could be used to transmit and receive electromagnetic waves, and in turn information, over long distances.

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Thank you for your attention.