Marconi, Tesla and the Radio Wars

(Presented by Bob Primak
To The Lexington Technology Group
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01:
(Image: https://allthatsinteresting.com/wordpress/wp-content/uploads/2016/03/tesla-marconi.jpg)

Inventors around the world were churning out new and exciting inventions left and right in the years leading up to the 20th century. Scientific work in radio technology was heating up too. Two men in particular, Serbian-American scientist Nikola Tesla and Italian physicist Guglielmo Marconi went head-to-head in what would become the race to invent the radio. But more than 120 years later, ask any two people who invented the radio and you're likely to get two different answers. The story is a murky one that mixes scientific discovery with lawsuits and good old-fashioned marketing.

02: (recaptured as a .png):
(Image: https://www.biography.com/.image/c_limit%2Ccs_srgb%2Cq_auto:good%2Cw_700/MTQ4NDI1NTU4NzM1MjAxNDgz/nikola_tesla_napoleon-sarony-public-domain-via-wikimedia-commons.webp)

After emigrating to the U.S. in 1884, Tesla invented the induction coil or Tesla coil, a device essential to sending and receiving radio waves and one the U.S.Patent Office would later say Marconi relied on for his work [source: Britannica]. But in 1895, a fire destroyed Tesla's lab as he prepared to send a radio signal approximately 50 miles (80 kilometers) to West Point, N.Y. [source: PBS].
https://science.howstuffworks.com/innovation/inventions/who-invented-the-radio.htm

03: (video, 4 mins.):
(At this point, a sidebar about Tesla Coils would be good.
https://www.youtube.com/watch?v=M-vz82dx6gQ&feature=youtu.be)
(4 mins.)

04:
(Image: https://cdn.hswstatic.com/gif/nikola-tesla-1.jpg)

In order to allay fears of alternating currents, Tesla gave exhibitions in his laboratory in which he lit lamps by allowing electricity to flow through his body. He was often invited to lecture at home and abroad. The Tesla coil, which he invented in 1891, is widely used today in radio and television sets and other electronic equipment. That year also marked the date of Tesla's U.S. citizenship.
https://www.askamathematician.com/2010/10/q-how-does-a-tesla-coil-work-2/

05:
(Image: https://www.askamathematician.com/wp-content/uploads/2010/10/tesquiz.jpg)

(That article (above) also has illustrations which show how the Tesla Coil can be modified to introduce a spark gap. Hence the later name coined by Marconi in 1900 in Europe -- the

spark gap radio transmitter. This is essentially what Tesla had patented in the US in 1897. See also the patent by Oliver Lodge in 1898 for “syntonic tuning”.)

06:

(Image: Spark Gap Transmitter

https://upload.wikimedia.org/wikipedia/commons/thumb/3/30/Morseapparat-2.JPG/370px-Morseapparat-2.JPG)

07:

(Lodge: https://ethw.org/Oliver_Lodge)

A Tesla coil is an electrical resonant transformer circuit designed by inventor Nikola Tesla in 1891. It is used to produce high-voltage, low-current, high frequency alternating-current electricity. Tesla experimented with a number of different configurations consisting of two, or sometimes three, coupled resonant electric circuits.

Tesla used these circuits to conduct innovative experiments in electrical lighting, phosphorescence, X-ray generation, high frequency alternating current phenomena, electrotherapy, and the transmission of electrical energy without wires. Tesla coil circuits were used commercially in spark gap radio transmitters for wireless telegraphy until the 1920s, and in medical equipment such as electrotherapy and violet ray devices. Today, their main usage is for entertainment and educational displays, although small coils are still used as leak detectors for high vacuum systems.

Footnote: Because early spark gap transmitters used a broadcast method known as CW (continuous wave) transmission, they transmitted on a primary frequency. But they also excited higher harmonic frequencies (think of chords in music). This resulted in broadband RF interference. Since the 1930s this type of broadcasting has been banned, as newer, more discreet methods of radio transmission were invented. This happened when vacuum tubes were introduced. The most relevant change to early (and modern) radio was audio modulation (AM) which also includes Shortwave and Longwave, as well as television and aircraft VHF and UHF radio transmissions. Frequency Modulation (FM) was introduced into radio broadcasting in the 1930s, because it greatly reduces interference and radio noise. It was also possible to broadcast in stereo in the pre-digital age only if FM was used. Today, digital radio and television signals have completely displaced analog AM and FM signals. We couldn’t have this technology without transistors and solid state integrated circuits, and what we now call microchips. Transistors date from 1947 (Bell Labs) and microchips date from the 1960s (several inventors). Both Tesla (died 1943) and Marconi (died 1937) were both dead by the time these later inventions transformed radio and digital communications.

Vacuum tube radios used a triode vacuum tube. (Invented by Lee DeForest in 1906.) Before this invention, neither AM nor FM radio could have been made practical. There were also developments in the use of heterodynes, which allow two signals to be combined or separated, allowing for a carrier frequency and the actual signal frequency to work together as a single broadcast signal.

https://www.britannica.com/biography/Nikola-Tesla

Triode Vacuum Tube (deForest design):

08:

https://history-computer.com/ModernComputer/Basis/audion.html

(Continues)

(Images:

09:

http://scihi.org/wp-content/uploads/2014/08/953px-Lee_De_Forest_with_Audion_tubes1.jpg

10:

https://history-computer.com/ModernComputer/Basis/images/Audion_1906.jpg)

11:

Heterodyne:
https://upload.wikimedia.org/wikipedia/commons/thumb/b/b8/Heterodyne_radio_receiver_circuit_1920.png/220px-Heterodyne_radio_receiver_circuit_1920.png

12:

Superheterodyne (still used in tuners today):
https://www.electronics-notes.com/images/superheterodyne-receiver-block-diagram-01.svg

(This block diagram shows the components and allows understanding of how they work.)

Articles about the history of FM Radio:

https://www.nps.gov/features/safr/feat0001/virtualships/vrmovies/muvr2hs11.htm

https://radiofidelity.com/the-history-of-fm-radio/

https://time.com/4630170/history-fm-radio-norway/

AM vs. FM Radio Signals, and Where in the Spectrum FM Radio and VHF Television are Located.

(https://www.pbs.org/wgbh/aso/tryit/radio/radiorelayer.html)

13:

(Image: https://upload.wikimedia.org/wikipedia/commons/thumb/a/a4/Amfm3-en-de.gif/250px-Amfm3-en-de.gif)

14:

(Image: https://upload.wikimedia.org/wikipedia/commons/thumb/a/ac/ElectromagneticSpectrum-Radio-VHF-FM.png/400px-ElectromagneticSpectrum-Radio-VHF-FM.png)

Who Lived When

(Image: Timeline of the Late Nineteenth and Early Twentieth Century in Science and Technology

1740-1960 – major scientists' life spans

15:

https://www.famousscientists.org/images1/hertz-place-in-time.png)

16:

(Photo of Tesla and his Tesla Coil, lighting light bulbs wirelessly

https://i.pinimg.com/736x/fc/20/04/fc20045d9d54e41bccddc6e697d9d246.jpg)

The most common attack on Marconi's claim comes from supporters of Nikola Tesla, one of history's most famous inventors. He invented the now famed Tesla coil, essential in transmitting radio waves, in 1891. Four years later, he was set to actually transmit radio signals, over a distance of 50 miles, before a fire destroyed his lab. But by 1897, he'd rebounded and filed several radio patents, which were eventually granted in 1900. Over the next three-plus years, Marconi's radio patents were routinely denied on the grounds that they relied too heavily on the work of Tesla (and a few other inventors).
(from: https://allthatsinteresting.com/famous-inventors/3)

17:
(Photo Early Ship's Radio Room
http://marconiheritage.org/ww1-orders_html_m743cd7de.jpg)

The Early Years of Radio

To the shipboard radio operators, it was a miracle -- a Christmas miracle. Instead of hearing the usual dots and dashes of Morse Code, these listeners heard an eerie Silent Night, played by a violin. It was Christmas Eve, 1906, and this broadcast was among the first to transmit sound.

It had only been eleven years since Guglielmo Marconi sent the first "wireless" transmission with his new invention, and only five since Marconi sent signals across the Atlantic. Making use of the high-frequency alternator, Canadian-born physicist Reginald A. Fessenden made his historic Christmas Eve broadcast, in which he transmitted music as well as human speech.

18:
(Image: https://www-tc.pbs.org/wgbh/aso/tryit/radio/images/b1marc01212.jpeg)

Another early broadcast took place in 1910 when Lee de Forest, inventor of a type of vacuum tube called a triode, aired programs from New York's Metropolitan Opera House.

But it was not until 1916, when a Westinghouse engineer named Frank Conrad played records for his friends over the air, that the idea of radio as a public medium took shape.

An executive at Westinghouse heard about Conrad's broadcast and realized its potential. Here was a medium available to the masses -- a huge potential audience. An audience that would listen to radio broadcasts... with radios made and sold by Westinghouse.

In 1920, Westinghouse's KDKA began regular broadcasts. That same year it aired the results of the 1920 presidential election before the results could be read in the papers. This caused a sensation and is considered the beginning of professional broadcasting.
(https://www.pbs.org/wgbh/aso/tryit/radio/earlyyears.html)

19:
(Image: https://www-tc.pbs.org/wgbh/aso/tryit/radio/images/d120kdka010000.jpeg)

Tesla and "Wireless Transmission" He got the physics completely wrong!

20:
(Image: https://sciencevibe.com/wp-content/uploads/2017/06/TeslaTower-1024x512.jpg)

Question: *Shouldn't Nikola Tesla be considered the "inventor of radio", given that in 1943 the United States Supreme Court (supposedly) overturned all of Guglielmo Marconi's patents and proclaimed Tesla "the true inventor"?*

Gut Reaction: *Are you joking??? In no way, shape or form can this guy be considered the "inventor of radio". Furthermore, contrary to what you might have read, the U.S. Supreme Court never said that he was -- not in 1943, not in any other year. If fact, if anything Tesla's "contribution" was to confuse and slow radio development, due to his misunderstanding of the physics involved. Fortunately, at the time few people were listening to his misguided and exaggerated "true wireless" ramblings.*

A More Dignified Response: A fuller answer is that although Tesla did do groundbreaking research in early electrical systems, most importantly wired power transmission using alternating current, his contributions to radio technology were minimal, overshadowed by the far more important practical work conducted by other inventors and scientists, including Heinrich Hertz, Oliver Lodge, Guglielmo Marconi, Karl Braun -- the latter two shared the Nobel prize for physics in 1909 -- Reginald Fessenden and John Stone Stone. And about that 1943 Supreme Court ruling --Marconi Wireless Tel. Co. v. United States - 320 U.S. 1-- this case actually did NOT even try to determine "who invented radio". Instead, it just set governmental compensation for the use of patents primarily during World War One -- not the original patents covering radio transmission and reception, but ones covering later improvements. One of these improvements was using an adjustable "four-circuit" transformer configuration for radio transmission and reception. And in this matter, the U.S. counterpart to Marconi's original British "four sevens" tuning patent was in fact invalidated. But, instead of awarding priority to Tesla, the court actually upheld a 1935 lower court ruling that Oliver Lodge's -- and especially John Stone Stone's -- earlier work and patents had priority. So, to recap, the 1943 decision

didn't overturn Marconi's original patents, or his reputation as the first person to develop practical radiotelegraphic communication. It just said that the adoption of adjustable transformers in the transmitting and receiving circuits, which was an improvement of the initial invention, was fully anticipated by patents issued to Oliver Lodge and John Stone Stone. (This decision wasn't unanimous, but the dissents sided not with Tesla, but with Marconi.)

In fact, it is bizarre to even claim Tesla "invented radio", since... at least through 1919 he didn't even believe that radio waves existed, or that any form of what he called "longitudinal space waves" could be used for long-distance communication. Instead, he had his own unworkable idea of what constituted "the true wireless", believing that alternating electrical currents somehow could be injected into the ground to provide, not just communication, but also electrical power "around the world".

(from: Nikola Tesla: The Guy Who DIDN'T "Invent Radio"
https://earlyradiohistory.us/tesla.htm)

See Also:
Famous Inventors Who Don’t Deserve Credit For Their Most Well-Known Creation

21:
(Photo Heinrich Hertz
https://upload.wikimedia.org/wikipedia/commons/thumb/3/30/HEINRICH_HERTZ.JPG/478px-HEINRICH_HERTZ.JPG)

Neither Nikola Tesla Nor Guglielmo Marconi Invented The Radio

https://allthatsinteresting.com/famous-inventors/3

[T]he final showdown between the two heavyweights is actually more of a smokescreen hiding the truly pioneering work that came before. Starting in 1886 — almost a decade before Marconi’s public demonstrations — German physicist Heinrich Hertz, seldom recognized as one of history’s most famous inventors, conducted a series of experiments in which he successfully observed and transmitted electromagnetic waves for the first time ever.

Before Hertz became the first person to conclusively prove the existence of radio waves, it was difficult for other researchers and inventors to know whether or not they may have been transmitting those same waves themselves. Nevertheless, British-American inventor David Edward Hughes seems to have a very strong claim for transmitting radio waves in 1879, seven years before Hertz’s first experiments.
(from: https://allthatsinteresting.com/famous-inventors/3)

[***But like Tesla, who didn’t believe in transverse electromagnetic (radio) waves, Hughes and Hertz may not have known what they had accomplished.***]

The esteemed scientists at London’s Royal Society concluded that Hughes hadn’t actually transmitted radio waves, but instead some kind of other, less significant,

electromagnetic waves. However, Hughes wasn't a trained physicist and thus couldn't sufficiently argue his case, strong as it was.

Plus, any official body (like the Royal Society) was quick to dismiss radio waves in the era before Hertz conclusively proved their existence.

Thus, many now claim that the dismissal of Hughes was unwarranted and that he in fact deserves credit for inventing the radio.

22:
(Photo David Edward Hughes
https://imgc.artprintimages.com/img/print/david-edward-hughes_u-l-pphfn30.jpg?h=550&p=0&w=550&background=fbfbfb)

Hughes' experiment

Hughes noted many unusual electrical phenomena while experimenting on his microphone, telephone, and wireless related projects. The telephone, by the way, had been invented in 1876 and plans for constructing them had circulated around the world. Hughes noticed a clicking noise in his home built telephone each time he worked used his induction balance, a device now often used as a metal detector. Fixing the circuit's loose contact stopped the signal.

Hughes correctly deduced that radio waves, electromagnetic, radiated emissions, were produced by the coil of wire in his induction balance and that the gap the spark raced across marked the point they radiated from. He set about making all sorts of equipment to test his hypothesis. Most ingenious, perhaps, was a clockwork transmitter that interrupted the circuit as it ticked, allowing Hughes to walk about with his telephone, now aided by a specially built receiver, to test how far each version of his equipment would send a signal.

At first Hughes transmitted signals from one room to another in his house on Great Portland Street, London. But since the greatest range there was about 60 feet, Hughes took to the streets of London with his telephone, intently listening for the clicking produced by the tick, tock of his clockwork transmitter. Ellison Hawks F.R.S., quoted and commented on Hughes' accounting, published years later in 1899: "He obtained a greater range by setting 'the transmitter in operation and walking up and down Great Portland Street with the receiver in my hand and with the telephoneto my ear.' We are not told what passers-by thought of the learned scientist, apparently wandering aimlessly about with a telephone receiver held to his ear, but doubtless they had their own ideas. Hughes found that the strength of the signals increased slightly for a distance of 60 yards and then gradually diminished until they no longer could be heard with certainty."

Since Hughes moved his experimenting from the lab to the field he had truly gone mobile. Although these clicks were not voice transmissions, I think it fair to credit Hughes with taking the first mobile telephone call in 1879. That's because his sparking induction coil and equipment put his signal into the radio frequency band, thus fulfilling part of our radio definition. Modulation, the act of putting intelligence onto a carrier wave such as the one he generated, would have to wait for others. This was an important first step, though, even

though his clockwork mechanism signaled simply by turning the current on and off, like inductance and conductance schemes before. Hughes' experimenting was profound and well researched, it was not accidental discovery.

Beginning in 1879 Hughes started showing his equipment and results to Royal Society members. On February 20, 1880 Hughes was sufficiently confident in his findings to arrange a demonstration before the president of the Royal Society, a Mr. Spottiswoode, and his entourage. Less knowledgeable in radio and less inquisitive than Hughes, a Professor Stokes declared that signals were not carried by radio waves but by induction. The group agreed and left after a few hours, leaving Hughes so discouraged he did not even publish the results of his work. Although he continued experimenting with radio, it was left to others to document his findings and by that time radio had passed him by.
https://nitum.wordpress.com/2012/09/28/biography-of-david-edward-hughes/

What is not in dispute is that Hughes did invent the loose carbon microphone, which was until very recently still used in home telephones.

23:
(Image: Carbon Microphone of an AT&T handset, ca. 1976:
https://upload.wikimedia.org/wikipedia/commons/8/8a/Carbon_Button_Microphone.JPG)

What Tesla Actually Did

24:
(Photo Tesla Coil "Lightning"
https://www.circuitcrush.com/wp-content/uploads/What-is-voltage.jpg)

25:
Static vs. Current Electricity

Summary:

1. Static electricity is caused by the build up of electrical charges on the surface of objects, while current electricity is a phenomenon from the flow of electrons along a conductor.

2. When objects are rubbed, a loss and/or gain of electrons occurs, which results in the phenomenon of static electricity.

3. Current electricity is normally controlled, and it is the more used phenomenon of electricity, in countless applications.

4. Static electricity is usually uncontrolled, and just happens sporadically.

5. Current electricity is generated by batteries and power plants.

http://www.differencebetween.net/science/difference-between-current-and-static-electricity/

When a lightning stroke, containing maybe 20,000 or more amperes of current, hits the ground all of this electricity doesn't just disappear into the earth. It spreads out in the ground as a potentially deadly current with its voltage decreasing with distance from where it hit.

Ground currents, which spread out over the ground after lightning strikes, are the the big danger, accounting for 50-55 percent of all lightning deaths and injuries, says the National Oceanic and Atmospheric Administration.

26:
https://www.washingtonpost.com/news/capital-weather-gang/wp/2013/06/27/how-lightning-kills-and-injures-victims/

27:
(Illustration of Natural Lightning:
https://www.researchgate.net/profile/Guillaume_Mejean/publication/237218507/figure/fig1/AS:671538005147660@1537118545665/Mechanism-of-lightning-initiation-a-stepped-leader-formation-b-initiation-of-an.png)

How Lightning Works
Positive Streamers and Exploding Air

As the step leaders approach the earth, objects on the surface begin responding to the strong electric field. The objects reach out to the cloud by "growing" positive streamers. These streamers also have a purplish color and appear to be more prominent on sharp edges. The human body can and does produce these positive streamers when subjected to a strong electric field such as that of a storm cloud. In actuality, anything on the surface of the earth has the potential to send a streamer. Once produced, the streamers do not continue to grow toward the clouds; bridging the gap is the job of the step leaders as they stage their way down. The streamers wait patiently, stretching upward as the step leaders approach.
https://science.howstuffworks.com/nature/natural-disasters/lightning4.htm

To put it another way, let's answer a question:

"I am trying to understand ground current in a power distribution system.

"The basics, of course, are simple: in the power grid, the "hot" wires carry high voltage, while the return path (the neutral wire) is connected to ground, so ground forms part of the circuit."

28:
(illustration: circuit diagram:
https://i.stack.imgur.com/JwTK0.png)

Your question contains one very common misconception, and that is that large amounts of current flowing through ground is normal.

In this diagram, notice the lack of a particular path for current flow into or out of ground. As long as everything remains balanced and a power line isn't touching the earth or a tree, there is no path for current to travel through ground (except some minor leakages).

29:
(Illustration: Wye Diagram:
https://i.stack.imgur.com/3Z16a.gif)

Here is a wye connected four wire system. Notice how the ground is connected directly to the neutral point in the center, and the neutral (N) line has no coil. In this system, the neutral line is the return path for all single phase loads - that is, anything that is connected from a phase to the neutral. Phase to phase connections are still available, of course. But current flow through ground is still not normal.

On the off chance that a line has been downed and grounded, the current flow will radiate away from the point of earth contact to whatever path is most favorable for current flow. If the topsoil is recently wet, it will tend to stay there. If everything around is fairly dry, there may not actually be much current flow at all, and it will radiate in nearly every direction as the voltage charges the ground. It will flow through ground water, if it can get there.

30:
As far as the difference between AC and DC grounding events, the physical characteristics of DC make it more likely that it does not find a good path back to the nearest system ground, **which makes it more likely to have a potentially lethal step voltage differential**. *[my emphasis.]*

(This last paragraph is relevant to the perception of dangerousness of AC vs. DC power transmission systems. See my previous talk on Edison vs. Tesla and The Current Wars. DC can actually create a greater momentary ground current than AC.)
https://electronics.stackexchange.com/questions/163216/understanding-ground-current

31:
(Photos of SWER:
http://cdn.ipernity.com/134/47/35/24684735.9b146747.240.jpg?r2
32:
https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcTYxWCg2EtpsRbhDaguDub5ec2VwgpIB1e-e1j1M2rAxof9C_YE&s)

SWER (Single Wire Earth Return) Power Transmission

At some point we have to consider why you can use the earth as the “ground” in a single-wire transmission system. Australia and some rural areas of North America use such systems, in which the return phase of a circuit is in fact the ground. But this is not transmission of electricity through the earth, nor even dry soil. The conductor in these systems is water in the ground. In fact, to make a single-wire system work in Australia, the grounding rods have to extend very deep.

33:
(Image: https://upload.wikimedia.org/wikipedia/commons/thumb/9/9e/Cahora_Bassa_%28HVDC%29_-_KNP_-_001.jpg/220px-Cahora_Bassa_%28HVDC%29_-_KNP_-_001.jpg)

34:

(Image: https://upload.wikimedia.org/wikipedia/en/1/12/Swer.gif)

https://en.wikipedia.org/wiki/Single-wire_earth_return
https://www.engineeringnz.org/our-work/heritage/heritage-records/single-wire-earth-return-swer/

Note that in these systems, the earth itself is not transmitting electricity. It is only participating in creating an electrical ground. What is induced is called a “Ground Current”. The same thing lightning induces. Only in this case, moist ground can act as the neutral or return part of an AC current loop.

35:
(Image: Earth internal structure: https://cdn.mos.cms.futurecdn.net/Tx6j5BXtU2dxcmRE5VhLi4-650-80.jpg)

Some Physical Concepts

According to "Essentials of Geology" (7th Ed., Prentice Hall, 2000) by Frederick K. Lutgens and Edward J. Tarbuck, Earth's crust is made up of several elements: oxygen, 46.6 percent by weight; silicon, 27.7 percent; aluminum, 8.1 percent; iron, 5 percent; calcium, 3.6 percent; sodium, 2.8 percent, potassium, 2.6 percent, and magnesium, 2.1 percent.

These minerals are extremely poor electrical conductors, and would normally not be good for conducting electricity or any kind of electromagnetic waves.

It isn’t until you go many, many miles down, into the Earth’s mantle, that the amount of iron becomes great enough to allow some electrical conductivity. But the real source of both the Earth’s magnetic field and its internal electrical current is at the boundary between the liquid core and the solid or plasma core, thousands of miles below the crust.
https://www.space.com/17777-what-is-earth-made-of.html

Worse for Tesla, the electrically charged layers in the Earth’s atmosphere, the ionosphere, are at almost one hundred miles above the Earth’s surface. For the Tesla Towers to work, these charged layers would need to be not much higher than the tops of high mountains. (And this was a common scientific belief until at least the 1920s. Later, modern radiosondes and high-flying aircraft explored the upper reaches of the Earth’s atmosphere. But you can’t have a radiosonde without miniaturization of the instruments and radio communications.)

36:
(Image: Layers of the Earth’s atmosphere:
http://solar-center.stanford.edu/SID/activities/images/image014.jpg)

37:
(Image: Charged Layers in the ionosphere and reflection of radio waves.
http://solar-center.stanford.edu/SID/activities/images/image016.jpg)

(These images show navy VLF radio waves. The layer involved is the E layer, mostly present during the daytime. Marconi was using the same frequencies due to better daytime reflection. Navy communications still prefer longer wavelengths, hence lower frequencies. Similar reflection takes place for AM and FM radio, but at the higher level F layer. These effects are noticed more strongly at night. AM radio reflects and can be received over longer distances than FM radio. Digital radio and television don’t work well with reflected signals. Though, UHF

DTV signals can sometimes be received by pointing an antenna upward at a 45 degree angle toward the signal source.)

The structure of the atmosphere is known only since the development of the radiosonde. This is an instrument package which is flown aloft using a weather balloon, and then solid-state instruments send radio signals back to earth to report measurements. None of this tech was available in 1900, or even 1920, when the early radio experimenters were working. You need radio and at least vacuum tubes to even begin to build a radiosonde. However, people could make direct measurements by flying in hot air balloons. Obviously, this had limitations, as observers had to remain conscious, and it gets very cold as you go upwards in the Troposphere.

38:
(Image: Weather balloon with radiosonde and payload:
http://radiosondemuseum.org/wp-content/uploads/2012/03/WhatIsARadiosonde-692x1024.jpg
39:
https://ars.els-cdn.com/content/image/3-s2.0-B9780123822253003443-f00344-04-9780123822253.jpg?_)

So knowledge of the earth's inner structure and the atmosphere's outward structures was very limited before about the 1920s.

So what did Tesla actually accomplish?

Tesla did run experiments in Boulder, CO in which he thought he was successfully sending electricity wireless through the earth and the air.

40:
(Photo Tesla Coil Apparatus lighting fluorescent tubes:
https://sciteen.com/wp-content/uploads/2018/08/Feature-72.jpg)

The Tesla Coils and Spark Gap Transformers

Note: A Tesla coil is not the same thing as a Van de Graaf generator, though they are sometimes confused because they are both popular methods of making high voltage. A Van de Graaf generator uses a rotating belt to separate charges between ground and a metal terminal. A Tesla coil does not accumulate static charge and is AC, not DC electricity.

A Tesla Coil is used to produce high-voltage, low-current, high frequency alternating-current electricity.

A streamer discharge, also known as filamentary discharge, is a type of transient electrical discharge.
https://en.wikipedia.org/wiki/Streamer_discharge

41:
(Photo Spark Gap Transmitter for telegraph:
https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcSBAESjA5VpGNhNS7DPFFwnaFzqYSKks4Yi3rzzE1fAA-WdyJWl&s)

Spark Gap Tesla Coil (SGTC)
Spark gap coils use an air gap to control the primary current. Using a transformer (often a neon sign transformer or “NST”) , a primary capacitor is charged to a high voltage. When the voltage is high enough, the spark gap breaks down, ionizing the air between the terminals and forming a short circuit. This allows current to flow between the primary capacitor and primary inductor, completing the primary circuit. Power is lost to dissipation in the coils due to their resistance, and the spark gap is soon extinguished. Then the primary is slowly recharged and the cycle starts again.

Nikola Tesla, in his investigation into high-frequency electricity phenomena, needed a way to go beyond the limitations of the iron-coil transformer to generate higher frequency radio waves. His inspiration lead him to invent a special transformer, without the iron-core, which allowed the secondary coil to be free to oscillate or "electrically vibrate" into higher and higher frequencies. The infamous Tesla Coil (invented 1891) is an air-core resonating transformer became the forerunner of the radio-frequency coil and allowed the "Radio Age" to take one of its first formative steps.

Tesla coils as spark radio transmitters have been phased out since the late 1950's, but have been miniaturized and today, form the heart of every television, radio and [OTA DVR]. *[My modification]*
https://www.teslaenergy.org/tcoil.html

See also: https://en.wikipedia.org/wiki/Tesla_coil

(In radio, vacuum tubes replaced spark gap transmitters in the 1920s. Today solid state components are used. Solid state components don’t generate any actual sparks.)

42:
(Illustration of Tesla’s Wardenclyffe Tower concept at completion:
https://teslauniverse.com/sites/default/files/styles/default_small_watermark/public/images/wardenclyffe_0051.jpg?itok=AURPTKpu)

Wardenclyffe, Long Island and Boulder, CO “Tesla Towers”

Tesla entered the twentieth century in triumph, at the peak of his career. And from that summit he wanted to realize the greatest of all his inventions—the Wardenclyffe Tower, the centre of a futuristic global telecommunication system. His grand idea was finally given the green light in 1901, but in less than a year the project went sideways and Tesla would eventually be ruined scientifically and economically by the venture. What happened in that year?

The brilliant inventions of Nikola Tesla ... had launched alternating current technology, making it possible to illuminate and supply power to large cities, something that would have made him a millionaire, if not for his ... naivety, for he had renounced most of the royalties agreed upon by the use of his patents. *[See my earlier talk on Edison vs. Tesla and The Current Wars.]* Even so, he had the privilege and the means to be able to investigate what he wanted, and he did so during the 1890s, culminating in his fascinating achievements at his experimental station at high altitude in Colorado Springs, [CO]…

43A:
(Image of Colorado Springs, CO Tesla Research Facility:
https://upload.wikimedia.org/wikipedia/commons/8/8d/Tesla_Colorado_Springs_laboratory_exterior.jpg)

From there Tesla returned to New York determined to realize his dream—to create a wireless telecommunications system with totally new technology. During the year 1900, the elegant and lanky Serb ... sought financing by wining and dining potential investors at select Manhattan venues: the luxurious Waldorf-Astoria hotel (where he then lived), The Players Club, and the famous restaurant Delmonico's. In this way he seduced the financier J.P. Morgan, who in March 1901 decided to invest $150,000 (equivalent to more than $4 million today) in the construction of the Wardenclyffe Tower.

43B:
(Photo: Wardenclyffe Tower as it was.
http://moreisdifferent.com/wp-content/uploads/2015/02/lab_photo-thumb-550xauto-98423.jpeg?w=300)

[J. P.] Morgan was very impressed by the achievements of Guglielmo Marconi, his rival in that technological race, but Tesla succeeded in persuading the tycoon, detailing the ambitious applications of his project: "As soon as completed, it will be possible for a business man in New York to dictate instructions, and have them instantly appear in type at his office in London or elsewhere," Tesla told him. "He will be able to call up, from his desk, and talk to any telephone subscriber on the globe, without any change whatsoever in the existing equipment," he added convincingly.

Everything was ready for the construction of the Wardenclyffe Tower to begin in August 1901, but by then Tesla's plans had already radically changed. His rival Marconi was ahead of him and had already managed to transmit radio signals between France and England, much further than Tesla and many physicists thought was possible. In June 1901, Marconi gave some details of his radiotelegraphy system in an article published in the magazine Electrical Review, and in his description detailed the use of "Tesla coils" connected to ground. This led him to think that Marconi was copying his idea: Tesla [proposed] using a so-called "terrestrial resonance" and a new class of stationary waves to transmit telegraphic messages—instead of the radio waves that Marconi used, of whose existence Tesla was skeptical despite being theoretically and experimentally proven.

This is how Nikola Tesla was reassured of his own theory that was never scientifically demonstrated. In 1899, during his experiments in Colorado Springs, he managed to wirelessly light some bulbs outside the laboratory where he had powered up a huge "Tesla coil." He believed that he had achieved the terrestrial resonance he sought, which he thought would work at any distance. That seemed enough to prove his ideas, and Marconi's article of June 1901 prompted him to continue on that path. A month later, he proposed to J.P. Morgan a much more ambitious plan to gain the upper hand over Marconi—not only would he send messages in Morse code across the Atlantic, but he would also transmit electricity long distance and without cables.

To achieve this, he felt that would need a tower almost double the height (300 feet) and, of course, much more money. Morgan refused to increase the investment and Tesla had to start the construction of the Wardenclyffe Tower in September 1901, staying true to the original plan. Two months later, the project received another blow—Marconi had managed to transmit

the letter “S” in Morse code across the ocean, from England to Newfoundland (Canada). In that era of financial uncertainty, investors preferred to bet on the Marconi system, which, having been less ambitious, had achieved historic success.

Tesla did not give up. He finished the Wardenclyffe Tower in 1902 and carried out experiments there until 1905, without managing to launch his beloved telecommunications station, the first of a great worldwide network. That year his alternating current patents expired, and this was the remaining source of funding. Tesla made a second mortgage of Wardenclyffe—the first had been to cover his debts at the Waldorf-Astoria Hotel, which reached $20,000 ($478,000 in today’s money)—but he still had to abandon the project, which the press was beginning to label a “hoax”.

After years of neglect and deterioration, Tesla lost ownership in 1915 as he was unable to afford the mortgages. The Wardenclyffe Tower was demolished in 1917 and the main building ended up being a factory of photographic material, until AGFA closed it in 1992.
https://www.bbvaopenmind.com/en/science/leading-figures/the-wardenclyffe-tower-the-dream-that-sank-tesla/

What Tesla thought physically he was accomplishing

Tesla thought on at least some occasions, he had succeeded in transmitting electricity through the earth. He did try to get the electrical discharges to go into the earth. But he never demonstrated at any long distances that he could receive the electricity and use it.

What in fact Tesla really did accomplish at Colorado Springs, CO

Sparks, Arcs and Light Bulbs

Colorado Springs 1899

In May 1899 Tesla and several assistants began constructing the Tesla Experimental Station in Colorado Springs to research wireless telegraphy using high-voltage and high-frequency electricity. During his experiments, Tesla created artificial lightning that generated reports of electrified butterflies, thunder that could be heard 15 miles away, and sparks that appeared on horse hooves and water pipes. He built the largest Tesla coil in history at Colorado Springs, almost 50 feet in diameter, a preliminary model of the magnifying transmitter he would build at Wardenclyffe just a few year later. Tesla left Colorado Springs in January 1900 and shortly thereafter received patents for a “system of transmitting electrical energy” and “an electrical transmitter.”
https://teslasciencecenter.org/pivotalmoments/colorado-springs/

For roughly nine months, the station was alive with experimentation.

He set up an experiment where he had some light bulbs in a field. And they were surrounded in a 50-foot square of wire. And he transmitted power so that an electrical field was created within that wire and the bulbs lit up," Jane Alcorn, President of the Tesla Science Center at Wardenclyffe, told PBS.

Within the confines of his grounded, wooden station, Tesla attempted to tune his magnifying transmitter and Tesla coil to Earth's supposed resonance frequency, which he thought would permit worldwide wireless power transfer. It apparently was not uncommon for ball lightning to flit about the laboratory. One night, he even thought he picked up radio signals from outer space through his transmitter.

Outside, Tesla produced artificial lightning from the station's metal mast. The largest bolt was 135-feet long and its thunder was reportedly heard fifteen miles away. It also knocked out power to all of Colorado Springs, and severely damaged equipment at the El Paso Electric Company. Afterwards, his free power came to an end.

In January 1900, Tesla concluded his experiments in Colorado Springs, claiming that he could transmit electric power abundantly and cheaply anywhere on the planet.

Damages to the El Paso electric power generating station

May, 1899 –

On the evening of the experiment, each piece of equipment was first carefully checked. Then Tesla alerted his mechanic, Czito, to open the switch for only one second. The secondary coil began to sparkle and crack and an eerie blue corona formed in the air around it. Satisfied with the result, Tesla ordered Czito to close the switch until told to cease. Huge arcs of blue electricity snaked up and down the center coil and bolts of man-made lightning of 135 feet in length shot out from the mast atop the station and producing thunder heard 15 miles distant.

When the terrific force suddenly fell in silent and the power was gone, Tesla quickly called the Colorado Springs Electric Company, demanding them to restore the power to find if he was the responsible of destroying the generator, causing it to erupt in flames. Tesla pulled so many amperes that he burned out the municipal generator. The largest generator of that side of the Mississipi was not working and during a short time Colorado Springs was engulfed in darkness. Fortunately for the town they had another generator to replace it, but company officials denied to Tesla the access to electricity with the condition of repairing the original generator at his own expense. And the generator was working again in only a few short days.

[***Thus, Tesla (unwittingly) demonstrated the need for backflow and overdraw prevention in electrical power grids, something which affects today's homeowners if we want to put in "backward metering" and feed our excess daytime solar electricity production into the power grid, receiving credit against our nighttime net withdrawals of electric power.***]

One night in his laboratory, Tesla noticed a repeating signal being picked-up by his transmitter. To his own amazement, he believed that he was receiving a signal from outer space. Tesla was widely ridiculed when he announced this discovery, but it is possible that he was the first man to detect radio waves from space.

A great deal of mystery still surrounds Tesla's work at Colorado Springs. It is not clear from his notes or his comments exactly how he intended to transmit wireless power. But it is clear that he returned back to New York City fully convinced that he could accomplish it.
https://www.pbs.org/tesla/ll/ll_colspr.html

(But Marconi's radio experiments dated back to 1894-1895 in Italy. His radio transmissions across the English Channel were accomplished between 1897 and 1901. In 1901 he transmitted wireless radio signals across the Atlantic. His signature was a triple-S which is exactly the type of signal Tesla received in Boulder, CO. So, ***maybe***???)

(Radio signals are reflected by the charged F Layer in the Earth's ionosphere, and also reflected by the earth's surface (land and oceans). [See previous section of this document.]

Marconi was using frequencies much lower than modern AM radio (but not the modulation method, which came later). This was because long wave radio transmissions reflect off the E Layer in the ionosphere, which allow better daylight reflection over distances. (The F layer reflection of AM radio works best at night and fades during daylight hours as the F layer splits into two separate layers and becomes a less effective reflector.)

[See diagram in previous section of this document.]
(This diagram is very useful to illustrate the phenomenon for Marconi's experiments, as he was using long wave signals as well.)
(http://solar-center.stanford.edu/SID/activities/images/image016.jpg)
This ionospheric reflection is the same principle used today to receive distant AM and shortwave radio signals around the earth.)

Milestones:Marconi's Early Experiments in Wireless Telegraphy, 1895

Achievement date range – 1895

MARCONI'S EARLY EXPERIMENTS IN WIRELESS TELEGRAPHY, 1895 In this garden, after the experiments carried out between 1894 and 1895 in the "Silkworm Room" in the attic of Villa Griffone, Guglielmo Marconi connected a grounded antenna to its transmitter. With this apparatus the young inventor was able to transmit radiotelegraphic signals beyond a physical obstacle, the Celestini hill, at a distance of about two kilometres. The experiment heralded the birth of the era of wireless communication.

MARCONI'S EARLY EXPERIMENTS IN WIRELESS TELEGRAPHY, 1895 On this hill, during the summer of 1895, the radiotelegraphic signals sent by Guglielmo Marconi from the garden of Villa Griffone were received. The reception was communicated to Marconi with a gunshot. This event marked the beginning of the new era of wireless communication

The plaques may be viewed at the two sites in which Marconi carried out his first experiments: in the garden of Villa Griffone (his family home, now the site of the Fundazione Guglielmo Marconi), where Marconi transmitted his wireless signals, and beyond the Celestini hill, where those signals were received. Villa Griffone, Marconi's family home in the second half of the 19th century, is now the site of the Guglielmo Marconi Foundation and of the Marconi Museum, which includes the young Marconi's laboratory, on the upper floor of the villa.

Guglielmo Marconi's first experiments in wireless telegraphy marked the beginning of radio communication. The technical system for wireless telegraphy needed fundamental improvements of the instruments used at the time for experiments with electromagnetic

waves. In particular, Marconi conceived the grounded antenna and after many experiments he decided to use lower frequencies.

Marconi's first experiments in wireless telegraphy were aimed at communicating without wires at increasing ranges. With this goal, he took the instruments that were being used for important experiments on electromagnetic waves in different universities out of the laboratory, in order to overcome natural obstacles. In the garden of his fathers villa, he was finally able to overcome the Celestini hill, at a distance of about 2 km. His use of the grounded antenna and of a very sensitive coherer were two crucial elements for the accomplishment.
https://ethw.org/Milestones:Marconi%27s_Early_Experiments_in_Wireless_Telegraphy,_1895

Thomas Alva Edison and David Edward Hughes and Microphones for Telephones

David Hughes, in full David Edward Hughes, (born May 16, 1831, London, England—died January 22, 1900, London), Anglo-American inventor of the carbon microphone, which was important to the development of telephony.

Hughes's family emigrated to the United States when he was seven years old. In 1850 he became professor of music at St. Joseph's College, Bardstown, Kentucky. Five years later he took out a U.S. patent for a type-printing telegraph instrument; its success was immediate, and in 1857 Hughes took it to Europe, where it came into widespread use and in some places continued in use until the 1930s. Hughes's microphone, invented in 1878, was the forerunner of the various carbon microphones that were used in most telephones produced in the 20th century.

From 1879 to 1886 Hughes performed a series of experiments in which his equipment transmitted wireless signals up to 500 yards. The observed effects were attributed to induction by other scientists. Hughes disagreed but did not know how the transmissions were working. It was not realized until 1899, after German physicist Heinrich Hertz's radio wave experiments in the late 1880s, that Hughes had been the first to produce radio waves.
https://www.britannica.com/biography/David-Hughes

Hughes vs. Edison – The Carbon Particle Microphone

44:
(Image Hughes and Microphone
https://images.fineartamerica.com/images-medium-large/hughes-carbon-microphone-19th-century-cci-archives.jpg)

Hughes was a man of short
stature, blue eyes deeply set under bushy eyebrows, flowing
[hair] and walrus moustache.
He was mild mannered, independent, sometimes stubborn, but
genial and sympathetic. He was
said to be always full of interesting experiences and of a light
heartedness that made him excellent company. However at times
he become a catalyst (or as some
viewed it a lightning rod) for
stimulating great debates within

the scientific community, either on the theory of electrical phenomena or on his experimental results.

(Images: Carbon Microphone and early Telephone Handset)

45:
(https://upload.wikimedia.org/wikipedia/commons/thumb/7/73/Hughes_carbon_microphone.jpg/105px-Hughes_carbon_microphone.jpg +
46:
https://upload.wikimedia.org/wikipedia/commons/thumb/5/51/HughesMicrophone.gif/200px-HughesMicrophone.gif)
47:
(https://upload.wikimedia.org/wikipedia/commons/thumb/6/65/Ericsson_carbon_microphone_opened.jpg/220px-Ericsson_carbon_microphone_opened.jpg)
48:
(https://upload.wikimedia.org/wikipedia/commons/thumb/8/8a/Carbon_Button_Microphone.JPG/220px-Carbon_Button_Microphone.JPG)

One of these instances came about with his discovery of the carbon microphone when he crossed swords with Thomas Edison. Edison believed he had invented the carbon microphone first and suspected one of the English government officials (William Preece), whom he had confided in, of leaking his secrets to Hughes.

Hughes's decision to give away his invention freely to the world only further infuriated Edison, who intended to capitalize on this invention. Unfortunately, the "Wizard of Menlo Park", as Edison was known, had misunderstood the circumstances, and before checking and discussing with Hughes, or others that he was accusing, immediately took the dispute public in the newspapers. Therefore, an affair that could have been settled amiably became a nasty war of words and accusations and counter accusations dragged out in the major technical journals and newspapers.

The dispute drew in the who's who of the scientific world, who waded in with their opinions and in support of their respective champion. The dispute eventually became nationalistic pitting the much larger scientific community

of Europe against the smaller one of America. In the end, it was concluded that each had carried out their research independently and there had been no leaks. Hughes, having discovered in the microphone a device that had wide applications and Edison having concentrated specifically on the telephone transmitter. The chief scientist of the day in Britain, Sir William Thomson (Lord Kelvin) scolded Edison in the press over the affair and requested an apology from him for his unfounded accusations - Edison never did reply.
http://davidedwardhughes.com/David_Edward_Hughes.pdf

The same Edison and Hughes microphones were used in wireless phones and radio studios. The carbon particle microphone was not superseded until the 1980s. Hughes, even before the dispute with Edison broke out, had decided to give away the idea and didn't patent it on his own.) (Hughes was already wealthy from his earlier wired telegraph patents.)

49:
(Image of Hughes Carbon Particle Microphone
https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcQtUf8_EsFMdMRAfvROlbil-21rMMseh9AkUHsTbJQ4PqxYIOWvwA&s)

Maxwell, Hughes, Stokes – The "Almost Invention" of Radio

50:
(Photo of David Edward Hughes
https://www.sciencesource.com/Doc/TR1_WATERMARKED/1/d/1/3/SS2494551.jpg?d63642441586)

Hughes was a brilliant inventor and practical experimenter as well as a gifted musician, ever inquisitive and a true lover of science. He was born when Michael Faraday and Joseph Henry were still uncovering the mysteries of "electricity", a time when they and others were wrestling with the observations that electricity could create magnetism, and magnetism could be used to create electricity. He lived through a period rich in famous names that are still familiar today, such as William Thomson (Lord Kelvin), Cyrus Field, Samuel Morse, Thomas Edison and Alexander Graham Bell.

Hughes was to leave his mark through his inventions and discoveries in the fields of telegraphy, telephony, wireless, metal detection, and audiology. He was an international scientist whose life was spent between America, Britain, and Continental Europe, and became

one of the most decorated scientists, receiving high honors from no less than nine countries. Hughes was one of the few self-made scientists who were able to amass a substantial sum of money over their lifetime, which upon his death he generously donated to the London Hospitals. However, like many of the early scientific foot soldiers that laid down the foundations of our communications industry his name has tended to sink below the history horizon.

51:
(Image: David Edward Hughes
https://media.sciencephoto.com/image/h4080375/800wm/H4080375-David_E_Hughes,_US_inventor.jpg)

WIRELESS DISCOVERY IN 1879?

His next discovery was probably his most innovative, but was to be a bittersweet story. His experimentation, resulting in the discovery of wireless, became virtually hidden for many years and his discoveries only became known in the waning years of his life. His experiments took place a number of years before Hertz and Marconi. History finally credited him with the discovery but over time it has slipped off the pages of history.

It all came about when Hughes was experimenting with his induction balance in the fall of 1879. He had started with a primary circuit consisting of a set of coils being pulsed from a battery by clockwork driven contactor. A secondary circuit consisted of a second set of coils inductively coupled to the first that were connected to a telephone receiver. When he rearranged this configuration, it gave him some unexpected results – in that he could still hear the make and break signal even when he thought he shouldn't. He suspected it was either due to an effect called the "extra current" (the current induced in an inductor when its magnetic field rises or collapses) or the breakdown in the insulation of one of the coils.

However, it turned out to be a loose connection between some wires. As the effect was puzzling,

he pursued it, substituting one loose connection for another by inserting one of his loose connection microphonic joints from his microphone experiments. Still he continued to hear the signal in his telephone receiver. The mystery grew as he separated the primary circuit from the secondary by some distance and only connected by a single wire. He was struggling to understand how the signal could be heard with a circuit that was apparently incomplete - that is an open circuit.

Although he continued to call the device a microphonic joint it had become a detector and through extensive experimentation it had taken on a much different form and characteristics. His experiments revolved around trying to improve this device so that he could hear signals louder. He settled finally on two configurations for the detector: one of oxidized copper wires looped together, and the other a steel needle resting on a piece of coke. He encapsulated these detectors into small bottles for protection. In arriving at these he had also tried many other forms of his microphone components with mixed results such as a glass tube filled with metal filings and iron wires dipped into mercury.

52:
(Hughes testing his wireless communication device
https://c8.alamy.com/comp/TX9145/telephone-radio-history-victorian-inventor-david-edward-hughes-arouses-a-policemans-suspicion-in-portland-street-london-whilst-experimenting-with-wireless-communication-and-telephone-conversations-TX9145.jpg)
(**Note:** Normally I would not use a Watermarked Stock Image from a Commercial Site. (Copyright issues.) But I find no other illustrations of this event anywhere online.)

Hughes next took his receiver and walked out into the street and continued walking, and was still able to hear the signal until by 500 yards it had faded away. This was an embryonic “wireless” experiment but the phenomenon of creating the invisible electromagnetic waves and being able to detect their presence was unknown at the time. It is interesting to note that his previous inventions of the microphone and induction balance and his use of the telephone

receiver were all necessary prerequisites and essential ingredients
leading up to this discovery.

53:
(Image of James Clerk Maxwell
https://upload.wikimedia.org/wikipedia/commons/5/57/James_Clerk_Maxwell.png)

Hughes had experimentally demonstrated just
what Maxwell had predicted and
had produced electromagnetic
waves and detected them – which
was the experimental validation of
his theory and the missing link.
Unfortunately, fate was to intervene, Maxwell died young in 1879,
the year Hughes made his discoveries, and Hughes, who was not a
mathematician, would not have
been able to decipher Maxwell's
complex mathematical equations.

*(**Note** – It was not Maxwell himself, but Oliver Heaviside, who put his Four Laws into the succinct form known to today's students of physics and electronics.*
https://spectrum.ieee.org/tech-history/dawn-of-electronics/the-long-road-to-maxwells-equations)

54:
(Image of George Gabriel Stokes, the President of the Royal Society, which governed among other things, British patents at the time.
https://upload.wikimedia.org/wikipedia/commons/a/ad/Ggstokes.jpg)
https://www.britannica.com/biography/Sir-George-Gabriel-Stokes-1st-Baronet

Hughes, however, was so ex-
cited by what he had discovered
that he repeated his experiments
in 1880 to important members of
the Royal Society, the premier scientific organization of the day
that included Professor Gabriel
Stokes. Stokes was also from Cambridge University and a mathematician who knew Maxwell and was aware of his work. Could he
possibly make the connection between Maxwell's theories and
Hughes experiments? However,
it all unraveled, and what could
have been the start to a brilliant
discovery, possibly Hughes greatest, and the verification of
Maxwell's work was stopped dead.

Stokes observed the experiment
and stated that it was not a new
phenomenon and could be explained by already known facts of
electromagnetic induction. He
failed to make any connection

with Maxwell's theories or recognize it as a new phenomenon. It was just like pricking a balloon, dashing Hughes's hopes and swaying the opinion of the other observers in the process. Thus, a promising discovery, instead of being encouraged, was scuttled. Hughes was frustrated and angry after the meeting. For some reason, though, Hughes did not appear to have talked about his theory of the signals being transmitted by lines of force, but talked about conduction, probably confusing the issue.

Hughes by this time had probably become aware that he was to be proposed for membership to the Royal Society, a status that he deeply sought. This provided a further reason not to strike any discord with Stokes or the other members of the Royal Society for fear of jeopardizing his election.

Had Hughes' work been recognized at the time it would have pre-dated Hertz by nearly a decade and Marconi by two decades. As it was, his wireless experiments were not to come to the attention of the general scientific community for another twenty years when Sir William Crookes made some remarks about witnessing some of Hughes wireless experiments many years earlier.

The author J.J. Fahie, who was close to completing a book on the "History of Wireless Telegraphy 1839-1899", was, like many others taken completely unaware. He immediately contacted Hughes to follow up on Crookes remarks. Hughes at first was reluctant to divulge the information, unwilling to upstage the work of Hertz and Marconi that had occurred in the intervening years. A generous gesture. Fahie was eventually successful in persuading Hughes to relate to him the experiments and included them into his book. They were also recounted in a number of technical journals.
http://davidedwardhughes.com/David_Edward_Hughes.pdf

55:
(Image Heinrich Hertz

https://www.slideshare.net/pam14/heinrich-rudolf-hertz)

Heinrich Hertz and the Second Invention of Radio

Heinrich Hertz Biography

Heinrich Rudolf Hertz was born on February 22, 1857 in the German port city of Hamburg. He was the firstborn of five children.

His mother was Anna Elisabeth Pfefferkorn, the daughter of a physician.

His father was Gustav Ferdinand Hertz, an attorney who became a Senator.

His paternal grandfather, a wealthy Jewish businessman, had married into a Lutheran family and converted to Christianity.

Both of Heinrich's parents were Lutherans, and he was raised in this faith. His parents, however, were more interested in his education than his religious status.

Aged 17, Heinrich returned to school, the Johanneum, for a year in order to fully prepare for the classics exams for university. Having passed the exams, he promptly changed his mind again, deciding to become an architect's apprentice. He moved to Frankfurt, where by day he worked in an architect's office and in the evening he read physics books in German, and Ancient Greek literature in the original Ancient Greek – naturally!

Architecture quickly bored him.

Homeschool and Building Scientific Apparatus

Aged 15, Heinrich left Dr. Lange's school to be educated at home. He had decided that perhaps he would like to go to university after all. Now he received tutoring in Greek and Latin to prepare him for the exams.

He excelled at languages, a gift he seems to have inherited from his father.

Professor Redslob, a language specialist who gave Heinrich some tuition in Arabic, advised his father that Heinrich should become a student of oriental languages. Never before had he met anyone with greater natural talent.

Heinrich also began studying the sciences and mathematics at home, again with the help of a private tutor.

He had a colossal appetite for hard work. His mother said:

When he sat with his books nothing could disturb him or draw him away from them.

Although he had left his normal school, he continued attending the technical college on Sunday mornings.

In the evenings he worked with his hands. He learned to operate a lathe. He built models and began constructing increasingly sophisticated scientific apparatus such as a spectroscope. He used this apparatus to do his own physics and chemistry experiments.
https://www.famousscientists.org/heinrich-hertz/

A Young Man in a Hurry

The first time Hertz thought seriously about proving Maxwell's theory was in 1879, when he was a 22 year-old student in Berlin. He decided against it. It seemed too hard, and anyway he wanted to concentrate on completing his doctorate.

In 1883, after getting his first lecturing job, he revisited Maxwell's theory. He wrote an impressive paper, reworking the theory mathematically.

In 1885 he moved to the University of Karlsruhe as a full professor of experimental physics. Now he decided the time was ripe to look for a way to prove Maxwell's theory.

In October 1886 Hertz saw an electrical spark, starting a train of thought that would end up transforming the world.

56:
(Image: Riess Spirals
https://www.famousscientists.org/images1/heinrich-herz-knochenhauer-spirals.png)

Playing around a little with this apparatus, Hertz connected a secondary spark-gap to the existing spark-gap, as shown.

He used the induction coil to generate high voltage ac electricity, producing a series of sparks at regular intervals at the main spark-gap.

Hertz found that when sparks flew across the main gap, sparks also usually flew across the secondary gap – that is between points A and B in the image; Hertz called these side-sparks.

Given that the electricity was ac, this suggested to Hertz that voltage waves were separately racing through the wire along paths CA and CB.

Much more detail than the following account:
How Heinrich Hertz Discovered Radio Waves
https://www.famousscientists.org/how-hertz-discovered-radio-waves/

Heinrich Hertz Aparatus

RADIO

This 5 letter word could be a prefix to give 3 broad meanings.
Radio waves (A section of the Electromagnetic spectrum)
A radio receiver (A device that can detect radio waves)
A radio transmitter.

The development of all these started with the production of current electricity.
In 1780, Luigi Galvani obtained for the first time in recorded history a continuous electric current while dissecting a frog. While he thought that it came from animal tissue , in 1790 Alessandro Volta showed that the current is produced by two kind of metals dipped in a suitable solution. (Now referred to as an electrolyte) , Hans Christian Oersted in 1820 discovered that an electric current can twist a magnetic compass needle placed nearby. This probably was the first time a human has produced action at a distance without a material connection. But the distance was too short for It to be of much use.

In 1830 Michael Faraday experimenting on these lines discovered that electricity and magnetism are inter convertible. Many scientists in Europe and America experimented with electricity and magnetism and came out with new discoveries and inventions.

One device that became a very vital piece of equipment for Radio transmission was the induction coil discovered around 1836 by an Irish Priest Father Nicholas Callan. This could multiply the pressure (Voltage) of a direct current by several Forty years later in 1860, James Clerk Maxwell mathematically proved the connection between electricity and magnetism and predicted that a wave must propagate due to changing of electric and magnetic lines of force. (Now referred to as Electromagnetic waves) Twenty five years after The Irish-German *[Errors in the original source]* Physicist Heinrich Hertz in 1885 demonstrated the existence of Electric / magnetic waves (Now called Radio waves). He was the first person known to have transmitted and received a radio wave although it did not carry a signal.

57:
(Image: Hertz Spark-Gap Transmitter and Receiver Apparatus:
http://www.simplescience.info/_/rsrc/1422520236320/general-knowledge/talesbehindinventions/hertz1.png)

When Hertz gave a high voltage current to charge the metal spheres a spark resulted between the two connecting wires. This produced a spark in the copper loop kept at a side unconnected.
http://www.simplescience.info/general-knowledge/talesbehindinventions

One hundred and thirty years ago, everything known about electromagnetic waves was theory, it was all mathematical equations on paper. At the time, there were two competing ideas regarding how quickly these waves traveled. One camp argued that electric and magnetic forces were transmitted immediately from one point to another. According to this theory, if you picked up a magnet and waved it around, that would immediately affect all the other charges in the room, with no time delay.

Maxwell's theory, on the other hand, predicted that electromagnetic waves propagated through space at the speed of light. [In other words, there would be a slight time delay.]

Hertz set out to find out which theory was right.
https://whyy.org/segments/the-history-of-heinrich-hertz-and-the-discovery-of-radio-waves/

[There was an economic depression when Hertz got his first appointment as a professor. He had few students as a result. The same sort of thing had happened to Sir Isaac Newton, allowing him time to do his experiments, including the ones with light.]

Hertz devoted all of his time and energy to designing a special setup for his experiments. On one side of a long table, he had an oscillator generating electrical currents and a spark or ignition. A few yards away, he set up a receiver or antenna made from copper wire bent into a circle. At the ends of the circle

were small knobs separated by a tiny gap. It looks like a big version of the kind of ring people use for piercing their belly button. He wanted to test if the sparks generated by the oscillator would travel to the antenna, and create a spark there, in that tiny gap.

“And when the ignition takes place here, Hertz noticed that in this antenna, here you find ignition, too,” said Krebs. “It’s a hundredth of a millimeter, so you can’t see it very clearly, so he had to darken the room, and then he had a microscope to look at this point and to notice whether there was ignition or not.”

And it worked. The spark generated on the one side propagates an electromagnetic wave, which travels through the room to the antenna, and a quick spark is seen when generated voltage is high enough.

Hertz was the first to detect this spark in the antenna. At the end of 1888, he wrote a famous paper demonstrating that Maxwell was right, electromagnetic waves aren’t infinitely fast, but instead, they travel at the speed of light.

“This paper was called ‘Strahlen elektrischer Kraft,'” said Krebs, which translates to “rays of electrical force.”

Or, to put things into Maxwell’s language:

Transverse (or Longitudinal) Electromagnetic Waves.

58:
(https://dashboard.dublinschools.net/lessons/resources/electromagnetic_waves_1406604096_md.jpg)

This is the backdrop against which Tesla’s experiments were conducted. Clearly, Tesla was nowhere near understanding how radio works. He didn’t at the time even believe in transverse electromagnetic waves. He also didn’t believe that electrons (then recently discovered) had anything to do with electricity.

59:
(Picture of Marconi with his radio
https://www.thoughtco.com/thmb/5RhQVUt4Qd2-S6VtMaPxXs3xegU=/768x0/filters:no_upscale():max_bytes(150000):strip_icc()/guglielmo-marconi--1874-1937---italian-physicist-and-radio-pioneer-654313946-5baa7d23c9e77c002c954e55.jpg)

Guglielmo Marconi and Real Radio Experiments

Marconi and the Third Invention of Radio
Biography

Born in Bologna, Italy, in 1874, Guglielmo Marconi was a Nobel Prize-winning physicist and inventor credited with the groundbreaking work necessary for all future radio technology. Through his experiments in wireless telegraphy, Marconi developed the first effective system of radio communication. In 1899, he founded the Marconi Telegraph Company. In 1901, he successfully sent wireless signals across the Atlantic Ocean, disproving the dominant belief of the Earth's curvature

affecting transmission. Marconi shared with Karl Braun the 1909 Nobel Prize in Physics. He died in Rome in 1937.

Born on April 25, 1874, in Bologna, Italy, into a wealthy family, and educated largely at home, Guglielmo Marconi possessed a strong interest in science and electricity. In 1894, he began experimenting with radio waves as a student at the Livorno Technical Institute. Incorporating the earlier scientific work of Henry R. Hertz and Oliver Lodge in electromagnetic radiation, he was able to develop a basic system of wireless telegraphy. Though not a scientist, Marconi recognized the value of wireless technology and was adept in putting the right people together to invest in it. In 1897 he received his first patent in England.

Marconi married for the first time in 1905, to Beatrice O'Brien, the daughter of Edward Donough O'Brien, 14th Baron Inchiquin. He and Beatrice had three children—a son, Giulio, and two daughters, Degna and Gioia—before their union was annulled in 1927. That same year, Marconi wed Countess Bezzi-Scali of Rome, with whom he had one daughter, Elettra, named after his yacht.

In his spare time, Marconi reportedly enjoyed cycling, motoring and hunting.

60:
(Photo of Marconi:
https://www.burrosabio.net/wp-content/uploads/2018/09/Macorni-500x277.jpg)

Groundbreaking Work and Nobel Prize

Marconi founded the London-based Marconi Telegraph Company in 1899. Though his original transmission traveled a mere mile and a half, on December 12, 1901, Marconi sent and received the first wireless message across the Atlantic Ocean, from Cornwall, England, to a military base in Newfoundland. His experiment was significant, as it disproved the dominant belief of the Earth's curvature affecting transmission.

Beginning in 1902, Marconi worked on experiments that stretched the distance that wireless communication could travel, until he was finally able to establish transatlantic service from Glace Bay in Nova Scotia, Canada, to Clifden, Ireland. For his work with wireless communication, Marconi shared the Nobel Prize in Physics with Karl Braun in 1909. Not long after, Marconi's wireless system was used by the crew of the RMS Titanic to call for assistance.

Marconi held several positions in the Italian Army and Navy during World War I, starting the war as a lieutenant in 1914 and finishing as a naval commander. He was sent on diplomatic missions to the United States and France. After the war, Marconi began experimenting with basic short wave radio technology. On his beloved yacht, Elettra, he conducted experiments in the 1920s proving the efficacy of the "beam system" for long-distance communication. (The next step would lead to microwave transmission.) By 1926, Marconi's "beam system" had been adopted by the British government as a design for international communication.

In addition to his groundbreaking research in wireless communication, Marconi was instrumental in establishing the British Broadcasting Company, formed in 1922. He was also involved in the development of radar.

Later Years

Marconi continued to experiment with radio technology in his native Italy until his death, on July 20, 1937, in Rome, from heart failure.

In 1943, the U.S. Supreme Court ruled that some of his patents' source of discovery was questionable and as a result restored some prior patents to other scientists, including Oliver Lodge and Nikola Tesla, predated some of his findings. The Court's decision had no effect on Marconi's claim that he was the first to produce radio transmission, he just couldn't claim credit for their work.
https://www.biography.com/inventor/guglielmo-marconi

Sir Oliver Joseph Lodge (Radio Wave Detector)
Sir Oliver Joseph Lodge, (born June 12, 1851, Penkhull, Staffordshire, Eng.—died Aug. 22, 1940, Lake, near Salisbury, Wiltshire), British physicist who perfected the coherer, a radio-wave detector and the heart of the early radiotelegraph receiver.
https://www.britannica.com/biography/Oliver-Joseph-Lodge

61:
(Photo:
https://upload.wikimedia.org/wikipedia/commons/thumb/f/fb/Oliver_Joseph_Lodge3.jpg/444px-Oliver_Joseph_Lodge3.jpg
)

62:
(Photo of Marconi
https://i.pinimg.com/originals/d2/5b/d9/d25bd96a2f9de504da4e90649702f40f.jpg)

Experiments, Patents and Commercial Success

It didn't hurt that, in addition to being a brilliant inventor, he had family connections and wealth on his side. As a young man, Marconi was privately educated, and he transformed the top floor of his family's Italian estate into a working laboratory for his experiments.

After reading an article about Heinrich Hertz's groundbreaking work with electromagnetic radiation, Marconi was determined to build a device to transmit radio waves over long distances. In 1895, at the age of 21, Marconi successfully sent wireless signals over a distance of one and a half miles. Next, he wirelessly communicated over a 12-mile distance and was granted the world's first patent for a system of wireless telegraphy. Over the following decade, he continued to stretch the technology across greater distances and found commercial success outside of the lab. In 1899, he established wireless communication between France and England across the English Channel and founded the Marconi Telegraph Company.

While his business grew, Marconi continued to patent new inventions and achieve milestones in developing radio communication. In 1900, he was granted a patent for "tuned or syntonic telegraphy" and in 1901, he sent and received the first wireless signals across the Atlantic Ocean, 2,100 miles from his now-famous Poldhu station in England to Newfoundland. This experiment disproved the common misconception that the earth's curvature would affect the way wireless signals transmitted on electromagnetic waves.

In 1902, he patented a magnetic detector that became the standard receiver for wireless communications for many years. In 1905, he patented his horizontal directional aerial, and in 1912, Marconi patented a “timed spark” system for generating continuous waves. He later transmitted wireless messages between Poldhu and stations at Glace Bay, Nova Scotia, and Cape Cod, Massachusetts. In 1907, Marconi opened the first transatlantic commercial service between Glace Bay and Clifden, Ireland. In 1912, Marconi’s wireless system was used by the crew of the RMS Titanic to send life-saving distress signals.
https://now.northropgrumman.com/you-can-thank-guglielmo-marconi-for-your-favorite-wireless-devices

On 2 July 1897, the young Italian inventor, Guglielmo Marconi, was granted a patent for his radio. When Guglielmo Marconi wrote to the Italian Ministry of Post and Telegraphs asking it to fund his experiments into wireless telegraphy', he never got a reply. Instead, the minister in charge, Pietro Lacava, wrote on the letter that the young inventor from Bologna had better take himself off to an insane asylum. Marconi packed his bags for England.

Arriving in 1896, the 21-year-old Marconi found a more receptive audience. The Post Office and the Admiralty showed a keen interest in his work.

Wireless telegraphy', as it was known, was nothing new. Experiments had been going on since the 1830s using water, earth and even railway lines. In 1888, German scientist Heinrich Rudolf Hertz produced the first transmissions of a signal using electromagnetic waves.

While several scientists worked on developing these Hertzian waves', it was Marconi that saw the full commercial potential. By 1894, he had built the first complete radio transmission system.

On 2 July 1897, patent number 12,039 was accepted by the Patent Office in London for "The improvements of transmitting electrical impulses and signals". Radio had been born.

Wasting no time, Marconi set up the Wireless Telegraph & Signal Company, which later changed its name to The Marconi Company. That same busy year, he established a radio station on the Isle of Wight, and in the months that followed, a factory in Chelmsford, Essex.

On the eve of the 20th century, radio waves were transmitted across the English Channel between Wimereux in France and South Foreland Lighthouse in Kent, followed by demonstrations in the United States that attracted widespread attention.

In 1909, Marconi was awarded the Nobel Prize in physics for his achievements and the king of Italy made him a marquis in 1924. As for the Marconi Company, that survived in various forms right up until 2006, when it finally went bust after buying expensively-priced internet assets at just the wrong time. Most of what was left was snapped up by Ericsson.
https://moneyweek.com/328008/on-this-day-in-1897-marconi-is-awarded-a-patent-for-radio

The technical feasibility of radio communication was demonstrated in 1899 by the Italian inventor Gugliermo (William) Marconi. He showed that a ship at sea could transmit and receive Morse code (telegraph) signals from a site on shore. Marconi created a company, Marconi Wireless, in London to develop the commercial possibilities of his invention. However there were other companies more formed elsewhere that would prove to be more effective competitors in the field than Marconi Wireless.

In Germany in 1904 the major leaders of the electrical equipment manufacturing, Siemens and AEG (Allgemeine Electricität Gesellschaft), formed a joint-venture company Telefunken to develop the wireless communication technology. For Americans of recent generations it is hard to realize that in the late nineteenth century that the United States was not the foremost leader in technology.

63:
(Photo George Westinghouse:
https://9b16f79ca967fd0708d1-2713572fef44aa49ec323e813b06d2d9.ssl.cf2.rackcdn.com/1140x_a10-7_cTC/George-Westinghouse-1571921638.jpg)

By the 1920's the situation was changing. In 1919 a group of American companies formed a joint-venture company analogous to what had been created in 1904 as Telefunken. The American companies were General Electric (GE), American Telephone and Telegraph (AT&T) and Westinghouse and their joint-venture was the Radio Company of America (RCA). RCA was actually created by GE but AT&T and Westinghouse participated by turning over to RCA the rights to patents they held in radio technology. The core of RCA was Marconi Wireless of America, the American subsidiary of Marconi's British company, which GE purchased for $3.5 million.

[George Westinghouse was by this time totally out of his investment relationship with Tesla for the development of Wardenclyffe.]

The wireless technology was applied to the important but limited field of ship communication. There was extensions into the fields now associated with what later was called shortwave radio communications. These applications were important and their importance was highlighted by the experiences of war during World War I but they were miniscule compared to what later developed for radio technology.

Amplification of electrical signals was achieved in Palo Alto, California in 1906 at a branch of Federal Telegraph, a San Francisco company. In a vacuum tube a weak electrical signal is allowed to control the flow of a much stronger electrical current. In effect, the vacuum tube is a valve which opens and closes the flow of current. In Britain such tube are in fact called valves. The leader of the group at Federal Telegraph was Lee DeForest, a man who for decades vociferously, almost hysterically, claimed credit for the invention of radio. He did not just call it his invention, he frequently called it his baby.

64:
(Lee DeForest with an early triode vacuum tube:
https://www.thehindu.com/children/9yus9m/article25203082.ece/ALTERNATES/LANDSCAPE_1200/21istbdeforest2jpg)

The early commercial development was in the hands of the Westinghouse Corporation. The founder, George Westinghouse, was adept at acquiring patents and developing products based upon those patents. He acquired from the Serbian inventor Nicola Tesla the patents for the alternating current (AC) electrical motor/generator. From Edwin Armstrong Westinghouse acquired patents for the circuitry of the early radios. Armstrong was a true technical genius who invented not just one type of radio receiver but three. The first vacuum tube radio receivers developed by Armstrong (1912) used a circuitry called the regenerative circuit based upon feedback. This also became the basis for radio transmitters. Later, while in Paris during World War I with the U.S. Army Signal Corps, Armstrong invented a much more powerful amplifier circuit called the superheterodyne circuit.

65:

(Superheterodyne apparatus: Early type:
https://upload.wikimedia.org/wikipedia/commons/thumb/3/3b/Homemade_superheterodyne_receiver_1920.jpg/527px-Homemade_superheterodyne_receiver_1920.jpg)

66:
(Later tube Superheterodyne receiver:
https://upload.wikimedia.org/wikipedia/commons/thumb/e/e7/Tuning_Neutrodyne_receiver_1924.jpg/520px-Tuning_Neutrodyne_receiver_1924.jpg)

Later, while in Paris during World War I with the U.S. Army Signal Corps, Armstrong invented a much more powerful amplifier circuit called the superheterodyne circuit. This is the basis for radio, television and radar reception to this day. This is AM (amplitude modulation) radio technology. His crowning achievement was the invention in the early 1930's of an entirely new technology for radio transmission and reception, FM (frequency modulation as opposed to AM, amplitude modulation) radio that provides much higher quality reception. Nefarious litigators bankrupted Armstrong and eventually drove him to suicide in 1954.

In the early 1920's Westinghouse began manufacturing radio receiving sets based upon Armstrong's AM patents. (FM technology was not commercially developed extensively until after World War II.) Westinghouse established the first commerciall radio broadcasting station, KDKA, in Pittsburgh, Pennsylvania in 1920. It was not however the first radio broadcasting station.

The first radio broadcasting station had been established in 1909 in San Jose, California only three blocks from the San Jose State University campus by Charles D. Herrold but it was not a commercial operation. It did broadcast under the call letters FN voice and music to a listening audience on a regular basis. Later, in 1921 its call letters were changed to KQW and finally in 1949 to KCBS.

By the end of 1922 the U.S. Department of Commerce had licensed 26 radio stations and in 1923 five hundred and thirty more so that by the end of 1923 there were 556 radio stations in America.
http://www.sjsu.edu/faculty/watkins/radio.htm

67:
(Photo of Marconi
https://pioneerinstitute.org/wp-content/uploads/marconi-700x466.jpg)

Patents in Europe, Patents in America

On 2 June 1896, Marconi applied for a British wireless telegraphy patent. Shortly thereafter he applied for and obtained a patent in the United States. He electrified the world when he succeeded in sending a wireless signal from Newfoundland to Ireland. Believing that radio waves, like light rays, on which signals had already been sent, shot out into space when they reached the horizon, some scientists did not believe his claim to have sent a signal across the Atlantic. (Only later was it learned that radio waves are reflected downward by an ionized layer of the atmosphere.)

British Professor Oliver Lodge was outraged over the acclaim that soon came to Marconi because he believed that much of it should have gone to himself and other scientists. He believed that Marconi's success was due to "great spirit and enthusiasm and persevering energy" and aid from government officials that enabled him to overcome "many practical difficulties and really begin to establish on a practical basis his system of Wireless Telegraphy by Hertzian waves."

68:
(Reginald Aubrey Fessenden:
https://www.edisonmuckers.org/wp-content/uploads/2019/10/Screen-Shot-2019-10-22-at-11.09.47-AM-624x352.png)

Once the problem of finding a way to transmit voice and music by radio was solved by Aubrey Fessenden, the development of a viable radio broadcasting industry became possible once the triode vacuum tube was developed. As a detector of radio waves it was much superior to the coherer used by Marconi. (The coherer was invented by Oliver Lodge and improved upon by Marconi.) The story of the triode tube began when, in 1904, John Ambrose Fleming, an English electrical engineer, made use of what was called the Edison effect after its American discoverer, Thomas A. Edison, to invent the diode tube. In 1906, American inventor/entrepreneur Lee deForest added a third element to this tube; thus creating a triode tube that could both detect and transmit radio waves. He called it the Audiron. Terribly outdated well before the twentieth century's end, nonetheless, this was one of the most important inventions of the century.

69:
(John Ambrose Fleming and his diode vacuum tube:
https://www.icr.org/i/articles/af/fleming_wide.jpg)

In 1916, U.S. courts ruled that deForest had infringed on Fleming's patent, and that Marconi had infringed on deForest's patent. This decision meant that neither deForest or Marconi, who had purchased Fleming's patent, could use the triode tube. [This meant they could not make a practical AM radio under the patent ruling.] Until the stalemate created by this and other patent conflicts could be settled, which did not take place until after World War I, a broadcasting industry could not be created.

In addition to technical problems, Marconi had to contend with competitors and hostile governments. The British government had no intention of letting him threaten the Post Office's monopoly, and it ceased being helpful to him after he allowed his cousin to form the Wireless Telegraph and Signal Company in 1897. Both this company and its American subsidiary lost money for many years before they turned a profit. One of the reasons his company fared relatively well is that he hired able men to manage it.
70:
(Ship’s Radio Room, 1920s:
http://www.pandosnco.co.uk/P&OSNCO/RadioDept/640_marconi-room.jpg)

Barred by law from equipping many of the world's navies and prevented in Great Britain and other countries from providing a message service ashore because this was a government monopoly, Marconi had to turn to providing communications to ships at sea and between continents. In the latter business he had formidable competition. Transatlantic communication was then the preserve of a British cable cartel that did not relish wireless competitors muscling in.

But, despite his lead on his competitors and his tireless and difficult pursuit of an international wireless monopoly, he was unable to achieve monopoly status. The fact that this quest often required the defense of his patents and attacks on others' patents illustrates a negative side of the patent system, for while the granting of a temporary monopoly provides an incentive to invent, even the potential of resulting monopoly profits leads to sometimes huge legal costs. Conflicts over patents, which was frequent in the early days of all branches of the electric industry, retarded progress.

71:
(US Navy Shore Station, World War I:
https://usnhistory.navylive.dodlive.mil/files/2017/05/05-067.jpg)

The American Marconi Company's initial refusal to sell its apparatus, and its insistence on providing men to operate it incensed the U.S. Navy, which did not want to use equipment owned and operated by a predominantly foreign-owned company. … The U.S. Navy became even more dissatisfied about the American Marconi company's foreign ownership after World War I broke out and the British cut America's cable connections with Germany – a country the U.S. was not yet at war with – and censored messages on still intact cables. The Navy responded by building its own shore stations, equipping them with radio transmitters and receivers purchased from Lee deForest, other Americans' firms, and a German firm.

Due in part to the Marconi Company's purchase of competitors who had infringed on its patents, by the time World War I broke out, the American Marconi Company dominated the American radio market; so it had no overwhelming need to develop a new [broadcast radio] service. In addition, Marconi had no surplus funds to plow into a new business. Shortly after the end of World War I, the U.S. government 's hostile attitude convinced Marconi that his company had no future in America, and he agreed to sell it to GE.

72:
(1928 RCA radio, saved as PDF download: (can also be viewed online)
http://www.indianaradios.com/RCA%20Radiola%2060%20Radio.htm)
(recaptured as a .png)

To make possible, it was claimed, the production of the most technologically advanced apparatus and a complete radio system, GE's Owen Young put together a patent pool consisting of GE, Westinghouse, American Telephone and Telegraph Company, United Fruit Company, and a newly-created and jointly-owned firm composed of American Marconi's assets, the Radio Corporation of America. (Subsequently, RCA would create the National Broadcasting Corporation.) Formed in 1919, RCA, which originally had a government representative on its board of directors, was supposed to become an international communications monopoly that would sell radio apparatus produced by GE and Westinghouse. Although it became the dominant company in the radio industry in the U.S., it fell short of achieving even a domestic monopoly. It took little more than a decade for the federal government's policy towards RCA to reverse, and in 1930 the Department of Justice charged RCA with using its portfolio of patents to restrain competition. This antitrust action dragged on for almost thirty years.

73:
(Tesla’s Wardenclyffe Tower, as he hoped it would be on completion:
https://www.teslasociety.com/pictures/wardenc3.jpg)

The Contribution of Nicola Tesla

Educated as an engineer at the Technical University at Graz, Austria and at the University of Prague, Nikola Tesla was failure as an entrepreneur and was nearly penniless when he died. Nicola Tesla's greatest contribution was the invention of a system for the generation of polyphase, alternating electric current. Unfortunately, this highly eccentric Serbian immigrant (1856-1943) made himself a laughing stock by claiming that he could split the Earth like an apple; had invented a death ray that could destroy

10,000 airplanes at a distance of 250 miles; would distribute free energy; and had received messages from Mars. (The mad scientist in 1940s Superman comics was patterned on him.)

A pioneer in wireless communication and fluorescent lighting, in 1891 he invented the Tesla coil which was widely used in radio and television sets. In 1943, the Supreme Court reversed a decision made by a lower court decades earlier that had rejected Tesla's challenge of Marconi's basic radio patents. It invalidated Marconi's patents on the basis of their having been anticipated by Telsa's work.

In 1885, he sold the patents to his alternating current system to George Westinghouse, head of the Westinghouse Electric Company, who used Tesla's system in 1893 to light the Columbian Exposition in Chicago. In 1896, Tesla installed the generating equipment that carried power from Niagara Falls to Buffalo, New York. His advocacy of alternating current for the transmission and distribution of electricity to homes and factories incensed his first American employer, Thomas Edison, who had blundered by choosing to use direct current. Edison mounted a smear campaign against Tesla and alternating current, which he said was unacceptably dangerous. To prove that alternating current was not too dangerous to use, Tesla allowed it to flow through his body and light a lamp he held in his hand. Although the nation was electrified with alternating current, this did not make Tesla a wealthy man because, when Westinghouse said that the financial burden of his contract with Tesla endangered his company, Tesla tore up the contract with his friend.

His failure as an entrepreneur wasn't because he was unable to get attention, as he attracted a great deal of press coverage because even the claims that he could back up seemed very wild at the time. He backed up one claim by demonstrating a boat guided by remote control in Madison Square Garden. Photographs were taken of his man-made lightning, which included flashes as long as 135 feet.

However, unlike Edison and Marconi, [Tesla] was never able to obtain the financial support he needed to make his company a success.

74:
(Tesla’s Wardenclyffe Tower, on the verge of demolition:
https://www.teslasociety.com/pictures/wardernc2.jpg)

[Tesla] had to abandon [the Wardenclyffe Tower] project when [J. P.] Morgan withdrew his support. Subsequently, for lack of money, many of his ideas never got beyond his notebooks. [Morgan did keep paying for Tesla to live lavishly in a hotel suite in Manhattan, NYC until Tesla’s death in 1943.]
https://www.westga.edu/~bquest/2001/radio.htm

(Tesla and Marconi:
https://allthatsinteresting.com/wordpress/wp-content/uploads/2016/03/tesla-marconi.jpg)

With his newly created Tesla coils, the inventor soon discovered that he could transmit and receive powerful radio signals when they were tuned to resonate at the same frequency. When a coil is tuned to a signal of a particular frequency, it literally magnifies the incoming electrical energy through resonant action. By early 1895, Tesla was ready to transmit a signal 50 miles to West Point, New York... But in that same year, disaster struck. A building fire consumed Tesla's lab, destroying his work.

The timing could not have been worse. In England, a young Italian experimenter named Guglielmo Marconi had been hard at work building a device for wireless telegraphy. The young Marconi had taken out the first wireless telegraphy patent in England in 1896. His device had only a two-circuit system,

which some said could not transmit "across a pond." Later Marconi set up long-distance demonstrations, using a Tesla oscillator to transmit the signals across the English Channel.

Tesla filed his own basic radio patent applications in 1897. They were granted in 1900. Marconi's first patent application in America, filed on November 10, 1900, was turned down. Marconi's revised applications over the next three years were repeatedly rejected because of the priority of Tesla and other inventors.

The Patent Office made the following comment in 1903:

Many of the claims are not patentable over Tesla patent numbers 645,576 and 649,621, of record, the amendment to overcome said references as well as Marconi's pretended ignorance of the nature of a "Tesla oscillator" being little short of absurd... the term "Tesla oscillator" has become a household word on both continents [Europe and North America].

75:
(The Four Robber Barrons of 1900-1930 – Rockefeller, Carnegie, Morgan and Ford:
https://comicvine1.cbsistatic.com/uploads/scale_super/11114/111142536/5278091-9k%3D.jpg)

But no patent is truly safe, as Tesla's career demonstrates. In 1900, the Marconi Wireless Telegraph Company, Ltd. began thriving in the stock markets—due primarily to Marconi's family connections with English aristocracy. British Marconi stock soared from $3 to $22 per share and the glamorous young Italian nobleman was internationally acclaimed. Both Edison and Andrew Carnegie invested in Marconi and Edison became a consulting engineer of American Marconi. Then, on December 12, 1901, Marconi for the first time transmitted and received signals across the Atlantic Ocean.

Otis Pond, an engineer then working for Tesla, said, "Looks as if Marconi got the jump on you." Tesla replied, "Marconi is a good fellow. Let him continue. He is using seventeen of my patents."

But Tesla's calm confidence was shattered in 1904, when the U.S. Patent Office suddenly and surprisingly reversed its previous decisions and gave Marconi a patent for the invention of radio. The reasons for this have never been fully explained, but the powerful financial backing for Marconi in the United States suggests one possible explanation.

76:
(Marconi Radio Logo from 1920s:
https://www.retrograph.com/wp-content/uploads//thumbnails/s116RGL006.jpg)

Tesla was embroiled in other problems at the time, but when Marconi won the Nobel Prize in 1911, Tesla was furious. He sued the Marconi Company for infringement in 1915, but was in no financial condition to litigate a case against a major corporation. It wasn't until 1943—a few months after Tesla's death— that the U.S. Supreme Court upheld Tesla's radio patent number 645,576. The Court had a selfish reason for doing so. The Marconi Company was suing the United States Government for use of its patents in World War I. The Court simply avoided the action by restoring the priority of Tesla's patent over Marconi.
https://www.pbs.org/tesla/ll/ll_whoradio.html

77:
(Photo – Marconi and Tesla

https://i.ytimg.com/vi/BNlGCG7t1bQ/maxresdefault.jpg)

Marconi Sues the US Government – Previous to the 1943 Case

Marconi had been conducting his own experiments and in 1896, sent and received Morse code-based radio signals at distances spanning nearly 4 miles (6 kilometers) in England. That same year, he applied for, and was granted, the world's first patent in wireless telegraphy in England [source: Nobel Prize].

Tesla applied for his first patents in radio work in 1897 in America. He also built and demonstrated a radio-controlled boat at Madison Square Garden in 1898. Here's where things get sticky.

In 1900, the U.S. Patent Office granted Tesla patents 645,576 and 649,621, the fundamental design of the Tesla coils, on March 20 and May 15 respectively. Tesla's radio patents gave him ownership over one of the key necessities in radio communications. That same year, on Nov. 10, Marconi filed patent No. 7777, for tuned telegraphy.

At first the patent office denied Marconi's applications on the grounds that his work relied on the use of Tesla coils [source: PBS]. Unfazed, Marconi used his father's connections and wealth to spearhead a profitable business based on his telegraph technology while continuing to pursue his radio patents. In 1901, he transmitted the first transatlantic telegraph.

Marconi reapplied for three years while he gained financial support from company investors Andrew Carnegie and Thomas Edison. Finally in 1904, the U.S. Patent Office inexplicably reversed its earlier decision and gave the Italian the patent for invention of the radio.

Marconi won the Nobel Prize for physics in 1909 [source: Nobel Prize], further fueling the rivalry with Tesla. In 1915, Tesla sued the Marconi Company for patent infringement to no avail. Marconi had won. Or had he?

In an ironic twist of fate, Marconi's company sued the U.S. government in 1943 for patent infringement during World War I. But the case never made it to court. Instead, to avoid the lawsuit altogether, the U.S. Supreme Court upheld patent 645,576, thus restoring Tesla (who had died a few months earlier) as the inventor of the radio. Nevertheless, many people still tend to think of Marconi as the father of the radio.
https://science.howstuffworks.com/innovation/inventions/who-invented-the-radio.htm

(That last paragraph needs to be examined and fact-checked:)

78:
(Photo of Marconi:
https://radiofidelity.com/wp-content/uploads/2019/05/Guglielmo-Marconi-6-2048x1280.jpg)

Supreme Court Ruling – Mere Months After Tesla's Death –
How Not to Read a Supreme Court Ruling

In the Court of Claims, Marconi Wireless asserted that the government had infringed four U.S. patents, among which were No.763,772 and reissue patent No.11,913. Both had been issued to Guglielmo Marconi himself. Additional Marconi company patents alleged to be infringed were one issued to

Oliver Lodge, No. 60,9154, and Ambrose Fleming's patent No. 803,684. In its 1935 decision, the Court of Claims ruled that the radio equipment used by the government had not infringed on the Marconi patent.

In its 1943 decision, however, the Supreme Court rejected the broad claims of this Marconi patent, for the most part declaring it invalid. Indeed, the majority Supreme Court opinion stated that Marconi's work had been anticipated by John Stone Stone (patent No.714,756) and Oliver Lodge (patent No. 609,154). The Supreme Court also examined Tesla's patent No. 645,576 and noted that Tesla had used four tuned circuits before Marconi. In addition, the Court observed that Lodge had provided a means for varying the tuning frequency, which was lacking in Tesla's patent.

Thus, while the Supreme Court declared the Marconi patent invalid, it affirmed prior work and patents by not only Tesla, but by Lodge and Stone as well. As for the Lodge and Tesla patents, the Supreme Court's opinion discussed Tesla's and Lodge's work in two pages and three pages respectively, but devoted a full twenty pages to Stone's work. What was so important about Stone's radio patent? "Stone's [patent] application," the Court wrote, "shows an intimate understanding of the mathematical and physical principles underlying radio communication and electrical circuits in general."

The Supreme Court never determined that Tesla invented radio. Contrary to Aitken's account, the validity of the Lodge patent was not in dispute before the Supreme Court; it was upheld in the Court of Claims where it was ruled that the government had infringed the patent. The matter was not appealed. Lee de Forest, though, came closest to the actual Court documents, but he did not acknowledge that Tesla was ahead of Stone in using four tuned circuits, even if Tesla failed to provide a variable inductance for adjusting them.

Finally, we might question whether the Court was correct in largely rejecting the Marconi tuning patent. The judgment in this matter was not unanimous. Chief Justice Harlan Stone wrote the majority opinion for five justices. One justice abstained and three, including the distinguished Felix A. Frankfurter, dissented. Both Justices Frankfurter and Rutledge argued in favor of the Marconi patent and against the importance of John Stone's invention. Historians might well continue to scrutinize this case.
http://www.mercurians.org/1998_Fall/Misreading.htm

79:
(Image of Vintage Radio: Saturday Evening Post – possibly a Norman Rockwell painting --
https://www.saturdayeveningpost.com/wp-content/uploads/satevepost/2017-mj-pg97-VintageAd_1929_02_09-400x526.jpg
)

So … Who Invented Radio?

NOT Tesla! Not really Marconi. Hughes came THIS CLOSE. I think it was really closest to Hertz, or maybe Hughes, though Hertz did not see the practical applications of his discovery, and Hughes had only a slight inkling of what he might have accomplished.

80:

(Image of Hertz:
https://prabook.com/web/show-photo-icon.jpg?id=1570078&width=220&cache=false)

One thing is clear – It took Marconi and his financial backers to put all the pieces together and give us what was to become modern radio, television, WiFi and telecommunications. We may never know whether the German, English or American Navies really got some of the pieces together first. But these military developers certainly moved radio development rapidly forward during World War I, as did the companies which became Marconi Radio, RCA (a General Electric spinoff) and others in the 1920s and 1930s.

– Bob Primak for Lexington Technology Group
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