THE ELECTRONICS REVOLUTION

Inventing the Future

J. B. Williams

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Introduction

On December 12, 1901, Guglielmo Marconi, a young man of mixed Italian and British parentage, was on the windswept Signal Hill at St Johns', Newfoundland.[1] He was sitting in a room in a disused military hospital at the top of the hill behind a table full of equipment. Outside, a wire ran up to a Baden-Powell six-sided linen kite which he and his assistant George Kemp were only keeping aloft with difficulty. They had already lost another kite and a balloon, and they were only using these because an antennae array at Cape Cod had blown down.

On the other side of the Atlantic, above Poldhu cove in Cornwall, almost as far west in Britain as you can get without falling into the sea, was another, much larger collection of equipment. A small power station generated 25 kW of electricity, and when a Morse key was pressed a huge arc leapt across a spark gap, dying away when the key was released. The signal thus generated was led to a set of wires held aloft by two 60 m towers. This arrangement replaced a much larger 120 m–diameter inverted cone array which, again, had blown down.

At 12.30 p.m., over the static, Marconi thought he heard something—dot dot dot. It was the Morse code for S that he had arranged to be transmitted from Poldhu. He passed the earpiece to Kemp who listened. He could hear it too. Twice more that day they heard the signal, but then the weather worsened and they had to stop. What they had achieved was to receive a wireless signal from the other side of the Atlantic, a feat that many experts thought was impossible.

Marconi now had the problem of when to announce his success, because the doubters were convinced that electromagnetic waves travelled in straight lines and couldn't bend around the curvature of the Earth. Basically they were right, but he had been lucky, as the particular range of frequencies generated by his transmitter would bounce off atmospheric layers and, hence, could be received way beyond the horizon. In the event, he waited a few days before saying anything to the press.

Later, he was to prove long-distance communication much more convincingly, and in the following decade or so the Marconi company built up a substantial business supplying wireless communication facilities, particularly to ships. When the 'Titanic' hit an iceberg

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and sank, it was the Marconi equipment installed on her which was used to call for help, and that on the 'Carpathia' which received the SOS which allowed her to come to the rescue and save many lives.

It might be thought that Marconi had mastered the technology for wireless communication, but what he was using was very crude and it was only refinement and huge amounts of power that enabled it to work at all. It fact, what he was using was purely electrical, and a blind alley. What was needed for really satisfactory equipment was the means to enlarge or amplify signals and the ability both to generate and receive them in a very narrow frequency band. This required electronics, and in 1901 it didn't exist.

In 1897, J. J. Thompson had discovered the properties of what he called 'corpuscules', and it was only slowly that the word 'electron', coined by George Johnstone Storey some 6 years before, came to be used. Electronics is one of those words that everyone knows what is meant by it, but when it comes to a definition, it slips through your fingers. As will be seen, a reasonable definition is 'equipment using devices that manipulate electrons'.

The Electronics Revolution is about how we went from absolutely nothing to the abundance of electronic items that we regard as normal today. For communication we expect mobile phones, and the Internet. Now it seems that every man, woman and child has a mobile phone in their pocket or handbag. Something that was the plaything of the few is now the norm for everyone. Modern business could not function without the instant communication of email.

For entertainment, there are radios and TVs, and music on tap for our personal use. We so expect instant TV from anywhere in the world that it is difficult to realize that it was as late as 1962 before the first live TV pictures flashed across the Atlantic, and they could only be maintained for a matter of minutes. The effect has been for us to think in terms of 'one world'. We become involved in wars or disasters in other countries in ways that would have been incomprehensible to our forefathers.

For work and play, there is computing. Home computers have become ubiquitous. Offices are full of computers, and yet more computers control whole organizations. But computers can also be in the form of microprocessors buried in appliances such as washing machines or central heating boilers. Outside, the household's car is very likely to have electronic management systems.

There is a long trail of successes, and some failures, but with one thing leading to another, often in an apparently unrelated way: wartime radar to microwave ovens, and moonshots to worldwide live TV. The intention is to follow these links to show how it all fits together. This not a 'history of technology' but one of how the technology produced all this diversity and, in doing so, how these developments created a revolution in everyday lives. For example, without radio and TV our modern democracy is barely imaginable. So often this impact of technology has been largely ignored.

How was all this achieved? Not by 'science', but by engineering and technology. There is often a great confusion between these, with the words being used interchangeably, but there is a key difference. Science is about ideas in the natural world, while engineering is about their exploitation into technology useful to humankind. Even once the science is in place, in order to introduce a major technological change there are three distinct phases: invention, development and exploitation.

The fundamental science comes first. James Clerk Maxwell predicted the existence of electromagnetic waves, and Heinrich Hertz proved he was right—that was the science. Others, such as Eduoard Branly who developed the coherer detector, or Oliver Lodge who demonstrated a wireless communication system which could ring a bell remotely, were the inventors.

At this point, though there was interesting knowledge, there was still nothing useful. It required a Marconi to come along and bring it all together. It was often said by his detractors that Marconi didn't invent anything. Besides being rather unkind about his abilities, it completely misses the point. What he was able to do was to take these various inventions and develop them into a system. He could then take this and exploit it to allow communication from a ship to the shore or vice versa. He had produced something useful to people.

Though most of the knowledge of the relevant physical laws of electricity was understood before the end of the nineteenth century, much concerning electronics had still to be learned. In some cases, it took some time to understand the devices that had been invented. With solid state physics, mostly investigated in the first half of the twentieth century, it was the search to understand that led to the invention of transistors. The fantastic bounty brought by integrated circuits and microcomputers, though, was more a matter of technology than of science.

To follow the story, we need to look at the people who made things happen. The twentieth century was characterized by the rise of the large research organizations such as Bell Labs so the developments are often hidden behind the corporate façade, but where the individuals can be identified their stories are told. Some of these people will be well known, but others may well be surprising. There are many unsung heroes who made vital contributions but received little credit because someone else was better at the publicity.

Some names are known, such as Tim Berners-Lee for the World Wide Web, and John Logie Baird for television (though his contribution was not quite what it is often assumed to be). People such as Isaac Schoenberg and Alan Blumlein, who really got the system going, are barely remembered, and what of Boris Rosing who always seems to be at the back of all the successful television developments? And who has heard of Nobel prizewinner Charles Kao whose determination gave us fiber optics on which modern communications depend?

We don't want to get bogged down in the sterile arguments about who was the first to invent something. When the time was ripe often a number of people come up with much the same idea. Simultaneous invention is quite common: Jack Kilby and Robert Noyce came up with integrated circuits at much the same time, though the concept was already known. What matters here is the turning of ideas into something useful.

At the end of all these developments we have reached a state where electronics have permeated every aspect of our lives. As so often, these things were summed up by a TV advert. An amusing one for Renault electric cars imagined a world where common items were powered by tiny engines and not by electricity. The star was a handheld card machine which had to be refuelled to work. In one way it made its point, but in another completely missed it. Without electricity there would be no electronics. Without electronics there would be no computers. Without computers credit cards would not exist so there would be no need for a card machine. In any case, the system depends on wireless and other electronic communication, so the handheld unit would not exist.

What did Marconi do when the world began to change to electronics? The record of people and organizations, when the technology on which they depend becomes obsolete, is not good. He was lucky in that he employed J. Ambrose Fleming as a consultant and so, by chance, his company came to hold one of the key patents. He had the foresight to employ Henry Round to develop the necessary devices, so the company smoothly made the transition. The great arc transmitters were phased out, and electronics took over.

NOTE

1. The whole story of Marconi's exploits is well covered at the website Marconi Calling available at: http://www.marconicalling.co.uk/introsting.htm

2

Missed Opportunities: The Beginnings of Electronics

Just because something doesn't do what you planned it to do doesn't mean it's useless.

Thomas A. Edison

One of the areas that particularly attracted the interest of experimenters in the nineteenth century was the behavior of evacuated glass tubes when excited by electricity. As the characteristics change with the amount of gas remaining in the equipment, the whole experiment depended on how well the air could be removed. Without the development of efficient vacuum pumps electronics would never have got started.

Though many people had played with these devices before, it was Herman Geissler who brought everything together. He was from a glassblowing family but had set up in Bonn in Germany as an instrument maker, which often involved working with glass.[1] In 1857, he produced a more efficient vacuum pump and used it to evacuate a glass tube into the ends of which he had sealed metal electrodes. The tube was energized with a high voltage produced by a Ruhmkorff coil, an induction coil similar to those now used to provide the spark for a petrol engine, and also as used later for generating wireless waves.

It was soon found that a very small amount of a particular gas gave rise to a discharge of a specific color. With a range of gasses, tubes exhibiting different shades could be produced. This work eventually led to gas discharge lamps, and in particular the neon lights so popular for shop signs. Geissler produced many tubes of complex shapes and colors which had quite a vogue as decorations, though his main work was used for experimental purposes by serious physicists within universities (Fig. 2.1).

Further work on vacuum pumps by Sprengel and others brought pressures sufficiently low to enable the development of electric incandescent lamps around 1879, but at the same time Englishman William Crookes managed to improve the pump still further, producing even lower residual pressures. What was discovered was that, as the amount of gas in the tube was decreased, a dark space started to appear in the glow in the tube at the cathode (negative electrode) end. As the vacuum increased this dark space would eventually fill the whole tube, but the end of the glass by the anode (positive electrode) would glow.

In an elegant paper presented to the British Association in 1879, Crookes demonstrated the properties of the particles, or whatever they were, in these tubes.[2] The anode could be

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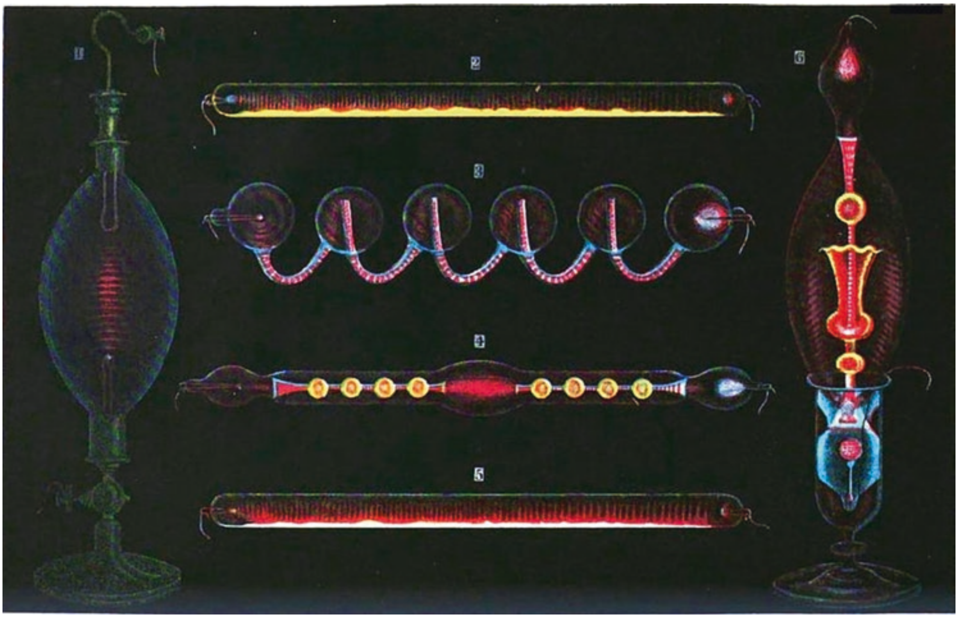

Fig. 2.1 An example of the different colors from Geissler tubes. *Source:* https://en.wikipedia.org/wiki/Geissler_tube#/media/File:Geissler_tubes.jpg

any shape he liked and the particles would go straight past and strike the end of the tube, which glowed because of phosphorescence. The particles were causing the glass itself to glow, and different glasses would produce different colors. His famous 'Maltese cross' experiment used an anode of that shape which cast a matching shadow on the end of the tube. Clearly the particles went in straight lines.

In other demonstrations he showed that the 'beam' of particles could be bent with a magnet and that it was strong enough to turn a small paddle wheel. It was all terribly interesting to the scientific community, but neither Crookes nor any of his colleagues had any idea of what they were looking at or what it could be used for apart from entertainment. Because various minerals were found to glow different colors in the 'beam' very fancy devices could be produced.

It was at this point that Thomas Edison entered this story, as in so many others. In the early 1880s he was trying to improve his incandescent lamps. One of the main problems was that the bulbs became blackened.[3] To try to prevent this he placed another electrode in the bulb and made this more positive than the filament. The theory was that, as it was known the carbon atoms from there were negatively charged, they might be attracted to the other electrode instead of the glass.

It didn't work in stopping the blackening, but he found that a current flowed. When he reversed the polarity, no current flowed. It was a very interesting result, but he had no idea what was happening, or what he could do with it. He demonstrated it to anyone who was interested, and it became known as the Edison effect. However, though many people experimented with the effect its significance was not appreciated for many years.

In 1897, J. J. Thomson took a Crookes tube and by using two lined-up apertures formed a beam of these particles.[4] He then carefully measured the deflections with both magnetic and electric fields. From this he could deduce that these particles always had the same charge-to-mass ratio, i.e., the amount of electricity they carried for their weight. They were also extremely light. Basically, he had discovered the electron, though he didn't call it that.

In the same year back in Strasbourg (then in Germany), Ferdinand Braun, a professor at Strasbourg University found a use for the Crookes tube. He built a long tube with a small hole in an aluminum plate so that he obtained a narrow beam producing a spot on the end phosphorescent 'screen'. A coil set horizontally with an alternating current in it caused the spot to move up and down in time with that source. By viewing the spot in a rotating mirror he was able to see the waveform of the signal in the coil.[5]

It was most ingenious. What he had produced was a means of examining waveforms—the oscilloscope, the essential tool of electronic engineering. Two years later, Braun's associate at Strasbourg, Jonathan Zenneck, added another coil to achieve a method of scanning the spot horizontally (a timebase). This meant that the waveform would appear on the end of the tube instead of in the rotating mirror.

The 'Braun tube' soon set people thinking about further ways in which it could be used. Its great advantage over other methods of displaying signals was that it used electrons of almost negligible mass so the beam could be moved around the screen at very high speed. This was to have a very important application in the future (see Chap. 4).

In 1899, J. Ambrose Fleming, then the professor of electrical engineering at University College, London, was made a consultant to the Marconi Wireless Telegraph Company.[6] Marconi, having pioneered wireless telegraphy, was in need of more technical expertise as his ambitions grew. This was particularly important for the attempt to transmit signals across the Atlantic and it was Fleming who designed the huge spark transmitter installed at Poldhu to enable this.

Fleming had had a complicated career as he struggled to educate himself and provide for his widowed mother. Much of his time had been spent teaching in one form or another. An important exception was when he worked for the Edison Lighting Company in London, starting in 1882 and remaining until 1885 after it had merged with Swann's company.[7] There he had known about the Edison effect and had conducted some research into it. In the 1890s, after returning to academia, he gave a number of public lectures on the subject. He was fascinated by it.

It was only in October 1904 that he had a 'sudden very happy thought' as to how he could use the Edison effect.[8] At the age of 55, he was becoming increasingly deaf and so was looking for a way of detecting the wireless waves which avoided the use of an earphone to listen to the output of the magnetic detector. The wave was oscillating backwards and forwards at a high frequency; it was an alternating wave. A normal electrical instrument could not follow this and so could not detect its presence. What he suddenly realized was that, if he passed the signal through a device showing the Edison effect, only half of the signal in one direction would go through. Now he had a signal that his meter would respond to.

It didn't take him long to set up a crude spark transmitter and then connect one of these modified light bulbs to the receiving aerial. With a suitable battery to light the lamp, sure enough his meter detected the presence of the radio signal. Realizing how important a discovery this was, he rushed out and patented it.[9] The trouble was that the terms of his consultancy with the Marconi Company meant that he had to assign the patent to them.

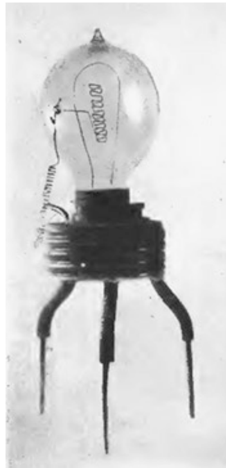

Fig. 2.2 An early Fleming 'valve', showing its derivation from a light bulb. The looped filament and the squiggly other electrode (anode) can clearly be seen. *Source:* Fleming J A, *The Thermionic Valve and its developments in Radiotelegraphy and telephony*

Fleming called the device the 'oscillation valve', which seems rather confusing today (Fig. 2.2). What he meant was that for an oscillation, in other words an alternating signal, the device acted like a 'valve' in that it only allowed the current to flow in one direction. Today, in the UK it is known as a 'thermionic valve', the last part of the name having stuck, though in America it became known as a 'vacuum tube'. What he had actually invented was a diode or rectifier to convert alternating current into direct current.

There were those who thought he had done very little, only using a known effect in a slightly different way.[10] This misses the point in that invention is often the taking of an idea from one area and applying it in another. What he achieved was to give the world the thought that vacuum tubes derived from light bulbs could be applied to electrical circuits with advantage. In other words, electronics had been invented.

The scene then moved to the United States where Lee de Forest was interested in the same area and had been experimenting with devices where one side was heated with a Bunsen burner. He heard about Fleming's presentation to the Royal Society in London on March 16, 1905 describing his oscillation valve. He patented a similar device but connected to a telephone receiver instead of Fleming's meter.[11] He probably thought that he had invented something different, but it was to lead to no end of difficulties later (Fig. 2.3).

By October of the following year he had had a better idea and patented a device 'for amplifying feeble electrical currents', which he called an Audion.[12] In this he added a third electrode in the glass envelope in the form of a wire grid lying between the heated filament and the current collecting plate or anode. A small change in voltage applied to this grid would cause a large change in the current between the filament or cathode and the anode. In a suitable circuit, amplification of a signal could take place. The patent was rather confused; it was unclear if he really understood what he had invented because he described the grid's movement as the cause of the change.

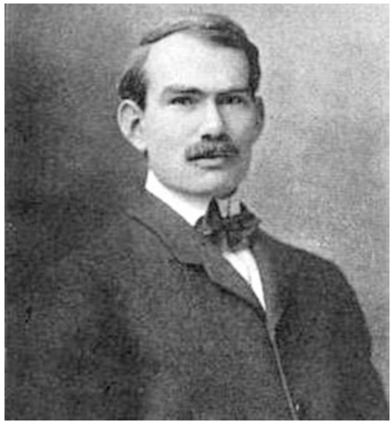

Fig. 2.3 Lee de Forest, the American inventor who was always embroiled in patent disputes. *Source:* http://upload.wikimedia.org/wikipedia/commons/6/65/Lee_De_Forest.jpg

Fleming took the view that the patents were deliberately confusing to disguise the fact that they were closely based on his work.[13] De Forest failed to acknowledge Fleming's contribution and this led to a feud between the two men. Also the problem for de Forest was that he couldn't use the devices in wireless receivers without infringing Fleming's patent. The ensuing patent battle between the Marconi Company in America and De Forest's company dragged on until 1916 when victory went to Fleming and Marconi.

It seems that de Forest didn't really understand how his device worked, particularly whether the electrons travelled through the small amount of residual gas or whether through the vacuum. Though he spent the next few years after its discovery trying to improve it, he was unable to make useful stable devices. As a result, he didn't really know what to do with his invention.

In Britain, the Marconi Company started to manufacture Fleming valves and use them as detectors in wireless receivers. Unfortunately, though more sensitive, they were not as reliable as the trusty magnetic detectors previously used. The filaments had a habit of burning out, so the sets were made with two vacuum tubes and a switch to change over between them should one fail mid-message.[14]

In 1911, de Forest let the British version of his patent lapse. The way was now open for the Marconi Company to make their own 'amplifying' vacuum tubes, and they produced the 'Round' valves. These were so named not because they were circular but after Henry Round who developed them for the company, though they were manufactured by the Edison Swann electric lightbulb company.

They were curious devices and difficult to make, though they worked well. They depended on a small amount of residual gas to function correctly. The problem was that during operation the gas molecules would 'stick to the walls', so reducing the performance. To overcome this, an asbestos pellet was used in a narrow extension at the top of the tube, and this adsorbed some of the gas. By heating this, more gas was released and the correct quantity could be maintained. The wireless sets incorporating the vacuum tubes had small electrical heating coils to do this, but the operators often preferred to use a lighted cigar for a little judicious warming.[15]

These vacuum tubes were satisfactory for Marconi's business where only relatively small numbers were required and the sets were attended by skilled operators, but for general use they were neither easy enough to make nor to use. Clearly some further improvement was necessary.

In America, de Forest was still struggling to improve his Audions, but they were far from satisfactory, suffering from unreliability of operation and short life. However, he thought that he could make a telephone amplifier which would be free of the patent disputes. In October 1912, he took his experimental unit to Western Electric so that the Bell Telephone engineers could look at it. They had a specific problem, in that while a relay would extend the distance of a telegraph signal there was no equivalent device for telephones. After a certain distance the telephone signal became too weak to be heard. The engineers were in great need of a way of boosting the signal so that conversations could take place right across the United States.

The Audion couldn't do this, but Western Electric engineers thought it held promise and in 1913 the company bought the rights to use the Audion for telegraphy and telephony. Harold D. Arnold set to work to improve the device. It was realized that the vacuum was not high enough and they obtained a superior vacuum pump to enable them to produce a 'harder' vacuum. After Western Electric had made numerous detail improvements they had a satisfactory device. In 1914 it enabled the company to extend the long-distance telephone system from New York to Denver and soon afterwards to San Francisco.[16]

Around the same time Irving Langmuir had finished his work on the blackening of electric lamps and started to look at the Edison effect.[17] By using the improved pump which he had developed for his work on the lamps he soon independently confirmed that the Audion worked much better with a higher vacuum. He investigated the characteristics thoroughly and soon produced greatly improved devices, which he called 'Radiotrons'. Inevitably, this led to yet another patent dispute as to who had improved the Audion, this time between General Electric and AT&T, Western Electric's parent company.

Around this time, other people were discovering some of the properties of these devices, and their uses. Edwin H. Armstrong, still a student, somehow got hold of an Audion and began to experiment with it. He found that if he fed back just enough of the output of the device to its input in a tuned wireless receiver he could achieve a much higher amplification. He had discovered 'regeneration' which was enormously valuable in improving the performance of the sets.

He also discovered that if he increased the feedback further the device would begin to oscillate, to generate a continuous signal at the frequency defined by the components around the Audion. At last a source of continuous output was available which eventually could replace all those intermittent sources like the spark transmitters. Inevitably he became embroiled in disputes with de Forest who claimed them as his invention, along with several others. Meanwhile, in Germany, a different route was taken. Two branches of the armed forces were interested in the possibilities of wireless communication. The Army was backing the Siemens Company who used Professor Braun as a consultant. The Navy supported AEG (*Allgemeine Elektrizitäts-Gesellschaft* or General Electricity Company), the other large electrical combine that depended on Professor Slaby in Berlin.[18] These two organizations fell out, and it was only after the intervention of the Kaiser that they combined their efforts, and thus the Telefunken Company was formed.

The German engineers also had access to the work of the Austrian Robert von Lieben who was trying to develop a vacuum tube based on the Braun tube. Later he developed a device with a grid, and though he claimed it was based on a different principle to the Audion he inevitably ended up in patent scuffles with de Forest. The vacuum tubes used a small amount of mercury vapor for their function.[19] At the time the need for high vacuum to make the true vacuum tube was still not properly understood.

Telefunken was aware that it needed something better. A mission to America was arranged, to visit the various companies and try to obtain more information on developments. The man they chose for this task was Frenchman Paul Pichon. In 1900, he had deserted from the French army and fled to Germany. There, he had taught French for a while, including to the daughter of Georg Graf von Arco, the technical director of Telefunken. Pichon decided to study electrical engineering and ended up working for the company.[20]

He became an international representative for Telefunken, and because he was a Frenchman it was felt that he would be less obvious about what he was up to in the charged atmosphere of 1914. He was remarkably successful, gathering examples of the latest wireless equipment but, crucially, he visited Western Electric. There he was given samples of the latest high vacuum Audions and information on how to use them. Quite on what basis he obtained them isn't clear.

Together with all his samples and information he took a ship back to Europe. It didn't look as though he was following events too closely because the one he chose docked first in Southampton. His timing was immaculate as it was August 3, 1914 when he landed, the very day that Germany declared war on France. Now he had a problem. As he was a French national he would be declared an enemy alien in Germany, and in France he was a deserter and liable to immediate arrest.

He is said to have consulted Godfrey Issacs, the managing director of the Marconi Company, as to what to do. If so, this was another example of missed opportunities as Issacs failed to understand the significance of what Pichon was carrying. Whether Issacs advised him to return to France or not, Pichon ended up in Calais and was promptly arrested. There his only hope was to get the French authorities to appreciate the importance of his samples.

Now his luck changed as his story reached the ears of Colonel Gustave Ferrié, the head of the French Military Telegraphic service (Fig. 2.4). He ordered that Pichon, with his baggage and papers, should be brought to him immediately. He understood their importance straight away. Unconcerned about patents and exactly who owned everything—there was a war on—he had the characteristics of the vacuum tubes tested, improved, and rapidly put into production. Pichon was much too valuable to rot in prison as he also knew about German developments and so was drafted into Ferrié's unit. After the war he returned to work for Telefunken. Unintentionally, he had rendered the enemies of Germany, and his company Telefunken, a vital service.

Ferrié had been in the French military since the 1890s and as an engineer he became involved in the development of wireless communication. He was responsible for the work on the Eiffel Tower station after Eiffel had handed over the tower for this purpose. Ferrié steadily increased the range until reliable communication was achieved between Paris and the forts on the German border. As a result of his work French military wireless communications were the best in the world when the War broke out.[21]

Fig. 2.4 Gustave Ferrié. *Source:* http://en.wikipedia.org/wiki/File:Gustave_Ferri%C3%A9.jpg

It took until early 1915, after some false starts, before a satisfactory vacuum tube was available. The French made a number of improvements to the American design, particularly by making it more robust and reliable. Ferrié now had the tool he needed for mobile communications, and to build up the *sapeurs-télégraphistes*, the unit to operate them. Not only were these using what had now become the conventional radio system, but also low frequencies which were transmitted through the ground using a couple of spikes driven in.

The production of vacuum tubes increased rapidly and a second manufacturer was also employed. These devices were given the mark TM (Télégraphie Militaire) and in 1916 100,000 were delivered. Production reached 1000 a day in November 1918.[22] This was not all, because the French had sent samples and information to their allies in Britain. Production began in 1916 with three manufacturers, British Thomson Houston, Ediswan and Osram (English General Electric), all electric lamp makers. These were known as 'R' valves or, more commonly, French 'R' valves.

With a regular supply of tubes (the early ones only lasted around 100 h) tremendous developments took place.[23] Sensitive receivers on the Eiffel Tower monitored German communications, giving clues to troop movements, and were instrumental in trapping the spy Mata Hari. In Britain, Henry Round developed sensitive receivers with directional antennae so that the position of ships could be determined. In May 1916, the receivers were monitoring transmissions from the German Navy at anchor at Wilhelmshaven. A 1.5° change in the direction of the signals was picked up, which suggested that the ships were leaving port.[24] This was reported to the Admiralty, who ordered the Grand Fleet to sea, hence giving them an advantage in the ensuing Battle of Jutland.

Wireless systems also took to the air; spotter planes flying over enemy lines could radio instructions back to the guns to range on the targets using a specific code to indicate where a shot fell and what correction was needed.[25] This had begun haphazardly, but rapidly became a system covering all the lines. The Royal Navy also used spotters when bombarding the Belgian ports where the Germans based their submarines. Ironically, when the United States entered the war they had no suitable equipment and were forced to copy French and British designs.[26]

As so often, war had driven the development of electronics. In 4 years it had come from the plaything of inventors to the mass communication for the military. Before the war, only the specialists in companies such as Marconi were familiar with basic electronics, but now thousands of people were aware of its possibilities. With the ending of the First World War a huge quantity of surplus equipment became available. This not only consisted of wireless sets and vacuum tubes but included other components, such as resistors and capacitors, which had also been the subject of considerable development.

With so many people now involved, there were continual advances in circuitry, finding out all the things that the vacuum tubes could do. Steadily the subject moved from the commercial and military arenas to the domestic. Now, 35 years after Edison had stumbled on his effect, something that had largely been hidden from the average person was set to impact on their lives.

NOTES

1. There are numerous sources, e.g., Dijkstra, H., Short biography of Johann Heinrich Wilhelm Geissler, available at: http://www.crtsite.com/Heinrich%20Geissler.html
2. A report of this meeting was given later in *The New York Times*, February 23, 1896.
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3

From Wireless to Radio

An inventor is one who can see the applicability of means to supplying demand five years before it is obvious to those skilled in the art.

Reginald A. Fessenden

I do not think that the wireless waves I have discovered will have any practical application. Radio has no future.

Heinrich Hertz

Marconi's objective had always been to set up a commercial wireless telegraphy system. This was modeled on the wired telegraphy network but dealt with the gaps that it could not easily fill, such as maritime communication. His single-minded development of commercial wireless telegraphy was very successful, and soon was standard equipment on ships. However, he and his adviser, Fleming, subscribed to the theory that the discontinuous signal of their 'spark' transmitters was essential for wireless transmission, and that it worked by a 'whiplash' effect.[1]

This mistake did not matter for Morse telegraphy transmissions which were just dots and dashes. With many of the early detectors it was, in fact, an advantage. However, if you wanted to send a more sophisticated signal, such as speech or music, it was totally inadequate. There were those who aspired to send 'telephony' and knew that, to achieve this, a continuous wave was necessary as the 'carrier'. The question was: how to generate such a signal?

Reginald Aubrey Fessenden was a Canadian by birth, but he had drifted south of the border in search of opportunities in electrical engineering. After a checkered career, including working for Edison for a time, be became a professor, first at Purdue University and then at the University of Pittsburgh. Later, he became the general manager of the National Electric Signaling Company. His interest, if not obsession, was to transmit speech by wireless.

His first attempt, in 1900 at Cobb Point, Maryland, used a spinning disk that effectively produced sparks at 10 kHz for his transmitter, but still was not a true continuous wave. The received speech was intelligible, but accompanied by an irritating noise due to the sparks. Still, he had succeeded in transmitting a message over a distance of just over a kilometer.[2]

J.B. Williams, *The Electronics Revolution*, Springer Praxis Books,
DOI 10.1007/978-3-319-49088-5_3

He realized that this was inadequate and spent the next few years looking at various ways of generating a true continuous wave.

Most of these methods derived from the work of the Dane Valdemar Poulsen on continuous arcs. An arc, as used in arc lamps for lighting, when powered by direct current but tuned with a suitable inductor and capacitor, would 'sing' at the resonant frequency determined by these components. Running this in various gases could increase the frequency it generated. Quite useful results were obtained with a number of these.

However, Fessenden's preferred method was the high-speed alternator. This requires a large number of poles and to be spun at high speed. It also must be small in diameter or the forces generated by the peripheral velocity will tear it apart. He asked General Electric to build him a suitable device; they delivered it in 1906, but it could only reach 10 kHz which was nowhere near a high enough frequency. He had it dismantled and rebuilt by the company's workshops to his redesign, and then he was able to reach around 80 kHz which was a usable frequency. He could now build a transmitter for 'telephony'.

On Christmas Eve 1906, along the American east coast, ships equipped with suitable radio receivers were astonished to hear speech and music coming from the earphones instead of the dots and dashes of Morse code. This was part of a 'concert' broadcast by Reginald Fessenden from Brant Rock, Massachusetts. He reported that:

> "The program on Christmas Eve was as follows: first a short speech by me saying what we were going to do, then some phonograph music. The music on the phonograph being Handel's 'Largo'. Then came a violin solo by me, being a composition of Gounod called 'O, Holy Night', and ending up with the words 'Adore and be still' of which I sang one verse, in addition to playing on the violin, though the singing of course was not very good. Then came the Bible text, 'Glory to God in the highest and on earth peace to men of good will', and finally we wound up by wishing them a Merry Christmas and then saying that we proposed to broadcast again New Year's Eve."[3]

It is unlikely that Fessenden fully realized what he had started. His objective for the broadcast was to demonstrate the capabilities of his system. He was interested in 'wireless telephony' in the same way that Marconi was concentrating on 'wireless telegraphy'. Despite his advances in the high frequency alternators they still couldn't really reach the frequencies that would be required of 1 MHz and beyond.

There was a sad end to Fessenden's work, in that the investors in the company tried to ease him out. After court battles he eventually turned his back on the wireless work and concentrated on other fields. As so often, the brilliant inventors are not the ones who develop the idea into a useful system. He was also very restricted by the monopolies already established by the Marconi Company, though his technology was almost certainly superior.

As far back as 1874, Ferdinand Braun (yes, him again) noted an interesting phenomenum. He found that if certain crystals were touched by a metal contact an electric current would flow more easily in one direction through this junction than in the other. Two decades later, the Indian inventor Jagadis Chunder Bose worked his way from the metal filings coherers to a single metal contact on a crystal as a way of detecting radio waves. He was working with much higher frequencies than were subsequently used by Marconi and others, but was only interested in the science and so didn't patent his ideas at the time. Eventually, in 1901, he was persuaded to do so.[4]

No one took much notice of Bose's work, and it wasn't until 5 years later that two patents for crystal detectors for radio waves appeared at almost the same time. General H. H. C. Dunwoody in the USA used carborundum (silicon carbide), while Greenleaf W. Pickard employed silicon as the crystal. Soon other materials such as galena (lead sulfide) were also being used.[5] A springy metal wire was used to press on the crystal as the other contact, and the resulting name of 'cat's whisker' was soon given to this type of detector. In use, the 'cat's whisker' had to be moved to different spots on the crystal until the wireless signal was suddenly heard in the earphone.

The detectors worked in much the same way as the diode or 'Fleming' valve by allowing only the signal in one direction to pass, hence cutting the incoming radio wave in half. By filtering out the carrier radio frequency (which the headphones would do anyway) only the required speech or music that had been 'modulated' on to it remained. It was a very simple and elegant way of detecting wireless signals which didn't require the batteries needed by vacuum tubes (Fig. 3.1).

Once these detectors became available it was now quite simple to produce a receiving set. With the increasing numbers of stations transmitting there was something to listen out for, and it wasn't long before amateurs started to be interested in building their own sets for both receiving and transmitting. In Britain, surprisingly, Parliament had been ahead of the game and in 1904 had given the Post Office, which had a monopoly on communications, powers to issue licences for wireless operation.

At the beginning, these licenses were mostly issued to Marconi and his competitors for commercial operation, but more and more were issued for 'experimental purposes' and were largely for amateurs. There was a huge rise in these from 1910 to 1912 (Fig. 3.2). In Britain, components, or even complete sets, could be bought from such places as Hamleys[6] and Gamages.[7]

A book on *Wireless Telegraphy for Amateurs* was first published in 1907 and revised many times in the next few years.[8] In April 1911 the Marconi Company published a magazine called the *Marconigraph*. This proved so popular that it grew from 16 to 52 pages in

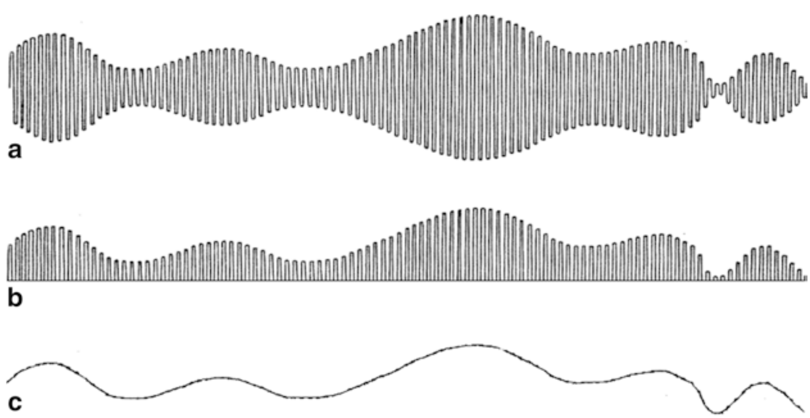

Fig. 3.1 Modulation of a radio wave. (**a**) modulated carrier wave; (**b**) cut in half by the detector; (**c**) the signal after filtering out the carrier. *Source:* Author

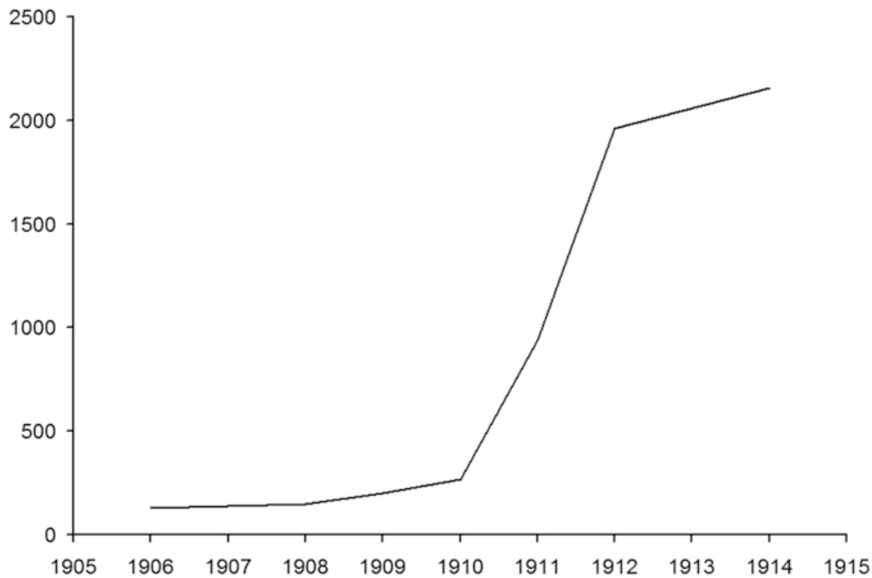

Fig. 3.2 The number of licences issued by the UK Post Office for wireless operation 1905–1914. *Source:* Author[9]

its first year. The following year it changed its name to the more encompassing *Wireless World* and its extent rose to 96 pages.[10] Interest in wireless communication was exploding as shown by the number of wireless clubs, including in 1913 the London Wireless Club, which later became the Radio Society of Great Britain. Just as it was really getting going, the First World War intervened, and on its outbreak the majority of the licence holders received a telegram ordering them to stop operating and hand in their equipment.[11]

Charles David Herrold's father was a bit of an inventor, so it was not surprising that his son should be interested in science and mechanics and study at Stanford University in California. Luck was not with him—his electrical engineering business was destroyed in the 1906 San Francisco earthquake. He turned to teaching in a college for a while before, on January 1, 1909, he set up his own 'Herrold School of Radio' in San José.[12]

To generate interest in his school, Herrold set up a transmitter to send out what amounted to advertisements. To encourage people to listen he also transmitted news and music from gramophone records. Initially, he used a spark transmitter, but the quality was not good and he soon changed to an arc transmitter of his own design. To get listeners he would go out and install crystal sets up and down the valley. From around 1910 he was transmitting on a regular schedule, well before the Radio Act of 1912 introduced licences and required all transmissions in America to have a 'call sign'.

Purists say that he wasn't 'broadcasting' because his listeners were amateurs and not ordinary members of the public.[13] This seems a bit nit-picking, as he was certainly moving over from 'communication' to 'entertainment'.

Like everyone else, he had to shut down when America entered the war in 1917. Afterwards, it took him some time to re-establish as the government introduced designated frequency bands. His was 360 m (833 kHz) which was a higher frequency than the 600 m (500 kHz) his arc transmitter was capable of reaching, so he had scrap his equipment and the station to start again.[14]

Over the next few years a few people were transmitting ‘programs’ but they were still amateurs doing it on a haphazard basis. Some transmissions of weather information also took place and altogether this provided enough traffic on the air to interest keen young men in building or obtaining receivers to experiment themselves. Despite this, the idea of ‘broadcasting’ had still to take root.

Meanwhile, Marconi had realized his error concerning the use of continuous waves for transmission, and was developing wireless telephony systems. In 1913, he bought out the French company, Compagnie Universelle de Telegraphie et de Telephonie sans Fil, in order to obtain the patent rights to the Goldschmidt generator outside Germany.[15] This was an interesting device in that it was able to multiply the basic frequency it generated inside the device. The result was that the speed at which it spun didn’t need to be as high as the American GE ‘Alexandersen’ alternators based on Fessenden’s work.

By the next year, Henry Round’s work on vacuum tubes was providing results, and though they still couldn’t produce the power achieved by the generators and arcs, they could more easily reach higher transmitting frequencies. In any case, the generators were not suitable on ships, Marconi’s main business area, as the movement produced gyroscopic effects that were likely to damage the high speed machines. In 1914, this work produced results, and successful trials were undertaken with the Italian Navy.[16]

Then the First World War intervened, and with it the enormous developments that war so often brings. Chapter 2 dealt with the tremendous advances in the vacuum tubes, but this then drove improvements in the transmitters and receivers. Once there was the ability to amplify signals, everything became a lot easier. In addition, many other things could be achieved with vacuum tubes and most of the basic circuit configurations were invented over quite a short space of time. By the end of the war there was not only a vast amount of radio equipment being used, but a large number of people familiar with using it.

The emphasis was still on using wireless for communication point to point either by telegraph using Morse code or, increasingly, by telephony. However, the idea of transmitting a signal to be picked up by many listeners was in the air. This had most clearly been expressed by David Sarnoff who worked for the American Marconi Company. He said: “I have in mind a plan of development which would make radio a household utility in the same sense as the piano or phonograph.”[17] However, most people in the industry were concentrating on the war and so his ideas were a little premature.

With the war over, the situation was different. By this time, Henry Round had succeeded in making high power transmitting vacuum tubes and in March 1919 a wireless telephony system linking Europe to America was set up. Meanwhile, the UK’s Postmaster General needed to be pressured to allow amateurs back on the air; it wasn’t until May that he relented, but the new licences for transmission were only issued for experimental purposes, and were not to interfere with military communications.[18] They were only allowed to use 10 W of power and use frequencies too high for high speed alternators or arc transmitters. Despite these limitations, interest in the subject grew.

In January 1920, a 6 kW telephony transmitter was installed at the Marconi works in Chelmsford for testing receivers and reception. The engineers soon became tired of reading from railway timetables to produce a test signal and turned to live music which was heard by amateurs and ships operators up to 1450 miles away. The next month they introduced a news service. They thought that the future of broadcasting lay in information.[19]

Over in Holland, the delightfully named Hanso Henricus Schotanus á Steringa Iderza had a more commercial objective in mind. He was trying to sell radio receivers, and he thought that if he transmitted speech and music there would be something for people to listen to, and then they were more likely to buy his receivers. On November 6, 1919 he started transmitting under the call sign PCGG.[20] He was pushing his luck as he only had an experimental licence, but no one stopped him. By November 1921, he was able to convert this to a full broadcast licence and he received sponsorship from the British newspaper, the *Daily Mail*, to transmit some of his output in English, as his signals could be received in England. The *Mail*, interested in technical advances, was keen to promote the use of radio.

In 1920, British Thomson Houston started manufacturing radio sets as there were now some stations that listeners could access, although it was still a very minority interest. Marconi, though mostly concentrating on their telegraphy and telephony business, decided on a publicity stunt. On June 15, 1920 they arranged for the singer Dame Nellie Melba to perform live and broadcast it from their transmitter at Chelmsford. This, too, was sponsored by the *Daily Mail*. One listener said that the transmission was 'perfectly wonderful' and that 'there must be a great future for wireless concerts'.[21]

Unfortunately, the Postmaster General (PMG) had other ideas. Though a number of companies had been given licences to make experimental broadcasts, he felt it was getting out of hand and, using the excuse that they were interfering with military communication systems, shut them all down. This position was not tenable for very long as many broadcasters were setting up in other countries, particularly America, and the growing number of set manufacturers could see the advantages of local broadcasting.

In February 1922, the Marconi Company was starting to hedge its bets though they were still unsure that the radio amateurs really constituted a market. They persuaded the PMG to issue them an experimental licence and started transmitting from one of their sites at Writtle under the call sign 2MT. The station was run by engineer Peter Eckersley, and broadcast everything from pieces performed by local people, songs, competitions and even a lonely hearts club. It rapidly built up a sizable audience and Marconi realized that they were on to something.[22]

By May, they had obtained another licence to transmit from the Marconi building in London under the call sign 2LO. With the number of amateur receiving licences beginning to climb rapidly, and numerous companies applying for broadcast licences, the Postmaster General, Mr. Kellaway, acted. His proposal was that the set makers should get together and set up a single broadcasting service. It took many months of negotiation to agree on a scheme, which was complicated by Marconi's patents and the need to have a means of financing the service. There was a slight suspicion over some of the arrangements when Kellaway ceased to be the PMG and promptly became a director of the Marconi Company.[23]

Eventually, on 14 November, financed by six electronics manufacturers, the British Broadcasting Company (BBC) was inaugurated and began transmitting on the medium