When I Think Back...

by Neville Williams

From sparks and arcs to solid state – part 1

By present-day standards, wireless telegraphy signals at the turn of the century could be fairly described as comprising little more than packaged man-made electrical noise. A further 10-15 years of development was necessary before wireless telephony became really practicable, with wireless waves able to convey directly the sound of voice and music.

It would need far more space than is available here to acknowledge the contributions that many scientists and inventors made, over the years, to the dawning comprehension of electrical phenomena and to the ultimate ability to communicate over a distance by electrical signals.

Historically, however, landline telegraphy became a reality, around 1840, due largely to the work of Samuel Finley Breese Morse, better known for the telegraphic code that bears his name. Landline *telephony* – the 'speaking telephone' – followed in 1876, thanks mainly to Alexander Graham Bell.

'Wireless' communication, in turn, owes much to a landmark experiment performed by the German physicist Heinrich Hertz in 1888 at the Karlsruhe Polytechnic. Ironically, Hertz did not have communication in mind at the time. Rather, as a dedicated academic and at the suggestion of the famous Hermann Helmholtz, he was seeking to verify the existance and behaviour of electromagnetic waves. Said to resemble light waves, they had been predicted by the brilliant mathematician Professor James Clerk Maxwell 25 years earlier.

An old-style artist's drawing in *The Electronic Revolution* (S. Handel, Pelican, 1967) depicts Hertz at a laboratory table using a hand driven magneto-like generator to create a sequence of discharges across a spark-gap separating two vertical metal rods, each one surmounted by a metal ring 30cm or so in diameter.

On another bench, at the far end of the laboratory is a similar rod and ring with a minute gap at the top. Each time a discharge was produced at the source, a spark occurred at the distant spark gap, suggesting that electromagnetic wave energy was indeed being generated and radiated, as predicted, from the source to the distant receptor.

Without setting too much store by the drawing, it has always intrigued me that, with intuitively assembled equipment, the energy level created and intercepted by Hertz was sufficient to produce a plainly visible spark.

In other days, as an amateur radio operator, I did my share of electronic 'plumbing', building UHF transmitters and receivers with tubular metal *Lecher* lines – but they were cut to very precise lengths, calculated by time-proven formulas. And, at the end of the day, I had access to signal detection equipment far more sensitive than a spark gap in an open loop!

Skill plus good luck

How Hertz arrived at the shape and dimensions for his historic spark 'transmitter' and 'receiver' is open to speculation but, in his recent article in *EA* on 'Syntony and Spark', Peter Jensen suggests that it was by a combination of undoubted scientific skill and sheer good luck.

Hertz' laboratory 'transmissions' have been variously reported as being on a wavelength between about one metre and a couple of centimetres. This would put them in the frequency range 300 to 15,000MHz, where they would indeed have behaved more like light waves than a signal of signficantly greater wavelength or lower frequency.

Moreover, by using a transmitter and a receptor of comparable physical dimensions, he would more likely have satisfied the need for a common resonant frequency – a requirement that was not formally demonstrated and documented until 1894, by Sir Oliver Lodge. Lodge referred to it as 'syntony', a term that has long since been displaced by 'resonance' or 'tuning'.

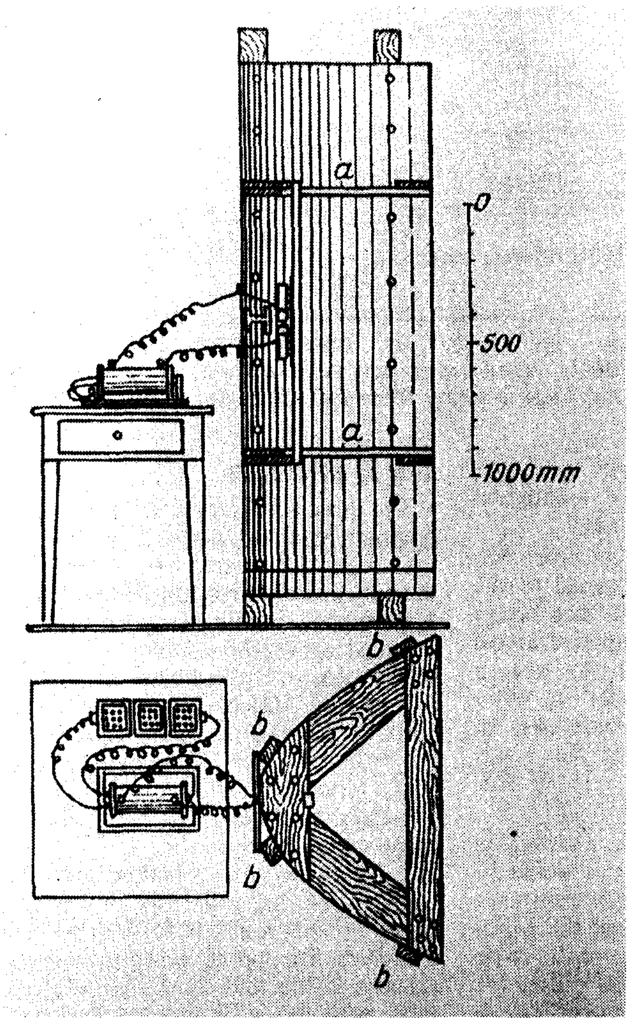
Curiously, research into wireless communication was not universally applauded by the scientific establishment of the day – as evidenced by the reaction of Lord Kelvin, who reportedly once remarked: "Wireless is all very well but I'd rather send a message by a boy on a pony!"

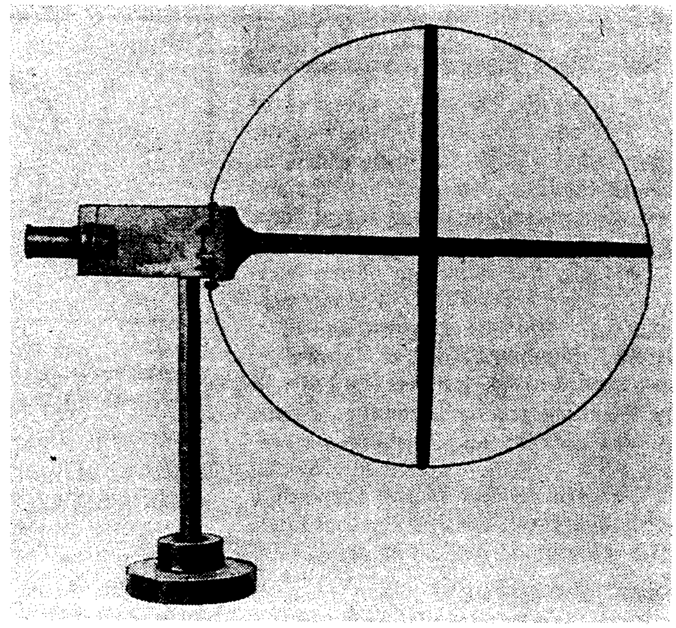
David Edward Hughes was an early victim of just such scientific scepticism. Born in London in 1831, he was raised in Virginia and became professor of music at Bardstown College, Kentucky. Fascinated by electrical communication, however, he is credited with having developed a telegraph printer in 1854-5 and a special microphone some years later.

In 1879, back in London and nine years ahead of Hertz, he set out to investigate what he described as the 'aerial' transmission of electromagnetic waves. Using simple handyman materials, he set up a primitive spark transmitter in one room of his home in Portland St, which was pulsed on and off automatically by a clockwork-driven switch.

What he used as a receiver is unclear, other than that it was apparently contrived around some sort of coherer, plus a transducer of his own design. In fact, the combination worked so well that it sensed the transmitter pulses, not just inside the house, but in the street outside over a distance of some 500 metres.

Encouraged by the results, Professor Hughes demonstrated them to the President of the Royal Society – of which he was a fellow – a Mr Spottiswood and to two secretaries, Professors Huxley and Sir George Stokes, in early 1880. While





Above: Hertz's receiver was a simple loop antenna with a tiny spark gap, viewed via a microscope.

Left: One of Hertz's early transmitting setups, with what amounts to a vertical dipole about 300mm long in a parabolic reflector.

seemingly impressed, they nevertheless refused to recommend an official presentation to the Society, on the grounds that what they had seen could have been due to ordinary magnetic induction: a captive magnetic field from one conductor inducing current in another conductor close by. They would simply not accept the notion of electromagnetic energy being launched, wave-like, into space.

Hughes was so discouraged by their rejection that he refused even to write a paper for the Society detailing his work, and it might have remained unknown had it not been for Sir William Crookes.

Age of wireless

Notable amongst other things for his pioneering work in the area of cathode-ray and X-ray tubes, Crookes was one establishment figure who foresaw the possibility of a totally new method of communication using Hughes' 'aerial' waves, or what later came to be known as 'Hertzian' waves. Other historic figures who clearly had a similar vision, including:

- Aleksandr Popov, the Russian pioneer, who mentioned the possibility of wireless telegraphy in his notes, even though he was primarily concerned with researching electrical storm phenomena.
- Mahlon Loomis, who was granted what may well qualify as the first US patent for 'aerial telegraphy' in July 1872, with a practical demonstration following in 1886.
- Professor Amos E.Tolbear of Tufts College, who sent and received electric impulses using gilt kites tethered by metal wires, as described in a *Scientfic American* supplement dated December 11, 1896.
- Nicola Tesla, a Croation scientist who emigrated to the USA and looked beyond mere communication in a book published in 1904, to 'education of the masses' (by wireless) in uncivilised countries.
- Sir Oliver Lodge, who in Britain closely studied the work of Hertz and devised a practical receiver and inker to receive and display Hertzian signals.
- Alan Campbell-Swinton, an early TV visionary, who commended the innovative young emigrant Marconi to William Preece, Chief of the Engineering Department of the British Post Office.
- Sir William Preece, who had long been seeking better means of warning lightships and lighthouses of impending storms. He subsequently gave 'warm' official support to Marconi.
- Sir Henry Jackson, belatedly credited with introducing wireless signalling between ships of the British Navy – under a predictable veil of secrecy!

There were many others, but Guglielmo Marconi proved, far and away, to be the dominating figure in the history of wireless communication. Born in Italy in 1874 of Italian/Irish parents, he emigrated to London in 1896 and began immediately to pursue his youthful committment to the technology.

Although not academically qualified, he was an outstanding innovator and entrepreneur, with the ability and the will to develop and apply his own and other people's ideas to projects for which most others were limited to conjecture.

With the backing of Sir William Preece, he installed a functional transmitter on the Isle of Wight in 1897, at Bournemouth/Poole in 1898 and, in that same year reported by wireless the results of the Kingstown regatta.

In 1889, the life-saving potential of his equipment was demonstrated in the *Elba* and *Goodwin Sands* disasters; he also reported the America Cup race and gave demonstrations to the Royal Navy and the US Navy and Army.

1900 saw the formation of the Marconi International Marine Communications Co, and the construction of a wireless station at Poldhu in Cornwall – preparatory to his successful attempt in the following year to bridge the Atlantic by wireless. In this, Marconi was assisted by Professor Ambrose Fleming and George Stevens Kemp, a one-time petty officer of the Royal Navy and personal assistant to William Preece.

Trial and error

The evolution of wireless components and technology during these formative years was very much a process of trial and error; of pursuing ideas and hunches to see if they worked, with the explanatory theory emerging later. The development of the 'coherer' was a case in point.

In 1835, a scientist named Munk, about whom little else is known, observed that the electrical resistance of a small pile of metal filings was mysteriously reduced by the discharge nearby of a Leyden jar – an early form of capacitor.

It seemed a pointless bit of scientific trivia until Professor Edouard Branly, of the Catholic University in Paris, poured some filings into a glass tube accessed by two separate contact wires and noted that the particles would clump together or 'cohere' if exposed to a pulse of RF energy. In the process, Munk's pointless pile of metal filings had been transformed into a possible 'detector' of wireless waves – a term which, in those days, had a different connotation from present usage.

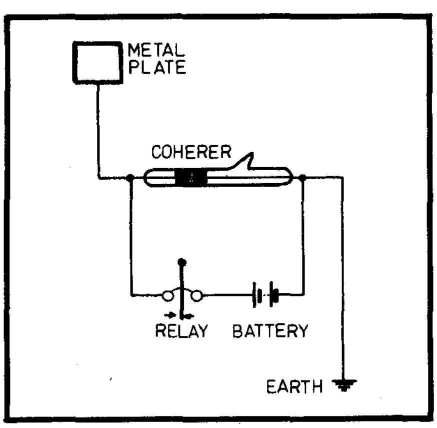


Fig.1: An early Marconi receiver, using his sealed coherer with a parallel battery/relay circuit.

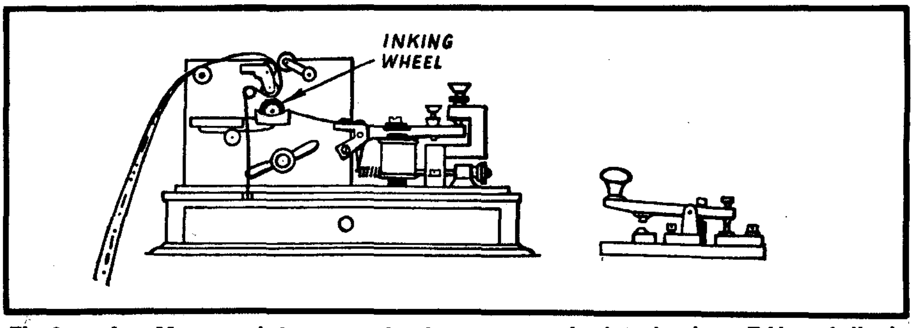


Fig.2: A Morse inker and key, as depicted in E.H. Jolley's 'Telecommunications' (1962). Experienced operators commonly ignored the tape, writing down the message directly from the clicks from the actuating relay.

In a wireless telegraph receiver, the coherer would be so connected to the signal collecting components that incoming RF pulses would be applied across the two connecting wires. As well, a battery and a galvanometer or other current sensing devices would also be connected across the coherer (See Fig.1, also the panel on page 37 of *EA* November 1989).

In the standby condition, awaiting an incoming signal, the particles would be loose in the container; their resistance would be relatively high and the galvanometer deflection quite small. With the arrival of an RF signal pulse, the particles would clump together or cohere; their effective resistance would be lowered and the galvanometer would register a significantly higher reading.

In short, the coherer did not operate as a rectifier/detector in the present-day sense of the term but, rather, as a signal sensitive switch or resistor – able to control the current through an external indicating circuit. As such, it could initiate a reading on a galvanometer in the presence of a signal, cause an audible click in a pair of headphones or operate a relay controlling a Morse code inked-paper recorder (Fig.2).

In its simplest form, the coherer needed to be tapped immediately afterwards, to de-cohere the particles and prepare the receiver for the next pulse – a tedious procedure which Branly, Lodge, Popov and Marconi obviated more or less independently by providing their coherers with an automatic, magnetically operated self-tapper.

It didn't take them long to realise that the self-tapper could, as easily, take the form of an electric buzzer or bell, serving both to vibrate the particles and to produce a recognisable sound with each RF signal pulse.

Try it and see

The question naturally arose as to the optimum size and shape of a coherer, the choice of contact wires and the quantity and nature of the filings. It was a question which obviously called for a practical approach: discovering by trial and error what worked best.

Typically, Marconi started out with what is described as: 'a large-size tubular bottle from which extended two rods, terminated inside the bottle on two discs, very close together. Between them could be seen bright filings or metal particles'. He experimented with copper, iron, brass and zinc, but finally ended up with a mix of 95% nickel and 5% silver. The 'bottle' was progressively reduced in size to a short piece of glass tube, with the leads inserted in a way that allowed the device to be evacuated and sealed (Fig.1).

Fitted with an automatic de-coherer, Marconi's miniature coherer worked so well that any uncertainty he might have had about the merit of his experiments vanished. To quote from his notes:

Every time I sent a train of electric waves, the clapper touched the tube and so restored the detector at once to its pristine state of sensibility. It was precisely at this moment that I thought for the first time of transmitting telegraphic signals and of substituting a Morse machine for the voltmeter.

While the coherer was probably the most widely used device in the 1890s for sensing the presence of RF signals, strenuous efforts were made to develop alternative types of signal detector, partly to avoid patent licensing fees and partly in a search for improved sensitivity and reliability. One such was Marconi's own magnetic detector. (See *EA* for November/December 1989).

The detection of incoming signals was, of course, an essential aspect of early wireless communication but, rather than pursue the subject in what is

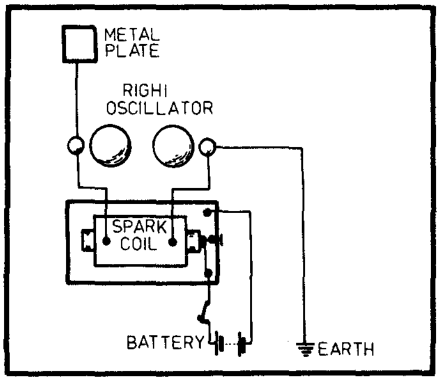


Fig.3: An early Marconi spark transmitter. The Morse key was in series with the battery.

essentially a survey of transmitting techniques, it may be better to devote a separate article to receivers generally and detectors in particular.

Structured noise

Fig.3 illustrates the basic transmitter technology which Marconi inherited informally from Professor Righi of Bologna University and took with him to Britain in 1896. Central to it was a spark coil with separate primary and secondary windings – a version of what we might these days describe as an electric buzzer.

When the unit was activated by depressing a Morse key in the battery circuit, current would flow through the primary winding of the spark coil, magnetising the iron core and attracting to it a spring-mounted vane. In moving towards the core, however, the vane would open a pair of contacts and interrupt the magnetising current, allowing it to flip back to its original position.

In moving to and fro – 'buzzing' or 'trembling' – the vane would thus make and break the current through the primary winding, causing a rapid sequential build-up and collapse of the magnetic field. This, in turn, would induce a corresponding sequence of high voltage pulses, or spikes, across a secondary winding wound with a large number of turns of fine gauge wire.

One side of the secondary winding is shown connected to earth, the other to a vertical rod supporting a metal plate. Between the connections are two metal balls, normally supported on threaded metal rods and capable of being adjusted so that the gap between them can be made small enough for a spark to occur with each high voltage pulse.

In principle, the device is reminiscent of the traditional Kettering ignition system fitted to motor vehicles. And just as ignition systems, in the days before noise suppression, created a lot of interference or 'hash' in radio receivers, so did spark transmitters, as in Fig.3, radiate a train of noise pulses.

As a rule, the buzzer or trembler was adjusted to operate at a make/break rate of a few hundred per second so that the signal, as heard, sounded like a continuous buzz rather than a series of plops.

In modern terms, it was a broad spectrum noise signal, much like that from any other piece of unsuppressed, spark-prone electrical equipment.

Aerial, earth, tuning

In the earliest transmitters or Hertz style 'oscillators', the spark gap was connected to bench-top metal rods terminated by rings or discs. Because of their modest dimensions and their relatively small mutual inductance and capacitance, they tended to be broadly resonant at some quite high frequency, thereby reinforcing the signal in that part of the spectrum; hence the earlier observation about the signals created by Hertz.

Subsequently, Marconi, Popov and others discovered that the effective range of the signals could be increased by connecting the rods respectively to earth and to a length of wire supported in space. In fact, the rods and discs could then be dispensed with. The same appeared to be true for receivers.

Although the reasons were only vaguely understood at the time, the aerial/earth arrangement was favouring the transmission and reception of signal components of greater wavelength or lower frequency, and with inherently different propagation characteristics. It was at this point that Sir Oliver Lodge intervened by rationalising inductance, capacitance and frequency and the need for deliberate 'syntonising' or *tuning*.

Up to about this time, Marconi had been concentrating on winning acceptance for wireless communication by relying mainly on brute force: i.e., by progressively increasing transmitter power.

In the process, another problem had emerged, namely that of mutual interference between separate wireless systems. An otherwise successful presentation by Marconi to the US Navy was discredited when he was unable to demonstrate independent communication between more than two stations at any one time.

1901 was a landmark year for Marconi in that he bridged the Atlantic with a wireless telegraph signal and patented a tuning system applicable to both transmitters and receivers – his famous patent No. 7777.

The patent attracted criticism that he had simply poached the ideas of Sir Oliver Lodge. In all fairness, however, while Lodge had spelt out the principles of syntony, it was Marconi who translated them into practice by resonating the coupling and antenna circuits of each transmitter to a particular frequency, and arranging for receivers to be individually tunable. Others adopted a broadly similar approach as a matter of necessity.

Admiralty Handbook

Surprisingly, my 1931 copy of the *Admiralty Handbook* contains helpful sections on spark and arc transmitters, along with the observation that such transmitters were still carried by some RN vessels as emergency communications equipment. At the time, a 'broad' distress signal was seen as a possible advantage, being more likely to be overheard by chance on nearby receivers.

Fig.4 shows their diagram for a contemporary low power spark transmitter, complete with aerial and earth and a

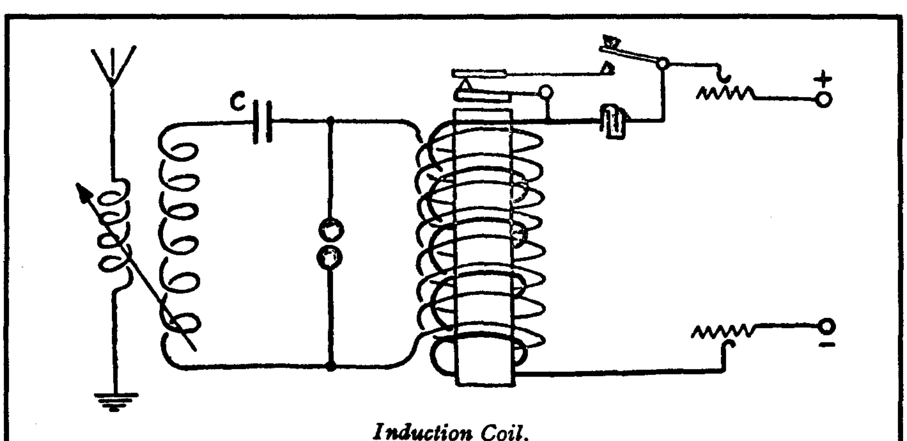


Fig.4: A buzzer type telegraphy transmitter. Pulses from the induction coil initiate bursts of oscillation in the aerial system.

tunable RF output coupling transformer. Fig.5 depicts the pulse generated across the secondary by the collapsing magnetic field.

According to the explanatory text, the moving vane or armature is typically a piece of soft iron attached to the end of a flat spring, with a screw adjustment for tension. Travel is normally about 1/16" or 1.5mm. Platinum contacts on the rear face provide the necessary make-and-break circuit. A capacitor across the make/break and key contacts minimises spark corrosion and reinforces the inductive behaviour of the induction coil. Variable resistors in the supply line allow the DC input to be adjusted as/if necessary.

In operation, the high voltage pulse generated across the secondary charges capacitor C. As the pulse approaches its natural peak, the spark gap breaks down, causing C to discharge through the associated inductor, thereby creating a new, reverse magnetic field.

At this point, due to 'flywheel' action, the total output circuit generates a damped oscillatory wavetrain at its natural resonant frequency which, presumably, has been adjusted to the intended figure. The duration of the wavetrain following each pulse depends on the merit or Q-factor of the tuned system and is limited, amongst other things, by the amount of oscillatory energy absorbed by and radiated from the antenna.

In short, the effect of a properly designed resonant output coupling circuit is to concentrate the energy from a sequence of broad spectrum pulses into damped RF wavetrains of one nominal frequency. According to the *Admiraly Handbook* the repetition rate is typically in the range 250-1000 per second, which therefore becomes the basic 'pitch' or tone of the transmission – in effect, its modulation.

However, because the pulses are completely separate and of random phase as RF signals, the transmission as a whole has widely dispersed sidebands characteristic of grossly overmodulated AM plus random FM – being therefore still a very 'broad' signal, as mentioned earlier.

Other approaches

Literature of the period mentions variations from the above arrangement, the *Admiralty Handbook* referring in particular to the 'attracted armature' buzzer using a common primary winding to drive the armature and energise the resonant output circuit. It is said to have provided a cleaner, if lower-powered RF signal, suitable for setting up contemporary direction-finding equipment.

A still further approach was the so-called 'motor-driven' buzzer, in which the make and break function was provided by metal fingers riding on the surface of a spinning disc carrying alternate conducting and insulating segments. The induction coil is quite separate from the drive motor and an energising spike occurs each time a conductive strip breaks contact with a stationary metal finger.

For higher power transmitters, and certainly for anything above the half-kilowatt level, the most practical approach, according to the *Handbook*, was to use an AC supply source which could be stepped up to the requisite high voltage by means of a suitable transformer. With sufficient step-up, it is possible to achieve and store a high level of charge in a condenser (capacitor) which may be restricted in capacitance by the resonance requirements of the RF output system.

The primary supply might be derived directly from the AC mains or from a motor/alternator combination. In the latter case, a higher supply frequency could usually be arranged, thereby providing a higher wavetrain repetition rate.

The basic circuit shown in Fig.6 looks much simpler than it really is and, in the *Admiralty Handbook*, provides the starting point for an examination of the role and choice of the various components more detailed than can be repeated here. Look it up if you have the

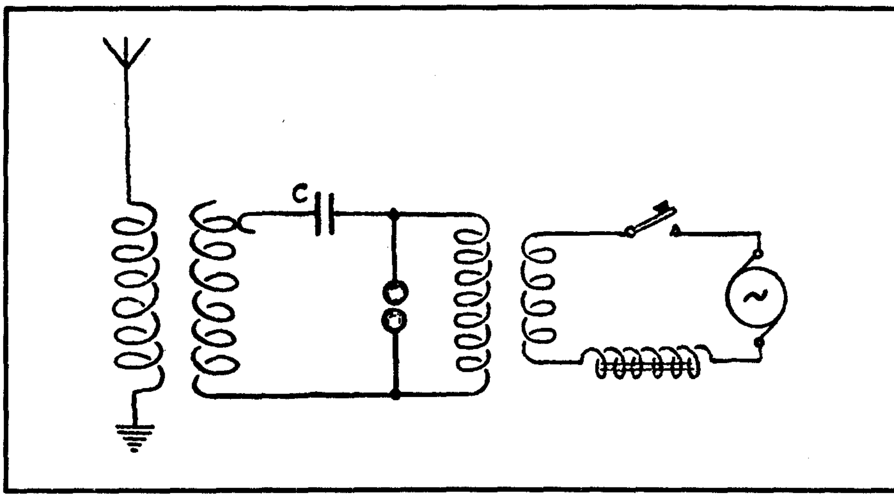


Fig.6: The basic circuit of an AC sourced spark transmitter. The design of such a circuit involved detailed design considerations...

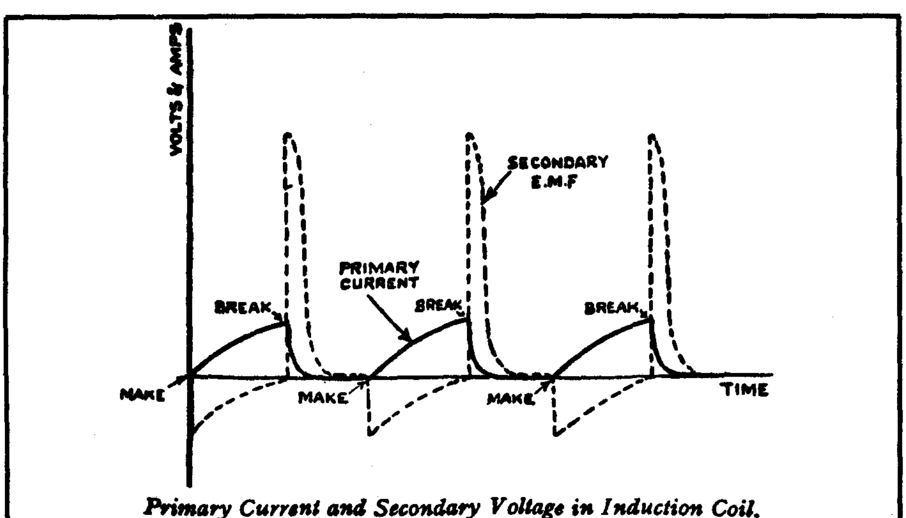


Fig.5: The current and voltage in a buzzer type induction coil, as illustrated in the Admiralty Handbook. The secondary voltage spikes initiate damped oscillatory wavetrains in the aerial output system.

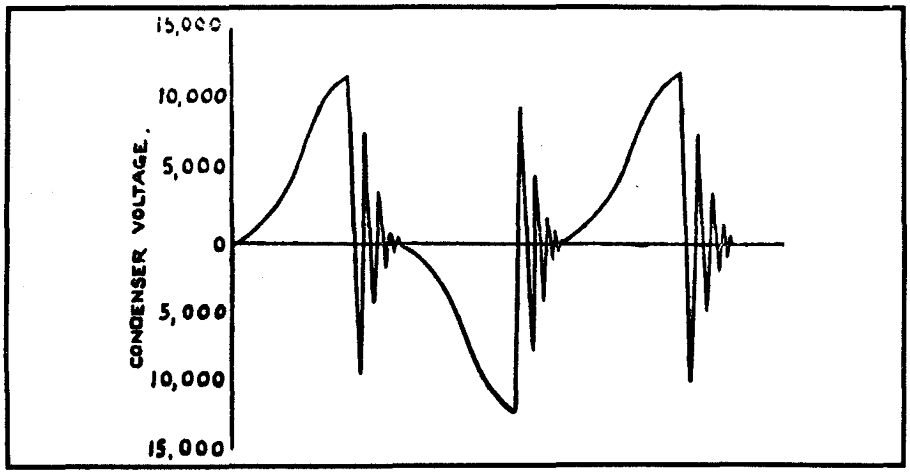


Fig.7: Illustrating the primary and secondary waveforms in an AC sourced transmitter with the gap set to break down, once per half-cycle, at something over 10 kilovolts.

opportunity, and you will gain a better appreciation of what Ambrose Fleming had to wrestle with in the construction of Marconi's Poldhu trans-Atlantic transmitter around the turn of the century.

Fig.7, from the *Admiralty Handbook*, illustrates the primary and secondary waveforms in a typical AC sourced transmitter, so adjusted that the spark gap breaks down just before the peak of each successive half-cycle.

Powered by a high frequency alternator, this would present an acceptable output signal but, operating directly from 50-60Hz AC mains, the pulse repetition rate would be less than optimum in terms both of average signal power and pitch, as heard.

To overcome the problem, at least in part, a non-synchronous rotating spark gap was commonly used, as in Fig.8. It involved a spinning disc with peripheral spark gaps, so adjusted that they would break down at a voltage well below the peak value of the AC input waveform.

By adjusting the speed of the disc, two or more discharges could take place within any one half-cycle of AC input (Fig.9) each spark being quickly quenched by the rapid relative movement of the gap components and of the surrounding air particles.

Inevitably, however, some wavetrains would fail to materialise when they coincided with the zero crossing region of the AC waveform. Use of an asynchronous gap, therefore, ensured a more audible, higher-pitched tone but also resulted in a broader, rougher signal by reason of the irregular timing of the wavetrains.

In short, while wireless telegraphy met the need for basic – and especially maritime – communication, the technology to this point in its development was relatively 'rough and ready' compared with the precision that was later to characterise electronic equipment.

It relied heavily on electro-mechanical disciplines, and on progress by trial-and-error, rather than on systematically applied research. Transmissions were unprecise and 'broad' in terms of the frequency domain, and were intercepted by receivers grossly deficient in reliability, gain and selectivity.

Despite this, professional operators developed amazing skill in using the medium, as was highlighted by an episode in the *Living History* series on ABC radio entitled 'Bright Sparks'.

Shipboard operators prior to and during World War I got to recognise other ships and stations from the sound of their transmitter. Individual operators were recognised by their 'fist' – their 'rhythm' in using the sending key. Maritime operators told how they could make an educated guess at the nationality of unfamiliar transmissions by German, Swedish, Norwegian, French, Italian and Egyptian operators, who unconsciously reflected their training in their operating style. Even the movement of distant ships could sometimes be deduced because their signals varied in a pattern that could be identified with known shipping routes.

In due course, the technology behind wireless telegraphy underwent a major revolution, partly because of the refinements which became necessary to accommodate wireless telephony, and partly because of the changes which spontaneously followed the adoption of thermionic valves. This will form the topic for next month's article.

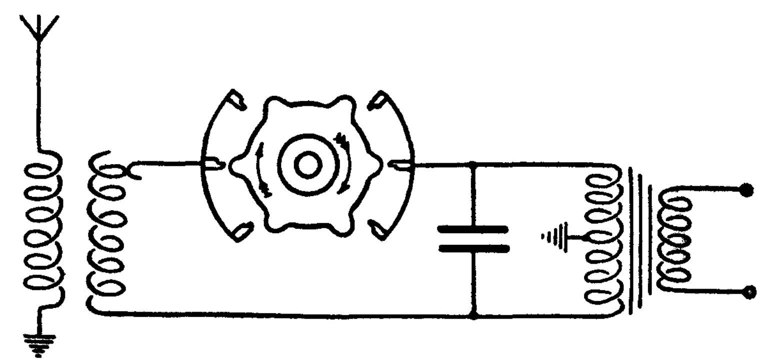


Fig.8: A rotating, asynchronous spark gap could raise the pitch of a mains-sourced telegraphy transmission – but with added 'roughness'.

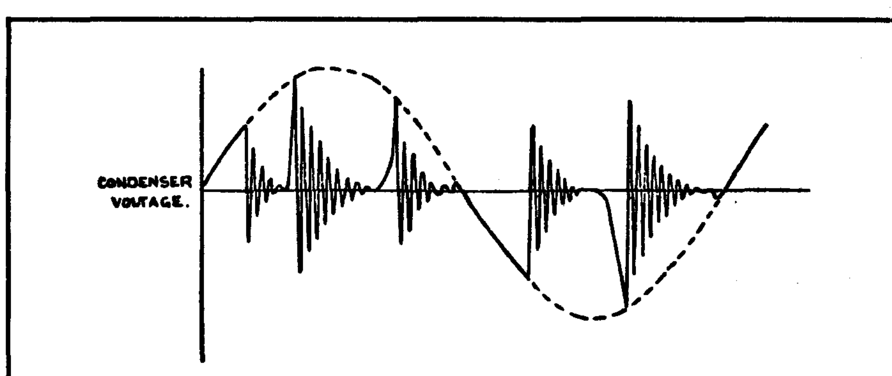


Fig.9: The effect of using a rotating spark gap in a mains sourced transmitter. There are two or more more wavetrains per half-cycle, giving a higher pitched tone but 'rough' because of less even spacing.