When I Think Back...

by Neville Williams

From sparks and arcs to solid state – 2

The relatively crude technology which sufficed for the establishment of wireless telegraphy had to be considerably refined before it could be used for telephony – direct transmission of the human voice or music. Many different arc and spark systems were tried, in an attempt to produce the necessary continuous RF carrier.

As indicated in the previous article, early wireless transmissions comprised a sequence of damped wavetrains, centred broadly on the frequency at which the antenna system and its associated feed circuit happened to be resonant – by chance or intent!

Each wavetrain was initiated by a high amplitude pulse created by the collapsing magnetic field of an induction coil, the recurrence rate being determined by the natural frequency of a 'buzzer' type contact, or a motor-driven switch mechanism or AC generator.

Normally set to a recurrence rate of a few hundred per second, the sequence of wavetrains assumed the character of an homogenous radio signal, coarsely modulated at an audio frequency of a few hundred hertz:

- Amplitude modulated, because each burst of signal or damped waveform tapered from a maximum value to zero. Also:
- Frequency modulated, because each wavetrain varied randomly from others in terms of the phase of the RF component.

For telegraphy, this inherent modulation of the signal was more an advantage than otherwise, being compatible with the then current detectors:

(1) It did not interfere with the ability of a coherer to function as a signal-dependent resistor controlling an external direct current to operate a relay and inker, a galvanometer, a telegraphic sounder or headphones.

(2) It also permitted a rectifier/detector such as a crystal or thermionic diode to demodulate the amplitude component and provide an audio component to feed headphones or (later) an audio amplifier.

Unsuitable for telephony

However, the pulsed nature of the RF signal rendered it unsuitable for simultaneous voice modulation, because the speech would be chopped up at the basic pulse rate. In his book *The Wireless Telephone* (1910-11), the well known technical author/editor Hugo Gernsback described his abortive attempts to modulate an existing spark transmitter. I quote:

The system worked fairly well over small distances but the voice can not be heard at all times, for the reasons explained... Entire words and consonants drop out, as the rate of sparking is far too low. Words containing many vowels are made out best such as : halloh, you, papa, etc. The vowel 'e' is never heard well.

Gernsback outlines various attempts to overcome the problem:

- An arrangement of his own, using multiple induction coils and spark gaps, which would hopefully produce a sequence of wavetrains with fewer interruptions.
- A Fessenden arrangement using what was essentially a capacitive microphone in parallel with the storage capacitor, the idea being that the timing of the sparks might be synchronised to an extent with the inflections of the voice.
- Possible variations of the above, suggested by an experimenter named McCarthy, including one which was effectively a microphone/buzzer combination to create sparks synchronous with the 'sonority' of the voice. Another used an induction coil with twin primaries – one connected to a buzzer, the other to a microphone. A third sought to combine an induction coil with an arc having its supply modulated by a microphone.

After describing still other schemes by Fessenden, Nussbaumer and Bathrick, Gernsback summed up the position as he saw it:

It is almost impossible at the present stage, to transmit the human voice wirelessly by means of the ordinary spark coil, because of the relatively long pauses between the discharges.

Timed sparks

The one scheme which won any commendation at all is as shown in Fig.1. It involves the use of a 3-phase AC supply, preferably from a relatively high frequency alternator, with a step-up transformer from each phase feeding a separate induction coil and spark gap. This could be expected to feed an accurately spaced sequence of sparks to a common antenna circuit with a repetition rate six times the frequency of the alternator.

In his book *Radio Telephony* (Wireless Press, 1918) Professor Alfred N. Goldsmith PhD FIRE AIEE is somewhat less pessimistic about modulating spark transmitters. He pictures a 'timed spark' system which had been developed by the Marconi Company for use in their transatlantic link from Carnarvon in the UK to Marion, Massachusetts USA.

As indicated in the circuit of Fig.2, it involves the use of four 'dischargers' (D1 to D4) mounted on a common motor-driven shaft. Four associated induction coil systems, fed with 10kV DC, are actuated by gap electrodes on the spinning discs, radially staggered so that 16 evenly spaced discharges are pro-

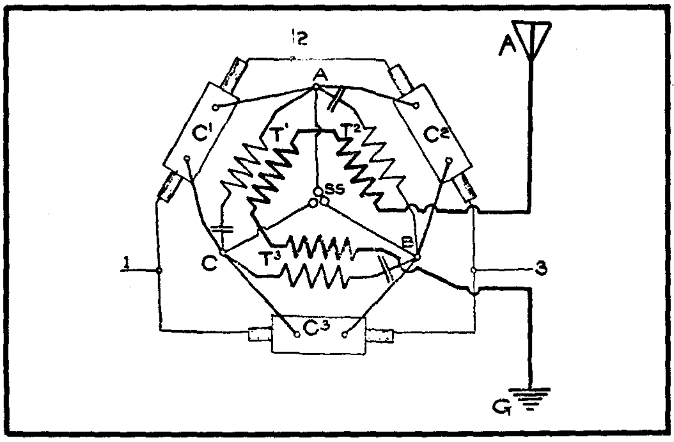

Fig.1: The most promising circuit Hugo Gernsback could come up with in 1911 for a spark type telephony transmitter. It assumes the use of a 3-phase AC supply connected to points 1,2 and 3. T1, T2 and T3 are matched RF transformers feeding the antenna system.

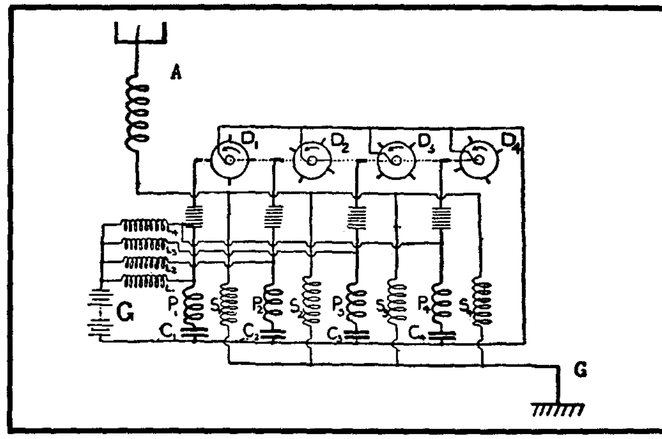

Fig.2: Taken directly from Goldsmith's book, this Marconi discharger operated from 10kV DC and provided 16 evenly spaced discharges per revolution. Optimally adjusted, it was said to have produced something very close to a continuous waveform.

duced per revolution.

By correlating the discharge rate with the nominal carrier frequency, the damped wavetrains can overlap and supplement each other to create what closely resembles a true CW (continuous wave) carrier, as illustrated in Fig.3.

Ironically, the emphasis within the Marconi Company was such that the primary objective in developing the system was to produce the purest possible telegraphy signal, which could be intercepted by a more selective receiver and rendered audible at a distinctive frequency by heterodyne beat reception.

Goldsmith observes that while such transmitters appear to provide a noticeably clean signal well suited to beat reception, 'equipment of this sort has not been used for radio telephony up to the present so far as the author is aware'.

Over and above Marconi's personal lack of enthusiasm for wireless telephony, logic would suggest that, with the technology of the period, it would not have been easy to maintain the spark rate as an accurate sub-multiple of the carrier frequency. In practice, arc systems emerged as the preferred method of generating continuous waves.

Arc transmitters

At first glance, use of an arc may appear to be a simple logical step: to progress from sequential pulses to a continuous signal, one needs only to move from individual sparks to a continuous discharge. In fact, the two are quite different in their mode of operation, as indicated by Goldsmith and discussed at some length in early issues of the *Admiralty Handbook*.

Fig.4, from the 1931 *Handbook*, shows the basic arrangement for a Poulsen type arc, associated with an oscillatory circuit L-C. Inductors L1 and L2 serve to isolate the RF components from the DC supply source and, also tend to limit and regulate the current to the arc system by inductively counteracting short-term variations.

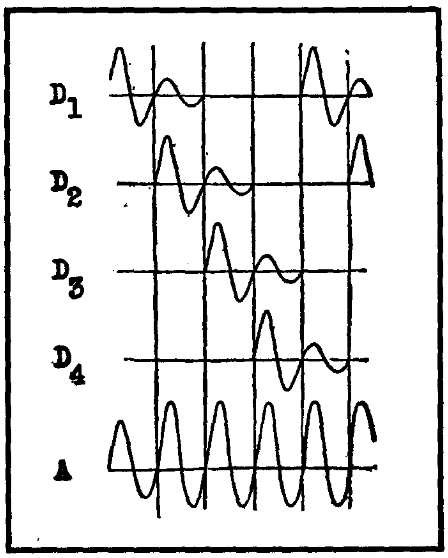

Fig.3: Optimally adjusted, a timed spark system could produce something very close to sustained radiation or a CW signal.

The positive electrode – or anode – is typically of copper, water cooled to prevent overheating. The negative electrode – or cathode – is of carbon, with the surface exposed to the arc operating at white heat. 'X' is a Morse key or key-operated relay, while L and C represent the oscillatory RF output circuit.

At white heat, the surface of the carbon electrode emits free electrons which collide with gas molecules in the gap, creating a conductive path across it; this comprises large numbers of positive and negative ions. In consequence, the conductivity of the arc is, by nature, quite different to that of other conductors.

If one plots the voltage across an arc against the current through it, the result is a curve similar to that shown in Fig.5, which indicates that, as the voltage increases, the current falls – the reverse relationship from that which Ohm's Law predicts for conventional resistive devices. In technical jargon, such an arc is said to exhibit a 'negative' resistance.

Arc-driven oscillators

In the context of oscillatory circuits, we have already seen that ordinary (positive) resistive loss or loading causes an oscillatory waveform to die away over a few cycles, resulting in a damped wavetrain. The less severe the loading, the longer does the wavetrain persist; in an ideal lossless, non-loaded circuit, the oscillation would continue indefinitely.

Not surprisingly, when a practical (less than ideal) tuned circuit is shunted by a *negative* resistance device, oscillation, once started, will continue indefinitely – providing the negative resistance is sufficient to cancel out the effect of the 'positive' losses and loading.

Consider again Fig.4. When the key is closed, capacitor C begins to charge through inductor L towards the arc voltage. Because L1 and L2 hold the total current 'I' constant in the short term, the charging current 'i' is subtracted from 'I' causing an instananeous reduction in the arc current 'i_a'. But because the arc behaves as a negative resistance, this will initiate an upward pulse in arc voltage, thereby supplementing the original positive pulse across 'C'.

At the end of this half-cycle, when the voltage across C begins to diminish,

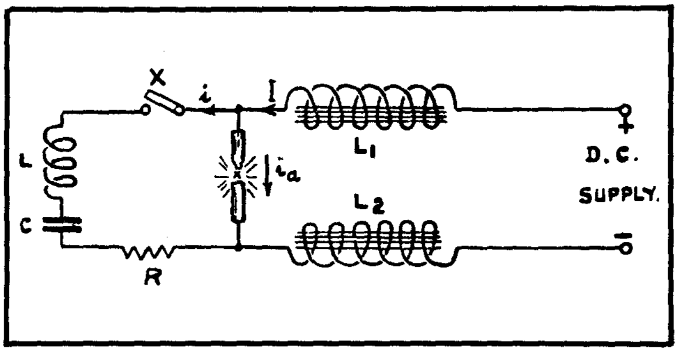

Fig.4: The basic circuit for a Poulsen arc type oscillatory system. Water cooling, a rotating cathode and hydrogenous vapour helped extend the operational life of the arc.

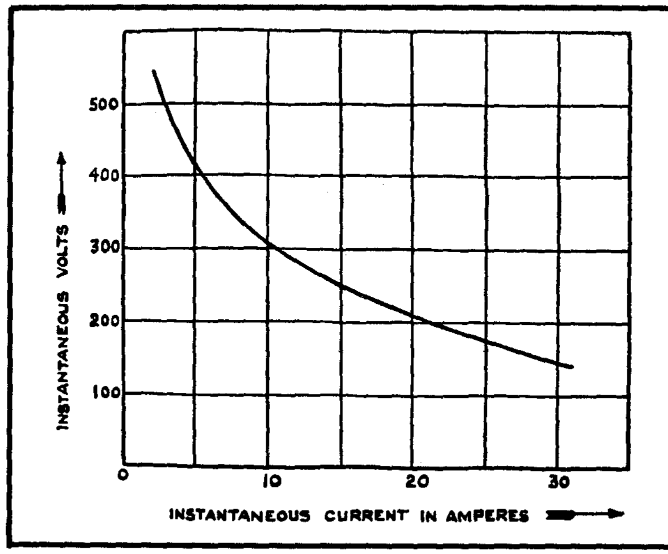

Fig.5: The volt-ampere curve for a Poulsen arc, as depicted in the 1931 Admiralty Handbook. As the voltage across the arc rises from 140V to 500V, the current falls from about 30 to 3 amps, by reason of its 'negative resistance' characteristic.

the discharge current 'i' adds to 'I', increasing the instantaneous value of 'I_a' and reducing the voltage across the arc, this time supplementing the negative half-cycle.

In other words, the effect of the negative resistance arc is to supplement the natural charge/discharge cycles of capacitor C. In effect, rather than dissipate the energy in the oscillatory circuit, it diverts energy to it from the DC supply. Properly set up, it can make up for the inherent losses in the oscillatory circuit and the energy radiated by the aerial system, thereby maintaining continuous oscillation.

As with spark equipment, arc transmitters were the subject of a great deal of experiment and development, both electrical and in terms of their physical presentation.

Typical technology

Poulsen's basic arc was housed in a heavy metal box with the elements mounted on large porcelain insulators to ensure mechanical stability. The carbon cathode, itself, was rotated slowly by means of an auxiliary motor to ensure that it burnt evenly, rather than at one particular spot on its surface.

In addition, it was operated in a hydrogenous vapour – commonly provided by a drip system dispensing alcohol or methylated spirit into the chamber, where it was vapourised by the heat.

The copper anode was cooled by water pumped through internal holes, with water cooling being provided also for the walls of the metal case, depending on the rating – and the heat output – of the particular arc. The cooling water needed to be pure, to avoid the risk of conductive losses.

L1 and L2 were supplemented by – or re-designed to double as – electromagnetic field coils, placed on either side of the arc. The purpose of the field was to bow the arc upward and confine it to the top of the gap, thereby stabilising it by minimising any tendency to flicker from point to point. As a bonus, being dependent on the arc current, the magnetic field could also make the arc simpler to set up and maintain.

Beyond that again, the *Admiralty Handbook* points out that adjustment of the magnetic field allowed the Poulsen arc to function in the so-called 'Beta' mode, in which the arc actually extinguishes for a brief period during the high voltage peak of each cycle, due to diminished current. In this mode the RF system reaches peak efficiency because the total supply current was available to charge the storage capacitance of the aerial system – on a once-per-cycle basis.

There is much more to it, but the purpose of this article is to offer an historical overview rather than a detailed study of arc technology. Sufficient to say that Goldsmith's book, mentioned earlier depicts a variety of arc-driven oscillators current in 1918, all looking externally quite different e.g: Berliner-Poulsen (of various ratings), Danish Poulsen, Lorenz-Poulsen, Continental Syndicate Poulsen, Federal Telegraph Co (60kW and 100kW), and Telefunken.

In the third of these articles we will look at the 'RF alternator' technique, which also had a brief period of popularity, and then at the way thermionic valves were used for the first really successful approach to radio telephony.