OBSERVATORY TIME BY RADIO: 1901 TO 1970

FROM THE EIFFEL TOWER TO UTC AND THE ARRIVAL OF RADIO CONTROLLED CLOCKS

by David Read

A clock might be stopped but time itself goes on. Fortunately, we can start the clock again and put it right by reference to another clock; but what clock to choose? The question is a very old one, but I am starting in 1859 with the great Westminster clock, now known as Big Ben.

From 1859 when Big Ben was finally completed, it was the best time standard for the general public in London. Within a few years, the performance of Big Ben was monitored by connections between Greenwich Observatory, the Dent Company, and Big Ben itself, using wire telegraphy and the kick of galvanometers.

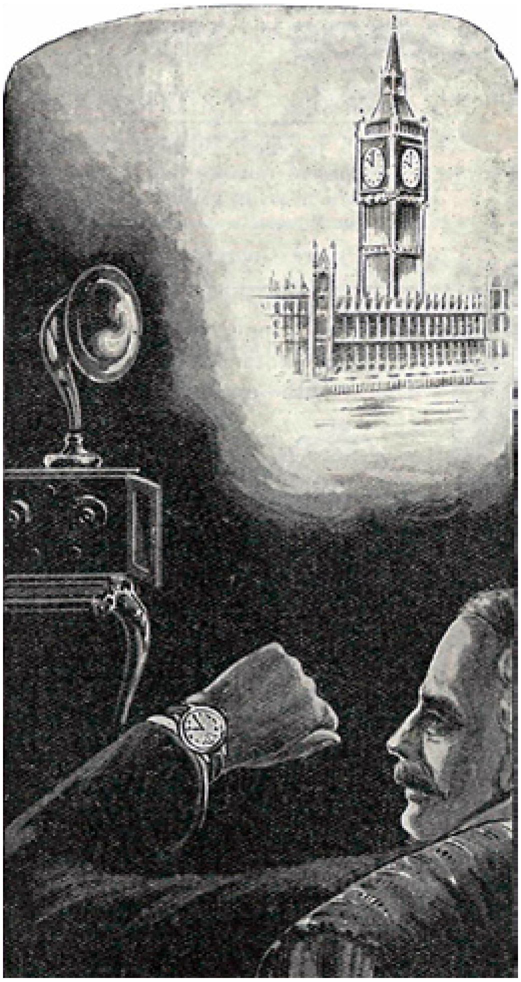


Fig. 1. A man checks his watch.

In a typical set of annual records, its daily error for 131 days of the year was better than 0.2 of a second. So if you worked or lived within sight of it you knew the correct time, generally to much better than a second. If you were not within sight of it but within 4 miles you could listen to the sound of the great bell and correct your watch or clock. If you were fussy, you could consider the delay before the sound reached you and in Clerkenwell the watchmakers knew that the delay was 8 seconds.

A time standard travelling through the air at the rather slow speed of sound is, nevertheless, still a time standard. When some years later a time standard could travel by radio waves at the speed of light, observatories still had to work out the delay.

With the arrival of public broadcasting in November 1922 it was soon possible to hear Big Ben on the wireless, the first broadcast taking place at midnight on New Year's Eve 1923.

The image shown in Fig. 2 is a crystal set made by Stockall & Marples, a maker of a variety of technical equipment including clocks. With the arrival of public broadcasting, Big Ben quickly became the best public time standard, not just for London, but for the whole country.

A crystal set, the most basic wireless receiver of all, required only a good aerial, earth, and high impedance headphones to listen to the BBC and thereby Big Ben as well. From the 9th March 1924 Big Ben was broadcast twice a day and although the six pips also became a regular feature, the general public continued to enjoy the sound of the Westminster clock and could visualise it at the heart of the capital and, indeed, the Empire.

Fig. 2. The Big Ben crystal set.

In the opening illustration from 1928 (Fig.1), a gentleman listens to his radio and checks his watch against the sound of the great bell. As he does so you can see that he has in his 'mind's eye' a picture of Big Ben. He receives the signal at 186,000 miles per second, and, although the great Westminster clock is now 70 years old, it is still the best time standard embodied in a public clock in the world.

The man visualises the actual time standard involved and knows what a fine clock is. He knows that Big Ben contains a pendulum whilst his watch has a balance wheel. The man knows perfectly well what his watch loses or gains in a day because he has the job of correcting it at the same time every day. Although not a specialist or interested in horology as such, he knows what a good pendulum clock generally consists of. He knows the difference between these timekeepers.

We now move forward to the present time. Since 1986, radio controlled clocks have been available to the general public, and from 1990 so called 'atomic wrist watches', advertised as accurate to a second in a meaningless number of years, have been on the market. Today there are lots of things that a man listening to a radio doesn't know and cannot visualise. Today, a man cannot imagine in his mind's eye the remote atomic frequency standard. Neither does he know what is inside his 'atomic' watch. Lastly, he doesn't know that his radio controlled watch is not, by itself, particularly accurate because he doesn't have the job of monitoring and correcting it.

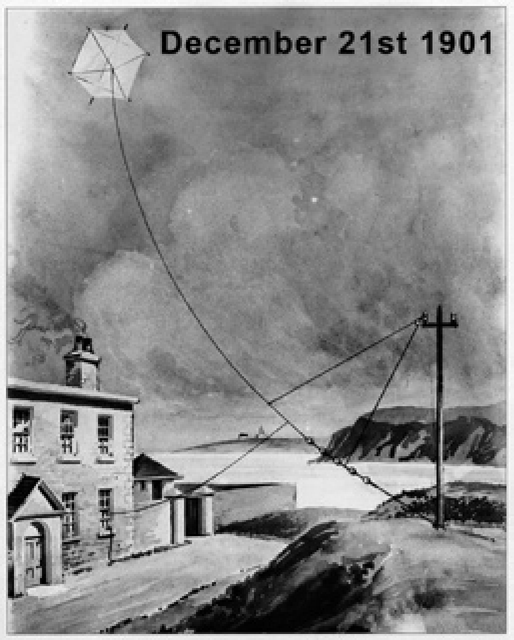


Fig. 3. Radio leaps the Atlantic Ocean.

Today we take Coordinated Universal Time (UTC) for granted, and whether it is received from the NPL in the UK or anywhere else, it is the average of more than 200 atomic clocks in laboratories around the world. So, what clock is used to put an atomic clock right? All the primary caesium standards in the world are checked against each other and their average is used for deriving UTC.

This article now traces the technological and horological steps that have taken place between the time standard that our grandfathers knew and that which we have today.

MARCONI'S ATLANTIC LEAP

I began with Big Ben, and the six pips representing Greenwich. These, as broadcast by the BBC from 1924, onwards were essentially intended for the population at large.

Time signals by wireless had a very much earlier beginning, unknown to the general public, which served the requirements of navigators and observatories on both sides of the Atlantic.

The story starts 21 years before the BBC. It starts from the moment in 1901 when a kite was flown at Signal Hill, St Johns, Newfoundland

Fig. 4. Launching the kite.

(Fig. 3). When the kite was pulled down, a watershed had occurred that was so significant and so far reaching, that almost everything in the world would eventually be changed by the new science and engineering that would spring from it. Wrapped in the mists of the Atlantic Ocean and battered by its storms, Newfoundland is seldom these days in the news. Yet, just over one hundred years ago it was, briefly, the most famous place on earth.

The kite was a wireless receiving aerial. Inside the small building sat Marconi, his assistant Kemp and some helpers. Marconi's astounding achievement was that he had succeeded in sending wireless signals across the Atlantic from Poldhu in Cornwall to what is now named Signal Hill. In so doing he confounded the greatest minds in the scientific establishment. It was the event that kick-started international wireless communications and gave rise to most of the invisible technologies that have created the modern world.

This historic photograph (Fig. 4) of launching the kite shows Marconi on the far left; a lonely figure poised in a moment of uncertainty. One can imagine what was in his mind. Several balloons had also been brought to serve as aerials but the violent weather just blew them away. This kite was all that was left. It was all or nothing. With Marconi's success, wireless time signals and weather reports from the Eiffel Tower would begin in less than a decade. But on that day in 1901, all that was claimed was that the letter S in Morse code had been received. Less than three months later he did it again, this time with conclusive proof on a Morse inker.

Overnight, Fig. 5 became the most famous image in all papers and magazines. It is Marconi sitting with his equipment at Signal Hill.

What Marconi did was thought to be impossible, because radio waves travel in straight lines, and between Poldhu and Signal Hill there

Fig. 5. Marconi at Signal Hill, St Johns, Newfoundland

is an insurmountable obstruction 186 miles high – the curvature of the earth. What possible point was there in using a feeble kite as an aerial?

Had Marconi believed that what he set out to do was impossible, he would not have attempted it. What he did could not be doubted, but at the same time it could not be explained. It illustrated the difference between academics employed at universities and amateurs who experimented in workshops and in the field. In Marconi's case, he was an experimental genius and he would go on to create the first global telecommunications company in the world; a company that became the springboard for an entire new industry.

Marconi, half Italian, half Irish, had found support for his ideas and created his company in England in 1896. Practical experiments with wireless signals had shown him that he had a chance to transmit around the earth's curvature despite theoretical opinions to the contrary. His new company had filed the world's first radio patent, and six months before his Atlantic leap his equipment was being fitted to merchant ships and coastal stations.

Marconi's Atlantic leap was seen as a body blow to the established wire telegraphy business that by then circled the earth. By 1898, there were fifteen submarine telegraph cables crossing the North Atlantic. In fact, when the kite flew on Signal Hill, the growing worldwide need for communications meant that the cable companies were going hell for leather. With telegraphy expansion in full flow the cable companies suddenly had to take stock and there was nobody more interested amongst the spectators at Signal Hill than the staff of the transatlantic cable stations.

It had been the custom for many years in the submarine cable service throughout the world to exchange Christmas greeting by means of cablegram. On Christmas day, less than two weeks following Marconi's transmission of the letter S, the following message was sent from Nova Scotia to the office in Liverpool, England at the other end of the cable.

> Best Christmas greeting from North Sydney, hope you are sound in heart and kidney,
> Next year will find us quite unable to send exchanges o'er the cable:
> Marconi will our finish see, the cable co's have ceased to be;
> No further need of automatics, retards, resistances, and statics.
> I'll then "across the ether sea" waft Christmas greeting unto thee.

From England came the reply:

> Don't be alarmed, the cable co's will not be dead as you suppose.
> Marconi may have been deceived in what he firmly has believed.
> But be it so, or, be it not, the cable routes won't be forgot;
> His speed will never equal ours; where we take minutes, he'll want hours.
> Don't be alarmed my worthy friend, full many a year precedes our end.

There was encouragement in this, and it warranted an acknowledgment. A final telegraph from Newfoundland to England read:

> Thanks old man for the soothing balm which makes me resolute and calm.
> I do not feel the least alarm, the signal "S" can do no harm;
> It might mean "sell" to anxious sellers, it may mean "sold" to other fellers.
> Whether 'tis "sold" or simply "sell", Marconi's "S" may go to – well!

The intellectual activity caused by Marconi's achievement was described as a task for giants, and the best minds in the world of science were forced to reconsider their strongest beliefs. At the same time, the success of Marconi's wireless transmissions caused a small flurry of predictions about time distribution. What one might call futurology. I will mention two now and one later:

Sir Howard Grubb, distinguished engineer and scientist, Fellow of the Royal Society, and builder of some of the world's finest telescopes said in a talk given to the Royal Dublin Society in November 1898:

> I do not put it forward as a proposition likely to be carried out in any way, except as an experiment, yet it undoubtedly would be perfectly possible to carry an apparatus in one's pocket, and have our watches automatically set by Marconi's waves as we walk about the streets.

Frank Hope-Jones, Manager of The Synchronome Syndicate Ltd, had attended a lecture given by Marconi at the Royal Society of Arts 6 months before his Atlantic Leap on the subject of marine communications and the allocation of standard frequencies for Admiralty and Post Office use.

Marconi had explained his tuning system whereby interference to receivers on different wavelengths could be prevented. Hope-Jones now believed he could see a wireless application for his favourite subject, the distribution of time, and in the following month he explained it in *Fielden's Magazine*; a periodical that described itself as 'Articles specially contributed by the world's experts.'

In conclusion to his article Hope-Jones wrote:

> Of one thing I am certain, that, whatever the future may have in store for us in the way of universal time transmitters there can be no doubt as to the ultimate form of the receiver clocks. They will be mere indicator dials driven by a simple form of step by step movement in electrical connection.

As for explaining the impossible, physicists speculated for a decade and took another 10 years to provide a complete and watertight scientific explanation for how radio waves could circle the earth. But by then Marconi had created a worldwide company whose patents gave him a virtual monopoly in every country including the USA. Radio waves did indeed travel in straight lines and it was reflection off the then unknown ionosphere that enabled communications to circle the earth.

We have seen that when wireless started, cable telegraphy was already an established

Fig. 6. Telegraphy Galvanometer.

industry. The distribution of time by wire was an integral part of this, and those elements that carried over into the wireless age formed a bridge between the old and the new.

Well before Marconi's landmark demonstration, and repeatedly from 1850 onwards, George Airy, the Astronomer Royal from 1835 to 1881, had been arguing for the dissemination of time signals throughout the country by use of wire telegraphy from the Greenwich Royal Observatory.

Because of Airy, standard time was delivered at 10 am every day down the railway telegraph system as a physical signal (e.g. the kick on a galvanometer as illustrated here in Fig. 6) and provided to post offices and other establishments for the checking and correction of clocks and watches.

Also in the days of the cable Morse messaging system, it became a requirement governed by international agreement that all telegraphs should indicate the time at which a message was sent. The means for doing this in Morse had been devised in the British railway system and consisted of a shorthand method by which the time could quickly be indicated by keying no more than three letters rather than laboriously spelling out the words in code. The dials of clocks and watches used by telegraphers working for the railroad companies were printed to facilitate this requirement and examples are shown in Figs 7 & 8.

Fig. 7. Telegraphy dial watch for Royal Signals - Benson.

Railway Signalling Instruments by W.E. Langdon, published in London in 1877 would seem to be the earliest reference to the system. The twelve letters A to M (excluding J) denote the twelve hours and these letters also denote the twelve periods of five minutes. The letters RSWX denote the four minutes within each five minute sector. When R, S, W or X is added to the two former letters, the exact minute can be denoted. In Fig. 7 the time shown would be represented by KBS.

In the British Army, the railway's method was taken up by the Signals Branch of the Royal Engineers, and was in place by the time that the new wireless telegraphy was in use for WWI.

Marconi's companies also used the railway time code system but adapted it to their own requirements, so that the code was extended to indicate night time as well as daytime (Fig. 8).

In the worldwide system of wireless telegraphy set up by Marconi's Wireless Telegraph Company (MWT), it was found necessary to add a further set of twelve letters to provide this differentiation and the letters N to Z (excluding U) were added to the dial; M meaning midday as before and Z meaning midnight.

Thanks to Marconi, the British now possessed an efficient wireless service between ships and coastal stations which embraced

Fig. 8. Marconi's Wireless Telegraph Co. Watch.

ships of all nations. Consequently, in 1906 an International Convention was signed that was based on the Marconi system. This had been devised by Andrew Gray, Chief Engineer of the Marconi Companies. He had overall responsibility for solving the many difficult international traffic problems at sea and producing the regulations for the conduct of the service.

The communications charts produced by MWT proved to be indispensable and were produced as evidence at Board of Trade enquiries into the loss of ships on every occasion. They show at a glance the ships that should receive calls and those close enough to render aid.

The chart for a month in 1912 is shown below and, today, it is astonishing to see the sheer quantity of traffic on the Atlantic. This chart was the marine equivalent of air traffic control today and time signals, to ensure precise navigation, combined with the exact time of every communication, were essential for it to work properly.

We have seen that Marconi had proved that wireless time signals were possible and his companies, together with the needs of shipping, had provided the stimulus for their development. They could now be applied to wider and scientific uses, and at this point in the story I can now leave Marconi and deal with time signals for coordinating time itself.

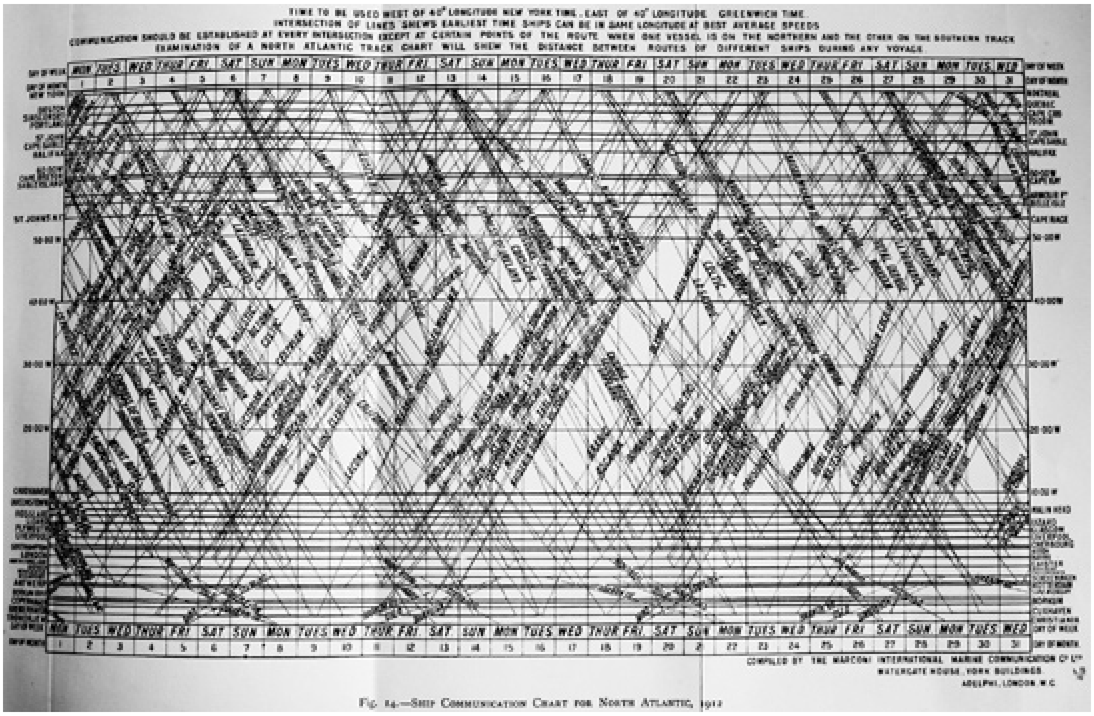


Fig. 9. MWT shipping communications chart.

Fig. 10. Ducretet transmits from the Eiffel Tower to the Pantheon.

COORDINATION OF TIME BY WIRELESS

The first wireless transmission from the Eiffel Tower took place on the 5th of November 1898. On that occasion the scientific instrument maker, Eugene Ducretet (1844-1915), made a public demonstration of wireless by setting up a transmitter on the 3rd floor of the tower and transmitting signals to a receiver and Morse paper tape recorder at the Pantheon in the Latin Quarter, a distance of 4 kilometres. The seventy fifth anniversary of the historic event was marked by the issue of a postage stamp as shown in the illustration (Fig. 10).

It was in the Pantheon in 1851 that Léon Foucault had set up his great public pendulum demonstration. By hanging a pendulum under its dome, and with no view of the outside world, he confirmed visually that the Earth rotated on its axis.

Ducretet's activity in the use of wireless did not escape the notice of the astronomer Guillaume Bigourdan, Director of the Paris Observatory. In the early part of 1904 it was reported in La Nature that:

> M. Bigourdan noted that the synchronization of a group of clocks had required a network of telegraph wires. However, Bigourdan now proposed a process that would allow the comparison of a central pendulum master clock to the subordinate clocks in the group, by the use of wireless telegraphy. The beats are transmitted in this way without losing intensity and the comparison has an error of 0.2 sec.

Clearly something was in the air, and in July of the same year in *La Nature*, Ducretet and

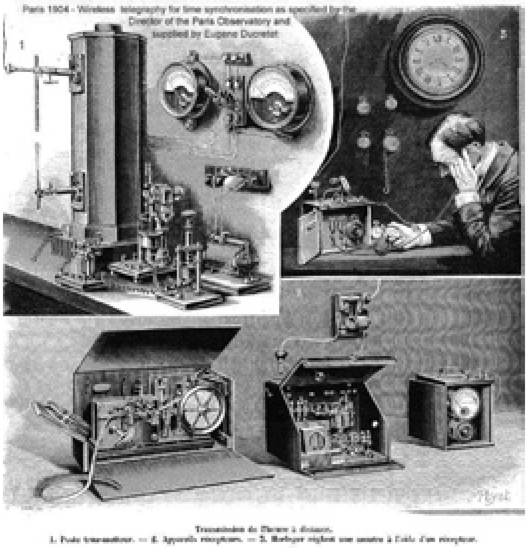


Fig. 11. *La Nature* July 1904 – wireless transmitting and receiving apparatus by Ducretet in collaboration with the Director of the Paris Observatory.

Bigourdan are described in an article called 'The Transmission of Time over Distance' as providing the first wireless signals in France that were designed solely with the transmission of time as their objective.

Here (Fig. 11) we see a number of fascinating images which illustrate the equipment involved. The article proves beyond doubt that radio was being used as early as 1904 to facilitate the correction of clocks in two districts of Paris and, also, of the clock on the wall at the door of the Paris Observatory as described in Bigourdan's article.

The correction of these clocks was in no way automatic. Whilst the secondary clocks were connected by wires, Bigourdan nevertheless underlines the fact that keeping an electric master clock and its large group of secondary clocks synchronised over two districts of Paris was not completely reliable in spite of their wired electrical connections to the master clock. The distribution of exact time by wireless enabled local monitoring, supervision and correction of clocks when needed.

We now move forward to 1909 when precise time begins to be truly intercontinental and the Eiffel Tower and Commandant Ferrié become the key European means for achieving this. A graduate of the best science university in France, Gustave Ferrié was a co-inventor of the electrolytic detector that replaced the

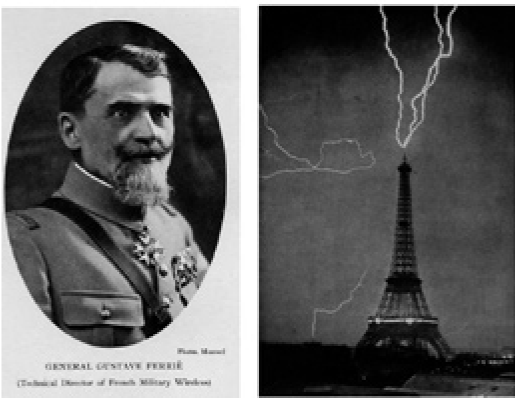


Fig. 12. Gustave Ferrié and the Eiffel Tower.

coherer. He joined the military signals division and when he saw WWI coming he turned to the development of the triode valve and mobile transmitters to enable military units to stay in radio contact with headquarters in Paris.

To do this he forced through in double time the development of the 'TM' valve (*Télégraphie Militaire*) which the British later copied to make the R valve on a B4 base. He assembled a corps of scientists and technicians who set up a network of radio direction finders from the English Channel to the Jura.

He was appointed a member of the Academy of Sciences, President of the International Scientific Radio Union, President of the International Commission on Longitudes by Radio and First President of the French National Committee of Geodesy and Géophysique. Ferrié without question was the most important figure in European military and civil communications. He created the concepts, chose the technologies and organised the means for coordinating time in Europe. He became so important to the French government that, uniquely, a special bill was passed so that he would never have to retire.

The civil offices responsible for providing standard time were the Bureau des Longitudes and the Paris Observatory. With Ferrié at their side, experimental transmissions of time signals from the Eiffel Tower for observatories (as well as ships in the Eastern Atlantic and the Mediterranean) began in 1909 and the official service was inaugurated in 1910.

With the time service in place it quickly became apparent that GMT as kept by the participating observatories varied by a few seconds. This was not altogether surprising but something needed to be done. International delegates from observatories and scientific institutions were invited to a meeting in Paris on 12th October 1912 where it was agreed to form the International Bureau of Time (BIH), together with plans for an international time service and a new International Time Code.

It was to be the BIH in Paris that would coordinate the results of the observatories and be responsible for calculating exact time for the world. The first Director of the BIH was none other than Guillaume Bigourdan, Director of the Paris Observatory, who, in 1904 with Ducretet, had arranged the distribution of time by wireless for the monitoring of city clocks that was mentioned earlier.

By 1913, standard time was being transmitted from both the US Naval Observatory and the Paris observatory, at high power, and on the same wavelength. In this way, on the 20th November 1913, the Paris Observatory exchanged and compared standard time with the United States Naval Observatory and Ferrié's signals soon formed the basis for coordination of time at observatories to a precision of 1/100th of a second. Progress with the constitution of the BIH, however, was brought to a halt by the Great War and it was not until 1920 that the international means of its supervision were agreed.

Three different codes were now in use for the transmission of time signals:

1. The ordinary (original) code continued for those who required a simple means of checking clocks and chronometers against GMT to an accuracy of ¼ second. The ordinary code was generated by a special clock in the Paris Observatory, fitted with the necessary output contacts, and the signals supplied to the transmitter in the tower by underground cable for transmission twice a day starting at 10.38 and 22.44.

2. The scientific code for exact coordination of observatory (sidereal) time to 1/100th of a second (or 1/1000th with special equipment) and intended for determining the difference in longitude between locations and for rating chronometers, transmitted twice a day in a 5 minute period starting at 10.00 and again at 22.00.

   The scientific signals were controlled by three Brillié ½ second pendulum clocks in the time room of the tower itself. The ½ second electromagnetically maintained pendulums were adjusted to run fast by 1 second in 49 and the resulting pulses issued to the transmitter in a series of 300 dots and regularly checked against the observatory regulator.

The vernier pulses transmitted every 49⁄50 or 0.98 of a sidereal second were then compared to local sidereal clocks or chronometers by the coincidence method in which the number of beats taken for the transmitted and local seconds to synchronize was noted.

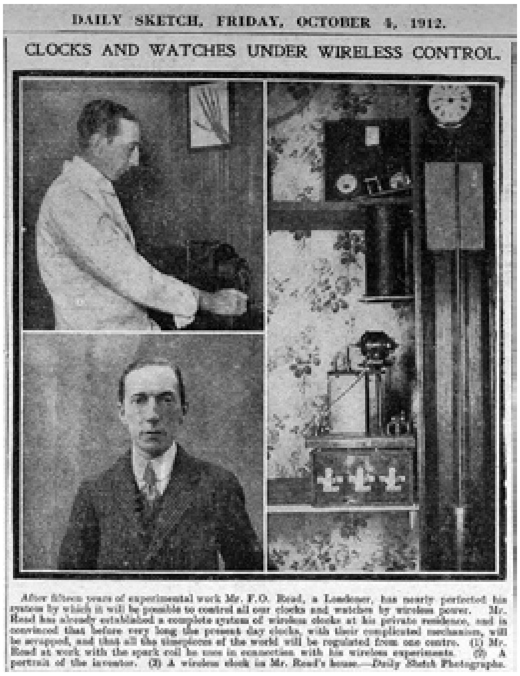
3. The international code was introduced to be the standard for all wireless time signals of GMT where a high standard of refinement was required. Navigation being of world wide importance, an international code was seen as the best way of transmitting the time in a common format or language. It was transmitted once every day at 09.23 to 09.30.

   It was a fully automatic system in which the pendulum of the master clock at the observatory synchronized a small electromagnetically maintained pendulum which in turn synchronized the motor of the highly complex Brillié-Leroy transmitting apparatus in the tower consisting of eight notched disks turning every ten seconds. Contacts followed the disks to establish and cut off current which acted on relays feeding the transmitter itself.

For all the codes, the start time allowed for transmission of preliminary 'call signs' before the actual time signals started.

THE POSITION IN THE UNITED KINGDOM

Thirteen years had now elapsed since Marconi's demonstration that stimulated Hope-Jones to indulge in some futurology and predict the certainty of clocks controlled by wireless. At that earlier period, wireless time signals of any sort did not exist at all and experimenters had to make their own signals with a home-based spark transmitter for which they needed a licence from the Post Office. It is interesting that with the transmission of time signals in place, Hope-



DAILY SKETCH, FRIDAY, OCTOBER 4, 1912.

CLOCKS AND WATCHES UNDER WIRELESS CONTROL.

After fifteen years of experimental work Mr. F.O. Read, a Londoner, has nearly perfected his system by which it will be possible to control all our clocks and watches by wireless power. Mr. Read has already established a complete system of wireless clocks at his private residence, and is convinced that before very long the present day clocks, with their complicated mechanism, will be scrapped, and that all the timepieces of the world will be regulated from one centre. (1) Mr. Read at work with the spark coil he uses in connection with his wireless experiments. (2) A portrait of the inventor. (3) A wireless clock in Mr. Read's house.—Daily Sketch Photographs.

Fig. 13. *Daily Sketch* article of 1912.

Jones became silent on the subject of using them to control remote clocks.

However, Mr F.O. Read, an established wireless experimenter and manufacturer did announce that he had nearly perfected the controlling of clocks by wireless. This was a bold claim and perhaps the first evidence of the much earlier visions of Grubb and Hope-Jones being turned into practical reality and the article shown in Fig. 13 appeared in the *Daily Sketch* on October 4th 1912. Notice that F.O. Read had been hard at work on this problem for fifteen years!

Marconi had demonstrated from the beginning that he could ring a bell in circuit with a coherer detector at one side of a room with a spark transmitter at the other side of the room. Now fifteen years later in 1912, official time signals did exist and experimenters had the challenge of using the Eiffel Tower rather than making spark transmissions themselves.

Unfortunately, one can only speculate about the image in Fig. 13. However much one examines it, it is not possible to work out exactly what the equipment represents. Nevertheless, like the earlier demonstrations it would seem from the photograph and accompanying text that the signals were still being provided by F.O. Read with a spark transmitter in his own home and although he now had the Eiffel Tower signals at his disposal he was not using them. We must assume that he was at the stage of going from using his home spark transmitter to receiving the Eiffel Tower and thought what follows would be a simple step. He had apparently established a system of wireless control in his house and was convinced that 'before long the present day clocks, with their complicated mechanism, will be scrapped and that all the timepieces of the world will be regulated from one centre.' [quoted from Fig. 13].

With hindsight the problems that he faced are easily stated: how would the code from Paris – barely audible without amplification and with varying conditions of reception – reliably trigger a relay from which all further interaction with a clock must take place? What would that interaction with the clock consist of and could it really be no more than the indexing of a single tooth as Hope-Jones had suggested? What would prevent the relay from responding to all the other pulses in the time code, and what if the signals did not mark the minute in a useful way?

It was a very long step indeed from using a home transmitter to close an armature and index a tooth, to controlling a clock by distant signals. The answer to the problem was still several years away and it would not be F.O. Read who would provide it. Nine years later in 1921 he was still in business (at Great Queen St Kingsway WC2) and advertising in *Wireless World*. He advertised that his sets would pick up numerous spark and continuous wave (CW) stations on all wavelengths. In this he was referring to transmissions from the continent of Europe such as the Eiffel Tower and he now had good 'R' valves at his disposal copied from the Ferrié TM. But there is no mention of clocks in connection with radio in his advertisement.

As mentioned above, Hope-Jones had become silent on the subject of radio control. He was not silent on other matters however and he again comes into view with respect to the developing scene of radio communications. We now see him as Chairman of the Wireless Society of London, this time as an insider to the art and a very influential one.

Hope-Jones knew and was an admirer of Ferrié and recognized that the UK had no equivalent figure of authority. The *Handbook of Wireless Telegraphy,* published annually in

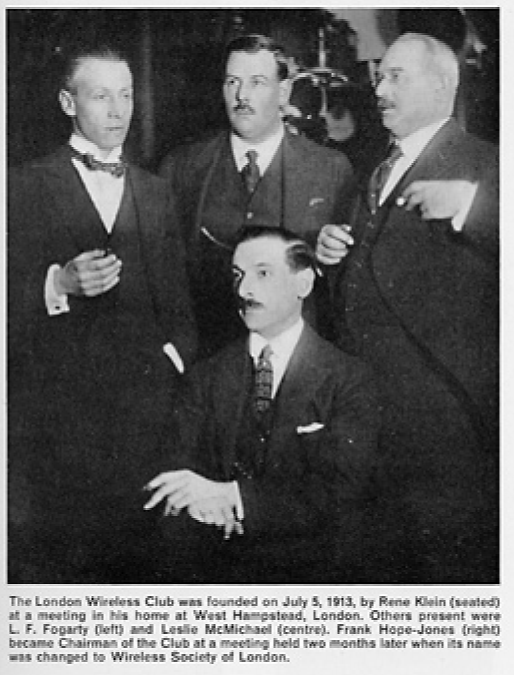


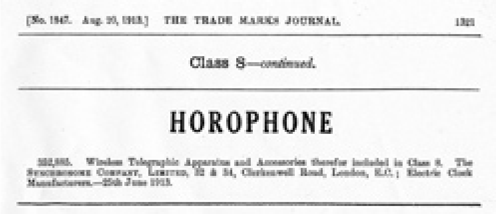
Fig. 14. Hope-Jones as Chairman of the Wireless Society of London in 1913, later to become the Radio Society of Great Britain, *photograph courtesy of RSGB*.

London, listed the International Transmitting Stations of the day. The entry referring to the UK for International Time Signals reads*:* 'The proximity of the Eiffel Tower and the elaborate arrangements made by our gallant ally obviate the necessity for any similar action on the part of Great Britain.'

Hope-Jones summed up the situation thus in his preface to the book by W.G.M. Mitchell on time signals and weather reports by wireless:

> The average Englishman imagines that Greenwich Time comes from Greenwich. This book will set him right. It used to, but unfortunately this country did not take the lead, did not take a fair share, nor in fact any share at all in the establishment of the International Service of Wireless Time Signals in 1912. Hence the Englishman who regarded Greenwich Time as something particularly British has been getting it from observatories and countries of his neighbours to an increasing extent for the last ten years.

Hope-Jones went on to say 'Thanks to the rhythmic signals, or time vernier, of General



[No. 1847. Aug. 20, 1913.] THE TRADE MARKS JOURNAL. 1321

Class 8—*continued.*

HOROPHONE

352,885. Wireless Telegraphic Apparatus and Accessories therefor included in Class 8. The Synchronome Company, Limited, 32 & 34, Clerkenwell Road, London, E.C.; Electric Clock Manufacturers.—25th June 1913.

Fig. 15. Horophone trade mark.

Fig. 16. Horophone crystal set, *photograph courtesy of Jonathan Hill.*

Ferrié their observatories are automatically pooled and they all help each other.'

Hope-Jones was very much in touch with activities at the Eiffel Tower having visited it as Ferrié's guest. As a result he was also very familiar with the scene in France where time signal receivers were already in production and, not surprisingly, he saw the potential for such a receiver in the UK. He applied for the Horophone trade mark in June 1913 and looked to one of the established French manufacturers to provide him with a suitable instrument.

The trade mark consists of the word Horophone only; i.e. it is without any illustration. Neither was it registered solely to cover time signal receivers. The mark is listed in Class 8 (Scientific Instruments etc.) and registered to apply generally to Wireless Telegraphy Apparatus and Accessories.

The photograph (Fig. 16) shows an actual example of a pre-war Horophone and reflects the typical type supplied in France. This instrument was examined by the writer shortly after its discovery and, curiously, although a push switch is provided for a buzzer, there is no evidence that one was fitted.

The Great War brought to an end all non-governmental wireless activity so I will now jump forward to developments that took place after the war.

In 1919 Hope-Jones resumed his role as Chairman of the Wireless Society of London. Public broadcasting was still three years away and transmissions from the Eiffel Tower still formed a major proportion of what could be received. Hope-Jones now advertised a post war British made Horophone. It is of typical British design and provided with two detectors and facilities for tuning various frequencies by use of variometer. An example of the post-war model has also been found and these two time signal receivers are the only genuine Horophones known to exist, suggesting that very few were actually sold.

Hope-Jones did not have the post-war market for time signal receivers to himself and a rather better product was sold under the name of Tempus (Fig. 17). As its name suggests, the Tempus, was manufactured specifically for time signal reception from the Eiffel Tower and other frequencies could not be tuned in. This was deliberate since a tuning coil dedicated to one frequency only will be more efficient. It was made by the firm of W. J. Badman in Weston Super Mare and is an instrument made to professional standards.

Badman was well known from the earliest days of wireless and had assisted Marconi in the erection of aerials for experimental transmissions

Fig. 17. Tempus time signal receiver.

on the south coast. In contrast to the cheaply made products of many small firms that began to exploit the potential radio market, W.J. Badman's receiver reflects in its design and attention to detail his experience at the leading edge of wireless experiments. A buzzer is provided to confirm that the detector is set to a sensitive adjustment together with means for fine tuning to the frequency of the Eiffel Tower. Time codes are provided in the lid together with the transmission times. The intended market for the Tempus receiver was the clock and watch trades as can be seen on the front page of the instructions as shown in Fig. 18.

In the period leading up to the Great War, transmitter technology had been based on spark generation and therefore limited to the broadcasting of Morse and other special codes by telegraphy. The period following the war was one of immense technological change for which the key driver was the thermionic valve, the development of which in France was driven forward by Gustave Ferrié in time for war use.

After the war, valve transmitters were perfected and the modulation and amplification of an electron stream within a vacuum tube now enabled the broadcasting of voice and music, namely, wireless telephony as distinct

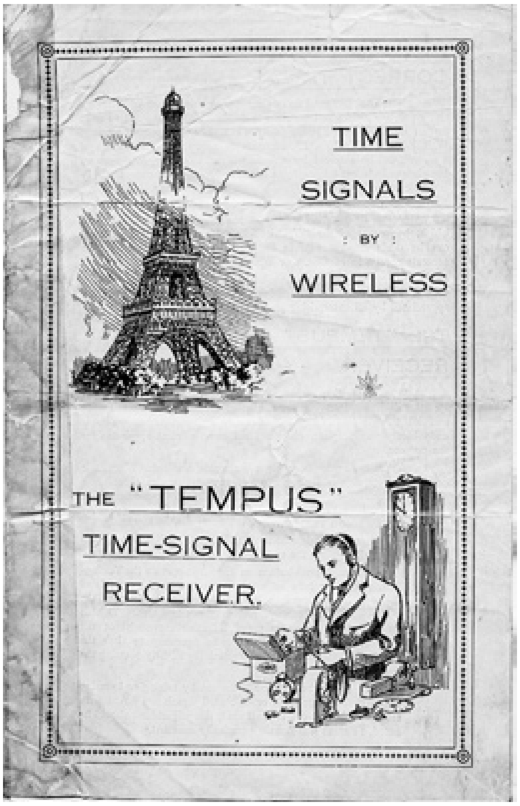


Fig. 18. Tempus instruction manual.

from telegraphy. The technology now existed that justified public broadcasting and in 1922, the year in which the BBC was founded, the first clocks that were actually corrected by radio signals made their appearance.

THE FIRST CLOCKS CORRECTED BY WIRELESS

Ferrié had earlier approached Brillié to supply clocks for the transmission of scientific signals and in spite of the poor quality image one can see in the centre of the picture (Fig. 19) the three

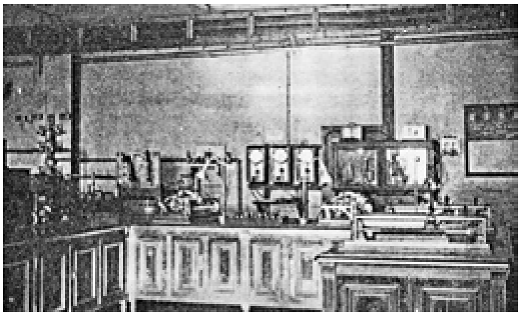


Fig. 19. The Time Room of the Eiffel Tower.


ex la science et la vie No 66 dec 1922

LA REMISE A L'HEURE AUTOMATIQUE DES PENDULES PAR LA T. S. F.

Par Gustave HARISSEL

Fig. 20. Brillié radio controlled clock at St Lazare.

½ second pendulum Brillié clocks in the Eiffel Tower used for this purpose. These clocks were continuously compared to the sidereal clock at the Paris observatory; however, their pendulums were adjusted so as to gain the one second in fifty necessary to produce the vernier beats as described earlier.

By 1922, advances made in the manufacture of thermionic valves enabled a means of actually correcting clocks by wireless rather than dreaming about it. Again, it was Ferrié who provided the stimulus. Orders were placed on Brillié to provide observatory time in the Paris main line stations and these clocks were the first to be successfully controlled by time signals. As we shall see shortly, a particular characteristic in the pattern of the International Code was utilized to make this possible.

By the middle of 1922, the first radio controlled clock was in place in the booking hall of the main line terminal at St Lazare as shown in Fig. 20. This remarkable clock consisted of a radio receiver and associated mechanisms that was automatically turned on at the correct time every day to receive and be synchronized by the International Time Code. In order to understand how this was achieved one must firstly examine the code so as to understand what the clock must identify and then respond to.

The chart (Fig. 21) shows both the international and the ordinary time signals with the international automatic signals in the top half of the chart. Signals in this period were intended for direct interpretation by technicians, not for directly synchronizing clocks. Moreover, it can be quickly seen that there are no regular seconds markers that, if amplified, might enable sympathetic synchronization of the pendulum and neither is there a suitable minute marker that might be chosen to trigger a sensitive relay.

To develop a clock that would receive these signals and be corrected by them required an ingenious and unlikely solution that Brillié achieved by using the long dash of five seconds that terminates at exactly 09.30. This is the only marker that stands out from the rest and I have marked it with a red pointer.

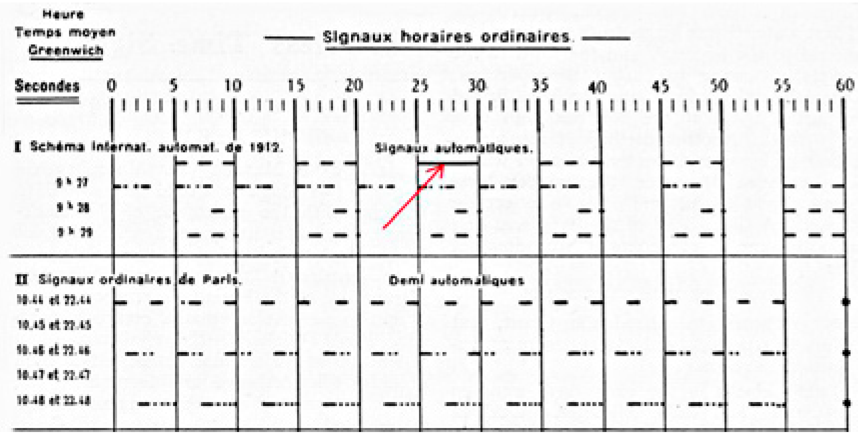


Fig. 21. Time signals chart.

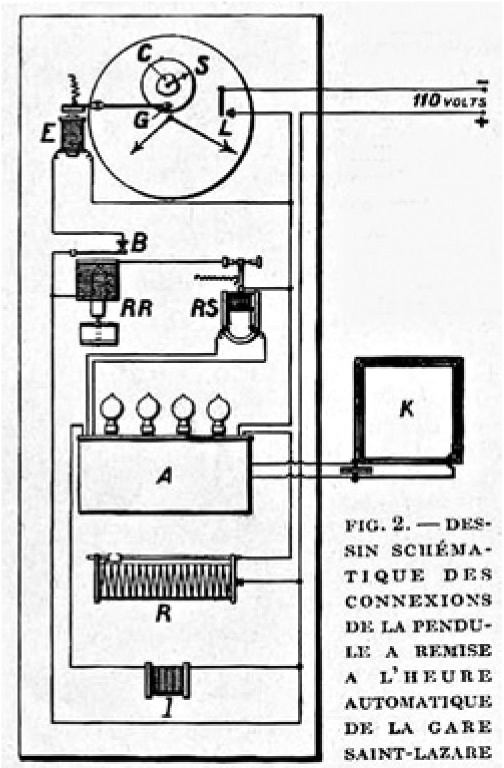


Fig. 22. Brillié schematic.

110 V DC is switched on by a 24-hour programme controller incorporated in the clock's wheel train that closes a mercury switch. Positive DC arrives at the wireless having been dropped to 4 volts by the rheostat R whilst the tuned frame aerial receives the international code.

All the dashes in the time code are amplified by the four valve amplifier A, rectified to DC, and act first on a relay of great sensitivity RS. The pulses of time code passing through the sensitive relay now reach a high current delaying relay RR whose contact closes against the pressure of a compressed air brake comprising a pneumatic tube and piston.

When fully compressed, the switch B closes and passes high current to a solenoid E whose armature G zeros the chronograph type cam C fitted on the seconds arbor and on which the seconds hand is carried. The delay taken to compress the pneumatic tube and piston is adjusted be exactly 4.5 to 5 seconds in order to synchronise the seconds hand correctly to the last ½ second of the long 5 second pulse in the time code.

In this way the seconds hand of the clock is corrected to observatory time and, because all other pulses are too short for the air brake to complete its action, the relay does not close on unwanted pulses in the time signal. Because the seconds are outside the friction clutch of the motion work, the minute hand will gradually move away from exact time in spite of the fact that the seconds hand is synchronised on a daily basis. One must assume that when this became too obvious a technician simply moved the minute hand onto the exact division on the dial.

This is an ingenious mechanism, but one can quickly see where the dangers lie. If the air brake takes a fraction less time in its closing, the seconds hand will be zeroed too soon whilst if it gets sloppy and the delay is further shortened, other pulses might be accepted and will cause chaos. On the other hand, if the delay is but a fraction too long, synchronisation will not take place at all. It is clear, therefore, that the time taken to compress the pneumatic brake must be exactly right and go on being right. I can find no records of how reliable this system was in the long term; nevertheless, it was a landmark clock representing a remarkable combination of technologies and seven years were to pass before another attempt at synchronising a clock to observatory time by wireless was to make its appearance.

On the 14th August 1929 an article was published in *Wireless World* under the title of 'Clock Setting by Wireless' in which the automatic synchronisation of an ATO ½ second pendulum clock from time signals transmitted from the commercial radio station Radio-Paris (founded originally as Radiola) was discussed. Radiola was a privately owned French radio station which broadcast under that name from its 80 KW transmitter at Essarts-le-Roi, 40 km southwest of Paris from 6 November 1922 until 28 March 1924. Renamed Radio-Paris on 29 March 1924, the station was taken into public ownership on 17 December 1933. It was to remain on air – under the control of the Nazi authorities and French collaborationists – throughout the German occupation of France in World War II until the liberation of Paris in August 1944.

The method employed by ATO worked basically on the same principle as that employed by Brillié 7 years earlier in which the time code was received, amplified, rectified, and passed through a relay system that acted on levers

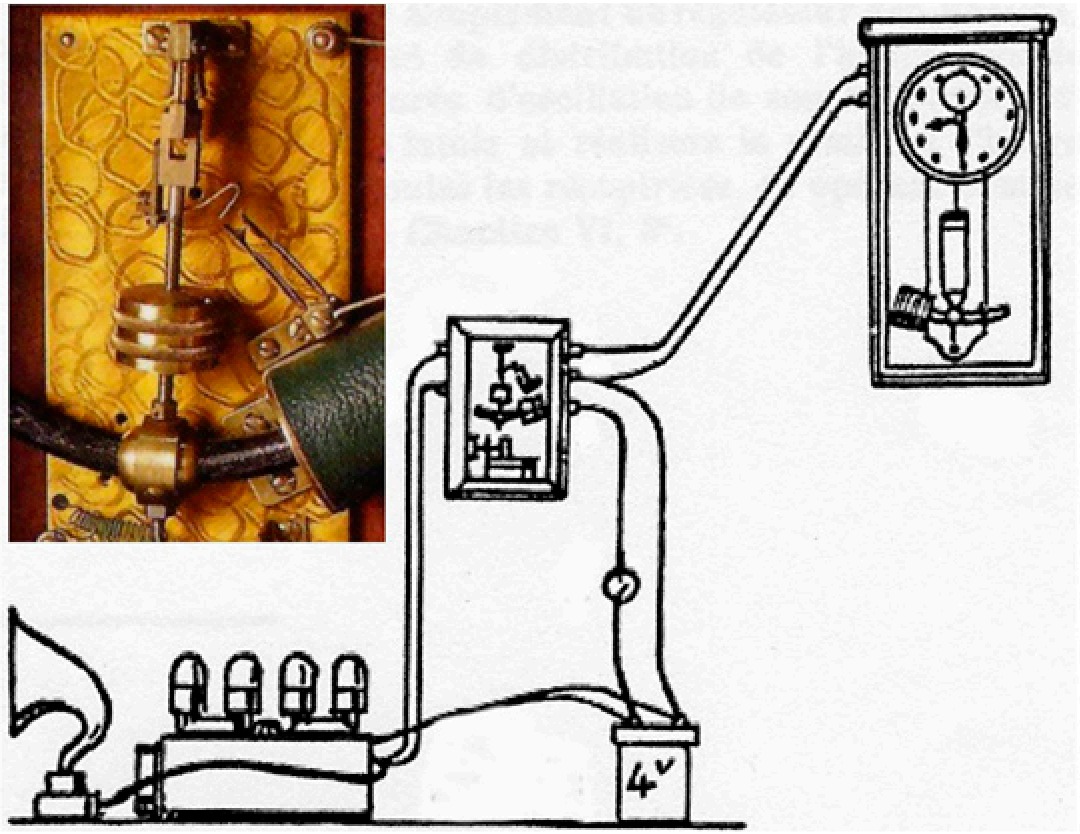


Fig. 23. Time signal receiver schematic and relay detail by ATO – Radiola.

and cams to correct the hands of a ½ seconds electromagnetic pendulum clock. Unlike the Brillié, however, in the ATO system the wireless receiver, amplifier/detector relay, and modified clock were introduced as separate units as we can see here in the drawing (Fig. 23), and the relay between signal and clock was operated by a sympathetic pendulum closing a switch via its rod as shown in the inset photograph.

The signals provided by Radio-Paris, were broadcast as a sequence of six 'rhythmic' dots ending on the exact time, similar to six pips provided by the BBC. The amplified and rectified pips of the signal were passed to the coil of a ¼ second pendulum that immediately started to swing in sympathetic motion and in so doing closed a switch thus acting as a relay. Many readers will recognise that this relay is a simple modification of the standard ATO ¼ second electromagnetic pendulum as provided on their small clocks and sympathetic slave dials.

Because the time dots from Radiola were transmitted not as time code but as rhythmic seconds, a delaying relay or other means of decoding is not required. However, the time taken by the sympathetic ¼ second pendulum to start its swing and reach the point of closing the switch must be shorter than the six pulses in the signal for the relay to pass a synchronising pulse to the clock itself.

On closing the switch the pendulum is damped and ceases to swing; however, should it again close the switch before termination of the signal, the hands of the clock would simply be reset a second time.

The ATO clock provided for this ensemble was also a modified clock from the range of ½ second wall clocks. Heart shaped cams, as used in chronographs, were carried on the arbors of the seconds and minute hand and were forcibly zeroed by the armature of a solenoid when the synchronising pulse was received. Since the hour hand is driven through motion work linked to the minute arbor in the usual way, it can be seen that all the hands were corrected in the ATO system.

The ATO system of correcting clocks by wireless was also introduced in Germany in association with Junghans who had an established market for the ATO type clocks, however, the lack of references to the wireless system and extreme rarity of these items today suggests that it was not a commercial success.

The position in the mid- to late 1920s, therefore, was one in which, whilst observatories and scientific institutions were able to coordinate time by use of scientific time signals, and pips representing exact seconds were provided to the public as an adjunct of broadcasting, the practical realisation of radio corrected clocks for the population at large was still limited by cost and the technologies available.

In short, a further 30 years and another world war would pass before the dreams of Sir Howard Grubb, Frank Hope-Jones and F.O. Read would begin to look possible.

THE FIRST TRANSMISSIONS OF TIME SIGNALS COMBINED WITH A PRECISE FREQUENCY STANDARD

Radio transmission at high power on both sides of the Atlantic from 1913 onwards had made use of high frequency alternators, Poulson arcs, or 'timed spark' systems of continuous wave operation. The stability of the frequency of such systems was poor and whilst this did not matter as far as the transmission of time signals was concerned, the frequency of the carrier wave was completely unsuitable for use as a frequency standard. In addition it had become unacceptable in light of the proliferation of transmitting stations and the resulting need for selectivity.

What was needed was the development of high-power transmitting valves and the precise control of the transmitted frequency. The breakthrough for both of these was pioneered in the United Kingdom where the manufacture of high-power water-cooled valves to replace spark generated transmission first took place and where they were first used in the Post Office station built at Rugby for international long wave telegraphy. The transmitter itself was designed to work at 16 kHz, the primary source being obtained from a tuning fork maintained in oscillation by a thermionic valve and vibrating at a frequency one-ninth of the radiated frequency. The Rugby station was the first to have its frequency precisely controlled in this way.

Figs 24 & 25. 1000 Hz tuning fork oscillator manufactured by General Radio Co., Cambridge Massachusetts, c.1927.

The transmitter opened for traffic on 1st January 1926, under the call sign GBR, and, having worldwide coverage, was an unqualified success. Transmissions included twice daily transmissions of time signals broadcast on the very low frequency of 16 kHz. The signals were of the vernier type enabling precise coordination of time for geographical surveys, astronomical work and laboratory purposes. For navigation, a quick check of chronometers could be made by ignoring the coincidence method and using only the first dash of the sequence.

In addition, experiments were carried out in radio telephony between the United Kingdom and America. The outcome of these tests was the first two-way telephone conversation across the Atlantic on 60 kHz (GBT) and the inauguration of the Transatlantic Telephone Service in January 1927.

The label of the oscillator (Fig. 25) illustrates the use in radio industries by the mid-1920s of tuning fork control of frequency, in this case in connection with non-commercial superheterodyne reception in Canada.

In the following years, the tuning fork as a frequency standard was improved by using Elinvar forks in a temperature controlled oven and by 1937 experiments with quartz oscillators for control of transmitter frequency had started. By 1939 crystal control of transmitter frequency enabled stability of two parts in a million and the technology became an important component in military communications during WW II.

The development of stable oscillators in the radio communications industries quickly led to the realisation by horologists that the days of pendulum clocks as primary timekeeping standards in observatories were numbered and from the late 1930s onwards observatories round the world began the move to quartz oscillators. In describing the quartz clock installation in the Royal Observatory in Greenwich, Sir Harold Spencer Jones wrote in 1945:

> The quartz clocks being installed at the Royal Observatory are all adjusted to give a frequency of approximately 100,000 per mean time second. By suitable gearing, the synchronous motor can give impulses every sidereal second and tenths of a second. Thus, the same clock can be made to serve both as a mean time and as a sidereal time standard. All time signals are, of course, sent out according to mean time; the sidereal time is required only for the actual time determination so that it is not necessary for all the clocks to have the gearing to give sidereal seconds.

Quartz clocks in this period were the size of filing cabinets or larger. The frequency of the valve-maintained quartz oscillator, being too high to use directly, had to be divided down electronically to a suitable frequency for driving a synchronous motor clock; usually 1000 Hz.

Using the very same clock to give both mean and sidereal time must have seemed astonishing to those working in observatories. Such clocks did not of course provide 'ticks' which were not only traditional in comparing time, but also superior to judging a hand's sweep. It was however easy to arrange a seconds pulse by adding further frequency dividers to the ensemble and the synchronous motor clock could also be arranged to tick if desired by closing a switch positioned in its wheel train.

In his landmark lecture 'The evolution of the quartz crystal clock' given to members of the BHI by Warren Marrison of the Bell Telephone Laboratories in November 1947, the point is made that an observatory time standard must be capable of sustained operation over long periods without interruption and that quartz clocks used for astronomical purposes to that date had not had a very commendable record. In addressing this issue, Marrison suggested improvements that could and would be made to two critical areas; the many thermionic valves involved, some of which could fail after a short life, and the synchronous motor which also had given problems. He was not to know that transistors would very soon enable the replacement of valves and the enormous clocks would shortly shrink to a portable package the size of a suitcase; or that synchronous motors would disappear and be replaced by stepping motors; or that in 1968 Hewlett-Packard would announce the first commercially available light emitting diodes.

In 1960 Hewlett-Packard introduced an outstanding portable frequency standard, the HP103AR used by NASA for its space programme. In combination with its 'companion' frequency divider and comparator clock, the HP113AR, this ensemble could also be used as a primary standard with its frequency readily compared to the time standard transmissions from the National Bureau of Standards. The stability of the HP103AR was in the region of 1 second in 20 years, a remarkable achievement for a portable quartz clock.

The price in 1960 was $5000, however it would soon be obsolescent because the atomic clock had already been made and portable versions were only a very few years away.

POST WORLD WAR II LEADING TO 'ATOMIC TIME' AND THE NEUCHÂTEL OBSERVATORY EUROPEAN TIME SERVICE

It was in 1929, shortly after the Post Office commissioned the long wave tuning fork controlled transmitter at Rugby that Louis Essen joined the National Physical Laboratory where he was instrumental in the improvement of tuning fork and quartz oscillators before being transferred to work on research in radio

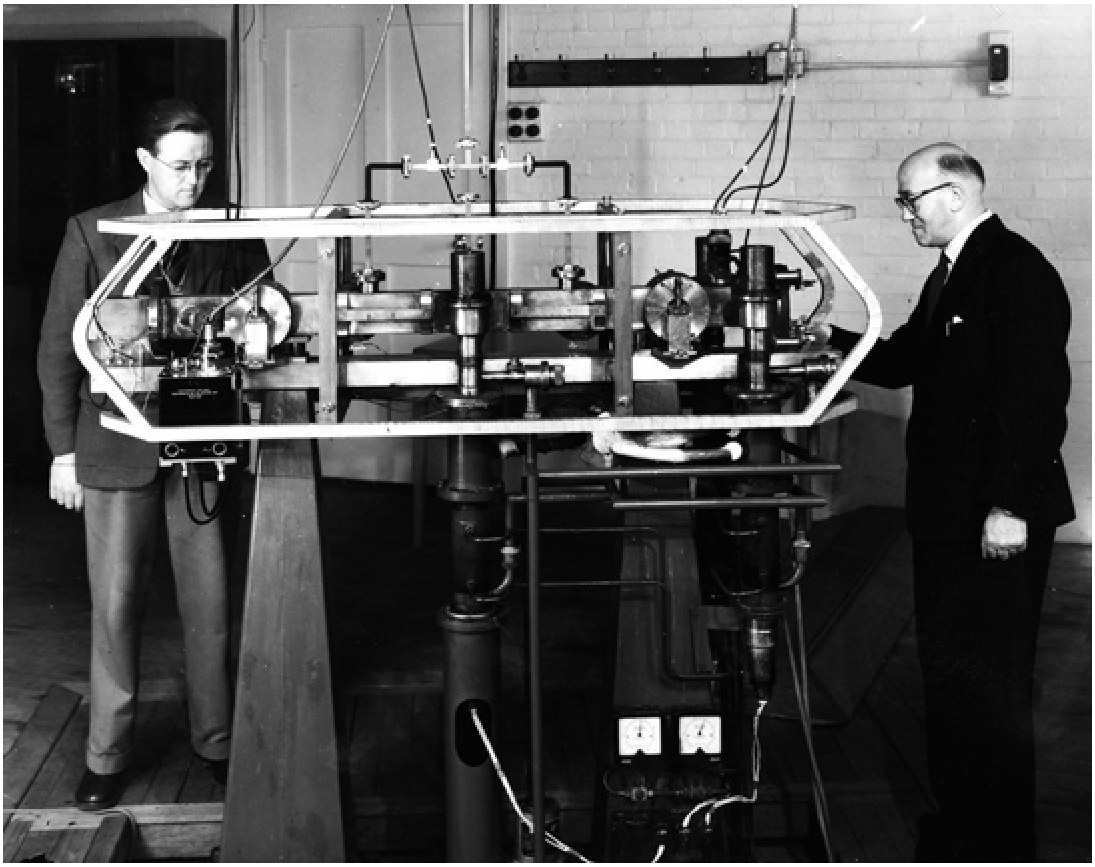


Fig. 26. The start of atomic timekeeping, *courtesy of NPL (c) Crown Copyright 1956.*

communications which was vital to the war effort.[1]

Post-war, he visited the USA where he discussed the feasibility of atomic frequency standards with scientists at MIT and Columbia University, and whilst the first experimental work on producing a caesium atomic standard took place in the USA, it was at the National Physical Laboratory in England that the first practical working standard was produced by Louis Essen and his assistant Jack Parry in 1955 (Fig. 26).

An atomic clock adjusts the frequency of a quartz oscillator to the transition frequency of electrons in transition between hyperfine orbits of the element caesium 133. The transition frequency is 9,192,631,770 Hz, and the process – much simplified in this description – works as follows: caesium is heated to boiling point causing the single electron in the outer orbit of the caesium atom to move from its stable (ground state) orbit to occupy one of two possible hyperfine orbits.

Atoms emerging from the heating process are distributed more or less equally between these two hyperfine states and are separated by magnetic techniques to leave only those in one hyperfine state to pass into the frequency detection process.

Detection is achieved by passing the selected atoms through a microwave field generated by a quartz oscillator tuned at or near to the frequency at which transition between the two hyperfine states occurs. The resonance phenomenon now causes the atoms to change from one hyperfine state to the other, emitting the transition frequency in the process.

The closer the quartz oscillator is to the transition frequency, the greater will be the number of atoms in transition. By tuning the

1. Louis Essen's memoirs are published on the internet and provide, *inter-alia*, an invaluable insight into how atomic clocks came into being.

oscillator to maximise the number of transitions, it will be known that the frequency of the quartz oscillator is precisely that of the caesium atom in transition and it is divided electronically to give us today's International Second

By 1960, the manufacture of caesium standards, particularly in the USA, had been developed to the point where they could be incorporated into the timekeeping systems at a number of other national standards laboratories leading to wide acceptance of this new timekeeping technology.

In 1964, Hewlett-Packard introduced the world's first transportable commercial caesium standard, the HP 5060A. A series of these were nicknamed 'the flying clocks' when they were flown from Palo Alto to Switzerland to compare time as maintained by the US Naval Observatory in Washington, DC, to time at the Swiss Observatory in Neuchâtel. Further comparing flights between 1965 and 1966 then took place, transporting the 'flying clocks' to many of the world's timekeeping centres in the pursuit of world-wide time synchronization.

In January 1966, 20 years before the Kundo and Junghans radio controlled clocks we are all familiar with made their debut, the first permanent, atomic referenced, round-the-clock long wave time service in the world came into operation in Switzerland. It was set up on the initiative of the Observatory at Neuchâtel and described in the official journal of the Swiss Watch Chamber of Commerce, *La Suisse Horlogere*, in March 1967, by P. Kartaschoff, Head of the Frequency Standards Department of the Swiss Laboratory for Horological Research, Neuchâtel, under the title 'Europe sets it clocks by Prangins Time.'

By comparison, as far as a continuous dedicated time service is concerned, Frankfurt did not add time signals to their standard frequency transmissions until 1973, and Rugby not until 1974 with calendar code added in November 1976.

Before Prangins, the only continuous transmissions of time signals had been in the shortwave bands. Other methods of time and frequency distribution were in use such as Loran C and the transportation of portable atomic standards from one place to another for purposes of comparison as mentioned above. However, shortwave signals were unsuitable for the transmission of the precise high stability frequency standards. The ionosphere that had enabled Marconi to bounce his signals round the curvature of the earth was satisfactory for time standards based on pendulums. However phase shifts inevitable with different bounce points in the ionosphere degraded the quality of time standards derived form the best quartz and now caesium oscillators.

Low frequency (longwave) transmissions in contrast are known for their stability and reliability and are well suited for time and frequency dissemination. The continuous transmission of synchronized universal time in the form of a precise frequency standard and time code, supplied from the atomic standard at the Observatory at Neuchâtel, was broadcast from the Radio-Suisse Transmitter at Prangins near Geneva. It was new, valuable, and the first in the world.

The signal comprised a 75 KHz carrier wave with 1 sec interruptions in a pattern to denote seconds, minutes and hours. Thus, according to their particular needs, users of the service could make use of the frequency standard defined by the carrier wave, or of the time scale marked with 'pips'.

The production of a completely reliable radio controlled clock was still a few years away, and in advance of the service going on air, research was carried out for the design and manufacture of a professional quality portable transistor radio receiver to pick up the time signal transmission and make it available to the user. It was developed at the Swiss Laboratory for Horological Research and a pilot series made in 1966. It was the eventual and complete realization of the time signal receiver idea going back to the pre-Great War *Recepteur Horaire* and Horophone tuned to the Eiffel Tower and in today's language it would no doubt be called an atomic radio!

Industrial manufacture of the registered model was taken over by Portescap at La Chaux-de-Fonds and marketed as Recepteur de Signaux Horaires T75A (Fig. 27). Retail sales were aimed at observatories and scientific institutions. By the beginning of 1967 an impressive number of sales had been made throughout Europe and it was true to say that (as far as timekeeping in scientific circles was concerned) Europe was, indeed, setting it clocks by Prangins time (Fig. 28).

Following the introduction of the T75A, a time signal receiver dedicated to the Prangins

Fig. 27. Portescap T75A time signal reciver.

Fig. 28. Observatories and metrology laboratories using the T75A receiver by January 1967.

signal was also made by the specialist manufacturer of quartz clocks Bernard Golay and an example is in National Maritime Museum collection at the Royal Observatory Greenwich.

Later, when radio controlled clocks for industry and commerce made their appearance in Switzerland, it was mostly professional equipment or in the form of master clocks and slave systems and, unlike those we have become familiar with, such clocks did not set, or reset, themselves but required initial setting to time by the user. Thereafter they remained synchronized with the Prangins signal, however, user intervention was again required for summer and winter time adjustment until logic was incorporated in later production series to bring this about automatically.

Two analogue examples are discussed here; the Imhof 'Observatory Time' (Fig. 29) and the

Fig. 29. Imhof 'Observatory Time'.

Favag E 80 HBG (Fig. 30), both from around 1980 or half a dozen years before those that would appear in Germany.

The Imhof 'Observatory Time' is a stand-alone battery clock, cased in a solid mahogany case with brass supports and mineral glass. It has a single stepping motor driving the seconds followed by conventional motion work for the minutes and hours and, like a conventional mechanical clock, one sets the time by hand via a friction clutch in the motion work. A liquid crystal display in the lower half of the dial shows the date, proving that this example was manufactured after addition of the full date code to the Neuchâtel time signal.

In order to synchronize the clock an electronic push switch under the rear cover is used to stop the seconds hand on 60. When this is done, the clock's logic circuits are set to zero. The seconds are started on an exact minute by releasing the push switch to coincide with a radio or telephone time signal.

The clocks logic system and own quartz time base now start and the display shows digital seconds in accordance with the seconds hand. After a brief period the correct date will appear to replace the indication of seconds and synchronization is complete.

An indication is provided in the display to warn that lack of signal or poor signal strength is preventing synchronisation every minute. The method for maintaining synchronization

Fig. 30. Favag E80 Master Clock.

is almost certainly similar to that used in the Favag Master Clock described below. Should it fail for any reason (such as poor reception conditions), the clock's own time base (currently better than 2 seconds/month) will keep accurate time until synchronization again takes place when conditions allow.

The advantage of this 'simple' time synchronization is that it does not need to decode the full time and date in order to synchronize time, but uses it to show the date in the LCD window.

The quality of the clock overall is outstanding and the stepping motor and wheel train are the same as chosen for the Omega marine chronometer for the French navy, Cal.1461, for which every single one manufactured was delivered with an observatory rating certificate from Neuchâtel.

The Favag E80 HBG (Fig. 30) is a radio controlled master clock with its own quartz time base specified at 0.1 seconds in 24 hours at 20ºc. The pilot dial in the image comprises a single stepping motor driving the motion work which can be run fast, stopped and started by means of a toggle switch as described later.

The clock is mains powered and provided with slave dial outputs of 24 volt alternate polarity minute pulses. Internal back up batteries are held on float charge and will power the clock for several hours in the event of mains failure.

The dial has a red LED reception indicator that will show the presence or otherwise of a good signal. To set the clock the user removes the dial cover and moves the toggle switch to fast forward the clock to a minute or two ahead of the correct time and then moves it to the stop position to stop the clock and return all time and logic circuits to zero.

The reception indicator should now be showing beating seconds with the 59^{th} second absent and a double blink on the minute. This pattern shows that the clock is receiving the Prangins signal correctly and waiting to be started on the exact minute. The toggle switch is next moved to normal on the minute signal's double blink, the clock's own time base and logic circuits start and the clock is synchronized.

The automatic system to maintain synchronization is simple and very effective. The logic circuits monitor both the Prangins minute marker and the minute marker of the clock's own quartz time base. Any divergence that might occur in the event of poor reception is thus measured and correction pulses of +/– 7.5 ms are applied every minute directly to the divider circuits until the clock is again synchronized.

THE DREAMS OF FULL RADIO CONTROL BY AUTOMATIC RESETTING AND AVAILABLE TO THE GENERAL PUBLIC ARE REALISED

Today, radio controlled timepieces are commonplace and in a comparatively short time have become a consumer item that is chosen on the basis of style, perceived quality, and price. As mentioned earlier, DCF Frankfurt did not add time signals to their transmissions until 1973, and MSF Rugby not until 1974 with calendar code added in November 1976. Radio controlled clocks tuned to Frankfurt did not, however, appear until a decade later when they were introduced by Kundo and Junghans in Germany in late 1985 when the cost of the technology had fallen to the point where sales could take place on the high street.

These clocks were not continuously synchronised as were the earlier Prangins clocks, but were reset once every twenty-four hours using a resetting logic based on patents of Dr Wolfgang Hilberg in which the clock's receiver was automatically switched on to look for a transmitted signal (usually a few times in the middle of the night) and the displays reset to the received signal by microprocessors. By definition, therefore, they were precisely correct only at the time of resetting and then only if the resetting procedure was successful.

The first radio controlled clock generally available to the public was introduced in

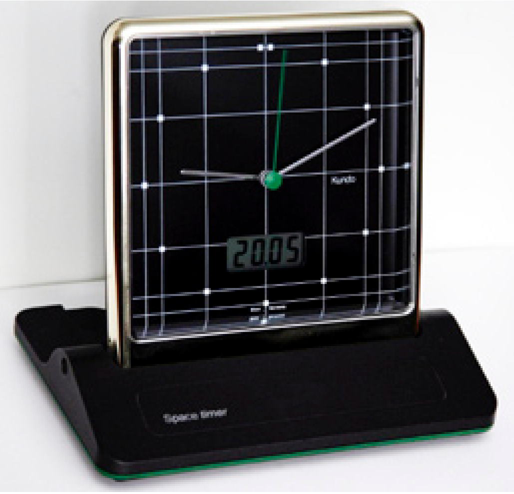


Fig. 31. Kundo model 351–0001 tuned to DCF Frankfurt.

Fig. 32. Junghans Mega 1 the world's first radio controlled wristwatch.

Germany in the Autumn of 1985 by Kundo and sold in small quantities in the UK during 1986.

German manufacturers such as Kundo and Junghans did not at first market radio-controlled clocks with receivers tuned to the UK's long wave transmission from Rugby. The first generation of German radio controlled clocks sold in the UK (Fig. 31) were tuned to DCF near Frankfurt and at this distance and in poor reception conditions mistakes were routinely experienced.

The Kundo brochure claimed accuracy of 1 second in 150,000 years guaranteed by synchronisation with standard time as monitored by the German Federal Physical-Technical Institute, with automatic adjustment for summer and winter time. The marketing was, of course, misleading as clocks that go through a complete resetting procedure every day do not work well when reception conditions are poor, in spite of the hype about atomic time.

Because of poor reception caused by weather conditions, or use in marginal reception areas, these early German clocks tended to have a poor reputation in the first few years that radio controlled clocks were available and something had to be done about it.

Junghan's turned to the patent of Wolfgang Ganter, filed in 1989, in which clocks failing to receive the complete code reverted to the time last successfully decoded in order to overcome these problems. Junghans had Ganter's patent assigned to themselves and radio-controlled clocks by Kundo gradually lost their place in the market.

Such was the pace of technological change and miniaturisation that the first radio-controlled wristwatch, the Mega 1, was introduced by Junghans in 1990. The watch used a liquid crystal display, thus dispensing with the need to develop the miniaturised stepping motors that would otherwise be needed to convert the setting instructions from microprocessors to correct or reset the hands.

The aerial was built into the strap and in the event of failing to receive a good updating signal the display stayed with the previously stored progress of time as in Ganter's patent. The external design was commissioned from Frog Design an international creative design company based in the USA with offices in Germany and other countries, and has become a classic, earning a place in many museums worldwide. But this more modern history is outside the scope of this article.

Today, the HBG long wave transmitter in Prangins still transmits UTC without interruption on 75.00 KHz, the responsibility resting with Swiss Federal Office of Metrology.

The quantity of atomic clocks in operation continues to increase and it is not surprising that there is a pecking order in the world's atomic clocks. It is also not surprising that those at the laboratory at Neuchâtel are still amongst the leaders. Neuchâtel is part of the Atomic Clock Ensemble in Space project, a mission in fundamental physics that will operate a new generation of atomic clocks in a microgravity environment in order to further develop the coordination of space-to-ground and ground-to-ground comparisons of atomic frequency standards.

Since Marconi's Atlantic leap, coordination of time between observatories has used all the means available to arrive at UTC, from direct connection by wires, to wireless transmissions and, carrying an atomic sub-standard by aeroplane calibrated just before take off. This is in effect a comparing watch as of old; one could call it the airborne version of the Belville's time service in carrying an Arnold around London in the nineteenth and twentieth centuries. And now, atomic standards are permanently in place in space in the GPS system.

At this point I come to the end of this history. But here is the irony; atomic time as embodied in the international second (SI) is now so accurate that we need two standards: one to serve as an absolute timescale for use in science and space and another for time suited to the fluctuations of our own planet. The former called TAI (Temps Atomique Internationale) measures real time and is the foundation of all time standards. The latter, UTC, is TAI adjusted by the use of leap seconds to keep our human time in line with the earth's rotation.

SOURCES AND ACKNOWLEDGMENTS

Research for this article was largely done using articles and illustrations appearing in contemporary periodicals and newspapers. Many of these are mentioned in the body of the text and include *La Nature*, *Nature*, *La Science et La Vie*, *Wireless World* and the *Post Office Electrical Engineer's Journal*. Particularly valuable material can be traced through the pages of the *Year Books of Telegraphy and Telephony* for the years 1918 to 1925. In addition, the following specific sources were used: The Marconi Archive, Bodleian Library; *Time and Weather by Wireless* by W.G.W. Mitchell (The Wireless Press, 1923); *History of Communications-Electronics in the United States Navy* (Washington DC: Bureau of Ships and Office of Naval History, 1963); *La Suisse Horlogere et Revue Internationale de L'Horlogerie* (March 1967); *BBC Engineering 1922 – 1972* by Edward Pawley, (BBC, 1972).