preserved in the museum of the Royal United Service Institution in Whitehall, while in the Painted Hall at Greenwich is his portrait in naval uniform painted by Nathaniel DANCE, R.A.

As a Commander, Navigator, Observer, Surveyor and practical Physician his merits were equally great. COOK'S record is truly wonderful and compared with his achievements the voyages of other navigators fade into insignificance. Of our famous Seamen he was the greatest Empire Builder of them all.

Together with a commanding personal presence, sagacity, decision and perseverance, he won the affection of all those who served under him.

As Seamen we may well be proud of his undying memory.

TIME DETERMINATION AND TIME BROADCAST

by

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As far back as history, and even legend, carry us, man has tried continuously to devise methods of determining and of keeping time. The earliest attempts were very crude and naturally divided themselves into two general groups: (1) those in which the positions of the stars and the sun were observed with reference to objects near at hand; and (2) those in which efforts were made to measure the elapsed time.

In the first class, whatever their form, all were some type of sundial or some crude form of a transit instrument. The first attempts were satisfied by a range between two widely separated objects that happened to lie in the meridian.

In the second class, the earliest efforts consisted in the burning of rope knotted at regular spaces, or the draining of water or sand from one container to another; or, as was reputed to have been done in early China, the burning of candles. Each effort was an attempt to improve on the best previous method.

All modern methods of time determination are based on the uniform rotation of the earth on its axis. The interval between two successive transits of the same star over the same meridian measures one complete revolution of the earth. That constitutes a sidereal day. It is conveniently divided into 24 hours and each hour is further divided into minutes and seconds.

The earth is our best master clock. It requires neither winding, resetting, oiling, nor repairing to make it keep accurate time. If by some trick of magic we could secure marks in the sky, indicating the hours, minutes and seconds, we could all throw away our watches and clocks. Inasmuch as that is impossible, we naturally turn to the stars which are our nearest approach to hour marks in the heavens. They are so distant that we can mark them with the greatest accuracy in measuring the period of the earth's rotation. As a matter of fact, if you know your stars, you can very closely approximate the hour marks in the heavens. Observing the stars as they apparently swing across the heavens, and noting the exact instant of the meridian passage by some clock, permits us to determine the error of that clock with great exactness.

The continuous effort for years to develop clocks, each expected to maintain time more accurately than all previous ones, parallels the history of man and measures his progress. For years, the most accurate clocks have been made abroad, England, France and Germany vying with each other to produce the most accurate timepiece in the world. And now we come to the latest development — the crystal oscillator — which at one stroke cuts loose from all the troubles inherent in pendulum clocks. True, it has faults of its own, but they will be overcome.

Returning to the stars, if you will memorize the right ascensions of some of the most prominent stars in the principal constellations, you will have established a celestial clock capable of use every clear night.

EARLY EFFORTS IN MECHANICAL BROADCASTING OF THE TIME PRIOR TO RADIO.

Prior to 1830, there was no satisfactory method of fulfilling the Navy's requirements. These requirements included charts, navigational instruments, chronometers, nautical information, etc. Whenever a ship was placed in commission, commercial agents abroad purchased the required instruments, charts, books, etc. As these commercial agents usually knew little about navigation, their inspection was more or less superficial, and when the equipment was received in the United States, it very frequently was found unsuited for the purpose. In addition, charts, books, pamphlets, etc., were in foreign languages and had to be translated; and, also, charts were not constructed with a common zero meridian so that they all had to be redetermined to obtain a uniform system for safe navigation.

When a ship was decommissioned, all of her equipment was stored in a storehouse in some navy yard. Little attention was paid to it and the result was inevitable. When the equipment was again needed, it was usually found unfit for use and the Navy had to repurchase, through the same commercial agents, new equipment which repeated the same defects.

A young naval officer, Lieutenant Goldsborough, recommended to the Department the establishment of a Depot of Charts and Instruments; and, in 1830, the Secretary of the Navy ordered Lieutenant Goldsborough to establish this Depot and take charge of it. One of his most important duties was the determination of accurate time and the dissemination of that time to ships of the Navy. In the beginning, there was no way of doing that except by actually carrying a chronometer, accurately rated, to the port in which ships were lying, where the chronometers on the ships could be compared and accurate rates established.

Until a comparatively recent date, ships on isolated stations had to determine their chronometer errors by celestial observations. If the ship happened to be in an American port, it obtained its error by "tick" through the Western Union Telegraph Company; but frequently, even as late as the beginning of the present century, the young assistant navigator had to take his artificial horizon ashore and make observations for chronometer error.

Until 1864, and in many places subsequent to that date, the only method of broadcasting time was by dropping a time ball from some conspicuous building visible to the surrounding country and harbor.

In 1864, the city of Washington established one of the first electrical central fire alarm systems. The Mayor of Washington — in those days Washington had a Mayor — was very proud of this system. The Superintendent of the Naval Observatory seized the opportunity to use the fire bells as a means of broadcasting accurate time. On his recommendation, a private wire was run from the Naval Observatory to the Central Fire Station and at 7 o'clock every morning and 6 o'clock every night, either the Superintendent himself or Dr. Harkness pushed the button which rang the fire bells all over the city. The State Department, which at that time occupied an old building on 14th Street requested that, when the signals were transmitted to the Central Fire Station, they be also transmitted to the State Department, because of its importance to them.

The Western Union Company had established an office in the building for the convenience of the State Department, and it happened that their operator was a very wide awake young man. Appreciating the value of time to his Company, every time the signal from the Naval Observatory came over the wire to the State Department, he repeated it to the Western Union Telegraph's Central Office. The Western Union Telegraph Company immediately appreciated the financial value of this accurate time service and they began transmitting time by wire to all cities. They advertised extensively the advantages of their time service. This is the origin of the Western Union Telegraph Company's time service.

In the early days, the Railroad Companies all determined their own time and operated their trains on their own schedules. Lines that ran across the continent had to change their time from point to point in order to approximate the local time. But it was seldom that the times agreed. For instance, in a Pittsburg station there were three clocks, one showing Philadelphia time, one showing time much further West, and one showing Pittsburg time. The passengers frequently missed their trains because of the resulting confusion.

In 1883, the railroads of this country in convention adopted the idea of a standard time. This was one of the most important steps in the standardization of time ever taken by any group of men. On the 18th of November, 1883, fifty different standards of time in the United States were resolved into four. The United States was divided into four zones, each zone based on the well known astronomical fact that the earth revolves through 15° per hour, or through 360° per day of 24 hours mean time. This revolutionary action aroused violent discussion. It was considered a violation of the acts of God, and it was predicted that this sacrilege would certainly result in dire disaster. It was even prophesied that divine manifestations would surely follow.

Upon the recommendation and invitation of the United States, an International Convention met in Washington in 1884 and established a standard time for the world and a standard marking of longitude. The meridian of Greenwich was established as the zero meridian of the world, from which all other meridians were measured.

In the early days, many municipalities wanted to buy time. A number of observatories determined time and sold it in their own localities. Finally, resentment against Western Union's monopoly of the dissemination of Naval Observatory time culminated in a congressional investigation which was sponsored by 23 observatories in the United States. It was stated that the Western Union Company charged those observatories so much for the transmission of time to their patrons that the observatories could not afford to sell time any longer. Therefore the Western Union had developed a monopoly.

Thanks to the logical reasoning of the Superintendent of the Naval Observatory, who premised his argument on the greatest good to the greatest number, it was shown to the satisfaction of the Congressional Committee how the arrangement between the Naval Observatory and the Western Union had started, how it had developed to the benefit of the whole country, and why it would serve no purpose, and do no good to stop the furnishing of time to the Western Union by the Naval Observatory.

One of the most progressive cities in this country, Leavenworth, offered to buy time once a month. It was to be transmitted to the principal jeweller in that city and by him was to be furnished to everybody in the city of Leavenworth.

Soon, time was telegraphed to many cities and to all seaports and time balls were dropped from a conspicuous building in each port.

In addition, arrangements were made so that any ship captain could visit any Western Union Telegraph office and receive the noon signal free of charge.

But it is to the scientists of the world that credit is due for the constant increase in the accuracy of time. Scientists always work with fundamental units, such as units of length, weight, and time. The units of length and weight are tangible, but the unit of time is not and yet time enters into practically all calculations.

Prior to 1904, the only means of transmitting time was by the Telegraph Companies. This introduced a lag due to the transmission of the signal over land wires. Naturally, this variable could not be known with great accuracy.

In September 1903, the Navy began building its first radio broadcasting station at Navesink, N.J. Throughout the winter they worked, and in the spring of 1904, the first broadcast of correct time by radio signal was inaugurated. Of course those early time broadcasts were not very powerful, but they stimulated all hands to greater effort. In those days, the present high power radio stations were only dreams; but the news of our little low powered radio broadcast from Navesink was heard around the world.

From that time on, anyone, whether at sea or on shore, could intercept our time signals and receive them with the greatest accuracy then known, if they were equipped with receiving apparatus capable of picking up our signals.

The Navy's next contribution to science was the completion of the Arlington High Power Radio Broadcasting Station. In December 1912, the Navy completed its big station and immediately began broadcasting accurate time on high power.

The Superintendent of the Naval Observatory again saw an opportunity to advance scientific progress. He recommended that an effort be made to determine the difference in longitude between Europe and the United States by means of radio. In 1913 and 1914, this was successfully accomplished, the Naval Radio Station at Arlington and the Eiffel Tower in Paris being used for the communication. These observations were the first direct determination of the difference of longitude and the velocity of transmission of radio waves between the United States and Europe. Years before, in 1846 and 1847, the Naval Observatory pioneered in the determination of differences of longitude by means of telegraph, first using Baltimore and Washington and later using Havana and various cities in the United States.

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In 1930, the Naval Observatory was broadcasting time three times daily with an accuracy of a couple of hundredths of a second. At the National Academy of Science's annual convention, in April of 1931, the requirements of the scientists were emphasized very strongly. They required more frequent and more accurate signals. The contrast between present day demands and those years ago when the city of Leavenworth wanted to buy time once a month, and pay for it, is very interesting.

We immediately jumped our program to six daily broadcasts. More would have been made but we were at the limit of our capabilities. We could not obtain additional funds to engage additional astronomers to handle the increased load on the time service. And without additional astronomers we could not undertake more broadcasts.

As always occurs when circumstances become compulsory, the good Lord provides. One night when working in my office near midnight, a solution flashed through my mind with such clearness, it was startling.

The next morning, the scheme was explained to the Navy Department and a small amount of money was obtained to commence construction. Progress was necessarily slow as funds were limited, and much of the work had to be done by our own force in addition to our regular work. It is therefore not surprising that the apparatus was not completed until May of 1934.

After an exhaustive unofficial test of about five months with the apparatus running continuously twenty-four hours a day, we began our official program of 20 broadcasts daily. I would have preferred twenty-four broadcasts daily, but the other equally important federal broadcasts prevented my obtaining the necessary time at nine and eleven a.m. or nine and eleven p.m. Since September 7, 1934, the Naval Observatory has been broadcasting accurate time twenty times daily, with reduced labor and increased accuracy. *

DETERMINATION OF TIME.

All observatories in the world have always determined time by observing visually the transit of the stars over their meridians. This method is subject to errors due to the possible flexures of the telescope and also the personal equations of the various astronomers. Due to the rotation of astronomers in observing the transits of time stars, another variable is introduced. Not being satisfied with this system, the Naval Observatory pioneered in an entirely different direction.

We have an instrument which has been used in the past for the determination of the variation of latitude. It is known as the Photographic Zenith Tube. One of the members of the staff, Mr. WILLIS, conceived the idea; and the P.Z.T. was modified to cover the new task. This instrument consists of a fixed vertical tube with a mercury basin at the lower end. Its objective and the carriage for the photographic plate are at its upper end. The light from a star passing near the zenith of the Naval Observatory passes through the objective, is reflected from the surface of the mercury, and comes to a focus on the under surface of a photographic plate mounted just under the objective. Due to the design of the objective, its optical centre is located below it in the plane of the photographic plate just mentioned.

This photographic plate is supported in a carriage driven back and forth along a track in either the East-West, or the West-East direction. This track is rigidly attached to the cell of the objective. The driving power for the movement of this plate carrier is furnished by a 1,000 cycle synchronous motor driven from the output of the piezo-electric crystal controlled oscillator. This same oscillator provides the power for driving the time signal transmitting apparatus. Because of this, the driving speed of the plate carrier is extremely uniform. The plate moves along the track at exactly the same speed that the earth's motion causes the star image to move.

The clear aperture of the objective is about 8", its focal length is 203", and the photographic plates are 1 ¾" square. Four exposures are made for each star. If the plate did not move these exposures would appear as line trails, but as the plate does move at the same speed as the stars apparently move, the photograph shows small sharp points. Alternate exposures are made with the plate in one position, the other two with the plate revolving through 180°.

From these four images the time of transit is determined.

On every clear night, 18 or more stars are observed. By comparing the known

* NOTE.

It was on May 23rd, 1910, that the Eiffel Tower Station was equipped for transmitting Time Signals from Paris Observatory, although previous trials had been made by means of an experimental station established at the Parc Montsouris by Mr. BIGOURDAN, astronomer of the Observatory.

In October 1912, an International Time Conference was held at the Paris Observatory, the aim of which was to promote rules for broadcasting the Time Signals from the various stations in the world from 1st January 1913. The *Bureau International de l'Heure*, created under the direction of the International Time Committee, was to centralise the time determinations carried out by the various observatories and to deduce from the comparisons the most accurate time.

times of meridian transits of the stars with their photographed times of transit, errors of the Observatory clocks are determined.

It is interesting to note that comparisons of the results obtained, extending over a long period, with this zenith tube and those obtained by visual transit instrument show a marked superiority in the photographic method. But this is to be expected inasmuch as the personal equation of the observers and the effect of tube flexures are entirely eliminated.

BROADCASTING OF TIME.

Prior to 1934, time signals were broadcast by the astronomer on watch who had to perform the various steps in checking the accuracy of the clock prior to each broadcast. This procedure included a comparison between the transmitting clock, maintaining mean time, and the standard clocks in the vault, maintaining sidereal time, by means of a chronograph. After the chronograph run was completed, the error of the mean time clock was calculated, and by reference to our established tables, the length of time necessary to apply an electrical influence through a solenoid at the centre of the pendulum swing was determined. After the application of this electrical current during a predetermined time, either to retard or to accelerate the swing of the pendulum, a second chronograph run was then made to determine how accurately the error of the clock on mean time had been absorbed. If the correction had been accurately made, the clock was ,then ready for broadcast. This operation required about 16 minutes for an expert astronomer. With our limited personnel, we therefore could not make more than six broadcasts a day.

The recently invented automatic broadcaster immediately changed this entire procedure.

AUTOMATIC TIME BROADCASTER.

The automatic time broadcaster has a triple personality: (1) it is a crystal controlled clock; (2) it is its own chronograph; and (3) it is an automatic time broadcaster.

The crystal controlled oscillator was made for us by the General Radio Company. The quartz crystal has a frequency of 30,000 cycles per second. This quartz crystal is enclosed in a double temperature controlled compartment. The 30,000 cycle output is fed directly into two sub-multiple generators. One of these generates a frequency of 6,000 cycles. The other one generates 5,000 cycles. These two are combined and fed into a detector and amplifier unit. The amplifier unit takes the difference of the two frequencies; that is, 1,000 cycles, and amplifies it to the full output of three standard type N° 41 tubes.

The resulting magnified power is then used to operate a synchronous motor. The field coils of the motor can be rotated. This permits the application of corrections to the device without interference with its operation. If the field coils are rotated through three hundredths of a revolution, a correction of exactly three one-thousandths of a second of time will have been applied.

The shaft of this synchronous motor is geared to a vertical shaft which is made to rotate at exactly one revolution per second. Mounted securely on this vertical shaft is a glass disc whose periphery is etched with 1,000 divisions. Inasmuch as the shaft and the glass disc revolve exactly one revolution a second, each of the divisions on the periphery of the glass disc therefore measures one one-thousandth of a second. Below this glass disc, in the lower compartment, is carried the master cam which produces the time signal beats.

From this description, you see that every time the neon light is made to flash by the standard clock in the vault, the etched marks on the revolving disc can be observed with great clearness. The shortness of the neon flashes causes the optical delusion that the rotating dial is stationary and makes it possible to read the time of the flash to the one one-thousandth of a second. In this way by connecting the neon light with any timepiece, a very quick and accurate comparison can be made with the transmitting device.

The procedure is as follows:

The astronomer slips the key through the hole in the side of the case abreast of the field coils of the synchronous motor. He observes the flash of the neon light, and turns the field coils either to the right or left until he observes by the flashes of the neon light that the error has been absorbed and the transmitter is exactly on time. He then withdraws the key, throws off the switch, and goes about his other duties.

Every hour during the day and night, except 9 and 11 a.m., and 9 and 11 p.m., this automatic apparatus throws its own switch which flashes a signal at Arlington. The radio man on watch throws his switch which places the automatic broadcaster in control of the broadcast through distant control. At exactly five minutes of the hour, the automatic broadcaster begins and transmits the signal with the accuracy of one one-thousandth of a second.

After the signal is on the air, and in order that we can determine any errors in the actual emission of the time broadcast, we receive over our own antenna the broadcast. Our receiving sets in the time service office, also made by naval personnel, then convert the signals into mechanical energy and operate a printing chronograph, which was invented by Mr. SOLLENBERGER some years ago. This gives us a permanent record of every signal from this Observatory. We can also receive and record signals from other sources.

One of the many advantages of this new automatic broadcaster is that by installing duplicate sets at distant points we can accurately rebroadcast our signals from those points. When the apparatus is installed at distant points, the neon light is flashed by the reception of the time signal by radio instead of by the beat of the standard clock in our vault. The operator at the distant points then corrects the broadcaster in the same manner we do here, using the radio broadcast signal received. When he has his broadcaster in step with the radio time signal received and has absorbed the lag due to the time of radio transmission, his apparatus is ready for rebroadcast, and he likewise goes about his other duties. At five minutes of the hour, at the times designated for his station, his apparatus rebroadcasts the Washington signal with the same accuracy.

In contrast with the 16 minutes consumed in preparation for broadcast under the old method, the automatic method can be set within five or ten seconds. As a result, with no increase in our astronomical staff, we are now able to broadcast signals once an hour. As soon as the new sets are completed and installed at Panama and at Honolulu, we will be able to reach naval vessels and American merchantmen any place in the world.

Our original automatic broadcaster was placed in service in May 1934, and has been used continuously ever since. We are now building a new set, approximately the same in general design, but differing in some mechanical details, in order to reduce wear of parts, insure greater durability, and reduce risk of interruption. The fundamental principles involved are identical.

In closing I wish to pay just tribute to the unfailing energy and loyal cooperation of all the personnel at this institution who so ably assisted in perfecting and machining all the parts for this rather complicated apparatus. In particular, I wish to emphasize the wholehearted cooperation of Mr. Paul SOLLENBERGER in the completion of this broadcaster.

During the International Astronomical Union's Convention in Paris, in July 1935, the Naval Observatory's automatic broadcaster occasioned considerable comment by the assembled delegates. Three representatives from foreign countries have already visited this institution and observed its operation.

THE CENTENARY OF THE POSITION LINE

Several publications have recently alluded to a memorable date in the history of Navigation — that of Monday, 18th December 1837, at the hour of 10 p.m. — which marks the wholly unexpected discovery by the American Captain Thomas Hubbard SUMNER of the position line, known as the "Sumner Line" or as the "line of position".

It has been considered appropriate to mention this memorable centenary in the *Hydrographic Review,* and to say a few words concerning the inventor and the circumstances in which he made his discovery.

Thomas Hubbard SUMNER was born at Boston on 20th March 1807 one of the eleven children of Thomas WALDRON and Elizabeth Hubbard SUMNER. His forefather, William SUMNER, was a navigator who had immigrated in 1636 to New England. His father, Thomas Waldron SUMNER, was an architect and Member of Congress for the State of Massachusetts from 1805 to 1811 and from 1816 to 1817. Young SUMNER attended Harvard University where in 1826 he obtained his degree of B. A., and it is recorded in the archives of the University that in the same year he shipped for Canton as a common sailor, sailing on the American clipper ships which at that time were circling the globe. On 10th March 1834, he married Selina Christiana MALCOLM, who bore him four children.