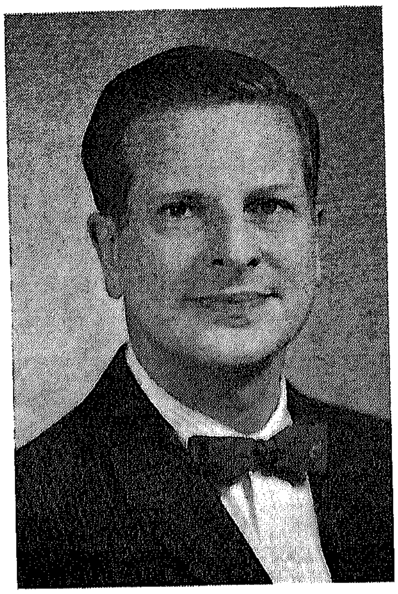
OF TIME AND FREQUENCY

By D. H. Andrews, National Bureau of Standards, U.S.A.

ABSTRACT

Following a short historical background of timekeeping, the author proceeds to describe Universal Time and how it is approximated by Atomic Time with corrections prescribed by the International Time Bureau. The use of radio broadcasts by various nations to disseminate time signals, standard radio frequencies, and standard audio frequencies is described. Other services are also noted. The article includes an extensive listing of worldwide radio stations broadcasting standard frequencies and/or time signals. This tabulation is divided into two parts, Table I listing stations using frequencies above 1 megahertz, and, Table II listing stations using frequencies below 1 megahertz.

Key Words: Standard frequency broadcasts; Universal time signals; International Time Bureau; Atomic Time; Time Scales.



Background

Time interval, a concept basic to time itself, may be described as the spacing between two events. These events are are usually repetitive. If one can develop a sequence of uniformly sized time intervals, larger intervals can then be developed. If these intervals can be related to a particular origin, a time-scale, usually termed "time" may be developed.

In essence then "time" requires an origin or "beginning," a uniform time interval that can be repeated indefinitely, and a system for counting the intervals.

The written narrative of mankind includes a reference in the Bible in the first chapter of Genesis to "the beginning," the origin; to the "evening and the morning were the first day," the time interval; and the "evening and the morning were the second day," the counting system. Thus we have all of the essentials of a timing system recorded at an early date.

As history progressed longer periods of time were necessary. Thus a week of seven days was incorporated, a month representing approximately the length of time between full moons, and the year to approximate the length of time for a complete cycle of seasons.

One could, if desired, find many other references to time intervals in the Bible. Among these would be included for longer periods the week (of years) or seven years and a thousand years. For shorter periods the hour is used and also the "twinkling of an eye" or "moment."

The terms that have been used above have one common failing and that is their inexactness. By this it is not meant to convey the idea that the terms are useless or meaningless, but only that it is difficult, for instance, to define a "twinkling of an eye" so that the interval could be exactly repeated.

Actually, the intervals of day and hour now are very precisely defined in terms of the second, the day being 86,400 seconds and the hour being 3,600 seconds. It is possible to derive from

*) In accordance with National Bureau of Standards policy, the international unit for frequency (hertz) is used in this article. The unit, hertz, is equal to one cycle per second.

1966 —[Offset = -300×10^{-10}]
No time adjustments were made during the first half of 1966.

The notation -300×10^{-10} means that the frequency used to generate UT time is 300 parts in 10^{10} lower than Atomic frequency or, in other words, is equal to 3 parts in 100 million slower than Atomic frequency. A clock run in accordance with this frequency offset will lose 2.592 milliseconds every day relative to Atomic time.

Time Signals

Different standard frequency stations make use of an assorted variety of time signals; however the most widely used signal is the second pulse generated in accordance with the International Radio Consultative Committee (CCIR) formula. This stipulates that the time pulse should consist of m cycles of 200 m hertz tone. *)

The majority of time signal stations use this formula with m = 5, thus the time pulse consists of 5 cycles of 1000 hertz tone.

WWVH uses 6 cycles of 1200 hertz and JJY uses 8 cycles of 1600 hertz. Other stations use gaps in the carrier, longer pulses, or other variations to suit the needs.

TABLE I. (Cont.)

CALL SIGN	LOCATION	LATITUDE LONGITUDE	CARRIER FREQUENCY AND POWER*	OPERATING SCHEDULE (UNIVERSAL TIME)
LB5/ LD2	Prague Czechoslovakia	50°07'N 14°35'E	3.170 MHz 13.985 MHz	
MA	Prague Czechoslovakia	50°07'N 14°35'E	2.5 MHz (M)	Continuous
PE	Rio de Janeiro Brasil	22°54'S 43°11'W	8.720 MHz	1330 and 2030
PR	Rio de Janeiro Brasil	22°54'S 43°11'W	1.308 MHz 4.244 MHz 6.421 MHz 8.634 MHz 17.194 MHz	0130; 1430; 2130.
RBT	Irkutsk U.S.S.R.	52°17'N 104°20'E	5.280 MHz 6.775 MHz 10.900 MHz 13.900 MHz	0200; 0600; 1200; 1400; 1600; 2200; 2400.
RPT	Tashkent U.S.S.R.	41°17'N 69°10'E	5.890 MHz 11.580 MHz 14.650 MHz	1800 1000
RWM/RES	Moscow U.S.S.R.	55°45'N 37°18'E	5.0 MHz 10.0 MHz 15.0 MHz 20.0 MHz	Hour Pairs in UT
SAJ	Stockholm Sweden	59°20'N 18°03'E	150 MHz (L)	Fridays from 0930 - 1130
SAZ	Enköping Sweden	59°35'N 18°03'E	100 MHz (L)	Continuous
VHP	Belconnen Australia	35°15'S 149°35'E	8.5 MHz	0025-0030 0755-0800 1355-1400 1955-2000
VHP	Belconnen Australia	35°15'S 149°00'E	4.286 MHz 6.4285 MHz 8.478 MHz 12.9075 MHz 17.2568 MHz 22.485 MHz	0300; 0800; 1400; 2000. 0300 and 0800
VNG	Lyndhurst Australia	38°00'S 145°14'E	5.425 MHz (L) 7.515 MHz (L to H) 12.005 MHz(H)	Continuous except 1200-1215 and 2200-2215

Although the main purpose of this discussion is to cover the stations operating at the specially allocated standard frequencies of 2.5, 5, 10, 15, 20, and 25 megahertz, it must be realized that time signals are broadcast at many other frequencies. At some loss in accuracy commercial broadcast stations rebroadcast time signals originally emanating from one of the standard frequency stations. Countries with large Navies often broadcast time signals for fleet use. Such signals may be broadcast at very low frequencies (10,000 to 30,000 hertz) as well as the customary high frequencies. Since such stations are primarily used for communications they do not broadcast in the standard frequency bands nor do they provide a continuous time service.

Standard Radio Frequencies.

Standard frequency radio broadcasts were started some forty years ago so that laboratories could intercompare their frequency standards and to enable commercial broadcast stations to check their transmitter frequencies. An accuracy of a few parts in 100,000 was an achievement at that time and was attained by precisely constructed inductance-capacitance (LC) resonant circuits. The advent of crystal controlled oscillators made a significant jump in the accuracy of frequency transmissions, and many radio stations use such oscillators. Intensive study on the type of cut, mounting, temperature control, and associated electronic circuitry has resulted in even better crystal oscillators today. It is not now unusual to find that a high quality crystal oscillator is capable of a stability approaching a part in 10^{12} per day. A

TABLE I. (Cont.)

CALL SIGN	LOCATION	LATITUDE LONGITUDE	CARRIER FREQUENCY AND POWER*	OPERATING SCHEDULE (UNIVERSAL TIME)
WWV	Fort Collins Colorado, USA.	40°41'N 105°02'W	2.5 MHz (M) 5 MHz (H) 10 MHz (H) 15 MHz (H) 20 MHz (M) 25 MHz (M)	Continuous except 45-49 minutes after each hour.
WWVH	Kihei, Maui Hawaii, USA.	20°46'N 156°28'W	2.5 MHz (M) 5 MHz (M) 10 MHz (M) 15 MHz (M)	Continuous except 15-19 minutes after each hour.
XSG	Shanghai China	31°12'N 121°26'E	6.4145 MHz 8.502 MHz 12.8715 MHz	0300; 0900
ZLFS	Lower Hutt New Zealand	41°14'S 174°55'E	2.5 MHz (L)	0100-0400 Tuesdays
ZUO	Olifantsfontein Rep. S. Africa	25°58'S 28°14'E	5 MHz (M)	Continuous
	Johannesburg Rep. S. Africa	26°11'S 28°04'E	10 MHz (L)	Continuous

* L (1 kw) M 1-5 kw) H) 5 kw.

the second smaller time intervals such as milliseconds (thousandths of a second), microseconds (millionths of a second) and picoseconds (millionths of a millionth of a second). All of these units are useful and practical.

Going in the other direction, however leads to trouble. A month for instance may be 28, 29, 30, or 31 days long. A year may be 365 or 366 days long; and one must remember that every 100th year is not a leap year unless it is divisible by 400.

A ray of light begins to dawn as it is realized that "time-to-live-by" is a variable sort of thing while "scientific-time" is precise and exact.

Now that "scientific-time," sometimes referred to as Atomic Time (AT), is a reality and because it is very accurate and repeatable, it is possible to use it with very carefully defined corrections to produce "time-to-live-by," known as Universal Time (UT) or Greenwich Mean Time (GMT).

Universal Time

Although at least two stations, WWVB in United States, and DCF77 in Germany, do broadcast atomic seconds the great majority of time signal broadcasts use the atomic approximation to UT2 (Universal Time with certain specified corrections), sometimes denoted UTC, meaning coordinated Universal Time. It is coordinated in the sense that a number of time signal stations seek to keep their time pulses synchronized to within ± 1 millisecond. In order to do this they develop their time scales from directions prescribed by the Bureau International de l'Heure (International Time Bureau) with headquarters in Paris, France. The directions that are given are dual in nature. First, they specify the exact frequency to be used to generate UTC, and second, they designate when step adjustments (usually 100 milliseconds) are to be made. These adjustments may be in the nature of an advance or retardation of the signals being transmitted. To illustrate how this information is specified, the data for 1965 and the first half of 1966 are tabulated:

1965 —[Offset = -150×10^{-10}]

January 1st. ... Retard 100 milliseconds
March 1st. .... Retard 100 milliseconds
July 1st .... Retard 100 milliseconds
September 1st. . Retard 100 milliseconds

TABLE I. HF STANDARD FREQUENCY AND TIME STATIONS

CALL SIGN	LOCATION	LATITUDE LONGITUDE	CARRIER FREQUENCY AND POWER*	OPERATING SCHEDULE (UNIVERSAL TIME)
ATA	New Delhi India	28°34'N 77°19'E	10 MHz (M)	0530-1030, Monday to Friday
BPV	Shanghai China	31°12'N 121°26'E	5.430 MHz 9.360 MHz	1100; 1300; 1500; 1700; 1900; 2100.
BPV	Shanghai China	31°12'N 121°26'E	5 MHz 10 MHz 15 MHz	Continuous
CHU	Ottawa Canada	45°18'N 75°45'W	3.33 MHz (L) 7.335 MHz (M) 14.67 MHz(M)	Continuous
DAM	Elmshorn Germany, F.R.	53°47'N 09°40'E	4.265 MHz 6.4755 MHz 8.6385 MHz 12.7635 MHz 16.980 MHz	1155 to 1206 and 2355 to 0006
DAN	Norddeich, Germany, F.R.	53°36'N 07°08'E	2.614 MHz	1155 to 1206 and 2355 to 0006
DIZ	Nauen Germany, D.R.	52°39'N 12°55'E	4.525 MHz	Continuous
FFH	Paris France	48°32'N 02°27'E	2.5 MHz (M)	0800-1630 Monday to Friday
FTH42	Pontoise France	49°04'N 02°07'E	7.428 MHz	0900 and 2100
FTK77	Pontoise France	49°04'N 02°07'E	10.775 MHz	0800 and 2000
FTN87	Pontoise France	49°04'N 02°07'E	13.873 MHz	0930; 1300; 2330.
HBN	Neuchatel Switzerland	46°58'N 06°57'E	5 MHz (L)	Continuous
GIC27	Rugby United Kingdom	52°22'N 01°11'W	7.3975 MHz	0900 and 2100
GIC33	Rugby United Kingdom	52°22'N 01°11'W	13.555 MHz	0900 and 2100
GIC37	Rugby United Kingdom	52°22'N 01°11'W	17.685 MHz	0900 and 2100
GPB60B	Rugby United Kingdom	52°22'N 01°11'W	10.3310 MHz	0900 and 2100
IAM	Rome Italy	41°52'N 12°27'E	5 MHz (M)	0730-0830, except Sunday

CALL SIGN	LOCATION	LATITUDE LONGITUDE	CARRIER FREQUENCY AND POWER*	OPERATING SCHEDULE (UNIVERSAL TIME)
IBF	Turin Italy	45°03'N 07°46'E	5 MHz (M)	45-60 minutes after hours 0600, 0800-1700 every day.
JAS22	Oyama Japan	36°16'N 139°48'E	16.170 MHz	From 1225 to 1230
JJY	Tokyo Japan	35°42'N 139°31'E	2.5 MHz (M) 5 MHz (M) 10 MHz (M) 15 MHz (M)	Continuous
LOL	Buenos Aires Argentina	34°37'S 58°21'W	5 MHz (M) 10 MHz (M) 15 MHz (M)	1100; 1400; 1700; 2000; 2300 except Sundays.
LQB9	Monte Grande Argentina	34°48'S 58°31'W	8.167 MHz	2330
LQC28	Monte Grande Argentina	34°48'S 58°31'W	17.5515 MHz	1005; 1130; 2305.
MSF	Rugby United Kingdom	52°22'N 1°11'W	2.5 MHz 5.0 MHz 10.0 MHz	5 min. every 10 min. (alternate with HBN.)
NBA	Balboa, C.Z. U.S.A.	09°04'N 79°39'W	5.4485 MHz 11.080 MHz 17.4975 MHz	0500; 1000; 1700; 2300.
NPG	Mare Island California, U.S.A.	38°06'N 122°16'W	4.010 MHz 6.42851 MHz 9.2775 MHz 12.966 MHz 17.0952 MHz 22.635 MHz	0600; 1200; 1800; 2400.
NPM	Lualualei Hawaii, U.S.A.	21°25'N 158°09'W	4.525 MHz 9.050 MHz 13.655 MHz 17.1824 MHz 22.593 MHz	0600; 1200; 1800; 2400.
NPN	Guam, U.S.A.	13°27'N 144°43'E	4.955 MHz 8.150 MHz 13.530 MHz 17.530 MHz 21.760 MHz	0600; 1200; 1800; 2400.
NSS	Annapolis Md., U.S.A.	38°59'N 76°27'W	5.870 MHz 9.425 MHz 13.575 MHz 17.0504 MHz 23.650 MHz	0300; 0600; 0800; 1200; 1400; 1800; 2400.

Radio Propagation Forecast

Standard Frequency stations is several instances transmit other helpful information. An instance of this is the forecast of propagation conditions as provided by JJY and WWV.

JJY provides a simple indication of propagation conditions at the time of broadcast. This is done by the use of three symbols, "N," "U" and "W" which are broadcast by International Morse Code. These signals, every five minutes, tell the prevailing propagation conditions. The "N" indicates normal conditions, the "U" an unsettled or unstable condition, and the "W" a disturbed condition. The latter condition is the one most likely to result in poor communication.

WWV uses the same letter symbols but adds to them a number. These numbers indicates the expected conditions during the subsequent six hours. The range extends from 1 to 9 and classifies conditions from "1," very poor to "9," excellent. WWV uses International Morse Code for these notices which are given during the last half minute of every five minute period. WWV's notices relate to the North Atlantic transmission path. WWVH used to give similar announcements for the Pacific area; however, these have been discontinued.

Geoalerts.

WWV and WWVH broadcast, once each hour, International Morse Code symbols for geophysical conditions of significance to scientists studying the earth's environment. The letters GEO are broadcast and are followed by another letter repeated five times. These letters with their meanings are listed below:

M = Magnetic storm
N = Magnetic quiet
C = Cosmic ray event
E = No geoalert issued
S = Solar activity
Q = Solar quiet
W = Stratospheric warming

Tables I and II

An attempt has been made to make an all-inclusive list of radio stations from which either standard frequencies or time signals may be received. To accomplish this it has been necessary to abbreviate the information given about each station and to record the best available information without recourse to full verification. The sources referred to in this compilation are considered to be reliable, however, some errors may have crept in and some changes may have been made since the references were printed. It is the hope of the author that the inclusiveness of this list may outweigh any inaccuracy that may be introduced.

A word about the tabulated material is in order. Table I lists those stations with their locations and geographical coordinates which broadcast above 1 megahertz. The assigned frequencies and, in some cases, estimates of the carrier powers are given. Also a notation is given as to when the station is expected to be on the air. Time is given in Universal (GMT) notation.

Table II lists the same information about stations operating below 1 megahertz. The tables have been divided since the HF stations, in general, may be received by any communications receiver but the LF and VLF stations usually require special receivers.

Conclusion.

No article of reasonable length can be expected to cover the many fascinating aspects of time and frequency broadcasting. In this description information has been given which will enable an interested listener to identify the various standard frequency and time stations which he may hear. Once the listener has identified a station he can usually obtain supplemental information directly from the station describing its own schedule and services.

stability of 1 part in 10^{10} per day is quite easily obtained.

At the present the standard unit of time interval, the second, is internationally accepted as the length of time required for a cesium atom (under carefully prescribed conditions) to complete 9, 192, 631, 770 oscillations. Frequency then, by definition, is the number of oscillations, or cycles, which occur in one standard second.

Standard frequencies used for the radio carriers will be either atomic or universal. As noted earlier, atomic frequencies are presently used by only a few stations. Universal frequency, used by most stations, is subject to annual change and is 300 parts in 10^{10} lower than atomic frequency for 1966.

Use of standard radio frequencies is most simply done by observing the beat note between a local oscillator and the received frequency. This may be done aurally or by visually observing a meter. Such techniques will enable one to resolve frequency to about 1 hertz; at 10 megahertz such resolution is equal to 1×10^{-7}, which is about the limit of accuracy to be achieved by skywave reception of HF signals.

Frequency comparisons at HF have been achieved with an accuracy of 1×10^{-10} by monitoring time signals for thirty days and observing the difference in time. Such measurements require highly precise oscillators at both transmitter and receiver.

To make possible frequency comparisons of higher accuracy it has been necessary to establish transmissions at VLF and LF frequencies, i.e., between 3 kilohertz and 300 kilohertz, where propagation effects are less deteriorating. Measurements made at these frequencies show that frequency accuracies of 1×10^{-10} may be realized in several hours of comparison and, for longer periods of time, accuracies of 1×10^{-11} or 1×10^{-12} may be obtained.

Standard Audio Frequencies

Audio frequencies of 1000, 600, and 440 hertz are transmitted from a number of the standard frequency stations. These frequencies are useful to power companies who wish to compare their generated frequencies against a standard frequency, to those who wish an audio signal of high accuracy for calibration purposes, and to musicians or musical instrument manufacturers for determining absolute pitch.

These frequencies are generally produced by synthesis (a technique for producing a new frequency which has a constant relationship to the original or source frequency) so that their accuracies are equal to those of the carriers.

TABLE II. LF/VLF STANDARD FREQUENCY AND TIME STATIONS

CALL SIGN	LOCATION	LATITUDE LONGITUDE	CARRIER FREQUENCY AND POWER*	OPERATING SCHEDULE (UNIVERSAL TIME)
BBC	Droitwich United Kingdom	52°18'N 02°06'W	200 kHz (H)	1800-2000
DCF77	Mainflingen Germany F. R	50°01'N 09°00'E	77.5 kHz (H)	0645-1035 and 1900-0010 (1 Nov.-28 Feb.) or 1900-0200(1 Mar.-31 Oct.) except Sundays.
FTA-91	St. André deCorcy, France	45°55'N 04°55'E	91.15 kHz (H)	0800; 0900; 0930; 1300; 2000; 2100; 2230.
GBR	Rugby United Kingdom	52°22'N 01°11'W	16 kHz (H)	Continuous except 1300-1430.
GQD	Anthorn Scotland		19 kHz	
GBZ	Criggion United Kingdom	52°43'N 03°03'W	19.6 kHz	
HBB	Münchenbuchsee Switzerland	47°01'N 07°27'E	96.05 kHz	0815
HBG	Prangins Switzerland	46°24'N 06°15'E	75 kHz (M)	Continuous
JG2AR	Tokyo Japan	35°42'N 139°31'E	20 kHz (M)	0530-0730 except Saturdays and Sundays
JG2AS JJM-6	Kemigawa Chiba C Japan	35°38'N 140°04'E	40 kHz (M)	Continuous
LORAN-C	Carolina Beach North Carolina U.S.A.	34°04'N 77°55'W	100 kHz (H)	Continuous
MSF	Rugby United Kingdom	52°22'N 01°11'W	60 kHz (H)	1430-1530
NAA	Cutler, Maine U.S.A.	44°39'N 67°17'W	17.8 kHz (H)	Continuous
NBA	Balboa, Canal Zone, U.S.A.	09°04'N 79°39'W	24.0 kHz (H)	Continuous
NBA	Balboa, Canal Zone, U.S.A.	09°04'N 79°39'W	147.85 kHz	0500; 1000; 1700; 2300.
NPG	Mare Island, California U.S.A.	38°06'N 122°16'W	114.95 kHz	0600; 1200; 1800; 2400
NPG/NLK	Jim Creek Washington U.S.A.	48°06'N 122°16'W	18.6 kHz (H)	Continuous
NPM	Lualualei, Hawaii, U.S.A.	21°25'N 158°09'W	131.05 kHz	0600; 1200; 1800; 2400.
NPM	Lualualei, Hawaii, U.S.A.	21°25'N 158°09'W	26.1 kHz (H)	Continuous
NPN	Guam, U.S.A.	13°27'N 144°43'E	484 kHz	0600; 1200; 1800; 2400.
NSS	Annapolis Md., U.S.A.	38°59'N 76°27'W	162 kHz	0200; 0600; 0800; 1200; 1400; 1800; 2400.
NSS	Annapolis Md., U.S.A.	38°59'N 76°27'W	21.4 kHz (H)	Continuous
OMA	Podebrady Czechoslovakia S.R.	50°08'N 15°08'E	50 kHz (M)	Continuous
ROR	Moscow, U.S.S.R.	55°45'N 37°18'E	88 kHz	0400; 0800; 1200; 1600; 2000; 2400.
RWM/RES	Moscow, U.S.S.R.	55°45'N 37°33'E	100 kHz (H)	Continuous except 0007-0100; 1207-1300; and 1607-1700.
VHP	Belconnen, Australia	35°15'S 149°06'E	44 kHz	0100 and 0800 except Tuesdays and Wednesdays.
WWVB	Fort Collins, Colorado, U.S.A.	40°40'N 105°03'W	60 kHz (H)	Continuous
WWVL	Fort Collins, Colorado, U.S.A.	40°41'N 105°03'W	20 kHz (M)	Continuous
XSG	Shanghai, China	31°14'N 121°26'E	458 kHz	0300; 0900

* L) 1 kw; M 1-5 kw; H) 5 kw