Errata

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HP References in this Application Note

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FREQUENCY AND TIME STANDARDS

APPLICATION NOTE 52

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APPLICATION NOTE 52

FREQUENCY AND TIME STANDARDS

FIRST EDITION

JANUARY 1961

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

OTHER HEWLETT-PACKARD PUBLICATIONS ON FREQUENCY AND TIME STANDARDS

The following (hp) Application Notes and (hp) Journal articles are available from either your local Hewlett-Packard representative or the Hewlett-Packard Company.

Cutler, Leonard F. "A New Frequency/Time Standard with 5 x 10^{-10}/Day Stability," Hewlett-Packard Journal, vol. 12, no. 3; November, 1960.

Hartke, Dexter C. "A New Clock for Improving the Accuracy of Local Frequency and Time Standards," Hewlett-Packard Journal, vol. 11, no. 3-4; November-December, 1959.

"Making VLF Frequency Comparison Measurements with (hp) Laboratory Equipment," (hp) Application Note 50.

"Microwave Measurements for Calibration Laboratories," (hp) Application Note 38.

"Utilizing VLF Standard Broadcasts with the Hewlett-Packard Frequency Divider and Clock," Hewlett-Packard Journal, vol. 11, no. 8-10; April-June, 1960.

SECTION I
GENERAL

1-1 INTRODUCTION

This application note explains the principles involved in maintaining precision frequency and time standards. Several system arrangements are described and system operation is discussed. Considerable emphasis is placed upon practical methods of frequency and time determination.

Hewlett-Packard frequency and time standard systems are used for frequency and time control or calibration at manufacturing plants, physical research laboratories, calibration centers, astronomical observatories, missile and satellite tracking stations, and radio monitoring and transmitting stations. System uses include the following: distributed standard frequencies in factories or research facilities ("house standards"), control of standard frequency and time broadcasts, synchronization of electronic navigation systems, investigation of radio transmission phenomena, frequency synthesizer control, and precise adjustment of single-sideband communications equipment.

The absolute accuracy which can be maintained with Hewlett-Packard systems depends not only upon equipment performance, but also on (a) the accuracy of the master time or frequency source and (b) local comparison and adjustment techniques. Frequency accuracy typically can be maintained within a part in 10^9 or better. Absolute time synchronization with a master time standard typically can be maintained within a millisecond or less.

High-accuracy master standards of frequency and time are provided in convenient broadcasts from radio stations such as WWV, WWVH, WWVL, NBA and many others throughout the world (paragraph 1-6). Two proven comparison techniques available to the user are discussed below. By careful use of suitable comparison and adjustment methods, high system accuracy can be maintained.

The necessary equipment characteristics provided by Hewlett-Packard systems include (a) suitable oscillator stability, (b) high-accuracy comparison capability, (c) reliability, and (d) operational simplicity.

The ease with which required system accuracy may be achieved is largely dependent on oscillator stability. Improved long-term stability directly increases the permissible time between oscillator adjustments required to maintain a given absolute accuracy. If an oscillator exhibits long-term stability of 5 parts in 10^{10} per day, for example, adjustments at 20-day intervals can provide accuracy of ±5 parts in 10^9 (assuming negligible error in both the master standard and comparison method); if long-term stability were 5 parts in 10^9 per day, adjustments at 2-day intervals would be required for the same accuracy.

Long-term stability of both the ⓗⓟ Model 103AR Quartz Oscillator and the Model 104AR Quartz Oscillator is conservatively rated at 5 parts in 10^{10} per day with substantially better performance to be expected under normal operating conditions. Such performance results from the use of (a) carefully tested, high-quality crystals, (b) precision-temperature ovens, (c) inherently stable circuitry, and (d) low-power dissipation in crystal (approximately 0.1 microwatt). Design of Hewlett-Packard oscillators includes attention to such details as shock and vibration isolation, shielding, load isolation, and stability with respect to variation of supply voltage.

The crystal operating level chosen provides the best compromise between long-term stability and short-term stability. Short-term stability for the Models 103AR and 104AR, for example, is 5 parts in 10^{10}, based on frequency average over 1-second intervals. This stability specification is held during variations in ambient temperature from 0-50°C, variations in dc supply voltage from 22-30 volts, and variations in load impedance from a few ohms to several hundred ohms. As a result short-term stability in the order of one part in 10^{10} can usually be expected when the oscillator is operating under normal laboratory conditions.

Hewlett-Packard instruments which are used as system components are listed in table 1-1 along with their abbreviated names (as used in this application note). Data sheets describing a few of these instruments in detail are included in appendix II. Consult your Hewlett-Packard representative (appendix III) for information on new instruments now in development and not listed here.

TABLE 1-1. SYSTEM COMPONENTS

ⓗⓟ Model Number	Complete Name	Abbreviated Name
103AR	Quartz Oscillator	Oscillator
104AR	Quartz Oscillator	Oscillator
113AR/BR	Frequency Divider and Clock	Clock
114AR/BR	Time Comparator	Comparator
120AR	Oscilloscope	Oscilloscope
724AR/BR	Standby Power Supply	Power Supply
725AR	Standby Power Supply	Power Supply

Hewlett-Packard frequency and time standard systems can be used in several configurations, depending both on principal system use (i.e. providing accurate frequency or providing accurate time) and on the source of master time or frequency signals (i.e. hf radio transmission or lf/vlf radio transmissions). The various system arrangements are discussed in the following paragraphs.

1-2 FREQUENCY DETERMINATION USING HF RADIO SIGNALS

Heterodyne or zero-beat methods of frequency determination using radio signals transmitted by standard-frequency broadcasting stations are commonly used if extreme accuracy is not required. Sky-wave signals, whose propagation path includes one or more reflections from ionospheric layers, are subject to Doppler-effect frequency shift caused mainly by vertical movement of the reflection layers. The frequency shift is a function of the velocity of layer movement. Received signal frequency often differs from the transmitted frequency by several parts in 10^8 per reflection*. Stations which receive multi-hop modes (i.e. several ionospheric reflections) therefore may experience frequency shifts in the order of parts in 10^7.

Hewlett-Packard frequency and time standards use high-frequency (hf) radio timing signals to measure frequency indirectly, and thus avoid the problem of Doppler frequency shift. The time-comparison measurements which are necessary for frequency computation are subject to some error caused by variations in radio transmission delay (mainly a function of ionospheric layer height and transmission mode; refer to paragraphs 4-3 and 4-4 for a detailed discussion), but the effects of this error can be minimized by making observations over an extended period of time.

Several system arrangements which use time signals from hf radio transmissions are shown in figures 1-1 and 1-2 (methods A and B). These systems consist basically of an oscillator-driven synchronous-motor clock which is periodically compared with the master time signals.

If the time intervals indicated on the system clock are precisely the same as the master time intervals, oscillator frequency is precisely its nominal value. If the clock loses time, oscillator frequency is low. If the clock gains time, oscillator frequency is high. Accurate measurement of the difference between the time interval indicated on the clock and that from the master time standard permits calculation of average oscillator frequency (or frequency error) during the measurement interval.

Example: A precision oscillator drives a clock which gains 2 milliseconds relative to the master time standard during a time interval of 1,000,000 seconds (about 11.6 days). The average oscillator frequency during the interval is therefore 2×10^{-3} seconds $\div$ 10^6 seconds or 2×10^{-9} high with respect to the master time standard.

* Shaull, J. M. "Adjustment of High-Precision Frequency and Time Standards," Proc. IRE, Vol. 38 pp. 6-15; Jan., 1950.

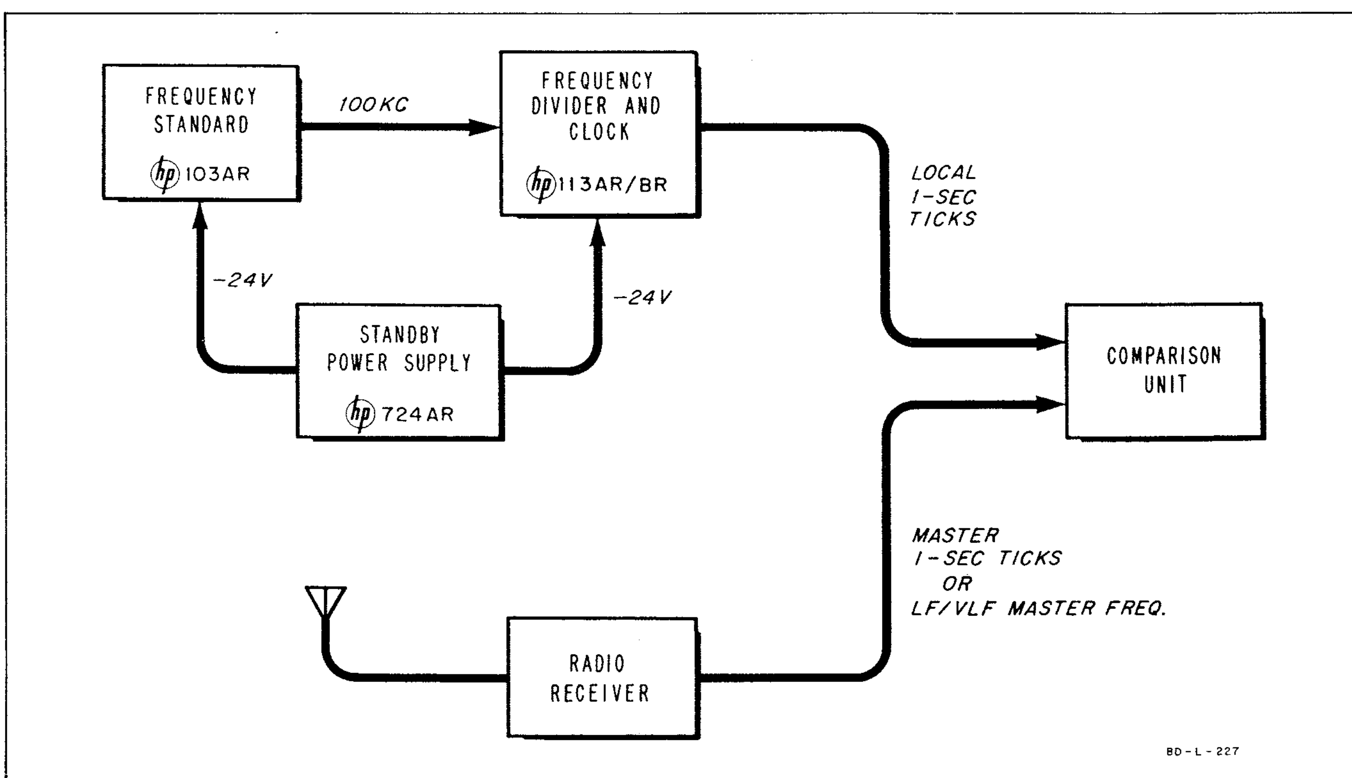

Figure 1-1. Basic Frequency and Time Standard System

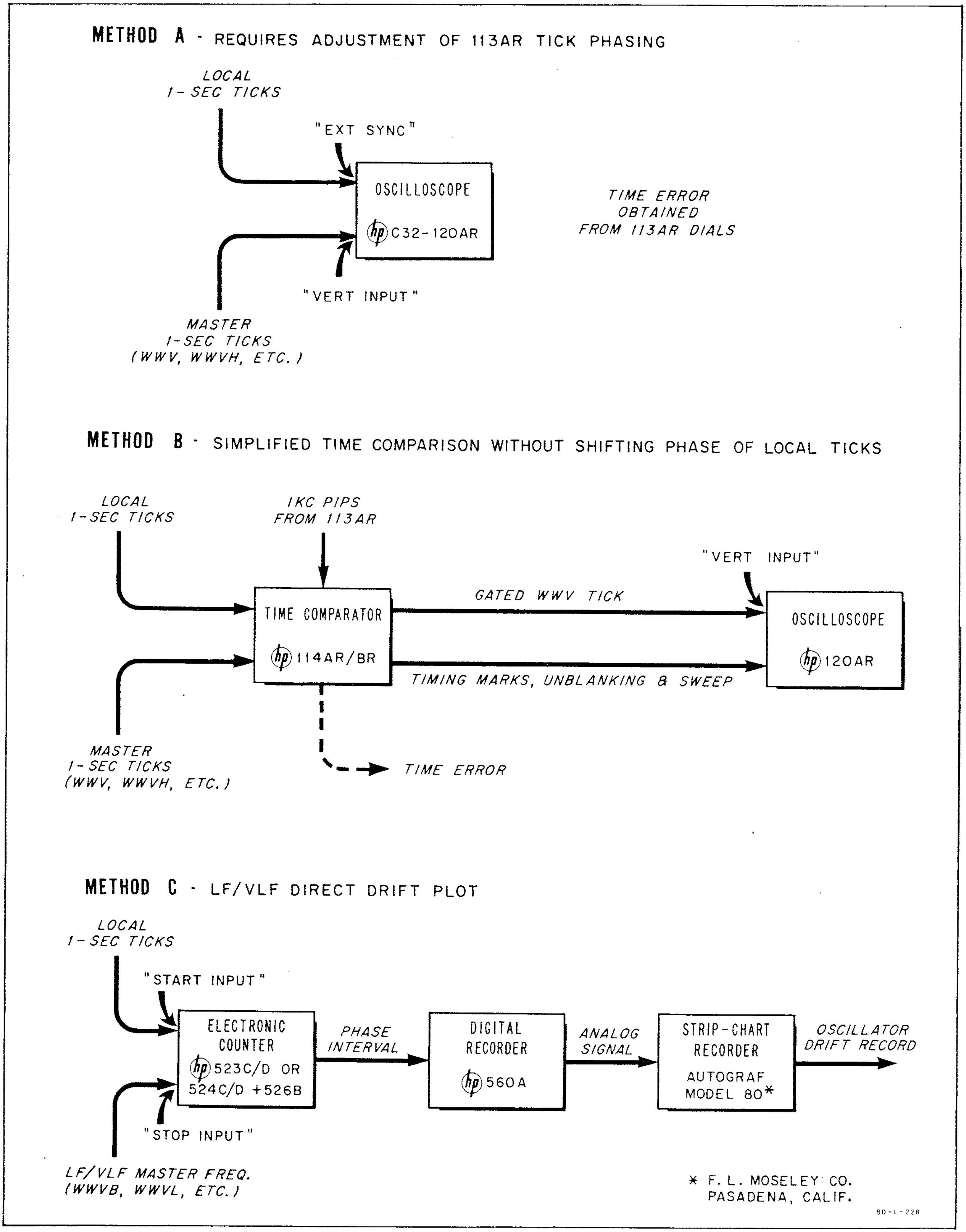

Figure 1-2. Comparison Units for Basic System

A precision oscillator can be assumed to have a fairly linear drift rate after its initial run-in period of several weeks. Therefore the value of the average frequency during the measurement interval is approximately equal to the instantaneous frequency at the midpoint of the interval. Thus, in the example given above, the instantaneous frequency 500,000 seconds after the start of the interval would be 2×10^{-9} high. A series of such frequency determinations can be plotted graphically to give a convenient record of oscillator frequency.

Note that determination of oscillator frequency depends on measurement of time intervals, and does not depend on absolute time setting or time synchronization with the master time source. Refer to section III for a complete discussion of frequency determination techniques.

1-3 FREQUENCY MEASUREMENT USING LF/VLF RADIO SIGNALS

Because of the relatively stable radio propagation conditions in the low-frequency (lf) and very-low-frequency (vlf) bands, precise frequency transmission services in these bands offer a means for direct determination of oscillator frequency. Suitable phase-comparison systems permit high-accuracy frequency determination in a somewhat shorter period of time than is possible with systems using hf time comparisons; however, exact time determination is difficult because of transmission bandwidth limitations in the lf/vlf bands.

Figure 1-2 (method C) shows a system installation of standard laboratory test equipment for evaluating lf/vlf signals to maintain precise frequency records. With this system, the output of the electronic counter indicates the phase relationship between the clock tick output and the received master frequency. The strip-chart recorder indicates oscillator drift with respect to the master frequency directly.

Detailed instructions for setting up a complete vlf phase-comparison system are given in ⓗ Application Note 50, "Making VLF Frequency Comparison Measurements with ⓗ Laboratory Equipment."

1-4 ACCURATE TIMEKEEPING

Equipment requirements for maintaining a precise time standard are similar to those for maintaining a precise frequency standard as illustrated in figure 1-2 (methods A and B). Once local synchronization with the master time standard has been made, corrections for oscillator drift can be calculated or determined graphically when the behavior characteristics of the oscillator are known. Synchronization with a master time standard (within about 1 millisecond) by means of radio transmissions (WWV, WWVH, etc.) requires determination of the propagation delay between transmitter and receiver. Methods of precise time synchronization are discussed in paragraphs 4-1 through 4-5.

1-5 TIME SCALES

Several time scales are used for time measurement. The time scales described below are frequently referred to in discussions of precise timekeeping.

A. UNIVERSAL TIME (UT). Universal Time (UT) or Greenwich Mean Time (GMT) or Greenwich Civil Time (GCT) is a system of mean solar time based on the rotation of the earth about its axis relative to the position of the sun. Several UT scales are in use: Uncorrected astronomical observations used in determining mean solar time are denoted UT0; the UT0 time scale when corrected for the earth's polar variation is denoted UT1; the UT1 time scale when corrected for annual variation in the rotation of the earth is denoted UT2. Standard time signals transmitted by radio station WWV are based on the UT2 time scale. Although UT is in common use, it is non-uniform because of progressive changes in the earth's speed of rotation.

For detailed definitions of UT0, UT1, and UT2, refer to Time Service Notice No. 4; U. S. Naval Observatory; Washington 25, D. C.; April, 1959.

Astronomical time measurements are frequently referred to the Greenwich mean sidereal time scale (denoted θ) which is based on the rotation of the earth relative to star position. An oscillator frequency of approximately 100.27379091 kc is required to operate the ⓗ Model 113AR/BR Frequency Divider and Clock on a mean sidereal time basis. Sidereal time, like UT, is non-uniform.

B. EPHEMERIS TIME (ET). Scientific measurement of precise time intervals requires a uniform time scale. The fundamental standard of constant time is defined by the orbital motion of the earth about the sun and is called Ephemeris Time (ET). (In practice, ET is determined from lunar observations.) In 1956, the International Committee of Weights and Measures defined the second as "the fraction 1/31,556,925.9747 of the tropical year for 12^hET of January 0, 1900" (January 0, 1900 = December 31, 1899).

The apparent offset between ET and UT2 as transmitted by WWV and other stations transmitting precise UT2 time signals is determined and published periodically to permit correction to the standard ET scale. Published corrections are discussed in paragraph 1-6.

C. ATOMIC TIME (AT). Molecular and atomic resonance characteristics can be used to provide time scales which are apparently constant and equivalent (or nearly equivalent) to ET. The designation A.1 has been given to the time scale derived from the zero-field $(4, 0) \longleftrightarrow (3, 0)$ resonance of cesium with one second equal to 9,192,631,770 periods of oscillation. The U. S. Frequency Standard at Boulder, Colorado, is maintained by reference to the A.1 time scale. Atomic standards are used for determining published corrections (accurate to about $\pm 2 \times 10^{-9}$ on the ET scale) for the time signals transmitted by WWV.

For a detailed discussion of AT and the A.1 system, refer to Time Service Notice No. 6; U.S. Naval Observatory; Washington 25, D.C.; January, 1959.

1-6 RADIO TIME SIGNALS

High-frequency (hf) time signals are broadcast in the United States by the National Bureau of Standards over radio stations WWV (located near Washington, D.C.) and WWVH (located in Hawaii). The important characteristics of these and other hf stations transmitting precise time signals are shown in table 1-2.

The U.S. Navy and the National Bureau of Standards are presently transmitting standard lf and vlf signals. The long-range groundwave and stable propagation of lf/vlf transmissions permit direct phase comparison while avoiding the problems of frequency shift and variation in transmission time which is associated with hf transmissions. The characteristics of these and other lf/vlf transmissions are whown in table 1-3.

The frequency offset of signals transmitted at any given time by NBS stations is available from the Radio Standards Laboratory, National Bureau of Standards, Boulder, Colorado.

Time is announced every 5 minutes in UT by telegraphic code over radio station WWV. Eastern Standard Time is announced in voice before and after each code announcement. 1-second timing pulses (or "ticks") transmitted by WWV normally consist of a 5-millisecond pulse of a 1000-cps sine wave, with exact time at the leading edge of the pulse (figure 1-3). Intervals of 1 minute are marked by omitting the last tick of each minute and by commencing each minute with 2 ticks spaced by 0.1 second. During the 1-minute binary-coded-decimal (BCD) time code periods (described below), seconds are indicated by a series of five 6-millisecond pulses of a 1000-cps sine wave, followed by a 2-millisecond pulse of a 1000-cps sine wave; exact time occurs at the leading edge of the 2-millisecond pulse.

Station WWVH announces time in telegraphic code every 5 minutes. The 1-second ticks transmitted by WWVH consist of 6 cycles of a 1200-cps sine wave (figure 1-3). Intervals of 1 minute are marked by omitting the last tick of each minute and by commencing each minute with two ticks spaced by 0.1 second.

A binary-coded-decimal (BCD) time-of-year signal is broadcast by WWV for 1-minute periods starting at minutes 7, 12, 17, 22, 27, 32, 37, 42, 52, and 57. Figure 1-4 shows pulse arrangement during the 1-second time-frame interval.

A four-pulse 1-2-4-8 BCD group is used. The binary "0" is represented by a 2-millisecond pulse (2 cycles of a 1000-cps sine wave), and the binary "1" is represented by a 6-millisecond pulse (6 cycles of a 1000-cps sine wave). Each BCD group can be converted to a decimal digit by adding the represented binary quantities. For example, a long-short-long-short BCD group indicates the digit 5 (1 + 0 + 4 + 0).

Index pulses of 6-millisecond duration are transmitted at 0.1-second intervals. Note that the 0.1-second index pulses mark the start of a BCD pulse group.

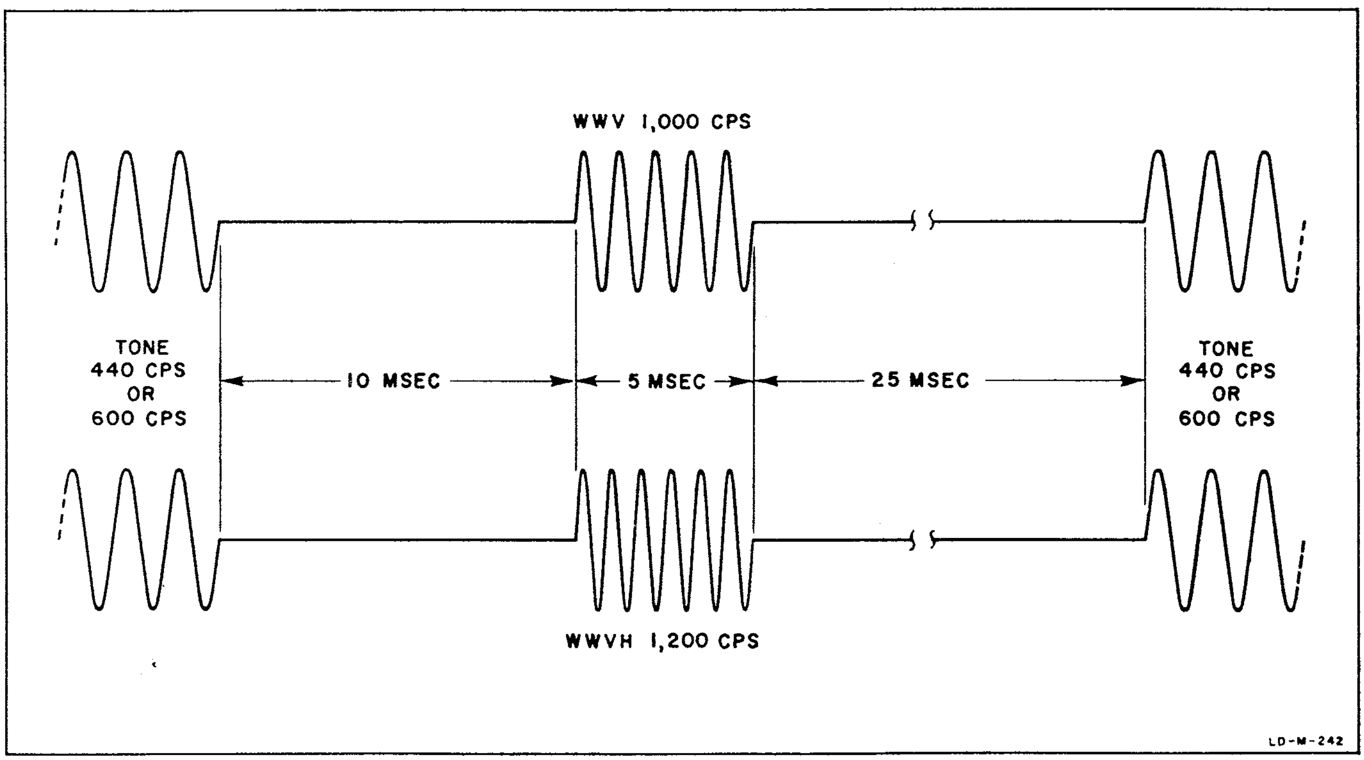

Figure 1-3. Tick Description WWV and WWVH

	ATA	CHU	FFH	HBN	IBF	JJY	LOL	MSF	OMA
aii	New Delhi India	Ottawa Canada	Paris France	Neuchâtel Switzerland	Torino Italy	Tokyo Japan	Buenos Aires Argentina	Rugby England	Pragu Czechoslo
.	28° 34' N	45° 17' 47" N	48° 46' N	47° 00" N	45° 03' N	35° 42' N	34° 37' S	52° 22' N	50° 07'
N	77° 19' E	75° 45' 22" E	2° 20' E	6° 57' E	7° 40' E	139° 31' E	58° 21' W	1° 11' W	14° 35'
	10	3.330 7.335 14.670	2.5 5 10	2.5 5	5	2.5 5 10 15	2.5 5 10 15 20 25	2.5 5 10	2.5
	M	L M M	L L L	L L	L	M M M M	M M M M M M	L L L	M
ept: -18, each - day.	5 days per week, 0534-0600 and 1030-1100 UT.	Continuous	Tues. and Fri. 9 hrs. per day except min. 25-30 each hr.	2.5 mc: Sat. 0700- Tues. 0700, Wed. 0700- Fri. 0700. 5 mc: Tues. 0700- Wed. 0700, Fri. 0700- Sat. 0700 UT.	Daily 0700-0730, 1100-1130 UT, except Sun.	2.5 mc: Daily 0700-2300 UT except min. 29-30 each hr. 5 mc: Mon. except min. 9-19, 29-39, 49-59 each hr. 10 mc: Wed. except min. 9-19, 29-39, 49-59 each hr. 15 mc: continuous except min. 29-39 each hr.	Daily 1100 - 1200, 1400 - 1500, 1700 - 1800, 2000 - 2100, 2300 - 2400 except Sun.	Continuous except min. 15-20 each hr.	Continuous e min. 40-45 hr.
) cps r 3 5 min.	1000 cps for 4 min. in each 15 min.	None	440 cps (1 min.) and 1000 cps (9 min.) for 10 min. in each 20 min.	500 cps square wave for 5 min. in each 60 min.	440 cps or 1000 cps (alternates) for 5 min. in each 10 min.	1000 cps for 4 min. in each 5 min.	440 cps or 1000 cps (alternates) for 4 min. in each 5 min.	1000 cps for 10 min. in each 15 min.	1000 cps for in each 15 m
	5 msec.	200 msec	5 msec.	10 msec.	5 msec.	20 msec.	5 msec.	5 msec.	5 msec
	1000 cps	1000 cps	1000 cps	5 carrier interruptions 1 msec. x 1 msec. (start of 1st int. is exact sec.)	1000 cps	Carrier interruption before sec.	1000 cps	1000 cps	1000 cp
9: l with rval	100 msec. tick for sec. 00.	500 msec tick for sec. 00; other ticks omitted (1000 msec tick for hour mark).	100 msec. tick followed by 100 msec. at 440 cps for sec. 00.	250 carrier interruptions for sec. 00.	Tick repeated 7 times with 10 msec. intervals for sec. 00.	200 ms interruption before sec. 00.	No tick sec. 59.	100 msec. tick for sec. 00.	100 msec. t sec. 00.
s	Continuous	Continuous	10 min. in each 20 min.	5 min. in each 10.	5 min. in each 10	Continuous	4 min. in each 60 min.	5 min. in each 15 min.	10 min. in e No tick mi 25 each hr.
.9	$\pm 20 \times 10^{-9}$ ± 1 millisec.	Several parts in 10^9	$\pm 20 \times 10^{-9}$ ± 1 μsec.	$\pm 3 \times 10^{-10}$ ± 1 μsec	$\pm 20 \times 10^{-9}$ ± 1 μsec.	$\pm 20 \times 10^{-9}$ ± 1 μsec.	$\pm 20 \times 10^{-9}$ ± 1 μsec.	$\pm 5 \times 10^{-9}$ ± 1 μsec.	$\pm 10 \times 10$ ± 1 μsec
	20 msec. step.	50 msec step on 1st day of month	50 msec. step on 1st Mon. of month.	Steering	Step	10 msec. step.	20 msec. step.	20 msec step on 1st day of month	Step

	CALL SIGN	WWV	WWVH
LOCATION	PLACE	Beltsville, Md. U.S.A.	Maui, Hawaii U.S.A.
	LATITUDE	38° 51' 33" N	20° 46' N
	LONGITUDE	76° 50' 53" W	156° 28' W
CARRIER	FREQ. (MC)	2.5 / 5 / 10 / 15 / 20 / 25	5 / 10 / 15
	POWER*	M / H / H / H / M / L	M / M / M
	SCHEDULE	Continuous except: min. 45-49 each hr.	Continuous except: min. 0-3, 15-18, 30-33, 45-48 each hr. and 1900 - 1934 UT each day.
	AUDIO MODULATION in addition to time signals	440 cps or 600 cps (alternates) for 2 min. in each 5 min. Time code (BCD) for 1 min. starting min. 7, 12, 17, 22, 27, 32, 37, 42, 52, 57.	440 cps or 600 cps (alternates) for 3 min. in each 5 min.
TIME SIGNALS	NORMAL TICK DURATION	5 msec.	5 msec.
	TICK MODULATION	1000 cps	1200 cps
	MINUTE MARK	No tick sec. 59: Tick repeated with 100 msec. interval for sec. 00.	No tick sec. 59: Tick repeated with 100 msec interval for sec. 00.
	SIGNAL DURATION	Continuous	Continuous
	INTERVAL ACCURACY	$\pm 2 \times 10^{-9}$ $\pm 1\ \mu$sec.	$\pm 10 \times 10^{-9}$ $\pm 1\ \mu$sec.
	ADJUSTMENT	step	step

* L < 1 kw
M 1-5 kw
H > 5 kw

TABLE 1-3. LF AND VLF FREQUENCY AND TIME STANDARDS

	CALL SIGN	WWVB	WWVL	NBA	DCF77	GBR	MSF	OMA
LOCATION	PLACE	Boulder, Colorado U.S.A.	Sunset, Colorado U.S.A.	Summit, C. Z. Panama	Mainflingen Germany	Rugby United Kingdom		Poděbrady Czechoslovakia
LOCATION	LATITUDE / LONGITUDE	40° 00'N / 105° 16'W	40° 02'N / 105° 27'W	9° 04' 30"N / 79° 34' 30"W	50° 01'N / 9° 00'E	52° 22'N / 1° 11'W		50° 08'N / 15° 08'E
CARRIER	FREQUENCY	60 kc	20 kc	18 kc	77.5 kc	16 kc	60 kc	50 kc
CARRIER	ACCURACY	$\pm 2 \times 10^{-10}$	$\pm 2 \times 10^{-10}$	$\pm 1 \times 10^{-10}$	$\pm 100 \times 10^{-10}$	$\pm 50 \times 10^{-10}$	$\pm 50 \times 10^{-10}$	$\pm 100 \times 10^{-10}$
CARRIER	OFFSET	Approx. -150×10^{-10} during 1961	Approx. -150×10^{-10} during 1961	Approx. -150×10^{-10} (rel. to A.1) during 1961	—	—	—	—
CARRIER	POWER*	Low	Med	High	Med	High	Med	Low
SCHEDULE		Mon. 1530 - Fri. 2400 except 1430 - 1530 UT Tues. thru Fri.	Continuous	Continuous except Wed. 1300 - 2100 UT	Mar thru Oct, weekdays 0700-0210; Nov thru Feb, 0700-0010; telegraphic traffic 1200-1859; no transmission after 1900 UT before Sun or holiday.	Daily, approx. 22 hrs.	Daily, 1430 - 1530UT	Continuous
MODULATION		Call sign broadcast at min. 00, 20, 40 each hour.	Call sign broadcast at min. 00, 20, 40 each hour.	Int. time sigs, call - sign and offset from A. 1 in parts in 10^{10} broadcast periodically	Standard 440 cps tone, 0710-0727. Standard 200 cps tone, 1010-1027. 1-sec ticks: Either (a) 20 msec pulsed carrier or 20 msec 440 cps tone, sec 00 prolonged (100 msec); or (b) pulsed carrier for 100 msec, sec 00 prolonged (500 msec); 0728-0735, 0800-0810, 1028-1035, 1100-1110, 1900-2010, 2057-2110, 2157-2210, 2257-2310, 2357-0010, 0057-0110, 0157-0210 UT. 2-min ticks (min 00, 02, 04, etc.): 440 cps for 40 msec; 0700-0709, 0736-0759, 0811-1009, 1036-1059, 1111-1200 UT. Standard deviation (σ) ≈ ±0.06 msec for 20 msec 1-sec ticks and 2-min ticks. Adjustment: 50 msec step Wed at 1400 UT.	Int. time sigs, telegraphic traffic	1000 cps for 5 min. in each 15 min.	Continuous except 1000 - 1101 UT: 100 msec pulsed carrier marks exact sec with sec 00 prolonged to 500 msec; accuracy $\pm 10 \times 10^{-9}$; 1000 - 1101 UT: continuous carrier with interruption for call sign each 15 min.
TIME SIGNALS		None at present but planned for near future	None at present but planned for near future	Dash starts on exact sec. Dash omitted on sec. 29, 56, 57, 58, 59 each min. Other dashes omitted during sec. 51-55 of last 5 min. of each hour, first dash each hour prolonged. Accuracy: same as carrier		Time sigs, 0955 - 1000, 1755 - 1800UT	—	

* Low < 10 kw
Med 10-100 kw
High >100 kw

1961 CH-L-86

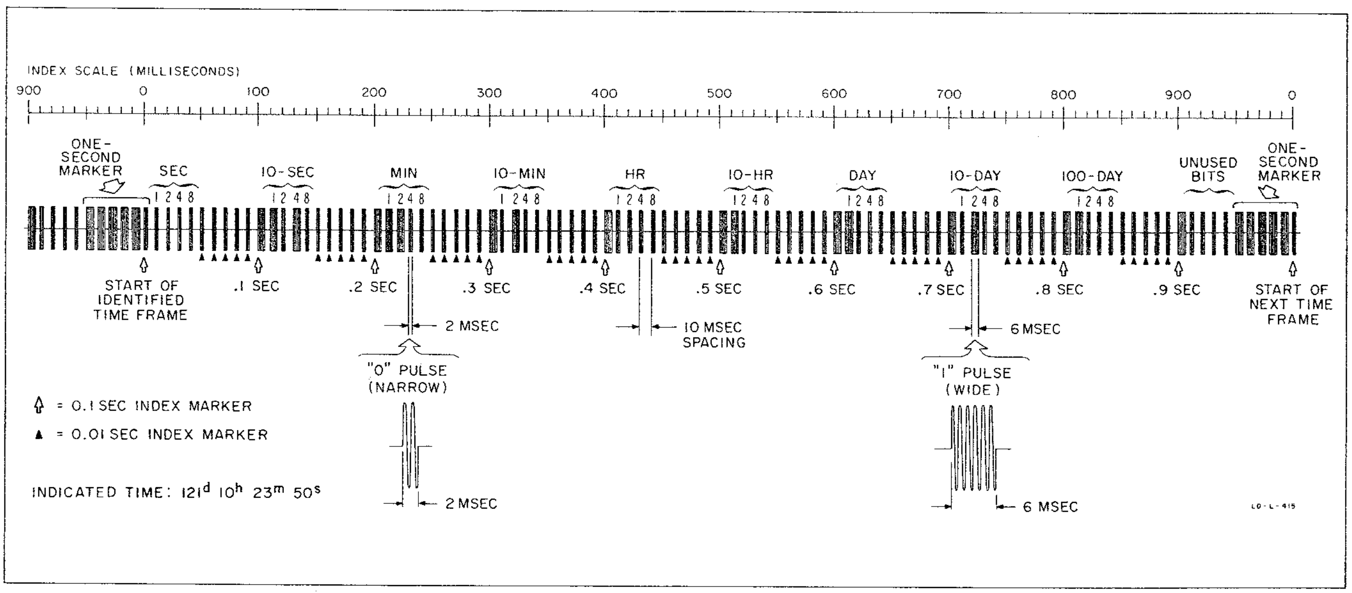

Figure 1-4. Time Code WWV, 36-Bit Binary-Coded-Decimal

TABLE 1-3. LF AND VLF FREQUENCY AND TIME STANDARDS

CALL SIGN	WWVB	WWVL	NBA	DCF77	GBR	MSF	OMA
LOCATION: PLACE	Boulder, Colorado U.S.A.	Sunset, Colorado U.S.A.	Summit, C. Z. Panama	Mainflingen Germany	Rugby United Kingdom		Poděbrady Czechoslovakia
LOCATION: LATITUDE / LONGITUDE	40° 00'N / 105° 16'W	40° 02'N / 105° 27'W	9° 04' 30"N / 79° 34' 30"W	50° 01'N / 9° 00'E	52° 22'N / 1° 11'W		50° 08'N / 15° 08'E
CARRIER: FREQUENCY	60 kc	20 kc	18 kc	77.5 kc	16 kc	60 kc	50 kc
CARRIER: ACCURACY	$\pm 2 \times 10^{-10}$	$\pm 2 \times 10^{-10}$	$\pm 1 \times 10^{-10}$	$\pm 100 \times 10^{-10}$	$\pm 50 \times 10^{-10}$	$\pm 50 \times 10^{-10}$	$\pm 100 \times 10^{-10}$
CARRIER: OFFSET	Approx. -150×10^{-10} during 1961	Approx. -150×10^{-10} during 1961	Approx. -150×10^{-10} (rel. to A.1) during 1961	—	—	—	—
CARRIER: POWER*	Low	Med	High	Med	High	Med	Low
SCHEDULE	Mon. 1530 - Fri. 2400 except 1430 - 1530UT Tues. thru Fri.	Continuous	Continuous except Wed. 1300 - 2100UT	Mar thru Oct, weekdays 0700-0210; Nov thru Feb, 0700-0010; telegraphic traffic 1200-1859; no transmission after 1900 UT before Sun or holiday.	Daily, approx. 22 hrs.	Daily, 1430 - 1530UT	Continuous
MODULATION	Call sign broadcast at min. 00, 20, 40 each hour.	Call sign broadcast at min. 00, 20, 40 each hour.	Int. time sigs, call-sign and offset from A. 1 in parts in 10^{10} broadcast periodically	Standard 440 cps tone, 0710-0727. Standard 200 cps tone, 1010-1027. 1-sec ticks: Either (a) 20 msec pulsed carrier or 20 msec 440 cps tone, sec 00 prolonged (100 msec); or (b) pulsed carrier for 100 msec, sec 00 prolonged (500 msec); 0728-0735, 0800-0810, 1028-1035, 1100-1110, 1900-2010, 2057-2110, 2157-2210, 2257-2310, 2357-0010, 0057-0110, 0157-0210 UT. 2-min ticks (min 00, 02, 04, etc.): 440 cps for 40 msec; 0700-0709, 0736-0759, 0811-1009, 1036-1059, 1111-1200 UT. Standard deviation (σ) $\approx \pm 0.06$ msec for 20 msec 1-sec ticks and 2-min ticks. Adjustment: 50 msec step Wed at 1400 UT.	Int. time sigs, telegraphic traffic	1000 cps for 5 min. in each 15 min.	Continuous except 1000 - 1101 UT: 100 msec pulsed carrier marks exact sec with sec 00 prolonged to 500 msec; accuracy $\pm 10 \times 10^{-9}$ 1000 - 1101 UT: continuous carrier with interruption for call sign each 15 min.
TIME SIGNALS	None at present but planned for near future	None at present but planned for near future	Dash starts on exact sec. Dash omitted on sec. 29, 56, 57, 58, 59 each min. Other dashes omitted during sec. 51-55 of last 5 min. of each hour, first dash each hour prolonged. Accuracy: same as carrier		Time sigs, 0955 - 1000, 1755 - 1800UT	—	

* Low < 10 kw
Med 10-100 kw
High >100 kw

1961

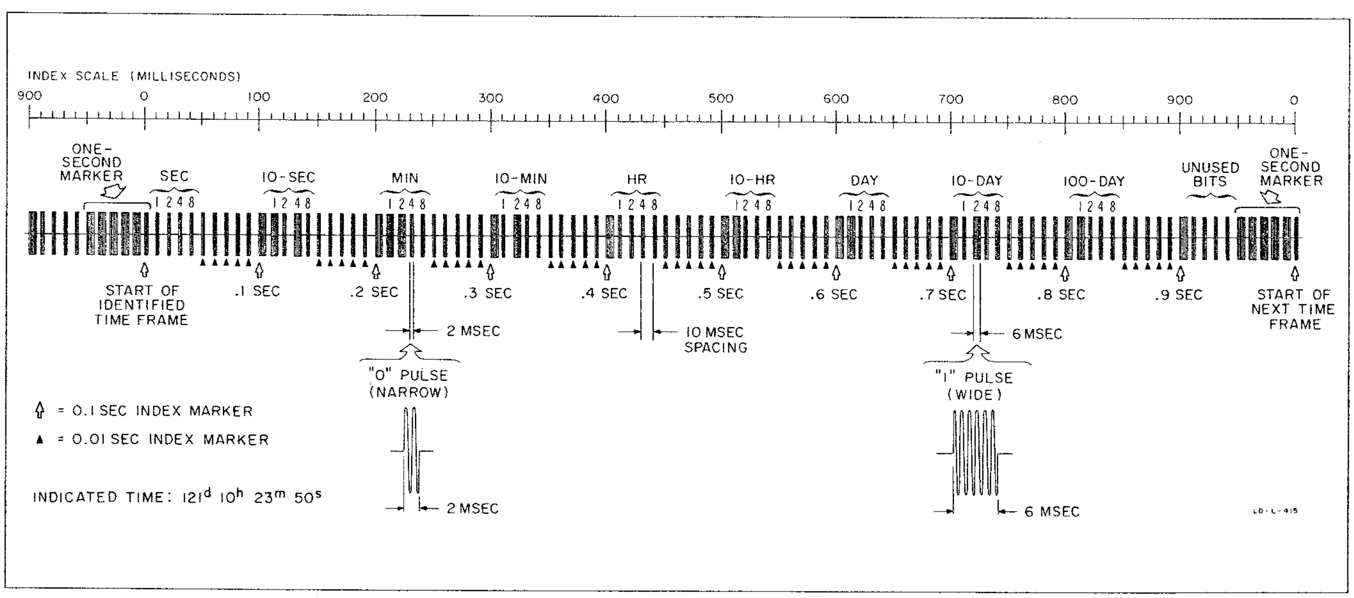

Figure 1-4. Time Code WWV, 36-Bit Binary-Coded-Decimal

All BCD information pulses maintain 10-millisecond spacing; unused areas include index pulses at 10-millisecond intervals. Exact time for 10-millisecond intervals occurs at the leading edge of all pulses. The 1000-cps sine wave within each pulse permits time resolution to 1 millisecond.

An NBS publication describing the time-of-year code, "Time Code on WWV", is available from National Bureau of Standards, Boulder Laboratories, Boulder, Colorado.

In addition to time signals, WWV and WWVH transmit (a) audio tones of 440 cps and 600 cps, (b) radio propagation forecasts in telegraphic code (symbol consists of the letter W, U or N followed by a numeral), and (c) geophysical alerts in telegraphic code (symbol consists of the letters AGI followed by AAAA, EEEEE, or three long dashes).

Receiving stations which are equidistant from WWV and WWVH may experience tick interference on 5, 10, and 15 mc. This problem can be reduced by either (a) using a directional antenna which favors the desired signal or (b) scheduling measurements for a time when only one station is transmitting. Station WWV is silent from minute 45 to minute 49 of each hour. Station WWVH is silent during minutes 0 to 3, 15 to 18, 30 to 33, and 45 to 48 of each hour and from 1900 to 1934 UT each day.

Since WWV time ticks are locked to the transmitted frequency, tick timing may slowly depart from UT2. Tick timing is adjusted at infrequent intervals in steps up to 50 milliseconds. Timing normally is adjusted at the beginning of the calendar year.

If it is desired to maintain a precise UT2 time standard, the U. S. Naval Observatory determines and publishes corrections for transmitted time signals. About two months after a particular transmission, preliminary corrections are given in "Time Signals, Bulletin B". Final corrections are released about six months after a particular transmission in "Time Signals, Bulletin A." Both of the above publications are available from the U. S. Naval Observatory, Washington 25, D. C.

Calculations of oscillator frequency which are based on the UT2 time transmissions from WWV may be corrected to the ET scale using frequency corrections which are published periodically in "Time Signals, Bulletin B" (see preceding paragraph), the Proceedings of the IRE" (published monthly by the Institute of Radio Engineers, Inc., 1 East 79 Street, New York 21, New York), and "Deviations of the Frequencies Broadcast by Station WWV with Respect to the United States Frequency Standard" (available from National Bureau of Standards, Boulder Laboratories, Boulder, Colorado). The published corrections refer directly to the transmitted frequency of WWV, but since the WWV time signals are locked to the frequency transmissions, the corrections are valid for frequencies whose value has been determined from the time signals.

1-7 BIBLIOGRAPHY

A detailed discussion of every aspect of the problems of frequency and time control, radio propagation, etc. is beyond the scope of this publication. The following selections provide additional information of interest to those engaged in maintaining precision frequency and time standards.

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Morgan, Alvin H. Precise Time Synchronization of Widely Separated Clocks, NBS Technical Note 22, Office of Technical Services, U.S. Department of Commerce, Washington 25, D. C.; July, 1959

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Ionospheric Radio Propagation, NBS Circular 462, U.S. Government Printing Office, Washington 25, D. C.; June, 1948

"Naval Observatory Time Service," Circular No. 49, U. S. Naval Observatory, Washington 25, D. C.; March, 1954

SECTION II
SYSTEM OPERATION

2-1 INTRODUCTION

This section describes the general operation of typical time-comparison systems such as those illustrated in figures 1-1, 1-2 (methods A and B). Detailed step-by-step instructions for installation and operation are given in the manuals which are supplied with the equipment.

2-2 RADIO RECEPTION

Radio receiver requirements differ widely, depending especially on the location of the receiving station. For hf reception, the receiver should be of communications receiver quality, tunable to all necessary frequencies (for WWV: 2.5, 5, 10, 15, 20, and 25 mc).

Time-comparison measurements can be speeded and simplified by giving careful attention to antenna design, location, and orientation. A directional antenna is preferred and should be oriented to favor the transmission mode which consistently provides the shortest propagation path. The Hewlett-Packard Company has had excellent results with a three-element rotary beam tuned to 10, 15, and 20 mc (Model WWV-33; Mosley Electronics, Inc., 4610 North Lindburgh Blvd., Bridgeton, Missouri).

Accuracy of measurements using hf timing signals can be greatly improved by observing a few precautions to lessen the effect of erratic variation in propagation delay:

(a) Schedule observations for an all-daylight or all-night transmission path between transmitter and receiver. Avoid twilight hours.

(b) Choose the highest transmission frequency which provides consistent reception.

(c) Observe tick transmission for a few minutes to get the "feel" of propagation conditions. The best measurements are made on days when signals show little jitter or fading. If erratic conditions seem to exist, indicated by considerable jitter in tick timing and much fading, postpone the measurement. Ionospheric disturbances causing erratic reception sometimes last less than an hour but may last several days.

(d) Make time-comparison measurements using the ticks with the earliest consistent arrival time.

2-3 BASIC TIME-COMPARISON MEASUREMENT

Time-comparison checks to determine time error relative to WWV (or other master time source) should be made daily. Keep a system log using a form similar to that shown in figure 2-1 (log sheets are included

Hewlett-Packard
FREQUENCY AND TIME STANDARD

PAGE ________

SYSTEM ________

DATE	TIME	SUPPLY					OSCILLATOR						CLOCK							RADIO RECP COND	REMARKS
		BATTERY VOLTAGE		BATTERY CURRENT		BATT CHK	CIRCUIT CHECK						CIRCUIT CHECK					TIME REFERENCE			
		BATT	LOAD	BATT	LOAD		SUPP	ACC	IN OVEN	OUT OVEN	100 KC	1 KC	SUPP	100 KC	10 KC	1 KC	CLK CURR	MILLI-SEC	MICRO-SEC		

LD-M-243

Figure 2-1. Sample Record Sheet

with each Hewlett-Packard system). The system log should include the master record of time-comparison measurements and daily records of equipment meter readings for future maintenance use.

The basic oscillator-clock-oscilloscope system (figures 1-1, 1-2 (method A) uses the tick output of the clock to trigger the oscilloscope sweep. By observing the WWV tick while adjusting the phasing of the clock tick output, both ticks can be brought into time coincidence or near-coincidence. The calibrated tick phasing control (reading accuracy better than 10 microseconds for the ⓗⓟ Model 113AR/BR) then gives the desired clock time reference.

During the adjustment procedure a selected portion of the WWV tick is positioned on a selected reference line on the oscilloscope screen. Any easily identified part of the WWV tick near the tick leading edge may be selected (such as the zero-crossing of the second cycle), but future time comparisons must be referenced to the same point. Likewise, any part of the oscilloscope screen can be used for reference (such as the center vertical graticule line or the start of the sweep), but again future measurements must be referenced to the same point. The selected reference points should be noted in the system log.

The oscillograms in figure 2-2 show the appearance of typical WWV signals (with severe amplitude fading) on an ⓗⓟ Model 120AR Oscilloscope during a time-comparison measurement. Note that in figure 2-2D the WWV tick starts about 3.2 milliseconds after the time of sweep triggering. The time read from the clock tick phasing dials in this case is 3.2 milliseconds ahead of the start of the received WWV tick.

2-4 MEASUREMENTS USING TIME COMPARATOR UNIT

Systems which include the ⓗⓟ Model 114AR/BR Time Comparator permit clock tick output to remain on-time during the time-comparison measurement. The comparator permits a controlled delay to be added to part of the clock tick output. The measurement procedure is similar to the basic procedure described in paragraph 2-3 but is simplified by comparator-generated time marks supplied to the oscilloscope and by direct-reading delay dials on the comparator.

During operation, the comparator switches which adjust oscilloscope sweep time and comparator delay are set to give a convenient oscilloscope presentation of the WWV tick. Comparator delay dials always indicate the delay between the clock tick and the start (left end) of the oscilloscope sweep. The time interval

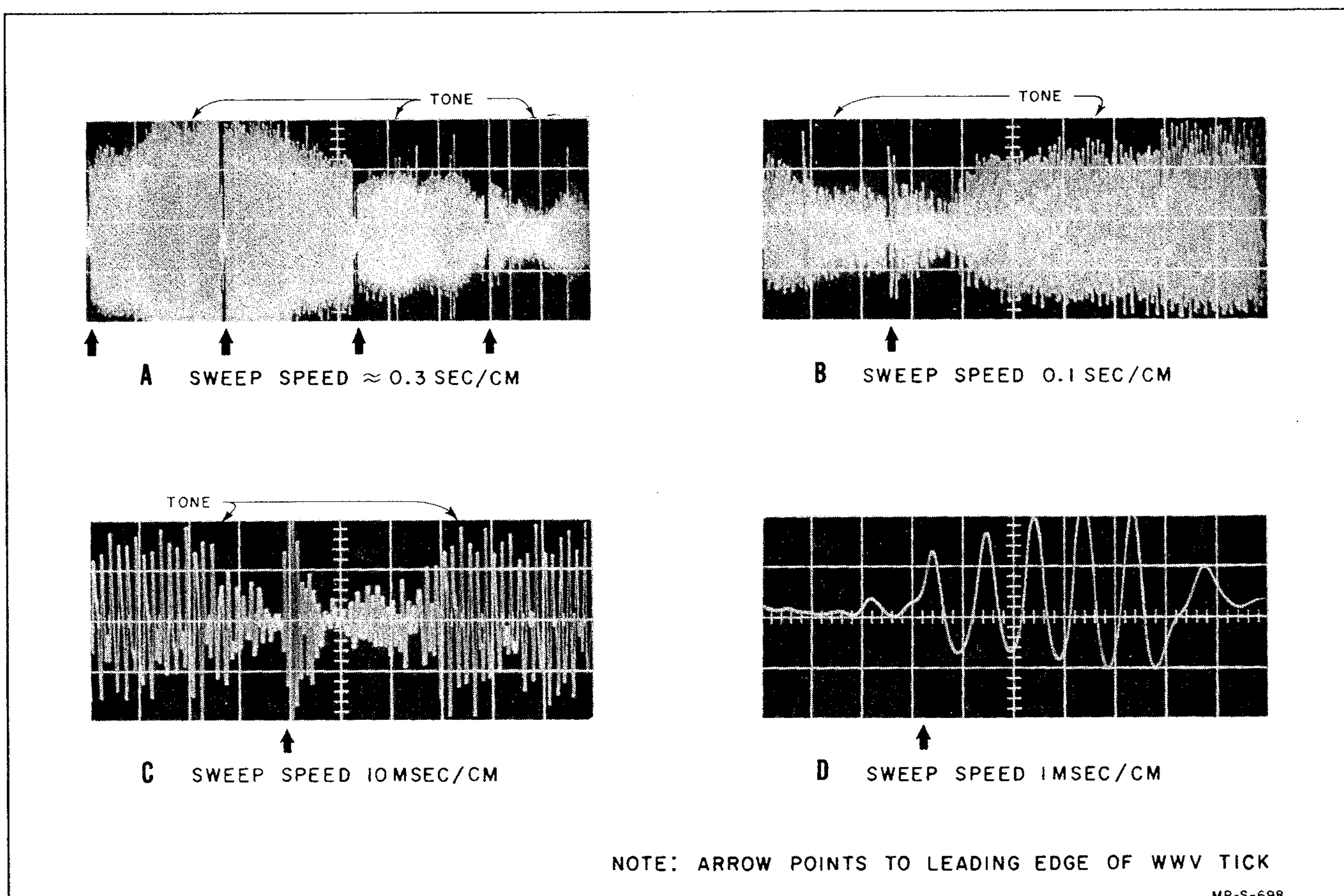


Figure 2-2. Typical WWV Waveform

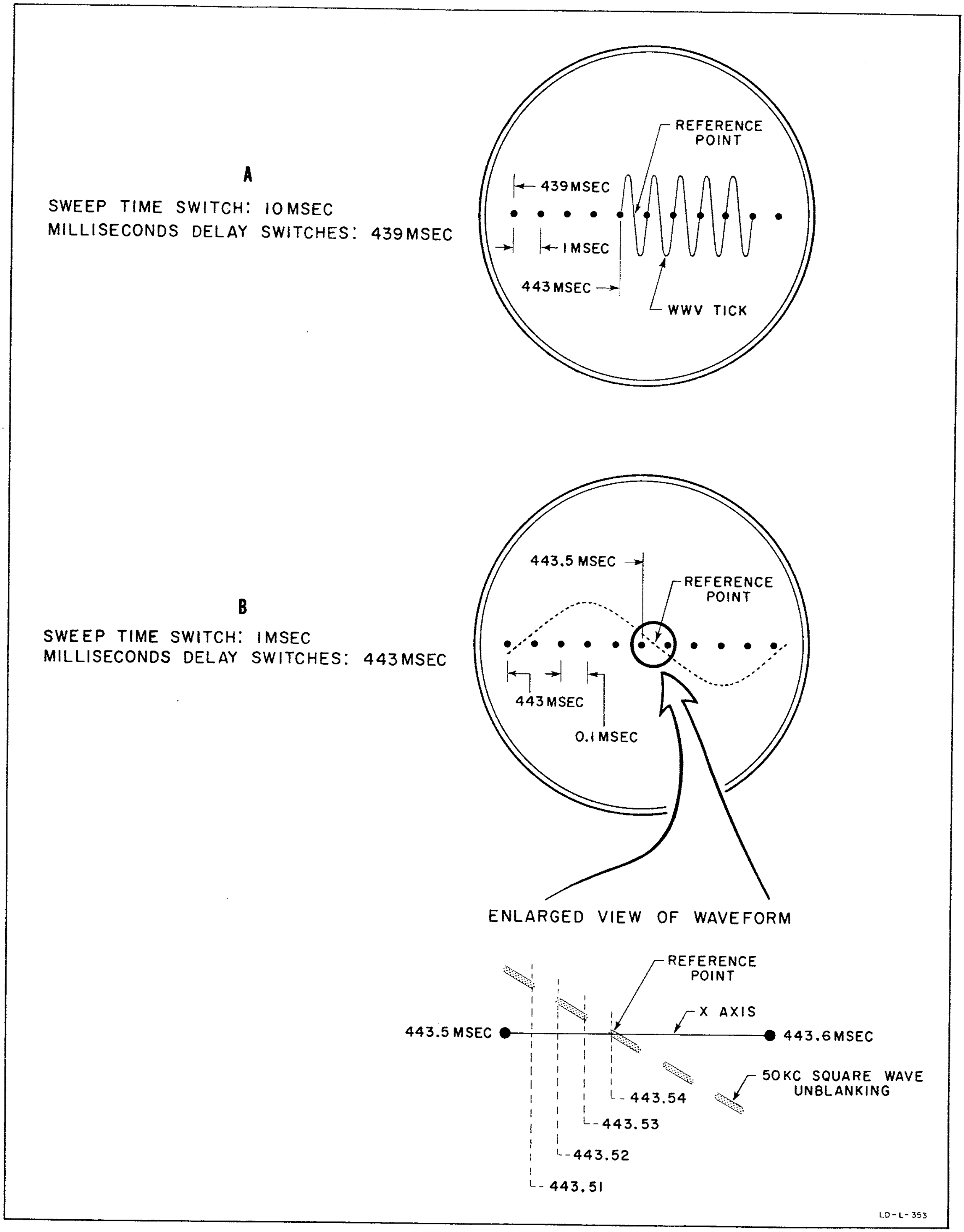


Figure 2-3. Waveform Interpretation Using Time Comparator

between the clock tick and the selected reference point on the WWV tick is equal to the delay dial reading plus the interval between the start of the oscilloscope sweep and the reference point on the WWV tick as indicated by the intensity-modulated time marks (figure 2-3).

If the WWV tick appears to be relatively free of jitter, readings can easily be made to within 10 microseconds by switching to 1-millisecond sweep time. Only one cycle on the WWV tick appears on the oscilloscope at this sweep speed. As shown in figure 2-3, intensity markers occur at intervals of 0.1 millisecond along the base line of the sweep. The 10-microsecond dashes on the waveform start at even 0.01 millisecond intervals, and the spaces start at odd 0.01 millisecond intervals.

2-5 PHOTOGRAPHIC TICK AVERAGING

Since random variations in the radio propagation path cause variation in the arrival time of each WWV tick, the accuracy of time-comparison measurements depends to a large extent on the ability of the operator to judge the time of tick arrival. Excellent results can be obtained with a photographic averaging technique using an hp Model 196A Oscilloscope Camera or equivalent. A time exposure of several seconds produces an oscillogram from which the time of earliest consistent tick arrival can easily be determined. If the oscilloscope sweep time is accurately calibrated, the location of the tick reference point on the oscillogram can be adjusted to the chosen oscilloscope reference point to determine the time-comparison reading. Figure 2-4 shows several examples of time-exposure oscillograms using this technique.

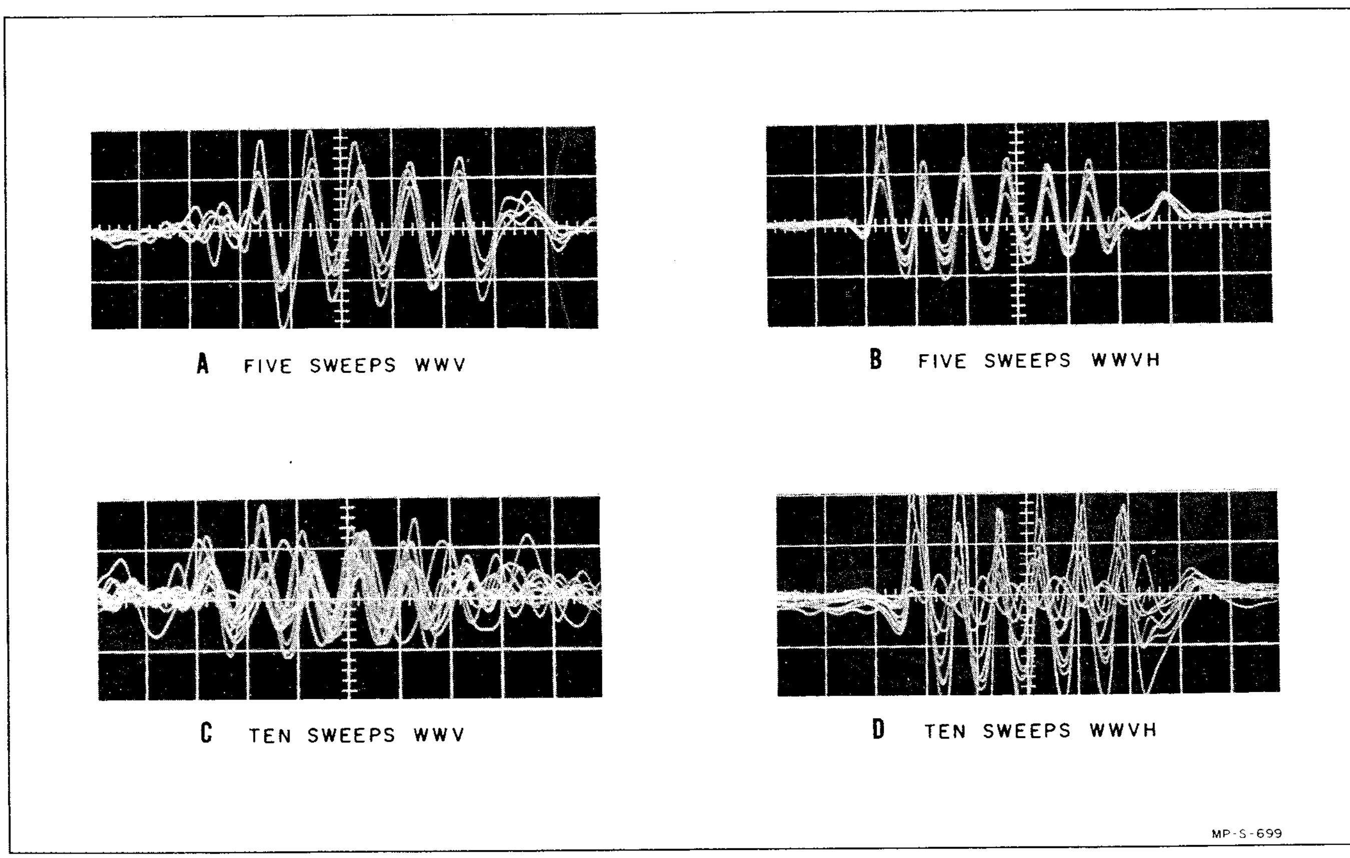


Figure 2-4. Photographic Tick Averaging

SECTION III
FREQUENCY DETERMINATION

3-1 DIRECT COMPUTATION METHOD

Two time comparisons are required to compute the average oscillator frequency (or average frequency error) during the time interval between readings (paragraph 1-2). Since precision oscillators have a nearly linear drift rate, average frequency during a single time interval can be considered equal to the instantaneous frequency at the midpoint of the interval. Frequency calculations can be plotted graphically as shown in figure 3-2, to help estimate oscillator frequency at any given time.

Average fractional error in frequency is equal to the fractional time error and is given by

$$\frac{\Delta f}{f} = \frac{t_2 - t_1}{T}$$

where $\frac{\Delta f}{f}$ = average frequency error

t_1 = initial time-comparison reading

t_2 = final time-comparison reading

T = elapsed time between readings.

Example: Time-comparison reading at 10:00 AM on June 1 is 563, 060 microseconds; reading at 10:00 AM on June 4 is 564, 040 microseconds. In this case,

$$\frac{\Delta f}{f} = \frac{564,040\mu s - 563,060\,\mu s}{3\text{ days}} \times \frac{1\text{ day}}{8.64 \times 10^{10}\mu s} = \frac{+3.8}{10^9}$$

That is, the average oscillator error during the period 10:00 AM on June 1 to 10:00 AM on June 4 (or, assuming linear frequency drift, the instantaneous error at 10:00 PM on June 2) is 3.8 parts in 10^9 high.

Average frequency of an oscillator during the measurement interval is given by

$$f_{av} = f_{nom}\left(1 + \frac{\Delta f}{f}\right)$$

where f_{av} = average frequency

f_{nom} = nominal oscillator frequency

$\frac{\Delta f}{f}$ = average frequency error.

Continuing with the example given above for an oscillator with a nominal frequency of 1 mc,

$$f_{av} = 10^6\left(1 + \frac{3.8}{10^9}\right) = 1,000,000.0038 \text{ cps}$$

3-2 SLOPE OF TIME-ERROR CURVE METHOD

Time-comparison measurements may be plotted directly (figure 3-1), thus eliminating the routine of daily frequency error computation. The slope of the time-error curve equals the instantaneous oscillator frequency error at that time.

To find oscillator frequency error, draw a smooth curve through the daily time-comparison plots. Draw a line tangent to the curve at the time for which the instantaneous frequency is required. Choose a convenient segment of the tangent line and divide its time error (projection on the TIME REFERENCE scale) by its elapsed time (projection on the ELAPSED TIME scale). The quotient (using the relationship 8.64×10^{10} microseconds = 1 day to cancel units of measurement) is the oscillator frequency error.

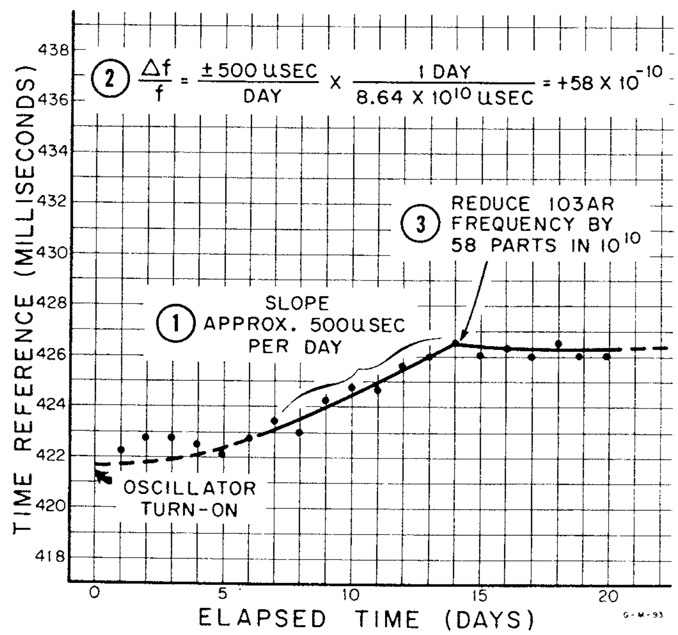


Figure 3-1. Time Comparison Plot

Time-comparison measurements permit determination of average oscillator error during a time interval which has already occurred. Present and future frequency error can be estimated graphically by extrapolation.

A simple technique can be used with the time curve to maintain oscillator frequency within specified limits. Determine the slope which represents maximum allowable oscillator error. When the time-error curve reaches this slope, readjust oscillator frequency accordingly. See figure 3-3.

DAY	TIME REFERENCE	
	MILLISEC	MICROSEC
0	293	700
7	290	680
14	290	680
28	292	190
35	295	810

$$\frac{\Delta f}{f} = \frac{(t_2 - t_1)\ \text{USEC}}{\text{T DAYS}} \times \frac{1\ \text{DAY}}{8.64 \times 10^{10}\ \text{USEC}}$$

FINAL TIME COMPARISON READING (t_2)

INITIAL TIME COMPARISON READING (t_1)

FREQ. ERROR ($\Delta f / f$)

ELAPSED TIME BETWEEN COMPARISON READINGS (T DAYS)

NUMBER OF MICROSECONDS IN ONE DAY (8.64×10^{10} USEC)

A FREQ. ERROR FIRST WEEK

$$\frac{\Delta f}{f} = \frac{(290\,680 - 293\,700)\ \text{USEC}}{7\ \text{DAYS}} \times \frac{1\ \text{DAY}}{(8.64 \times 10^{10})\ \text{USEC}} = -50 \times 10^{-10}$$

B FREQ. ERROR SECOND WEEK

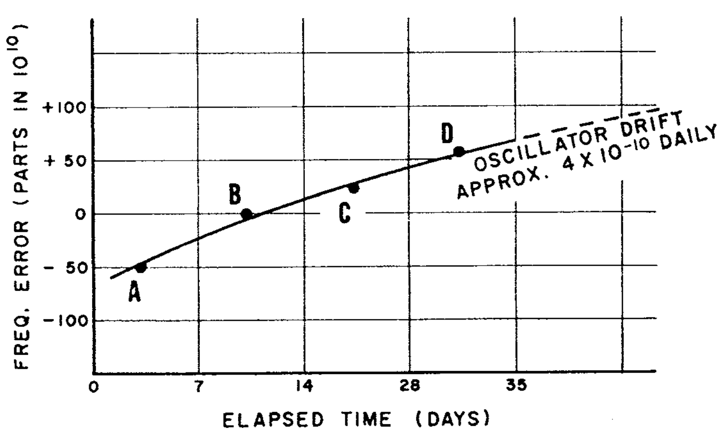
$$\frac{\Delta f}{f} = \frac{290\,680 - 290\,680}{7} \times \frac{1}{8.64 \times 10^{10}} = 0$$

C FREQ. ERROR THIRD WEEK

$$\frac{\Delta f}{f} = \frac{292\,190 - 290\,680}{7} \times \frac{1}{8.64 \times 10^{10}} = +25 \times 10^{-10}$$

D FREQ. ERROR FOURTH WEEK

$$\frac{\Delta f}{f} = \frac{295\,810 - 292\,190}{7} \times \frac{1}{8.64 \times 10^{10}} = +60 \times 10^{-10}$$



CH-L-87

Figure 3-2. Direct Frequency Plot

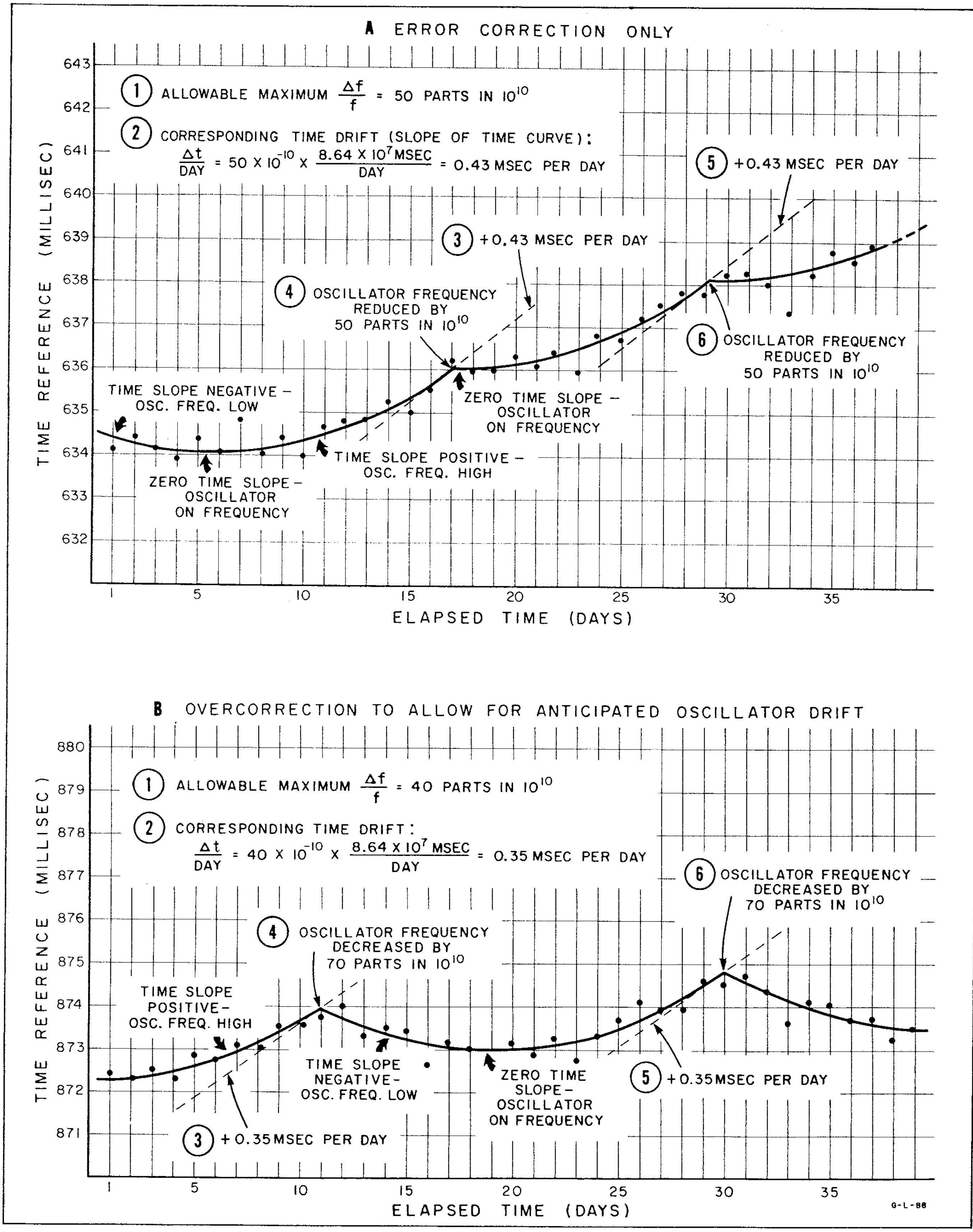


Figure 3-3. Slope-Limit Frequency Control

Inspection of the shape of the time curve can quickly give information on the general nature of oscillator behavior. For example, a parabolic time curve which is concave as viewed from the top indicates positive and linear drift of oscillator frequency. The vertex of the parabola corresponds to zero oscillator error. See figure 3-4.

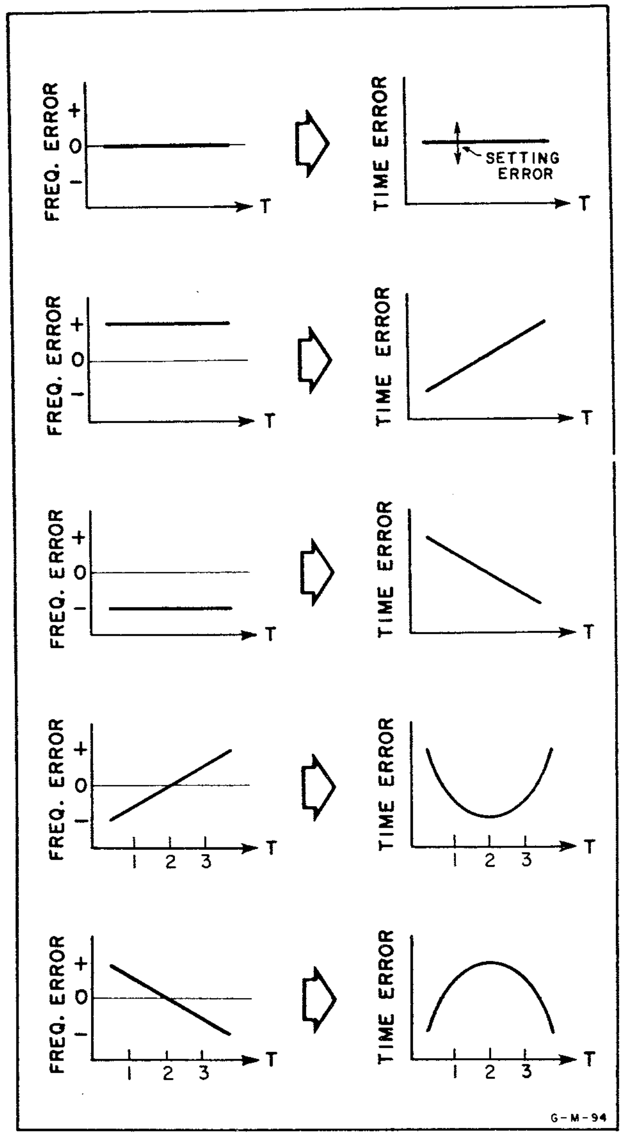


Figure 3-4. Corresponding Frequency and Time Curves

SECTION IV
TIME DETERMINATION

4-1 INTRODUCTION

Accurate timekeeping depends upon (a) understanding oscillator behavior and (b) accurate time synchronization with a master timing source. Oscillator behavior, i. e., drift rate and change in drift rate, can be determined by inspecting the frequency or time plots described in paragraphs 3-1 and 3-2. Absolute synchronization between two or more clocks presents a problem which has been solved in several ways:

A. TRANSPORTING A MASTER CLOCK. Time synchronization accuracy to about ±1 microsecond or less can be made by transporting a master clock to each clock station. Achieved accuracy depends largely upon the comparison method. The rate (i. e. the daily time gain or loss) and acceleration (i. e. the change in rate) of the master clock must be accurately known and an appropriate correction must be made at each clock station.

B. TWO-WAY RADIO TRANSMISSION. Time synchronization accuracy as good as ±10 microseconds can be made using a transponder at the clock station. The propagation delay which the timing pulse undergoes between the master transmitter and the clock station can be accurately determined at the master transmitter from the following relationship:

$$t_{prop} = \frac{t_{tot} - t_{tr}}{2}$$

where t_{prop} = one-way propagation delay between master transmitter and clock station

t_{tot} = total delay at master transmitter between transmission of timing signal and receipt of transponder signal

t_{tr} = delay at the transponder between receipt of timing signal and retransmission of the signal.

Time synchronization by this method requires special transmitting and receiving equipment at both the master time source and the station requiring synchronization and is therefore impractical for most time standard systems.

C. ONE-WAY RADIO TRANSMISSION. Time synchronization accuracy to ±1 millisecond or less can be made using presently available standard time signals such as those transmitted by station WWV. With this method the propagation delay between the transmitter and clock station must be determined and then applied as a correction to the clock reading.

The principal factors which affect the propagation delay for hf signals are (a) the great circle distance between transmitter and receiver, (b) the transmission mode (i. e. the number of earth-to-ionosphere reflections between transmitter and receiver), and (c) the virtual height of the ionospheric reflection layers. Since lf and vlf transmissions are propagated for relatively great distances by ground wave, propagation delay for these frequencies can usually be found directly after computing the great circle distance. A detailed discussion of distance determination is given in paragraph 4-2, transmission mode estimation in paragraph 4-3, layer height estimation in paragraph 4-4, and delay determination by graphic means in paragraph 4-5.

Once the propagation delay has been determined, the tick-phasing dial on the clock can be positioned to allow for the delay. The 1-second clock ticks are then produced in synchronism with the transmitted master timing signal.

> Example: A clock station (using oscillator-clock-oscilloscope system) located 3100 kilometers (about 10.80 milliseconds transmission delay) from WWV is required to synchronize its clock ticks with the WWV ticks as transmitted. Time-comparison readings are taken when the zero crossing of the second cycle of the received WWV tick is aligned with the vertical center-line of the CRT (1 millisecond-per-centimeter sweep speed); the leading edge of the received WWV tick therefore occurs 4 milliseconds after the clock tick (which triggers the oscilloscope). Inspection of the smoothed curve on the time-comparison graph shows that for a particular day, the tick phasing dials on the clock should be set to 231, 770 microseconds for clock-tick coincidence with the received WWV tick. The tick phasing dial setting for synchronization with the transmitted WWV ticks on this day is determined as follows:

Time-comparison graph	231, 770 μ sec
Reading correction	+ 4, 000
Transmission delay	- 10, 800
Final dial setting	224, 970 μ sec

4-2 GREAT-CIRCLE DISTANCE

The great circle distance between points A and B whose latitude and longitude are known can be rapidly determined from the following relationship (see figure 4-1):

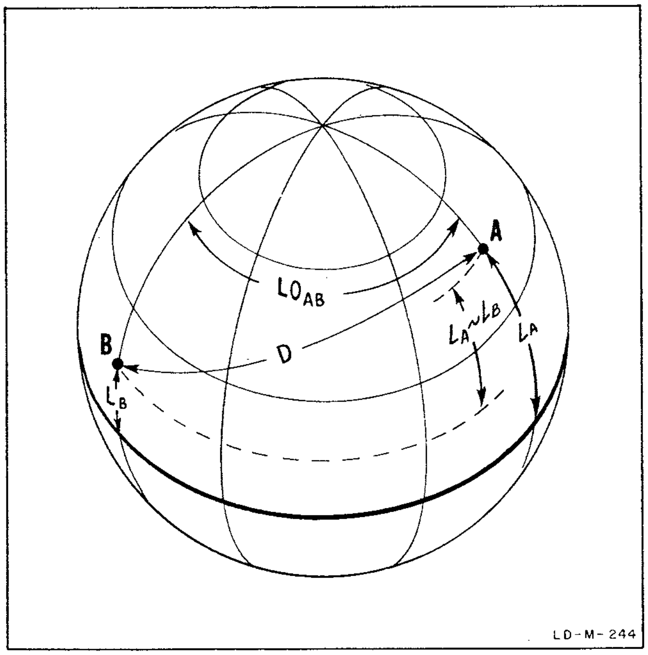


Figure 4-1. Great Circle Distance Calculation

$$\text{hav } D = \cos L_A \cos L_B \text{ hav } Lo_{AB} + \text{hav } (L_A - L_B)$$

where D = great circle distance A to B expressed in degrees of arc

L_A = latitude of A

L_B = latitude of B

Lo_{AB} = difference of longitude between A and B

$(L_A \sim L_B)$ = the difference of L_A and L_B if A and B are on the same side of the equator or the sum of L_A and L_B if A and B are on opposite sides of the equator.

Note: The haversine of angle $\theta = 1/2$ versine $\theta = 1/2 (1 - \cos \theta) = \sin^2 1/2\ \theta$; also, hav θ = hav $(360^o - \theta)$; thus, hav 210^o = hav 150^o.

Computations made using the haversine and cosine tables in appendix II are sufficiently accurate for most sky-wave propagation delay estimates. Distance errors of as much as 10 to 20 miles contribute less error to the delay estimate than is expected to result from errors in estimating propagation mode and ionospheric height. A more extensive haversine table permitting distance calculation to within a mile, is given in Bowditch, American Practical Navigator, Part II, U. S. Government Printing Office, Washington 25, D. C.

Example: Find the distance between radio station WWV (point A), $39^o00'$N $76^o51'$ W, and Palo Alto, California (point B), $37^o23'$N $122^o09'$W.

$L_A = 39^o00'$N

$L_B = 37^o23'$N

$Lo_{AB} = 45^o18'$

$L_A \sim L_B = 1^o37'$

log cos L_A = log cos $39^o00'$ = 9.8905 - 10

log cos L_B = log cos $37^o23'$ = 9.9001 - 10

log hav Lo_{AB} = log hav $45^o18'$ = 9.1712 - 10

8.9618 - 10

Taking antilog from haversine table, log hav to nat hav:

antilog 8.9618 - 10 = 0.0916

hav $(L_A \sim L_B)$ = hav $1^o37'$ = 0.0002

0.0918

D = arc hav 0.0918 = $35^o17'$.

Since 1' of arc = 1 nautical mile = 1.151 statute miles = 1.853 kilometers, then $35^o17'$ = 2117 nautical miles = 2439 statute miles = 3923 kilometers.

4-3 TRANSMISSION MODE

The ground-wave propagation path (most lf/vlf transmissions and short-distance hf transmissions) closely follows the great-circle route between the transmitter and receiver. However, hf transmissions over a distance of more than about 160 kilometers follow sky-wave paths.

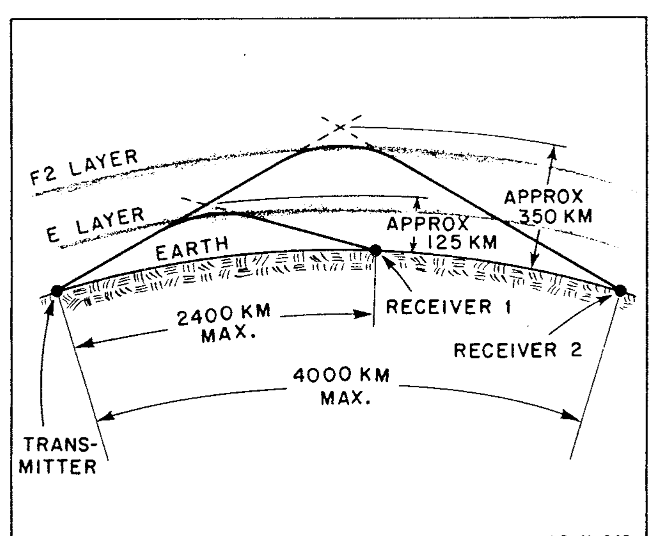


Figure 4-2. Single-Hop Sky-Wave Paths

The maximum distance that can be spanned by a single hop (i. e. one reflection from the ionosphere) via the F2 layer is about 4000 kilometers (figure 4-2). Therefore, the fewest number of hops between transmitter and receiver is the next integer greater than the great-circle distance (in kilometers) divided by 4000. Transmission modes with one or two more hops than the minimum number of hops occur frequently (figure 4-3), but modes of higher order are greatly attenuated during transmission and are of little concern.

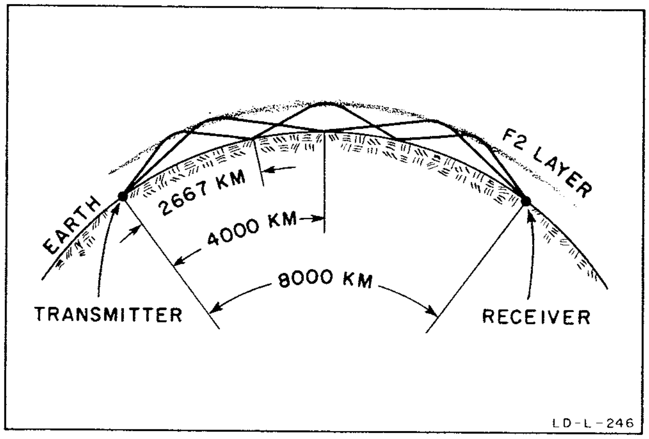


Figure 4-3. Multiple-Hop Transmission Path

Example 1: Find the minimum number of hops for a distance of 3923 kilometers. Solution: A one-hop F2 mode is possible (3923 ÷ 4000 <1).

Example 2: What modes are likely to be received at a distance of 7687 kilometers? Solution: Two-hop, 3-hop and 4-hop F2 modes can be expected (7687 ÷ 4000 >1, but <2).

Useful transmissions via the E layer (daytime only) are usually limited to one-hop modes up to a distance of about 2400 kilometers.

Remember that some locations may receive transmissions from both the E and F2 layers and that transmissions may be reflected occasionally from layers other than the E and F2.

The following approach should improve your estimate of propagation delay:

1) Determine which modes are possible at your location.

2) Tune to the highest frequency which provides consistent reception to reduce interference from high-order modes.

3) If several modes are being received (indicated by multiple tick reception or tick jitter between fairly constant positions), select the tick with earliest arrival time for measurements.

4) After plotting time measurements for several weeks, either disregard measurements which are conspicuously out of place, or correct the measurement to the more likely mode if the plot is mistimed by the difference in time between possible modes.

4-4 HEIGHT OF IONOSPHERE

Long-distance hf transmissions are usually reflected from the F2 layer, which varies in height from about 250 to 450 kilometers. Experience has shown that the virtual height of the F2 layer averages about 350 kilometers (figure 4-2). Unless special studies permit determination of layer height at the point of reflection to high accuracy, an assumed height of 350 kilometers can be used for delay estimation.

The E layer exists only during the daytime at a virtual height of about 125 kilometers (figure 4-2). One-hop E modes may provide very steady daytime reception at distances up to about 2400 kilometers.

4-5 DELAY DETERMINATION

Once the transmitter-to-receiver distance, possible transmission modes, and layer heights have been determined, transmission delay can be found graphically from figure 4-4. The shaded area along the F2 curve shows the possible extremes of height variation.

As shown in the following examples, the delay for a one-hop mode can be read directly from the transmission delay graph for a given distance and layer height.

Example 1: Find the one-hop delay for a distance of 3923 kilometers. Solution: Expected F2 delay is about 13.60 milliseconds. No one-hop E mode is likely since the distance is greater than the usual limit of 2400 kilometers for the one-hop E mode.

Example 2: Find the one-hop delay for a distance of 2200 kilometers. Solution: Expected F2 delay is about 7.90 milliseconds; expected E delay is about 7.50 milliseconds.

For a multi-hop mode, (a) determine the distance covered by each hop, (b) find the delay for a single hop, then (c) multiply the single-hop delay by the number of hops to determine the total delay.

Example 3: Find the two-hop delay for a distance of 3923 kilometers. Solution: Each 1962-kilometer hop contributes a delay of about 7.15 milliseconds; the total delay is 7.15 x 2 or 14.30 milliseconds. Note that the two-hop delay for a 3923-kilometer distance is 0.7 milliseconds greater than the one-hop delay for the same distance determined in example 1 above.

Example 4: Find the three-hop delay for a distance of 7687 kilometers. Solution: The delay contributed by each 2562-kilometer hop is about 9.05 milliseconds; the total delay is 9.05 x 3 or 27.15 milliseconds.

Example 5: Find the four-hop delay for a distance of 7687 kilometers. Solution: The delay contributed by each 1922-kilometer hop is about 6.95 milliseconds; the total delay is 6.95 x 4 or 27.80 milliseconds. Note that the four-hop delay for a 7687-kilometer distance is 0.65 milliseconds greater than the three-hop delay for the same distance determined in example above.

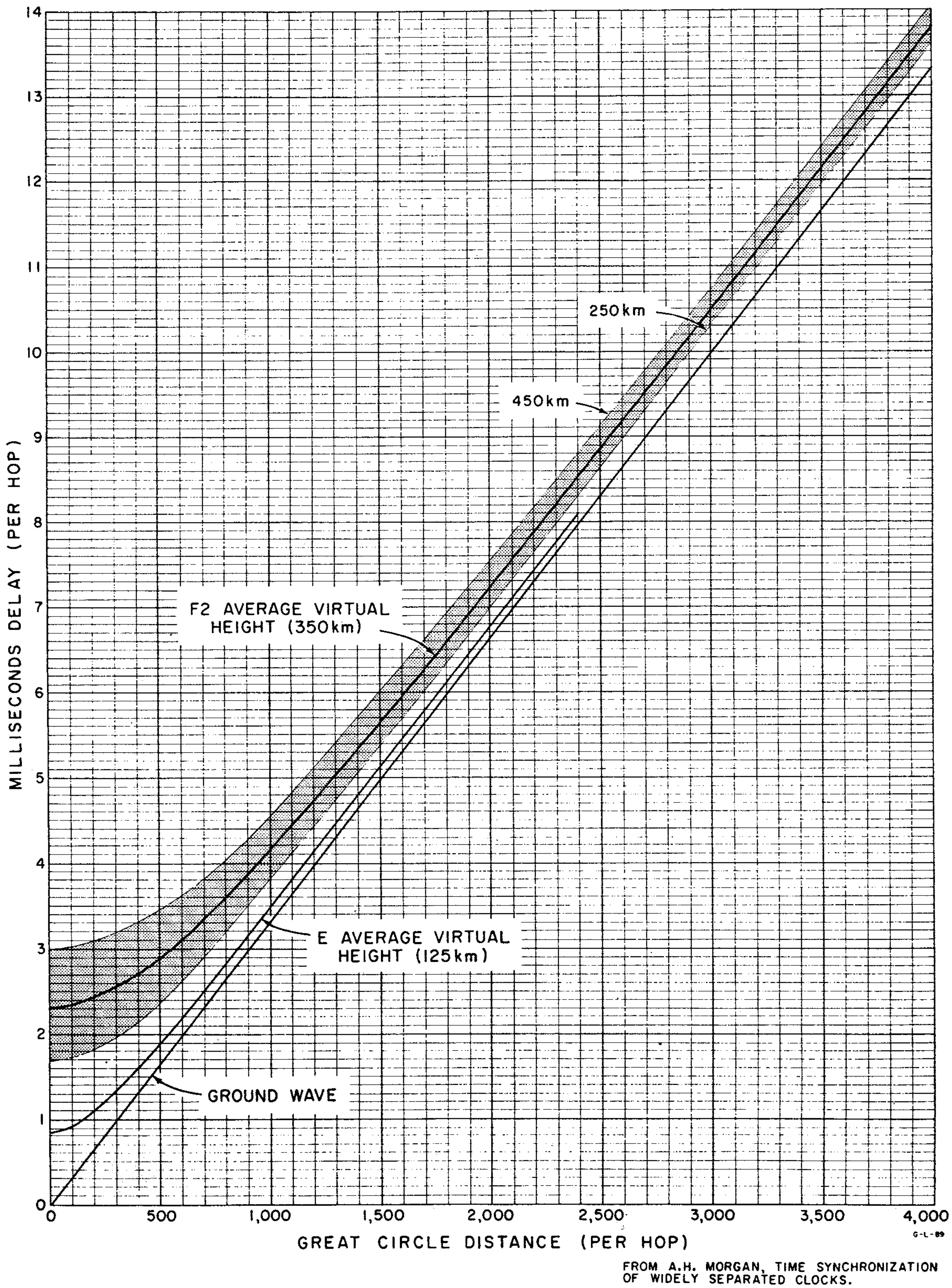


Figure 4-4. Transmission Delay Graph

APPENDIX I

TABLES

TABLE 1. EQUIVALENTS

1 day = 8.64×10^{7} milliseconds
= 8.64×10^{10} microseconds

1' of arc on surface of earth = 1 nautical mile
= 1.151 statute miles
= 1.853 kilometers

1° of arc on surface of earth = 60 nautical miles
= 111.195 kilometers

1 kilometer = 0.6214 statute miles

TABLE 2. LOGARITHMS OF COSINE FUNCTION
(0^o to 45^o)

Note: Append -10 to each logarithm

°	0'	10'	20'	30'	40'	50'	60'
0	0.0000	0.0000	0.0000	0.0000	0.0000	9.9999	9.9999
1	9.9999	9.9999	9.9999	9.9999	9.9998	9.9998	9.9997
2	9.9997	9.9997	9.9996	9.9996	9.9995	9.9995	9.9994
3	9.9994	9.9993	9.9993	9.9992	9.9991	9.9990	9.9989
4	9.9989	9.9989	9.9988	9.9987	9.9986	9.9985	9.9983
5	9.9983	9.9982	9.9981	9.9980	9.9979	9.9977	9.9976
6	9.9976	9.9975	9.9973	9.9972	9.9971	9.9969	9.9968
7	9.9968	9.9966	9.9964	9.9963	9.9961	9.9959	9.9958
8	9.9958	9.9956	9.9954	9.9952	9.9950	9.9948	9.9946
9	9.9946	9.9944	9.9942	9.9940	9.9938	9.9936	9.9934
10	9.9934	9.9931	9.9929	9.9927	9.9924	9.9922	9.9919
11	9.9919	9.9917	9.9914	9.9912	9.9909	9.9907	9.9904
12	9.9904	9.9901	9.9899	9.9896	9.9893	9.9890	9.9887
13	9.9887	9.9884	9.9881	9.9878	9.9875	9.9872	9.9869
14	9.9869	9.9866	9.9863	9.9859	9.9856	9.9853	9.9849
15	9.9849	9.9846	9.9843	9.9839	9.9836	9.9832	9.9828
16	9.9828	9.9825	9.9821	9.9817	9.9814	9.9810	9.9806
17	9.9806	9.9802	9.9798	9.9794	9.9790	9.9786	9.9782
18	9.9782	9.9778	9.9774	9.9770	9.9765	9.9761	9.9757
19	9.9757	9.9752	9.9748	9.9743	9.9739	9.9734	9.9730
20	9.9730	9.9725	9.9721	9.9716	9.9711	9.9706	9.9702
21	9.9702	9.9697	9.9692	9.9687	9.9682	9.9677	9.9672
22	9.9672	9.9667	9.9661	9.9656	9.9651	9.9646	9.9640
23	9.9640	9.9635	9.9629	9.9624	9.9618	9.9613	9.9607
24	9.9607	9.9602	9.9596	9.9590	9.9584	9.9579	9.9573
25	9.9573	9.9567	9.9561	9.9555	9.9549	9.9543	9.9537
26	9.9537	9.9530	9.9524	9.9518	9.9512	9.9505	9.9499
27	9.9499	9.9492	9.9486	9.9479	9.9473	9.9466	9.9459
28	9.9459	9.9453	9.9446	9.9439	9.9432	9.9425	9.9418
29	9.9418	9.9411	9.9404	9.9397	9.9390	9.9383	9.9375
30	9.9375	9.9368	9.9361	9.9353	9.9346	9.9338	9.9331
31	9.9331	9.9323	9.9315	9.9308	9.9300	9.9292	9.9284
32	9.9284	9.9276	9.9268	9.9260	9.9252	9.9244	9.9236
33	9.9236	9.9228	9.9219	9.9211	9.9203	9.9194	9.9186
34	9.9186	9.9177	9.9169	9.9160	9.9151	9.9142	9.9134
35	9.9134	9.9125	9.9116	9.9107	9.9098	9.9089	9.9080
36	9.9080	9.9070	9.9061	9.9052	9.9042	9.9033	9.9023
37	9.9023	9.9014	9.9004	9.8995	9.8985	9.8975	9.8965
38	9.8965	9.8955	9.8945	9.8935	9.8925	9.8915	9.8905
39	9.8905	9.8895	9.8884	9.8874	9.8864	9.8853	9.8843
40	9.8843	9.8832	9.8821	9.8810	9.8800	9.8789	9.8778
41	9.8778	9.8767	9.8756	9.8745	9.8733	9.8722	9.8711
42	9.8711	9.8699	9.8688	9.8676	9.8665	9.8653	9.8641
43	9.8641	9.8629	9.8618	9.8606	9.8594	9.8582	9.8569
44	9.8569	9.8557	9.8545	9.8532	9.8520	9.8507	9.8495

TABLE 2. LOGARITHMS OF COSINE FUNCTION (Cont'd)
(45° to 90°)

Note: Append -10 to each logarithm

°	0'	10'	20'	30'	40'	50'	60'
45	9.8495	9.8482	9.8469	9.8457	9.8444	9.8431	9.8418
46	9.8418	9.8405	9.8391	9.8378	9.8365	9.8351	9.8338
47	9.8338	9.8324	9.8311	9.8297	9.8283	9.8269	9.8255
48	9.8255	9.8241	9.8227	9.8213	9.8198	9.8184	9.8169
49	9.8169	9.8155	9.8140	9.8125	9.8111	9.8096	9.8081
50	9.8081	9.8066	9.8050	9.8053	9.8020	9.8004	9.7989
51	9.7989	9.7973	9.7957	9.7941	9.7926	9.7910	9.7893
52	9.7893	9.7877	9.7861	9.7844	9.7828	9.7811	9.7795
53	9.7795	9.7778	9.7761	9.7744	9.7727	9.7710	9.7692
54	9.7692	9.7675	9.7657	9.7640	9.7622	9.7604	9.7586
55	9.7586	9.7568	9.7550	9.7531	9.7513	9.7494	9.7476
56	9.7476	9.7457	9.7438	9.7419	9.7400	9.7380	9.7361
57	9.7361	9.7342	9.7322	9.7302	9.7282	9.7262	9.7242
58	9.7242	9.7222	9.7201	9.7181	9.7160	9.7139	9.7118
59	9.7118	9.7097	9.7076	9.7055	9.7033	9.7012	9.6990
60	9.6990	9.6968	9.6946	9.6923	9.6901	9.6878	9.6856
61	9.6856	9.6833	9.6810	9.6787	9.6763	9.6740	9.6716
62	9.6716	9.6692	9.6668	9.6644	9.6620	9.6595	9.6570
63	9.6570	9.6546	9.6521	9.6495	9.6470	0.6442	9.6418
64	9.6418	9.6392	9.6366	9.6340	9.6313	9.6286	9.6259
65	9.6259	9.6232	9.6205	9.6177	9.6149	9.6121	9.6093
66	9.6093	9.6065	9.6036	9.6007	9.5978	9.5948	9.5919
67	9.5919	9.5889	9.5859	9.5828	9.5798	9.5767	9.5736
68	9.5736	9.5704	9.5673	9.5641	9.5609	9.5576	9.5543
69	9.5543	9.5510	9.5477	9.5443	9.5409	9.5375	9.5341
70	9.5341	9.5306	9.5270	9.5235	9.5199	9.5163	9.5126
71	9.5126	9.5090	9.5052	9.5015	9.4977	9.4939	9.4900
72	9.4900	9.4861	9.4821	9.4781	9.4741	9.4700	9.4659
73	9.4659	9.4618	9.4576	9.4533	9.4491	9.4447	9.4403
74	9.4403	9.4359	9.4314	9.4269	9.4223	9.4177	9.4130
75	9.4130	9.4083	9.4035	9.3986	9.3937	9.3887	9.3837
76	9.3837	9.3786	9.3734	9.3682	9.3629	9.3575	9.3521
77	9.3521	9.3466	9.3410	9.3353	9.3296	9.3238	9.3179
78	9.3179	9.3119	9.3058	9.2997	9.2934	9.2870	9.2806
79	9.2806	9.2740	9.2674	9.2606	9.2538	9.2468	9.2397
80	9.2397	9.2324	9.2251	9.2176	9.2100	9.2022	9.1943
81	9.1943	9.1863	9.1781	9.1697	9.1612	9.1525	9.1436
82	9.1436	9.1345	9.1252	9.1157	9.1060	9.0961	9.0859
83	9.0859	9.0755	9.0648	9.0539	9.0426	9.0311	9.0192
84	9.0192	9.0070	8.9945	8.9816	8.9682	8.9545	8.9403
85	8.9403	8.9256	8.9104	8.8946	8.8783	8.8613	8.8436
86	8.8436	8.8251	8.8059	8.7857	8.7645	8.7423	8.7188
87	8.7188	8.6940	8.6677	8.6397	8.6097	8.5776	8.5428
88	8.5428	8.5050	8.4637	8.4179	8.3668	8.3088	8.2419
89	8.2419	8.1627	8.0658	7.9408	7.7648	7.4637	--

TABLE 3. HAVERSINES
(0^{o} to 44^{o})

Note: Characteristics of the logarithms are omitted.

°	0' Nat	0' Log	10' Nat	10' Log	20' Nat	20' Log	30' Nat	30' Log	40' Nat	40' Log	50' Nat	50' Log
0	.0000	—	.0000	$\bar{6}$.3254	.0000	$\bar{6}$.9275	.0000	$\bar{5}$.2796	.0000	$\bar{5}$.5295	.0001	$\bar{5}$.7233
1	.0001	$\bar{5}$.8817	.0001	.0156	.0001	.1316	.0002	.2339	.0002	.3254	.0003	.4081
2	.0003	.4837	.0004	.5532	.0004	.6176	.0005	.6775	.0005	.7336	.0006	.7862
3	.0007	.8358	.0008	.8828	.0008	.9273	.0009	.9697	.0010	.0101	.0011	.0487
4	.0012	.0856	.0013	.1211	.0014	.1551	.0015	.1879	.0017	.2195	.0018	.2499
5	.0019	.2794	.0020	.3078	.0022	.3354	.0023	.3621	.0024	.3880	.0026	.4132
6	.0027	.4376	.0029	.4614	.0031	.4845	.0032	.5071	.0034	.5290	.0036	.5504
7	.0037	.5714	.0039	.5918	.0041	.6117	.0043	.6312	.0045	.6503	.0047	.6689
8	.0049	.6872	.0051	.7051	.0053	.7226	.0055	.7397	.0057	.7566	.0059	.7731
9	.0062	.7893	.0064	.8052	.0066	.8208	.0069	.8361	.0071	.8512	.0073	.8660
10	.0076	.8806	.0079	.8949	.0081	.9090	.0084	.9229	.0086	.9365	.0089	.9499
11	.0092	.9631	.0095	.9762	.0097	.9890	.0100	.0016	.0103	.0141	.0106	.0264
12	.0109	.0385	.0112	.0504	.0115	.0622	.0119	.0738	.0122	.0852	.0125	.0966
13	.0128	.1077	.0131	.1187	.0135	.1296	.0138	.1404	.0142	.1510	.0145	.1614
14	.0149	.1718	.0152	.1820	.0156	.1921	.0159	.2021	.0163	.2120	.0167	.2217
15	.0170	.2314	.0174	.2409	.0178	.2504	.0182	.2597	.0186	.2689	.0190	.2781
16	.0194	.2871	.0198	.2961	.0202	.3049	.0206	.3137	.0210	.3223	.0214	.3309
17	.0218	.3394	.0223	.3478	.0227	.3561	.0231	.3644	.0236	.3726	.0240	.3807
18	.0245	.3887	.0249	.3966	.0254	.4045	.0258	.4123	.0263	.4200	.0268	.4276
19	.0272	.4352	.0277	.4427	.0282	.4502	.0287	.4576	.0292	.4649	.0297	.4721
20	.0302	.4793	.0307	.4865	.0312	.4935	.0317	.5006	.0322	.5075	.0327	.5144
21	.0332	.5213	.0337	.5281	.0343	.5348	.0348	.5415	.0353	.5481	.0359	.5547
22	.0364	.5612	.0370	.5677	.0375	.5741	.0381	.5805	.0386	.5868	.0392	.5931
23	.0397	.5993	.0403	.6055	.0409	.6116	.0415	.6177	.0421	.6238	.0426	.6298
24	.0432	.6358	.0438	.6417	.0444	.6476	.0450	.6534	.0456	.6592	.0462	.6650
25	.0468	.6707	.0475	.6764	.0481	.6820	.0487	.6876	.0493	.6932	.0500	.6987
26	.0506	.7042	.0512	.7096	.0519	.7150	.0525	.7204	.0532	.7258	.0538	.7311
27	.0545	.7364	.0552	.7416	.0558	.7468	.0565	.7520	.0572	.7572	.0578	.7623
28	.0585	.7674	.0592	.7724	.0599	.7774	.0606	.7824	.0613	.7874	.0620	.7923
29	.0627	.7972	.0634	.8021	.0641	.8069	.0648	.8117	.0655	.8165	.0663	.8213
30	.0670	.8260	.0677	.8307	.0684	.8354	.0692	.8400	.0699	.8446	.0707	.8492
31	.0714	.8538	.0722	.8583	.0729	.8629	.0737	.8673	.0744	.8718	.0752	.8763
32	.0760	.8807	.0767	.8851	.0775	.8894	.0783	.8938	.0791	.8981	.0799	.9024
33	.0807	.9067	.0815	.9109	.0823	.9152	.0831	.9194	.0839	.9236	.0847	.9277
34	.0855	.9319	.0863	.9360	.0871	.9401	.0879	.9442	.0888	.9482	.0896	.9523
35	.0904	.9563	.0913	.9603	.0921	.9643	.0929	.9682	.0938	.9721	.0946	.9761
36	.0955	.9800	.0963	.9838	.0972	.9877	.0981	.9915	.0989	.9954	.0998	.9992
37	.1007	.0030	.1016	.0067	.1024	.0105	.1033	.0142	.1042	.0179	.1051	.0216
38	.1060	.0253	.1069	.0289	.1078	.0326	.1087	.0362	.1096	.0398	.1105	.0434
39	.1114	.0470	.1123	.0505	.1133	.0541	.1142	.0576	.1151	.0611	.1160	.0646
40	.1170	.0681	.1179	.0716	.1189	.0750	.1198	.0784	.1207	.0819	.1217	.0853
41	.1226	.0887	.1236	.0920	.1246	.0954	.1255	.0987	.1265	.1020	.1275	.1054
42	.1284	.1087	.1294	.1119	.1304	.1152	.1314	.1185	.1323	.1217	.1333	.1249
43	.1343	.1282	.1353	.1314	.1363	.1345	.1373	.1377	.1383	.1409	.1393	.1440
44	.1403	.1472	.1413	.1503	.1424	.1534	.1434	.1565	.1444	.1596	.1454	.1626

TABLE 3. HAVERSINES (Cont'd)
(45^{o} to 89^{o})

Note: Characteristics of the logarithms are ommitted.

°	0'		10'		20'		30'		40'		50'	
	Nat	Log	Nat	Log	Nat	Log	Nat	Log	Nat	Log	Nat	Log
45	.1464	.1657	.1475	.1687	.1485	.1718	.1495	.1748	.1506	.1778	.1516	.1808
46	.1527	.1838	.1537	.1867	.1548	.1897	.1558	.1926	.1569	.1956	.1579	.1985
47	.1590	.2014	.1601	.2043	.1611	.2072	.1622	.2101	.1633	.2129	.1644	.2158
48	.1654	.2186	.1665	.2215	.1676	.2243	.1687	.2271	.1698	.2299	.1709	.2327
49	.1720	.2355	.1731	.2382	.1742	.2410	.1753	.2437	.1764	.2465	.1775	.2492
50	.1786	.2519	.1797	.2546	.1808	.2573	.1820	.2600	.1831	.2627	.1842	.2653
51	.1853	.2680	.1865	.2706	.1876	.2732	.1887	.2759	.1899	.2785	.1910	.2811
52	.1922	.2837	.1933	.2863	.1945	.2888	.1956	.2914	.1968	.2940	.1979	.2965
53	.1991	.2991	.2003	.3016	.2014	.3041	.2026	.3066	.2038	.3091	.2049	.3116
54	.2061	.3141	.2073	.3166	.2085	.3190	.2096	.3215	.2108	.3239	.2120	.3264
55	.2132	.3288	.2144	.3312	.2156	.3336	.2168	.3361	.2180	.3384	.2192	.3408
56	.2204	.3432	.2216	.3456	.2228	.3480	.2240	.3503	.2252	.3527	.2265	.3550
57	.2277	.3573	.2289	.3596	.2301	.3620	.2314	.3643	.2326	.3666	.2338	.3689
58	.2350	.3711	.2363	.3734	.2375	.3757	.2388	.3779	.2400	.3802	.2412	.3824
59	.2425	.3847	.2437	.3869	.2450	.3891	.2462	.3913	.2475	.3935	.2487	.3957
60	.2500	.3979	.2513	.4001	.2525	.4023	.2538	.4045	.2551	.4066	.2563	.4088
61	.2576	.4109	.2589	.4131	.2601	.4152	.2614	.4173	.2627	.4195	.2640	.4216
62	.2653	.4237	.2665	.4258	.2678	.4279	.2691	.4300	.2704	.4320	.2717	.4341
63	.2730	.4362	.2743	.4382	.2756	.4403	.2769	.4423	.2782	.4444	.2795	.4464
64	.2808	.4484	.2821	.4504	.2834	.4524	.2847	.4545	.2861	.4565	.2874	.4584
65	.2887	.4604	.2900	.4624	.2913	.4644	.2927	.4664	.2940	.4683	.2953	.4703
66	.2966	.4722	.2980	.4742	.2993	.4761	.3006	.4780	.3020	.4799	.3033	.4819
67	.3046	.4838	.3060	.4857	.3073	.4876	.3087	.4895	.3100	.4914	.3113	.4932
68	.3127	.4951	.3140	.4970	.3154	.4989	.3167	.5007	.3181	.5026	.3195	.5044
69	.3208	.5063	.3222	.5081	.3235	.5099	.3249	.5117	.3263	.5136	.3276	.5154
70	.3290	.5172	.3304	.5190	.3317	.5208	.3331	.5226	.3345	.5244	.3358	.5261
71	.3372	.5279	.3386	.5297	.3400	.5314	.3413	.5332	.3427	.5349	.3441	.5367
72	.3455	.5384	.3469	.5402	.3483	.5419	.3496	.5436	.3510	.5454	.3524	.5471
73	.3538	.5488	.3552	.5505	.3566	.5522	.3580	.5539	.3594	.5556	.3608	.5572
74	.3622	.5589	.3636	.5606	.3650	.5623	.3664	.5639	.3678	.5656	.3692	.5672
75	.3706	.5689	.3720	.5705	.3734	.5722	.3748	.5738	.3762	.5754	.3776	.5771
76	.3790	.5787	.3805	.5803	.3819	.5819	.3833	.5835	.3847	.5851	.3861	.5867
77	.3875	.5883	.3889	.5899	.3904	.5915	.3918	.5930	.3932	.5946	.3946	.5962
78	.3960	.5977	.3975	.5993	.3989	.6009	.4003	.6024	.4017	.6039	.4032	.6055
79	.4046	.6070	.4060	.6086	.4075	.6101	.4089	.6116	.4103	.6131	.4117	.6146
80	.4132	.6161	.4146	.6176	.4160	.6191	.4175	.6206	.4189	.6221	.4203	.6236
81	.4218	.6251	.4232	.6266	.4247	.6280	.4261	.6295	.4275	.6310	.4290	.6324
82	.4304	.6339	.4319	.6353	.4333	.6368	.4347	.6382	.4362	.6397	.4376	.6411
83	.4391	.6425	.4405	.6440	.4420	.6454	.4434	.6468	.4448	.6482	.4463	.6496
84	.4477	.6510	.4492	.6524	.4506	.6538	.4521	.6552	.4535	.6566	.4550	.6580
85	.4564	.6594	.4579	.6607	.4593	.6621	.4608	.6635	.4622	.6648	.4637	.6662
86	.4651	.6676	.4666	.6689	.4680	.6703	.4695	.6716	.4709	.6730	.4724	.6743
87	.4738	.6756	.4753	.6770	.4767	.6783	.4782	.6796	.4796	.6809	.4811	.6822
88	.4826	.6835	.4840	.6848	.4855	.6862	.4869	.6875	.4884	.6887	.4898	.6900
89	.4913	.6913	.4927	.6926	.4942	.6939	.4956	.6952	.4971	.6964	.4985	.6977

TABLE 3. HAVERSINES (Con't)
(90^{o} to 134^{o})

Note: Characteristics of the logarithms are omitted.

°	0' Nat	0' Log	10' Nat	10' Log	20' Nat	20' Log	30' Nat	30' Log	40' Nat	40' Log	50' Nat	50' Log
90	.5000	.6990	.5015	.7002	.5029	.7015	.5044	.7027	.5058	.7040	.5073	.7052
91	.5087	.7065	.5102	.7077	.5116	.7090	.5131	.7102	.5145	.7114	.5160	.7126
92	.5174	.7139	.5189	.7151	.5204	.7156	.5218	.7175	.5233	.7187	.5247	.7199
93	.5262	.7211	.5276	.7223	.5291	.7235	.5305	.7247	.5320	.7259	.5334	.7271
94	.5349	.7283	.5363	.7294	.5378	.7306	.5392	.7318	.5407	.7329	.5421	.7341
95	.5436	.7353	.5450	.7364	.5465	.7376	.5479	.7387	.5494	.7399	.5508	.7410
96	.5523	.7421	.5537	.7433	.5552	.7444	.5566	.7455	.5580	.7467	.5595	.7478
97	.5609	.7489	.5624	.7500	.5638	.7511	.5653	.7523	.5667	.7534	.5681	.7545
98	.5696	.7556	.5710	.7567	.5725	.7577	.5739	.7588	.5753	.7599	.5768	.7610
99	.5782	.7621	.5797	.7632	.5811	.7642	.5825	.7653	.5840	.7664	.5854	.7674
100	.5868	.7685	.5883	.7696	.5897	.7706	.5911	.7717	.5925	.7727	.5940	.7738
101	.5954	.7748	.5968	.7759	.5983	.7769	.5997	.7779	.6011	.7790	.6025	.7800
102	.6040	.7810	.6054	.7820	.6068	.7830	.6082	.7841	.6096	.7851	.6111	.7861
103	.6125	.7871	.6139	.7881	.6153	.7891	.6167	.7901	.6181	.7911	.6195	.7921
104	.6210	.7931	.6224	.7940	.6238	.7950	.6252	.7960	.6266	.7970	.6280	.7980
105	.6294	.7989	.6308	.7999	.6322	.8009	.6336	.8018	.6350	.8028	.6364	.8037
106	.6378	.8047	.6392	.8056	.6406	.8066	.6420	.8075	.6434	.8085	.6448	.8094
107	.6462	.8104	.6476	.8113	.6490	.8122	.6504	.8131	.6517	.8141	.6531	.8150
108	.6545	.8159	.6559	.8168	.6573	.8177	.6587	.8187	.6600	.8196	.6614	.8205
109	.6628	.8214	.6642	.8223	.6655	.8232	.6669	.8241	.6683	.8250	.6696	.8258
110	.6710	.8267	.6724	.8276	.6737	.8285	.6751	.8294	.6765	.8302	.6778	.8311
111	.6792	.8320	.6805	.8329	.6819	.8337	.6833	.8346	.6846	.8354	.6860	.8363
112	.6873	.8371	.6887	.8380	.6900	.8388	.6913	.8319	.6927	.8405	.6940	.8414
113	.6954	.8422	.6967	.8430	.6980	.8439	.6994	.8447	.7007	.8455	.7020	.8464
114	.7034	.8472	.7047	.8480	.7060	.8488	.7073	.8496	.7087	.8504	.7100	.8513
115	.7113	.8521	.7126	.8529	.7139	.8537	.7153	.8545	.7166	.8553	.7179	.8561
116	.7192	.8568	.7205	.8576	.7218	.8584	.7231	.8592	.7244	.8600	.7257	.8608
117	.7270	.8615	.7283	.8623	.7296	.8631	.7309	.8638	.7322	.8646	.7335	.8654
118	.7347	.8661	.7360	.8669	.7373	.8676	.7386	.8684	.7399	.8691	.7411	.8699
119	.7424	.8706	.7437	.8714	.7449	.8721	.7462	.8729	.7475	.8736	.7487	.8743
120	.7500	.8751	.7513	.8758	.7525	.8765	.7538	.8772	.7550	.8780	.7563	.8787
121	.7575	.8794	.7588	.8801	.7600	.8808	.7612	.8815	.7625	.8822	.7637	.8829
122	.7650	.8836	.7662	.8843	.7674	.8850	.7686	.8857	.7699	.8864	.7711	.8871
123	.7723	.8878	.7735	.8885	.7748	.8892	.7760	.8898	.7772	.8905	.7784	.8912
124	.7796	.8919	.7808	.8925	.7820	.8932	.7832	.8939	.7844	.8945	.7856	.8952
125	.7868	.8959	.7880	.8965	.7892	.8972	.7904	.8978	.7915	.8985	.7927	.8991
126	.7939	.8998	.7951	.9004	.7962	.9010	.7974	.9017	.7986	.9023	.7997	.9030
127	.8009	.9036	.8021	.9042	.8032	.9048	.8044	.9055	.8055	.9061	.8067	.9067
128	.8078	.9073	.8090	.9079	.8101	.9085	.8113	.9092	.8124	.9098	.8135	.9104
129	.8147	.9110	.8158	.9116	.8169	.9122	.8180	.9128	.8192	.9134	.8203	.9140
130	.8214	.9146	.8225	.9151	.8236	.9157	.8247	.9163	.8258	.9169	.8269	.9175
131	.8280	.9180	.8291	.9186	.8302	.9192	.8313	.9198	.8324	.9203	.8335	.9209
132	.8346	.9215	.8356	.9220	.8367	.9226	.8378	.9231	.8389	.9237	.8399	.9242
133	.8410	.9248	.8421	.9253	.8431	.9259	.8442	.9264	.8452	.9270	.8463	.9275
134	.8473	.9281	.8484	.9286	.8494	.9291	.8505	.9297	.8515	.9302	.8525	.9307

TABLE 3. HAVERSINES (Cont'd)
(135^o to 180^o)

Note: Characteristics of the logarithms are omitted.

°	0' Nat	0' Log	10' Nat	10' Log	20' Nat	20' Log	30' Nat	30' Log	40' Nat	40' Log	50' Nat	50' Log
135	.8536	.9312	.8546	.9318	.8556	.9323	.8566	.9328	.8576	.9333	.8587	.9338
136	.8597	.9343	.8607	.9348	.8617	.9353	.8627	.9359	.8637	.9364	.8647	.9369
137	.8657	.9374	.8667	.9379	.8677	.9383	.8686	.9388	.8696	.9393	.8706	.9398
138	.8716	.9403	.8725	.9408	.8735	.9413	.8745	.9417	.8754	.9422	.8764	.9427
139	.8774	.9432	.8783	.9436	.8793	.9441	.8802	.9446	.8811	.9450	.8821	.9455
140	.8830	.9460	.8840	.9464	.8849	.9469	.8858	.9473	.8867	.9478	.8877	.9482
141	.8886	.9487	.8895	.9491	.8904	.9496	.8913	.9500	.8922	.9505	.8931	.9509
142	.8940	.9513	.8949	.9518	.8958	.9522	.8967	.9526	.8976	.9531	.8984	.9535
143	.8993	.9539	.9002	.9543	.9011	.9548	.9019	.9552	.9028	.9556	.9037	.9560
144	.9045	.9564	.9054	.9568	.9062	.9572	.9071	.9576	.9079	.9580	.9087	.9584
145	.9096	.9588	.9104	.9592	.9112	.9596	.9121	.9600	.9129	.9604	.9137	.9608
146	.9145	.9612	.9153	.9616	.9161	.9620	.9169	.9623	.9177	.9627	.9185	.9631
147	.9193	.9635	.9201	.9638	.9209	.9642	.9217	.9646	.9225	.9650	.9233	.9653
148	.9240	.9657	.9248	.9660	.9256	.9664	.9263	.9668	.9271	.9671	.9278	.9675
149	.9286	.9678	.9293	.9682	.9301	.9685	.9308	.9689	.9316	.9692	.9323	.9695
150	.9330	.9699	.9337	.9702	.9345	.9706	.9352	.9709	.9359	.9712	.9366	.9716
151	.9373	.9719	.9380	.9722	.9387	.9725	.9394	.9729	.9401	.9732	.9408	.9735
152	.9415	.9738	.9422	.9741	.9428	.9744	.9435	.9747	.9442	.9751	.9448	.9754
153	.9455	.9757	.9462	.9760	.9468	.9763	.9475	.9766	.9481	.9769	.9488	.9772
154	.9494	.9774	.9500	.9777	.9507	.9780	.9513	.9783	.9519	.9786	.9525	.9789
155	.9532	.9792	.9538	.9794	.9544	.9797	.9550	.9800	.9556	.9803	.9562	.9805
156	.9568	.9808	.9574	.9811	.9579	.9813	.9585	.9816	.9591	.9819	.9597	.9821
157	.9603	.9824	.9608	.9826	.9614	.9829	.9619	.9831	.9625	.9834	.9630	.9836
158	.9636	.9839	.9641	.9841	.9647	.9844	.9652	.9846	.9657	.9849	.9663	.9851
159	.9668	.9853	.9673	.9856	.9678	.9858	.9683	.9860	.9688	.9863	.9693	.9865
160	.9698	.9867	.9703	.9869	.9708	.9871	.9713	.9874	.9718	.9876	.9723	.9878
161	.9728	.9880	.9732	.9882	.9737	.9884	.9742	.9886	.9746	.9888	.9751	.9890
162	.9755	.9892	.9760	.9894	.9764	.9896	.9769	.9898	.9773	.9900	.9777	.9902
163	.9782	.9904	.9786	.9906	.9790	.9908	.9794	.9910	.9798	.9911	.9802	.9913
164	.9806	.9915	.9810	.9917	.9814	.9919	.9818	.9920	.9822	.9922	.9826	.9924
165	.9830	.9925	.9833	.9927	.9837	.9929	.9841	.9930	.9844	.9932	.9848	.9933
166	.9851	.9935	.9855	.9937	.9858	.9938	.9862	.9940	.9865	.9941	.9869	.9943
167	.9872	.9944	.9875	.9945	.9878	.9947	.9881	.9948	.9885	.9950	.9888	.9951
168	.9891	.9952	.9894	.9954	.9897	.9955	.9900	.9956	.9903	.9957	.9905	.9959
169	.9908	.9960	.9911	.9961	.9914	.9962	.9916	.9963	.9919	.9965	.9921	.9966
170	.9924	.9967	.9927	.9968	.9929	.9969	.9931	.9970	.9934	.9971	.9936	.9972
171	.9938	.9973	.9941	.9974	.9943	.9975	.9945	.9976	.9947	.9977	.9949	.9978
172	.9951	.9979	.9953	.9980	.9955	.9981	.9957	.9981	.9959	.9982	.9961	.9983
173	.9963	.9984	.9964	.9985	.9966	.9985	.9968	.9986	.9969	.9987	.9971	.9987
174	.9973	.9988	.9974	.9989	.9976	.9989	.9977	.9990	.9978	.9991	.9980	.9991
175	.9981	.9992	.9982	.9992	.9983	.9993	.9985	.9993	.9986	.9994	.9987	.9994
176	.9988	.9995	.9989	.9995	.9990	.9996	.9991	.9996	.9992	.9996	.9992	.9997
177	.9993	.9997	.9994	.9997	.9995	.9998	.9995	.9998	.9996	.9998	.9996	.9998
178	.9997	.9999	.9997	.9999	.9998	.9999	.9998	.9999	.9999	.9999	.9999	.9999
179	.9999	.9999	.9999	.9999	1.0000	.0000	1.0000	.0000	1.0000	.0000	1.0000	.0000
180	1.0000	.0000										

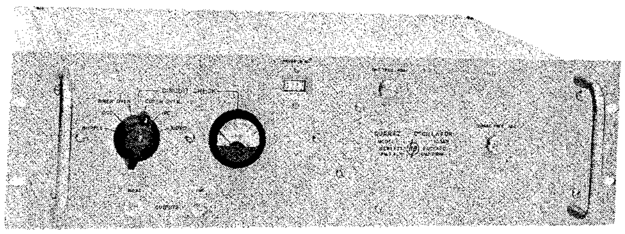
APPENDIX II
DATA SHEETS

Model Number	Description
103AR	Quartz Oscillator
104AR	Quartz Oscillator
113BR	Frequency Divider and Clock
114BR	Time Comparator
120A	Oscilloscope
724BR	Standby Power Supply
725AR	Standby Power Supply

TECHNICAL DATA

HEWLETT-PACKARD COMPANY · 1501 PAGE MILL ROAD · PALO ALTO, CALIFORNIA, U.S.A.
CABLE "HEWPACK" TELEPHONE DAVENPORT 6-7000

hp MODEL 103AR QUARTZ OSCILLATOR



ADVANTAGES

- 5 parts in 10^{10} per day stability
- Completely transistorized for low power consumption
- Powered by hp standby power supply for operation through ac power interruptions
- Extended operation from standby batteries
- 5-1/4 in. panel height conserves rack space

USES

- High stability frequency and time standard systems
- Secondary frequency standard

DESCRIPTION

Hewlett-Packard Model 103AR is a stable quartz oscillator for primary frequency and time standards. The hp 103AR, an hp standby power supply and hp 113 Frequency Divider and Clock are the basic elements of a primary frequency and time standard of moderate cost, small size and capable of high absolute accuracy. For hf time comparisons a receiver and triggered oscilloscope such as hp Model 120AR complete the system. You may make vlf comparisons by using equipment and techniques described in hp Application Note 50. Comparison techniques are summarized in the appendix of this data sheet. Power for the hp 103AR is obtained from hp standby power supplies and batteries so that interruptions of ac power have no effect on performance.

For use as a secondary frequency standard, only the 103AR and power supply are required.

Two output signals, 1 mc and 100 kc, are provided from a low impedance source at a power level well suited for distribution over 50-ohm systems. A separate 100 kc output signal is furnished for driving hp Model 113 Frequency divider and Clock for time comparison measurements and generating time signals.

STABILITY

Stability of 5 parts in 10^{10} per day, or better, is achieved by housing the high quality crystal and all critical elements in a double oven having proportional control. Short-term stability is 5 parts in 10^{10} averaged over one-second intervals. Under reasonably constant conditions, short-term stability is typically one part in 10^{10} averaged over one-second intervals.

The oscillator is well isolated from external circuit influences and each output signal is isolated such that short-circuiting any output will not affect the other output signals.

Coarse and fine frequency controls are located behind threaded plugs and are accessible from the front panel. The fine frequency control is equipped with a digital indicator calibrated directly in parts in 10^{10}.

Careful design of the basic oscillator and output circuits of the 103AR provide a signal of unusual spectral purity. For applications requiring extreme spectral purity at high frequencies the hp Model 104AR is available. Model 104AR provides a 5 mc output whose spectral is only a few cycles wide in the gigacycle (kmc) region.

STANDBY OPERATION

To enable continued operation in the event of power line failure, the hp 103AR and the hp 113 operate from direct current, which may be supplied by hp standby power supplies or other dependable sources. Power requirements of both instruments have been minimized by transistorization. As a result, they will operate for extended periods from standby batteries of moderate size and cost.

DEPENDABLE PERFORMANCE

To provide the performance required of modern primary standards, design of the hp Model 103AR is conservative and premium components are used well below ratings. Crystal operating level is maintained at a constant low level by the use of automatic gain control. Further, the 100-kc output is derived by a regenerative divider which responds neither to noise or spurious inputs but will stop and remain stopped with any interruption in input signal or supply power. Thus, the presence of 100 kc output from the hp 103AR assures the user that the divider has neither gained nor lost time with respect to the crystal frequency.

A front panel meter and selector switch are provided for checking supply voltage, oscillator voltage, oven currents, and 100 kc and 1 mc output voltages.

hp 103AR EEM 2900

SPECIFICATIONS

Stability:*
Short Term: Better than 5 parts in 10^{10} averaged over 1 sec. intervals.
Long Term: 5 parts in 10^{10} per day.

► Output Frequencies:
1) 1 mc sine wave, 1 volt rms into 50 ohms
2) 100 kc sine wave, 1 volt rms into 50 ohm
3) 100 kc output for driving hp 113 Frequency Divider and Clock.

Harmonic Distortion:
At least 40 db below rated output

Non-Harmonically Related Output:
At least 80 db below rated output

Output Terminals:
Outputs 1 and 2: BNC connectors on front panel and at rear.
Output 3: BNC connector at rear.

Frequency Adjustments:
Coarse: Screwdriver adjustment with range of approximately 1 part in 10^6. Accessible through front panel by removing threaded plug.

Fine: Front panel control with range of approximately 600 parts in 10^{10}. Accessible through front panel by removing threaded plug. Digital indicator calibrated directly in parts in 10^{10}.

Monitor Meter:
Ruggedized front-panel meter and associated selector switch monitors:
1) SUPPLY voltage
2) OSC voltage
3) INNER OVEN current
4) OUTER OVEN current
5) 1 MC output
6) 100 KC output

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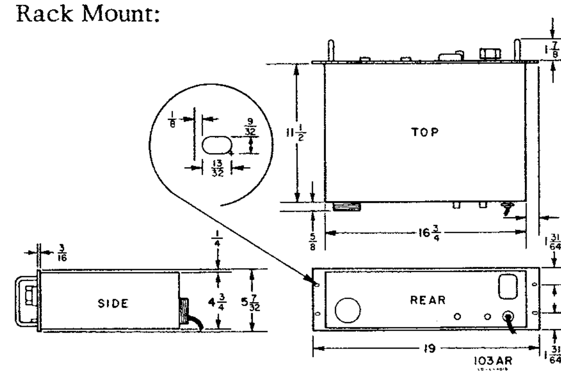
* After 21 days of continuous operation

Temperature Range:
0-50°C

Size:
Rack Mount:



Weight:
Net 17 lbs. Shipping 32 lbs.

Power Requirements:
22 to 30 volts dc, approximately 5 watts after warmup at room temperature. Approximately 10 watts maximum during warmup. hp 724/725 Standby Power Supplies with standby batteries recommended.

Accessories Furnished:
Cable for connecting hp 103AR Frequency Standard to hp standby power supply.

Complementary Equipment:
hp Model 724BR Standby Power Supply, with battery, 16 ampere-hour standby capacity, $850.00

hp Model 725AR Standby Power Supply with battery, 2 ampere-hour standby capacity.

hp Model 113BR Frequency Divider and Clock, $2,750.00

hp Model 120AR Oscilloscope, $450.00.

Prices f. o. b. factory

DATA SUBJECT TO CHANGE WITHOUT NOTICE

7/15/60
2/1/61

00168-2

CALIBRATION OF -hp- FREQUENCY AND TIME STANDARDS

Calibration of the -hp- Frequency and Time Standards will ordinarily be accomplished by comparison with national standards through the Standard Broadcasts. Both time and frequency information is contained in broadcasts from hf radio stations such as WWV and WWVH and vlf station NBA. The accuracy which can be achieved and maintained with the Hewlett-Packard Frequency/Time Standard depends on the techniques of comparison and adjustment used for calibration with these standard broadcasts. Comparison techniques are discussed below as they apply to frequency calibration and time synchronization.

FREQUENCY STANDARDS

A local frequency standard may be calibrated against the transmissions from a standard radio station by either of two basic methods. These are frequency comparison and time comparison. Although suitable for many applications, frequency comparison with the carrier of hf standard stations is limited in accuracy due to doppler shift. For the usual case of hf sky-path transmission, the frequency, as received, can be different from that transmitted by up to several parts in 10^7 because of ionosphere movement. As a result, hf frequency comparison is generally not suitable for adjustment of high stability oscillators such as the -hp- 103AR.

Much better comparison accuracy may be achieved by time comparison with hf broadcasts.

Time Comparison with HF Broadcasts

Time comparisons with broadcast standard time signals may be made as shown in Figure 1. The only equipment required in addition to the 113AR, 103AR, and 724AR is a triggered oscilloscope such as the -hp- 120AR and a receiver. Transmissions from WWV (WWVH, MSF, JJY or any other station transmitting precise time signals) are received and their "time ticks" are connected to the vertical input of the oscilloscope. The -hp- 113AR Frequency Divider and Clock derives local ticks from the 103AR Oscillator. These local ticks are used to trigger the oscilloscope.

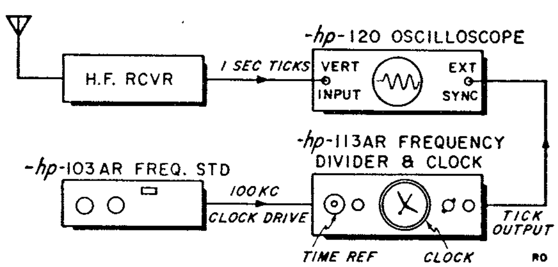


Figure 1. Time Comparison for Frequency Standard Calibration.

By successive adjustment of the 113AR TIME REFERENCE control and the oscilloscope sweep speed, a reference condition is established in which the time between the two ticks is very short and is accurately known. As the oscillator under test drifts with respect to the received time signals, the TIME REFERENCE control may be adjusted to re-establish the reference condition between the two ticks. The amount by which the TIME REFERENCE control must be adjusted indicates the time drift of the oscillator under test. By plotting the data obtained over a period of time, drift rate and frequency error may be determined very accurately and oscillator frequency can be readjusted to keep it within predetermined accuracy limits. While changes in propagation time cause scatter in the time of receipt of the time signals, comparisons made over extended periods serve to average out the effects of this scatter. Time comparisons made over several days can yield comparison accuracy of a part in 10^{10} or better.[1]

Frequency Comparison Using VLF Transmissions

An alternate solution to the doppler shift problem is to make frequency comparisons with the VLF standard stations such as NBA and WWVL.[2] VLF transmissions are virtually free of the propagation problems encountered with hf signals. Figure 2 shows the equipment set-up that can be used for this measurement. A Time Interval Counter (-hp-523C/D or -hp-524C/D) and a receiver are used with the basic frequency standard system.

A comparison accuracy of one part in 10^9 may usually be achieved in less than one hour. Tests conducted for longer periods will increase the comparison accuracy proportionally.

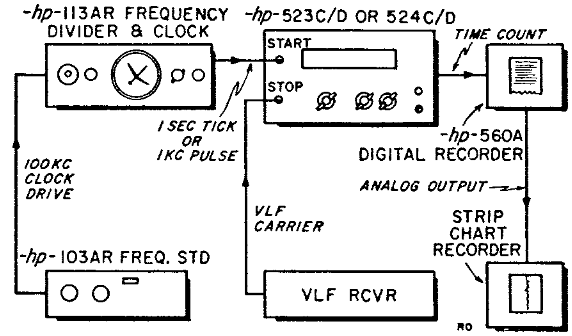


Figure 2. VLF Comparison System.

For comparison measurements with the CW carrier of WWVL, the 1 KC output from the 113AR Clock is used to start the Time Interval Counter and the next cycle of the 20 KC carrier is used as the stop signal. The Time Interval Counter trigger level and slope controls permit selecting given and repeatable points on the start and stop signals. The resulting time-interval readings are printed by the -hp-560A Digital Recorder and continuously plotted on a strip chart recorder using the analog output from the -hp-560A. This analog record shows the relative time drift of the oscillator under test as compared to WWVL. This, of course, is related to frequency error and frequency drift.

The carrier of NBA is keyed at a one pps repetition rate with a 30% duty cycle. Frequency comparison measurements in this case can be made only during the "on" time of the carrier, and for this reason it is necessary to use the one pps tick from the 113AR, positioned by the TIME REFERENCE control to occur in the middle or late portion of the received VLF pulse. In other respects, the measurement techniques are the same as those for WWVL.

TIME STANDARDS

The time signals carried by the standard broadcasts are locked to the nominal frequency of the transmissions and may be used to synchronize the -hp- time standard with national standards. The method most commonly employed for time synchronization of widely separated clocks is one-way transmission of time signals using hf propagation.[3]

HF Time Signals. This method of synchronization requires precise knowledge of the signal path length between the transmitter and the local receiver.[4] From longitude and latitude data, the great circle distance can be calculated and from this, ground-wave propagation time is easily determined. The next step is to calculate propagation times for a given mode sky-wave signal. These calculations are simplified by published curves for assumed layer heights, etc. and propagation modes.

Once propagation time is known, the 113AR Clock is set to agree with the time information contained in the standard broadcast transmissions. Corrections, as required, can then be made to the 103AR Frequency Standard and to the 113AR Clock itself to maintain the required time accuracy.

VLF Time Signals. To date, information bandwidth characteristics have limited the use of VLF for time-of-day information and for time comparison measurements. Improvement in the ability to synchronize accurately from VLF time signals is expected, however, since development is continuing in government and industry on equipment and techniques.

For more information, see -hp- Application Note 50, "Making VLF Frequency Comparison Measurements with -hp- Laboratory Equipment."

[1] Dexter Hartke, "A New Clock for Improving the Accuracy of Local Frequency and Time Standards," -hp- Journal, Vol. 11, No. 3-4, Nov.-Dec., 1959.

[2] For a complete discussion of VLF frequency comparison measurements with -hp- laboratory equipment, Application Note 50 is now available from Hewlett-Packard upon request.

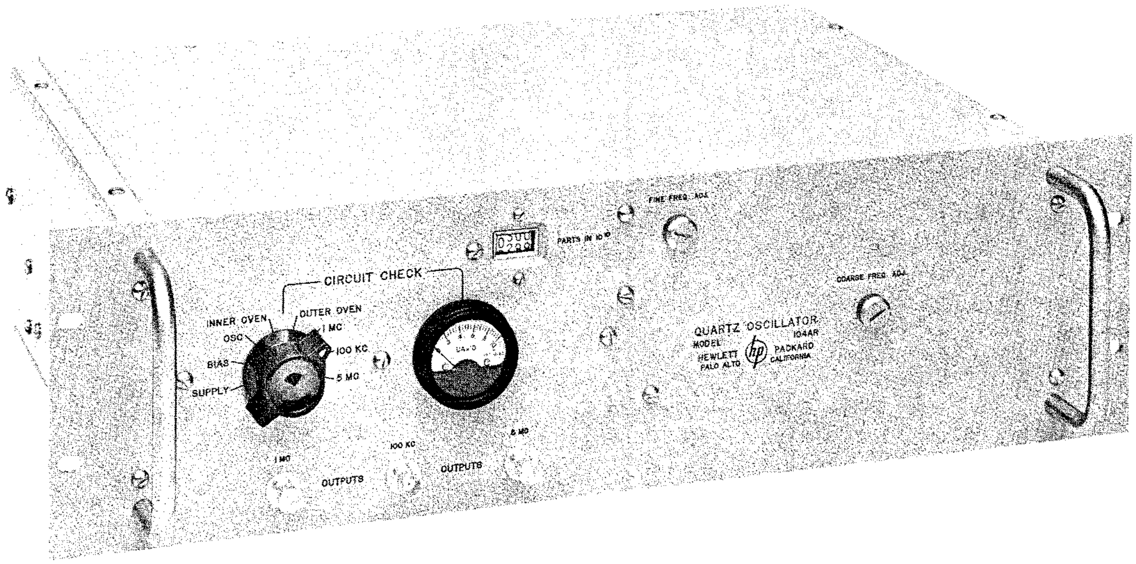
[3] For other approaches see NBS Technical Note No. 22. "Precise Time Synchronization of Widely Separated Clocks" by A. H. Morgan.

[4] NBS Report 6077, National Standards of Time and Frequency in the United States, by J. M. Richardson.

TENTATIVE DATA

HEWLETT-PACKARD COMPANY • 1501 PAGE MILL ROAD • PALO ALTO, CALIFORNIA, U.S.A.
CABLE "HEWPACK" TELEPHONE DAVENPORT 6-7000

hp MODEL 104AR QUARTZ OSCILLATOR



ADVANTAGES

- Extreme spectral purity for microwave spectroscopy
- 5 parts in 10^{10} per day stability
- Short-term typically 1 part in 10^{10}*
- Completely transistorized for low power consumption
- Extended operation from standby batteries
- 5-1/4 inch panel height conserves rack space

USES

- High stability frequency source for use in primary frequency and time standard systems
- Microwave spectroscopy
- Analyzing spectra of oscillators and multipliers
- Comparisons with atomic standards
- Doppler measurements on satellites
- Advanced communication and navigation systems

DESCRIPTION

hp Model 104AR Quartz Oscillator, like Model 103AR, makes possible improved accuracy in primary frequency and time standard systems because of increased stability, high-order reliability and ease of operation. In addition, Model 104AR provides a 5 mc output of extreme spectral purity that retains the stability of the 1 mc oscillator. Spectra only a few cycles wide may be obtained in the gigacycle (10^9 cps) region by multiplication of the 5 megacycle output. A high order of spectral purity in a reference signal is essential for accurate doppler measurements, microwave spectroscopy and similar applications where the reference frequency is multiplied by a large factor.

Long-term stability of Model 104AR is conservatively rated at 5 parts in 10^{10} per day. Short-term stability is specified as 5 parts in 10^{10}, including effects of variations in supply voltage, load resistance, ambient temperature and other environmental conditions. hp Model 104AR typically displays short-term stability of one part in 10^{10} when operated from an hp standby power supply in a reasonably constant environment.

A proportionally-controlled double oven in this instrument houses the 1 mc oscillator and all critical frequency-determining elements. 1 mc crystal dissipation level is constant at less than 1/4 microwatt as a result of AGC action. Frequency changes due to variations in supply voltage and load impedance are virtually eliminated as a result of internal voltage regulation and excellent buffering.

Completely transistorized, hp Model 104AR Quartz Oscillator is compact and rugged; it will withstand severe environmental conditions and operate for extended periods from standby batteries of moderate size.

*Based on 1-second average and reasonably constant environment.

hp 104 EEM 2900

SPECIFICATIONS

Stability:
Long-Term: 5 parts in 10^{10} per day*

Short-Term: Better than 5 parts in 10^{10}

Averaged over 1-sec. intervals

Output Frequencies:
5 mc, 1 mc, 100 kc, 1v rms into 50 ohms, 100 kc for driving 113BR

Harmonic Distortion:
At least 40 db below rated output

Non-Harmonically Related Output:
At least 80 db below rated output

Output Terminals:
5 mc, 1 mc, 100 kc, front and rear BNC connectors. Clock drive 100 kc, rear BNC connector.

Frequency Adjustments:
Coarse: Screwdriver adjustment with range of approximately 1.5 parts in 10^6. Accessible through front panel by removing threaded plug.

Fine: Front panel control with range of approximately 600 parts in 10^{10}. Accessible through front panel by removing threaded plug. Digital indicator calibrated directly in parts in 10^{10}.

*Achieved within 21 days of continuous operation.

Monitor Meter:
Ruggedized front-panel meter and associated selector switch monitors:
- SUPPLY voltage
- BIAS
- OSC voltage
- INNER OVEN current
- OUTER OVEN current
- 1 mc output
- 100 kc output
- 5 mc output

Temperature Range:
0-50°C

Dimensions:
Rack Mount: 5-1/4 in. high, 19 in. wide, 14 in. deep behind panel, include cable allowances, 16 in. deep overall

Weight:
Net approximately 20 lbs.

Power Requirements:
22-30 volts dc, approximately 5 watts operating, 10 watts maximum during warmup. Dual power connectors at rear

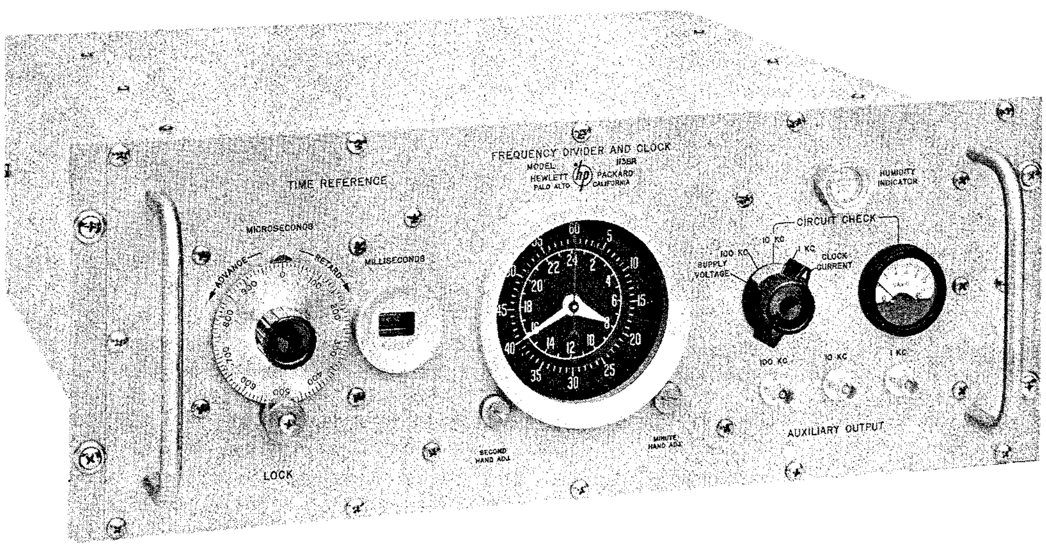
Accessories Furnished:
6 foot power cable for connecting Quartz Oscillator to ⓗⓟ 724BR or 725AR Standby Power Supply.

DATA SUBJECT TO CHANGE WITHOUT NOTICE

TECHNICAL DATA

HEWLETT-PACKARD COMPANY • 1501 PAGE MILL ROAD • PALO ALTO, CALIFORNIA, U. S. A.
CABLE "HEWPACK" TELEPHONE DAVENPORT 6-7000

hp MODEL 113BR FREQUENCY DIVIDER AND CLOCK



ADVANTAGES

- Permits greater absolute accuracy from frequency or time standards
- Suitable for hf or vlf comparisons
- Useful with atomic or quartz oscillators
- Provides time comparison capability of $\pm 10\ \mu$sec
- Generates precise time signals
- Requires low power from standby batteries
- Saves space

FEATURES

- Meets performance requirements of MIL-E-16400
- Well suited to mobile applications
- Frequency dividers and clock in single unit seven inches high
- Conservative design, premium electronic and mechanical components
- Fully transistorized

DESCRIPTION

The hp Model 113BR Frequency Divider and Clock[1] permits adjustment of frequency or time standards for maximum absolute accuracy by providing the means for more precise comparisons with broadcast standard time and frequency signals. Comparisons with standard time signals broadcast by WWV and other stations provide detailed records of drift rates as well as time or frequency differences between oscillators in widely separated systems. These data may be obtained efficiently and conveniently with the 113BR.

Model 113BR also permits high-accuracy comparisons with standard frequencies broadcast in the very low frequency spectrum by stations such as NBA, WWVL and others.[2]

Improved comparisons are possible because overall time comparison accuracy is 10 microseconds and the 113BR outputs are virtually free from jitter. These characteristics result primarily from the use of (1) a directly calibrated, precision resolver as a TIME REFERENCE control and (2) a unique optical gate system which cannot contribute jitter to output signals.

For maximum dependability, design of the hp 113BR is conservative and fail-safe. Premium electrical and mechanical components, derated by substantial margins, insure maximum reliability and long life. Model 113BR is fully transistorized and meets all performance requirements of MIL-E-16400.

Frequency dividers and clock are contained in one compact, rack-mounting unit seven inches high. The 113BR operates from 24 volts dc and, since power requirement is low, it will operate for extended periods from standby batteries of moderate size. The hp Model 724/725 Standby Power Supplies are designed specifically for supplying power to the 113BR.

[1] Dexter Hartke, "A New Clock for Improving the Accuracy of Local Frequency and Time Standards." Hewlett-Packard Journal, Vol. II, No. 3-4.

[2] "Utilizing VLF Broadcasts with the hp Frequency Divider and Clock", Hewlett-Packard Journal, Vol. II, No. 8-10.

hp 113 EEM 2900

FAIL-SAFE OPERATION

Reliability is critically important in comparison equipment. Success of time comparisons, typically made over periods of weeks or months, is dependent upon continuous operation. Operation must be fail-safe so that output from the clock accurately represents the integrated output of the oscillator under test.

Frequency dividers of the regenerative type have generally been preferred for frequency and time standard systems. Unlike other systems such as pulse counters, regenerative dividers will not respond to noise or other spurious signals. Another advantage of regenerative dividers is that they can be made non-self-starting. These two characteristics ensure that regenerative dividers will neither gain nor lose time with respect to the output of the driving oscillator.

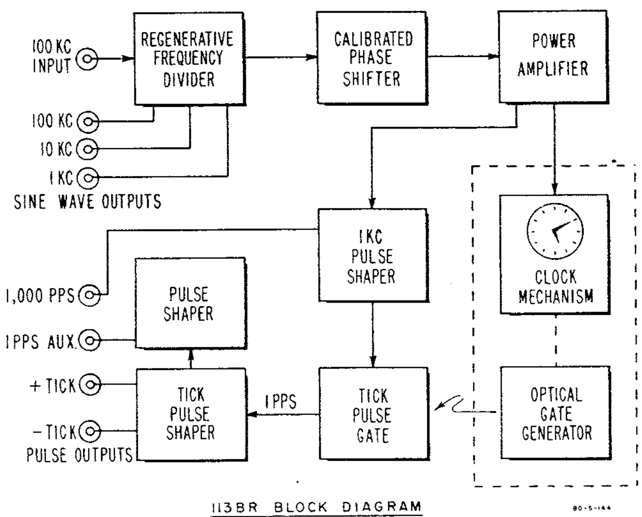


Figure 1. hp Model 113BR Block Diagram

As may be seen in the block diagram, figure 1, the hp 113BR divides the 100-kc input to 1 kc by means of regenerative dividers. For further division to 1 pps, a phase-stable motor and precision gear train are used.

Because of the frequency divider characteristics discussed above, the presence of output from the 113BR will indicate to the user not only that there has been no interruption in driving signal or supply power, but also that the clock has not gained or lost time with respect to the input signal.

The optical gate generator, which is driven by the clock mechanism, consists of two slotted, rotating disks which allow light to pass from a long-life bulb to a photoconductor once per second. The electrical pulse thus developed opens the tick pulse gate which passes one pulse per second from the 1 kc pulse shaper. By this means the 1 pps output tick is derived from the oscillator under test. The time position of the output tick cannot be affected by the gating system. Since the length of the optical gate is approximately 1 millisecond and the pulse to be passed by the gate is approximately 20 microseconds wide, jitter in the optical gate cannot in any way affect the tick.

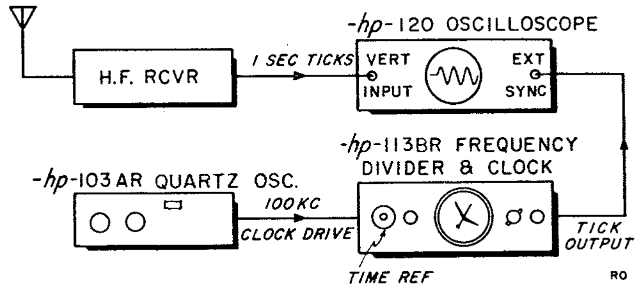


Figure 2. Time Comparison with hp Model 113BR

TIME COMPARISON

Time comparisons against broadcast standard time signals may be made as shown in figure 2. The only equipment required in addition to the 113BR is a triggered oscilloscope and a receiver. Transmissions from WWV (WWVH, MSF, JJY or any other station transmitting precise time signals) are received and these "time ticks" are connected to the vertical plates of the oscilloscope. The hp 113BR Frequency Divider and Clock generates local ticks which represent the integral of the output frequency from the oscillator under test. These ticks are used to trigger the oscilloscope.

At the beginning of a test, ticks from WWV and from the 113BR may be as much as 1/2 second apart. With oscilloscope sweep time of one second or more, the tick from WWV may be located with reference to the 113BR tick. The TIME REFERENCE CONTROL may be adjusted to decrease the time difference between the two ticks, and the WWV tick will move toward the beginning of the oscilloscope trace. By successive adjustment of the TIME REFERENCE CONTROL and the oscilloscope sweep speed, a reference condition may be established in which the time between the two ticks is very short and accurately known. At that point the TIME REFERENCE CONTROL reading is logged. As the oscillator under test drifts with respect to the received time signals, the TIME REFERENCE CONTROL may be adjusted to re-establish the reference condition between the two ticks. The amount by which the TIME REFERENCE CONTROL must be adjusted indicates the time drift of the oscillator under test. By plotting the data obtained over a period of time, drift rate and frequency error may be determined very accurately and oscillator frequency can be readjusted to keep within predetermined accuracy limits. This procedure establishes the absolute accuracy of the frequency standard. In addition, the 1000 pps and 1 pps outputs become standard time signals of high accuracy. Once sufficient drift rate data have been obtained and the oscillator frequency has been adjusted, the clock may be set by use of received time signals to provide accurate time-of-day indication.

TIME COMPARISON ACCURACY

Variations in propagation path lengths encountered in high frequency transmission of standard frequency signals cause Doppler shifts in the received frequency which may amount to several parts in 10^7. Such errors[3] greatly limit the usefulness of frequency comparison for adjustment of high-stability oscillators. Substantial improvement in comparison accuracy is achieved by time comparison in such applications. While changes in propagation path length cause scatter in the time of receipt of the time signals, comparisons made over extended periods serve to average out the effects of this scatter. The ±10 microsecond capability of the 113BR means that measurement will not be limited by the comparison equipment. Overall accuracy achieved in practice depends upon signal conditions and the lengths of tests.

Since the scatter encountered in most locations is in the order of ±50 to ±500 μsecond,[4] the total error in a time comparison (two time checks) would be 100 to 1000 μsecond. Since there are nearly 10^5 seconds in one day, two checks made 24 hours apart can be expected to affort comparison accuracy of approximately one part in 10^8 to one part in 10^9. Comparison accuracy increases with the length of time between checks, so it is possible to achieve comparison accuracy of one part in 10^9 to one part in 10^{10} with tests conducted over a period of a few weeks.

It should be noted that the absolute accuracy of the oscillator thus calibrated is dependent upon the absolute accuracy of the standard time signal as broadcast, in addition to the accuracy of comparison.

VLF FREQUENCY COMPARISONS

Frequency comparison against vlf signals may be made as shown in figure 3. The method is convenient, automatic and provides a continuous record.

[3]For comprehensive discussion see "Adjustment of High-Precision Frequency and Time Standard" by John M. Schaull, Proc. I.R.E., January 1950, pp. 6-15.

[4]Alvin H. Morgan, "Precise Time Synchronization of Widely Separated Clocks." NBS technical Note No. 22. Available from Office of Technical Services, U. S. Department of Commerce, Washington, D. C., Price $1.50.

The 113BR tick, representing the integrated output from the oscillator under test, starts a time interval counter. The counter is stopped by the next following cycle of the vlf carrier. An analog plot of the time interval shows the time drift of the oscillator under test with respect to the vlf signal. From this record the drift rate may be accurately and quickly determined.

VLF COMPARISON ACCURACY

VLF transmissions are virtually free of propagation problems encountered with hf signals and may usually be neglected. Inasmuch as there are approximately 10^{11} microseconds in one day, a time drift of 10 microseconds in 2.4 hours represents a frequency difference of approximately 1 part in 10^9. The jitter on the 113BR tick is less than 1 microsecond, and the time interval between the tick and a point on a given vlf carrier cycle may be measured to within a few microseconds. This means that comparison accuracy of one part in 10^9 may usually be achieved in less than one hour and longer tests can increase the accuracy proportionally.

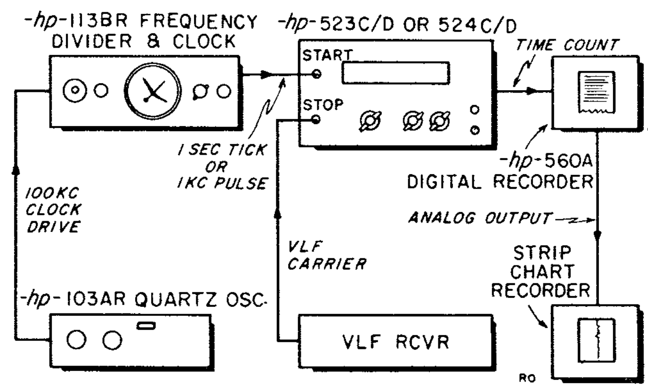


Figure 3. VLF Comparison with (hp) Model 113BR

SPECIFICATIONS

Input Frequency:
100 kc for solar time, input bandwidth ±300 cps.
100.3 kc for sidereal time, on special order.

Accuracy:
1) Accuracy of output pulse and sine-wave signals determined by accuracy of input frequency.

2) Time reference dial linearity ±10 μsec.

Input Voltage:
0.5 to 5 volts rms

Input Impedance:
300 ohms nominal

Auxiliary Output:
100, 10 and 1 kc sinusoidal, 0.25 volts rms, min. Source impedance 1,200 ohms nominal. Front panel BNC connectors.

Tick Pulse Outputs:

Pulse Rate:	1 pps	1 pps
Amplitude:	+10v, min*	-10v, min*
Rise Time:	2μs max	2μs max
Duration:	20μs min	20μs min
Jitter:	1μs max	1μs max
Min. Recommended Load Impedance:	4.7K ohms min. shunted by 200 pf max.	1 meg. min shunted by 100 pf max
Connector:	Rear BNC	Front BNC

*For any load impedance from minimum recommended to open circuit.

SPECIFICATIONS (CONT'D)

Pulse Outputs:

	Positive	Positive**
Pulse Rate:	1 pps	1000 pps
Amplitude:	+4v min.open circuit,+2v min. across 50 Ω	+4v min.
Rise Time:	1μsec max.	2μsec max.
Duration:	200μsec	20μsec min.
Jitter:	1μsec max.	1μsec max.
Min. Recommended Load Impedance:	50 ohms,min. shunted by 5000 pf max.	1000 ohms min shunted by 1000 pf max.
Connector:	Rear BNC	Rear BNC

**Negative pulses available on special order

Time Reference:
Continuously adjustable. Directly calibrated in 10 microsecond increments on dial and in milliseconds on mechanical counter.

Frequency Divider:
Manually starting, regenerative type, fail-safe.

Effect of Transients:
Will not gain or lose time because of:
1) ±300 volt step function on 100 kc input.
2) 0 to 50 volt pulses, 0 to 500 pps, 1 to 10 μsec duration on 100 kc input.
3) ±4 volt step in 26 vdc input.

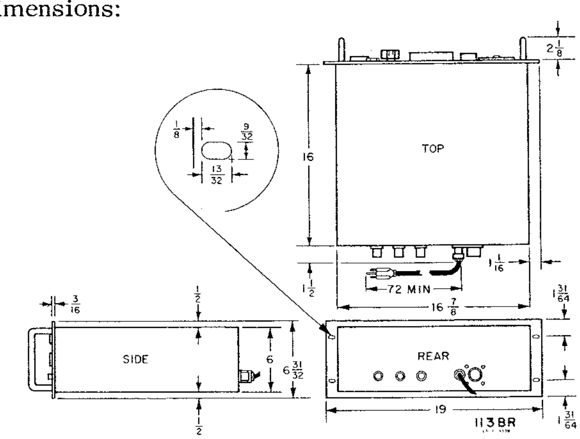
Clock Mechanism:
24-hour dial; minute hand adjustable in 1 minute steps; second hand continuously adjustable. Manual start. Front panel adjustment of clock hands does not affect tick output. (12-hour dial on special order.)

Monitor Meter:
Ruggedized meter and selector switch on front panel for checking supply voltage, divider operation (100 kc, 10 kc, 1 kc) and total clock current.

Power Required:
22-30 vdc, approximately 2 watts, recommended supply, ⓗⓟ 724BR or 725AR.

Power Connector:
GS02-14S-2P-112

Dimensions:



Weight:
Net 35 lbs. Shipping approximately 51 lbs.

Accessories Furnished:
113A-16E Cable, 6 feet long connects 113BR to 724BR or 725AR Standby Power Supply.

Complementary Equipment:
ⓗⓟ 724BR Standby Power Supply, 16 ampere-hour standby capacity with batteries, $850.00

ⓗⓟ 725AR Standby Power Supply, 2 ampere-hour capacity

ⓗⓟ 103AR Quartz Oscillator, $2,500.00

ⓗⓟ 120AR Oscilloscope, $450.00

Price:
ⓗⓟ 113BR, $2,750.00

Prices f.o.b. factory
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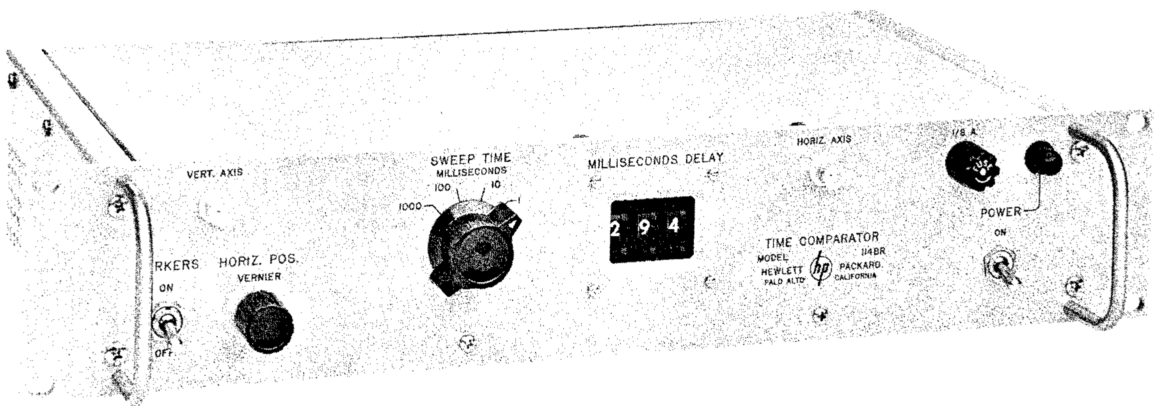
TECHNICAL DATA

HEWLETT-PACKARD COMPANY • 1501 PAGE MILL ROAD • PALO ALTO, CALIFORNIA, U.S.A.
CABLE "HEWPACK" TELEPHONE DAVENPORT 6-7000

MODEL 114BR TIME COMPARATOR



ADVANTAGES

- Simple to operate
- Convenient, fast
- Minimum size, weight, power consumption
- Meets performance requirements of MIL-E-16400, Class 4
- Completely transistorized

USES

- Increase efficiency and speed time comparisons for Primary Frequency or Time Standards
- Simplify time comparisons with more than one standard time signal
- Make time comparisons without affecting operation of the basic Frequency or Time Standard
- Can be used with vlf or hf time signals

DESCRIPTION

Hewlett-Packard Model 114BR Time Comparator provides additional speed and flexibility in making time comparisons between stable oscillators and standard time signal transmissions such as those from WWV. Model 114BR is an auxiliary unit used in conjunction with the hp Model 113BR Frequency Divider and Clock and an oscilloscope in Primary Frequency or Time Standard systems. If time signals generated by the hp Model 113BR Frequency Divider and Clock are to be used with computers or for system timing signals or similar purposes, the 114BR provides a method of making time comparisons without disturbing outputs from the 113BR. Model 114BR is also a convenient time-saver in applications requiring repeated comparisons using time signals from several stations.

The hp 114BR Time Comparator consists of an adjustable, preset, digital delay generator, a sweep generator and a marker generator. An oscilloscope such as hp Model 120AR is used as an indicator. All critical controls on the 114BR are detented selector switches, and time markers are automatically adjusted to sweep speed. As a result, time comparison by means of the 114BR is simple and fast. Adjustment of the 114BR will not affect operation of the Frequency or Time Standard in any way.

Model 114BR provides the capability for resolving, to ± 10 μsec (where signal conditions permit), the time difference between the received one-per-second standard time signal and the tick output from the hp 113BR. The data thus accumulated over a period of days, weeks or months may be used to determine the long-term drift of the stable frequency source or for time checks in Time Standard Systems.

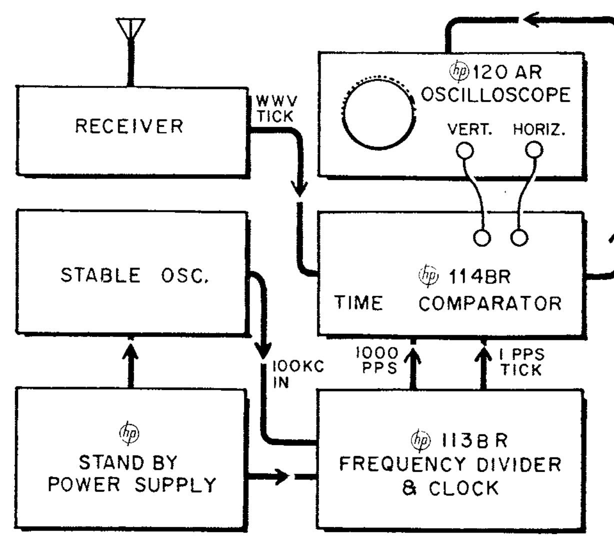


Figure 1. Block Diagram

hp 114BR EEM 2900

MOBILE OPERATION

Operation in sea-going vessels, aircraft or mobile vans requires time corrections to account for variations in propagation time due to movement of the system. Frequent time comparisons against several stations (WWV, WWVH, etc.) may also be required. In such cases, addition of the hp 114BR Time Comparator to the system simplifies operation and increases efficiency.

USE OF GENERATED TIME SIGNALS

If time signals generated by the hp 113BR in the Frequency or Time Standard are to be used with computers or for system timing signals or similar purposes, the 114BR provides a method of making time comparisons without disturbing the basic Primary Standard System or the 113BR ticks.

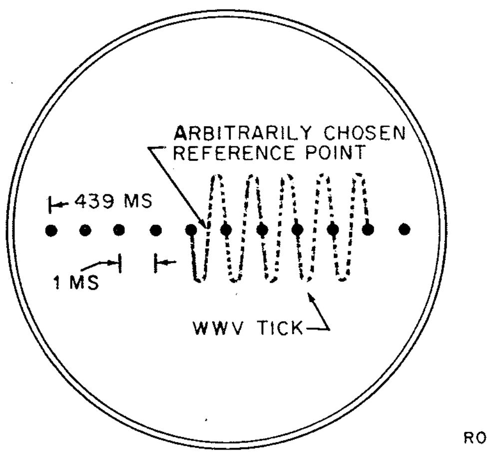


Figure 2. 10 ms Trace showing Unblanked WWV Tick

OPERATION

Use of the hp Model 114BR is shown in the block diagram, figure 1. With the system in operation, the millisecond delay dials are first set to 001 and SWEEP TIME is set to 1000 milliseconds for a sweep duration of 1 second. The example assumes a time difference of approximately 1/2 second. Intensity markers, generated by the 114BR appear at 100 ms intervals on the 120AR Oscilloscope, permitting the operator to determine the delay between the ticks from WWV and the hp 113BR to better than 100 ms. The HUNDREDS ms delay switch may then be set to start the oscilloscope sweep less than 100 ms before the WWV tick. If the sweep duration is decreased to 100 milliseconds, intensity markers appear at 10 ms intervals and the TENS ms delay switch may be adjusted. Sweep duration may then be decreased to 10 ms and the time between the 113BR tick and a reference point of the WWV tick may easily be read to the nearest millisecond by observing the 1 ms intensity markers as shown in figure 2.

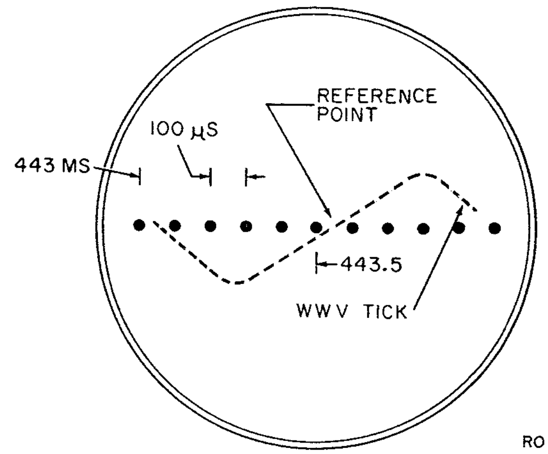


Figure 3. 1 ms Trace showing One Cycle of WWV Tick

After the UNITS ms delay switch has been adjusted, the sweep duration can be decreased to 1 ms. Intensity markers at 100 μsec intervals make it possible to estimate closely the time difference (figure 3).

To permit further resolution, the WWV tick itself is unblanked with a 50 kc square wave derived from the 113BR and in synchronism with the 100 μsec markers.

Figure 4, which magnifies the trace around the reference, illustrates how the hp 114BR resolves the time difference between the hp 113BR tick and a reference point on the WWV tick to ±10 μsec. Accuracy obtained in practice will depend on the signal-to-noise ratio and propagation path conditions.

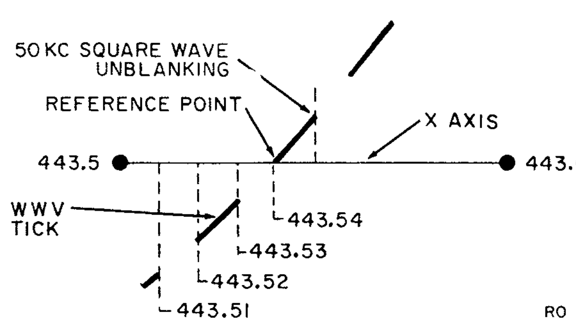


Figure 4. Portion of Figure 3 Magnified to show 50 kc Unblanking Detail

SPECIFICATIONS

Sweep Delay Range:
0-999 milliseconds in 1 millisecond steps with direct reading, in-line front panel switches

Sweep Output:
a) From HORIZ. AXIS. BNC connector on front panel.

b) Duration: 1000, 100, 10, or 1 millisecond as selected by front panel SWEEP TIME switch.

c) Amplitude: 1 volt peak-to-peak; dc coupled.

d) Position Control: front panel HORIZ. POS. VERNIER control provides fine adjustment of dc level of sweep voltage.

e) Recommended Display Unit: hp Model 120A/AR.

WWV Tick Output:
WWV Tick, gated at 1-second intervals to provide stable base line for intensity markers between ticks, appears at VERT. AXIS. BNC connector on front panel.

Z Axis Output: (MS 3102R-14S-7S Connector on Rear)

Intensity Markers:

a) Intervals automatically adjusted to 1/10 of the sweep duration.

b) Length automatically adjusted with SWEEP TIME.

c) Intensity markers may be switched on or off by front panel MARKERS switch.

Unblanking Voltage:

50 kc unblanking square wave synchronized with standard frequency for interpolation to 10 μsec or better. Amplitude 40 volts peak-to-peak.

Input Requirements:
a) 1 kc positive pulses from hp 113BR, BNC connector on rear.

b) 1 pps positive pulses from hp 113BR, BNC connector on rear.

c) WWV tick, 0.1-10 volts peak-to-peak, BNC connector on rear.

Self Check:
Each digit of the delay setting may be checked by means of front panel CHECK pushbutton.

Power Requirements:
115/230 volts ±10%, 50-1000 cps; approximately 7 watts. AN3102A-10SL-3P connector at rear.

Dimensions: (Rack Mount)
3-1/2 in. high, 19 in. wide, 13-1/2 in. deep overall, 11-1/2 in. deep behind panel, including cable allowance.

Weight:
Net, approximately 11 lbs.

Accessories Furnished:
hp 114BR-16A power cable, 6 feet long, with NEMA line plug and MS3106A-10SL-3S plug for chassis power connector.

hp 114BR-16B Z-axis cable, 3 feet long, with MS3106E-14S-7P plug for chassis connector.

hp 114BR-16C horizontal axis output cable, 6-1/2 inches long; BNC to banana plug connector

hp 114BR-16D vertical axis output cable, 10 inches long, BNC to banana plug connector.

Complementary Equipment:
hp 103AR Quartz Oscillator, $2,500.00
hp 113BR Frequency Divider and Clock, $2,750.00
hp 724B Standby Power Supply, 20 ampere-hour standby capacity, $850.00
hp 120AR Oscilloscope, $450.00

Price:
hp 114BR, $1,200.00.

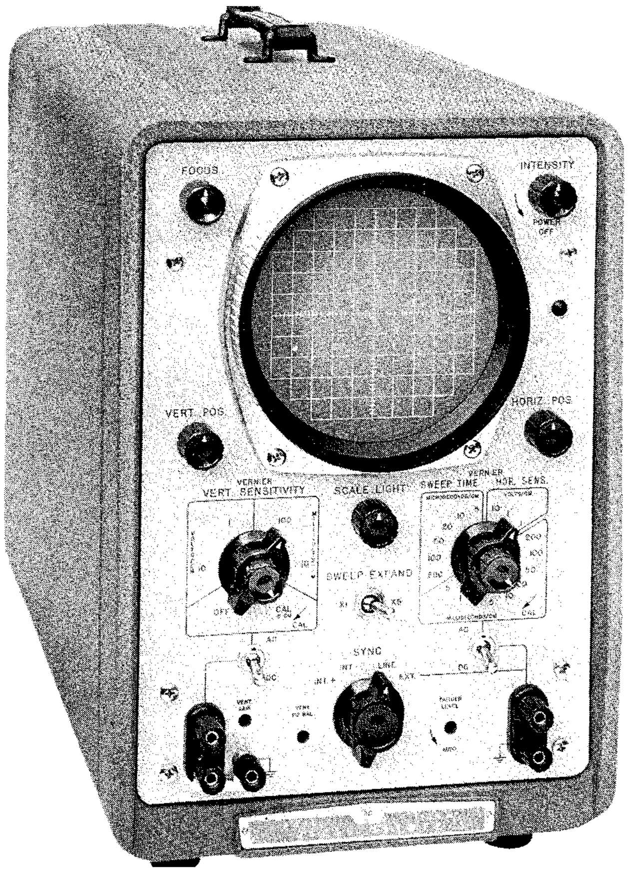
Prices f.o.b. factory

DATA SUBJECT TO CHANGE WITHOUT NOTICE

TECHNICAL DATA

HEWLETT-PACKARD COMPANY · 1501 PAGE MILL ROAD · PALO ALTO, CALIFORNIA, U.S.A.
CABLE "HEWPACK" TELEPHONE DAVENPORT 6-7000

ⓗⓟ MODEL 120A OSCILLOSCOPE

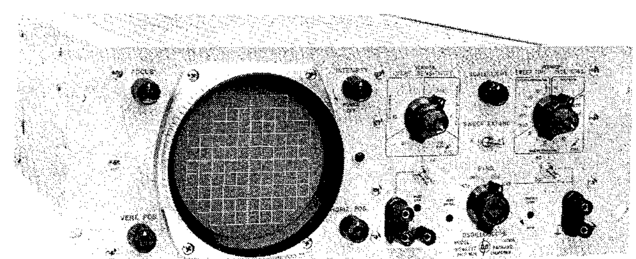


ADVANTAGES

- Saves time on your production line
- Avoid computation, read sweep time directly
- Automatic triggering for easy operation
- Quicker observations with sharp focus, uniform trace
- Measure complex voltages accurately with calibrated amplifiers

FEATURES

- Five inch, non-astigmatic CRT
- Linear Integrator for accurate sweeps
- X5 sweep expansion
- Bezel securely mounts camera
- Built-in ±2% amplitude calibrator



DESCRIPTION

The ⓗⓟ Model 120A is a simple, easy to use, precision oscilloscope. On the production line your personnel can learn this oscilloscope's operation quickly and conveniently. There are no trigger controls to be misset; just connect the signal and accurate sweeps are automatically triggered. Also, that search for a spot is ended since the base line is automatically presented even when no trigger signal is present. Yet, for photographic work involving transients, or whenever the automatic base line would interfere with observation, it may be easily locked-out.

Observations are made quickly and accurately and the trace easily focused with one control because the five inch flat-face cathode ray tube does not require continual adjustment of an astigmatism control and is sharply focused over the whole viewing area. This high quality type CRT is usually found only in more expensive instruments.

15 DIRECT READING SWEEP TIMES ACCURATE WITHIN 5%

When you are using the 120A, computations are avoided and possibilities of error are reduced by direct reading, calibrated sweeps. A single knob selects 15 calibrated sweeps from 5 microseconds/cm to 200 milliseconds/cm or determines the calibrated sensitivity of the horizontal amplifier. Continuous control of sweep time and horizontal sensitivity between calibrated steps is provided by a vernier control which also extends the 200 milliseconds/cm sweep time to at least 0.5 sec/cm and lowers the sensitivity of the 10 volt/cm step of the horizontal amplifier to at least 100 volts/cm. The accurate linear sweeps are obtained from a Miller Integrator hard tube type sweep circuit.

X5 SWEEP EXPANSION

You can speed observation and analysis of transients by expanding any two centimeter segments of a trace to 10 centimeters for easy viewing of detail. This X5 sweep expander, may be used on all sweep time settings and expands the fastest sweep time to 1 microsecond/cm.

UNIQUE AUTOMATIC TRIGGERING

No time is wasted adjusting trigger controls on the ⓗⓟ Model 120A, - it's automatic - just connect the synchronizing signal to obtain a stable, steady trace. Nor is that all, the automatic trigger ends hunting for the spot and facilitates establishing a base line when a synchronizing signal is not present, because this circuit triggers the sweep generator to provide a baseline on the CRT. In applications where it would be more convenient to have a baseline only in response to an applied trigger, as in photographic work involving transients, the automatic baseline provision may be easily and quickly locked-out and a trigger level established which is adjustable from at least -10 to +10 volts of an external trigger. This lockout can not be accidentally or inadvertantly actuated because it is located just behind the front panel where it is accessible with a screwdriver.

CALIBRATED AMPLIFIERS FOR MEASUREMENT AS WELL AS OBSERVATION

Accurate voltage measurements on all kinds of waveforms are quickly made with the 120A, because the amplifiers are calibrated and accurate within ±5%. Reliability and confidence is assured by a built-in calibrator which is accurate within ±2% and so permits quick verification and standardization of vertical amplifier sensitivity. The high sensitivity and dc to 200 kc bandwidth, which is independent of attenuator setting, makes the 120A useful for medical and geophysical, and industrial applications.

Phase shift measurements can be made accurately with this oscilloscope over a wide range of input frequencies. Relative phase shift between the vertical and horizontal amplifiers is less than 2° at 100 kc.

CABINET AND RACK MOUNTING

The ⓗⓟ Model 120A Oscilloscope is available as a cabinet mount for bench or portable use and as a rack mount for installation in a standard 19 inch equipment rack. Only 7 inches of rack space is required for the 120AR and it may be supported in the rack by the front panel or on slides (on special order) for easy withdrawal from the rack.

SPECIFICATIONS

SWEEP

Sweep Range:
1 μsec/cm to at least 0.5 sec/cm. 15 Calibrated sweeps, accurate to within ±5%, in a 1, 2, 5, 10... sequence, 5 μsec/cm to 200 millisec/cm. Vernier permits continuous adjustment of sweep time between calibrated steps and extends the 200 millisec/cm step to at least 0.5 sec/cm.

Sweep Expand:
X5 sweep expansion may be used on all ranges and expands fastest sweep to 1 μsec/cm. Expansion is about the center of the CRT and expanded sweep accuracy is ±10%.

Synchronization:
Automatic from 50 cps to 250 kc; internally from vertical deflection signals causing 1/2 cm or more vertical deflection; from external signals at least 2.5 volts peak-to-peak, and from line voltage.

Trigger Point:
Zero crossing, negative slope of external sync signals, zero crossing, positive or negative slope of vertical deflection signals. Screwdriver operated control overrides automatic and permits the trigger point to be set between -10 to +10 volts. Turning fully counter-clockwise into auto restores automatic operation.

VERTICAL AMPLIFIER

Bandwidth:
DC coupled: dc to 200 kc.
AC coupled: 2 cps to 200 kc.
Bandwidth is independent of sensitivity setting.

Sensitivity:
10 millivolts/cm to 100 volts/cm. 4 calibrated steps accurate within ±5%, 10 mv/cm, 100 mv/cm, 1 v/cm, and 10 v/cm. Vernier permits continuous adjustment of sensitivity between steps and extends 10 v/cm step to at least 100 v/cm.

Internal Calibrator:
Calibrating signal automatically connected to vertical amplifier for standardizing of gain, accuracy ±2%.

Input Impedance:
1 megohm, approximately 50 pf shunt.

Balanced Input:
On 10 mv/cm range. Input impedance, 2 megohms shunted by approximately 25 pf.

Common Mode Rejection:
Rejection at least 40 db. Common mode signal must not exceed ±3 volts peak.

Phase Shift:
Vertical and horizontal amplifiers have same phase characteristics within ±2° to 100 kc when verniers are in CAL.

SPECIFICATIONS (CONT'D)

HORIZONTAL AMPLIFIER

Bandwidth:
DC coupled: dc to 200 kc.
AC coupled: 2 cps to 200 kc.
Bandwidth is independent of attenuator setting.

Sensitivity:
0.1 volt/cm to 100 volts/cm. 3 calibrated steps, accurate within ±5%, .1 v/cm, 1 v/cm, and 10 v/cm. Vernier permits continuous adjustment of sensitivity between steps and extends 10 v/cm step to at least 100 v/cm.

Input Impedance:
1 megohm, nominal, shunted by approximately 100pf

Phase Shift:
Horizontal and vertical amplifiers have same phase characteristics within ±2° to 100 kc when verniers are in CAL.

GENERAL

Cathode Ray Tube:
5AOP1 mono-accelerator normally supplied; 2500 volt accelerating potential. P7 and P11 phosphors are also available. P2 is available if desired for special applications.

CRT Bezel:
Light proof bezel provides firm mount for oscilloscope camera and is removed easily for quick change of filter.

CRT Plates:
Direct connection to deflection plates via terminals on rear. Sensitivity approximately 20 v/cm.

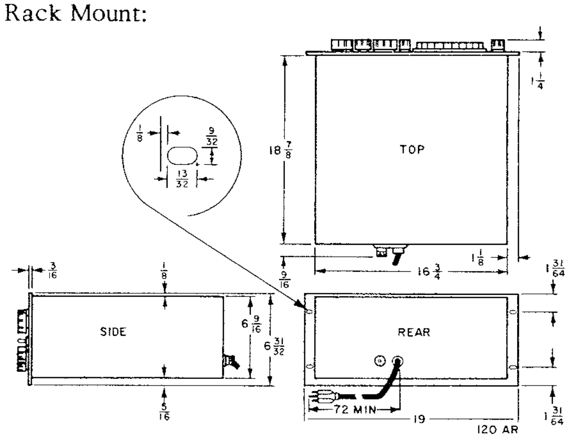
Intensity Modulated:
Terminals on rear. +20 v to blank trace of normal intensity.

Filter Supplied:
Color of filter compatible with CRT phosphor supplied; Green with P1 and P2; Amber with P7; Blue with P11.

Illuminated Graticule:
Edge lighted with controlled illumination, 10 cm x 10 cm, marked in cm squares. Major horizontal and vertical axes have 2 mm subdivisions.

► Dimensions:
Cabinet Mount: 9-3/4 inches wide, 15-5/8 inches 20-3/4 inches deep.

Rack Mount:



Weight:
Cabinet Mount: Net 34 lbs., shipping 43 lbs.
Rack Mount: Net 32 lbs., shipping 48 lbs.

Power:
115/230 volts ±10%, 50-1000 cps; 130 watts.

Equipment Slides:
Can be installed at the factory.
Specify C01 120AR; $87.50 extra.

Accessories Available:
AC-83A Viewing Hood; face-fitting molded rubber, Price: $5.00.

► Price:
Model 120A Cabinet Mount: $450.00
Model 120AR Rack Mount: $450.00
Normally supplied with P1 phosphor. When ordering P2*, P7 or P11, specify by adding phosphor number after model.

*P2 is not recommended for general purposes.

Prices f.o.b. factory
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10/30/60
2/1/61

TENTATIVE DATA

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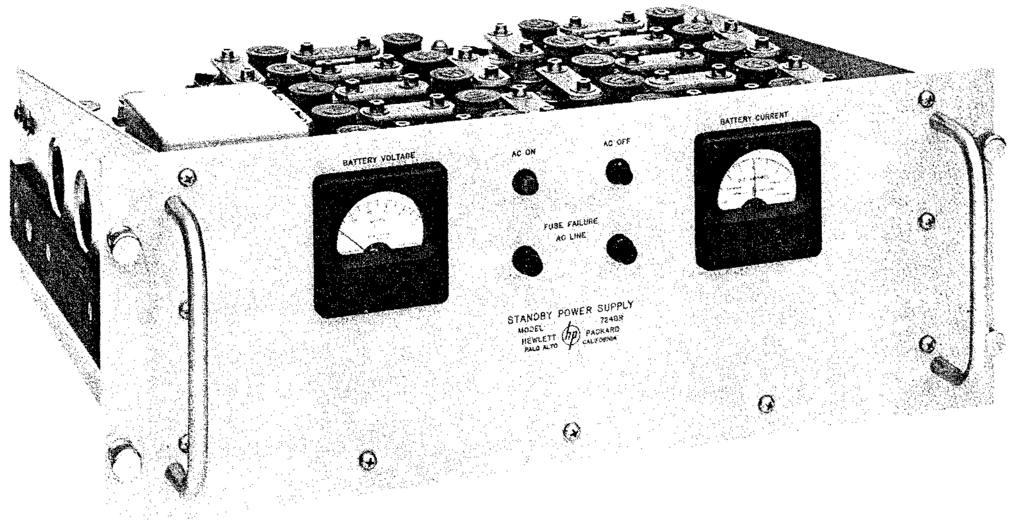
hp 724BR STANDBY POWER SUPPLY



ADVANTAGES

- Standby battery provides up to 84 hours operation of frequency and time standard equipment operation in the event of power line failure
- Compact design; all solid-state components
- No switching between battery and load, or battery and charging circuitry
- Built in alarm circuits, provision for remote alarm
- Recharges internal battery automatically after power failure

USES

- Provides power for hp Models 103AR/104AR Quartz Oscillators and hp Model 113BR Frequency Divider and Clock
- Suitable as standby power supply for other standard systems or equipment requiring continuous operation from 24 volts dc

DESCRIPTION

Hewlett-Packard Model 724BR Standby Power Supply enables continued operation of primary frequency or time standards in the event of ac line failure. It also permits use of the standard at various locations, since the system can be kept in operation for up to 84 hours during transport.

Model 724BR is designed specifically to provide power for the hp 113BR Frequency Divider and Clock and for hp 103AR or 104AR Quartz Oscillators, or for other stable oscillators operating from 24 volts dc. The 724BR is designed to operate with its standby battery floating across the regulated output, so that the battery automatically assumes the load in case of ac failure. Since no switching is employed between battery and external load, transfer of load to and from the standby battery does not affect the operation of the hp Frequency/Time Standard System. When ac power is restored, it reassumes the load and the battery is recharged automatically.

STANDBY BATTERY OPERATION

A 16 ampere-hour vented nickel-cadmium standby battery fits inside Model 724BR. In normal operation the standby battery is charged to approximately 60% of full charge. When the battery has its normal charge it will provide a minimum of 48 hours standby operation (at an average ambient temperature of 25°C) of an hp Model 113BR Frequency Divider and Clock and an hp Model 103AR or 104AR Quartz Oscillator. A switch at the rear of the instrument provides for charging the battery to full capacity when longer standby operation is anticipated. A fully charged battery provides up to 84 hours standby operation. When the battery is discharged, a maximum of two weeks operation from the ac line brings the battery to normal charge. Model 724BR is also equipped with a connector for external batteries, if additional standby capacity is required, or if remote battery location is preferred.

ALARM SYSTEM

Front panel alarm lights show the operating condition of the standard system, indicating whether

hp 724 EEM 4000

operating voltage is AC LINE or BATTERY. Additional lights show the existence of FUSE FAILURE on the ac line.

A DPDT relay (form C) is provided for operating remote alarms from an independent power source. These contacts may be wired to indicate the operating condition as AC LINE or BATTERY.

CHASSIS TRACKS FOR CONVENIENCE

Model 724BR is rack mounted and is equipped with heavy duty chassis tracks to facilitate inspection and maintenance of the internally mounted standby batteries.

On special order, a model can be supplied to meet performance requirements of MIL-E-16400, class 4.

SPECIFICATIONS

Output Voltage:
24 ±1 vdc

Rated Current (Total External Load):
300 ma, nominal*

Over Current Protection:
Current limiter provides short-circuit protection, eliminates need for load-fuses.

Alarm Indicators:
Panel lamps indicate OPERATING VOLTAGE as (1) AC LINE or (2) BATTERY. Additional lamps indicate AC LINE FUSE FAILURE.

Remote Alarm Provisions:
DPDT relay contacts (form C) provided at rear terminals for operating remote alarm from separate power system. Contacts rated at 3 amperes (resistive) at 115 volts ac or dc.

* Suitable for operating ⓗⓟ 113BR and 103AR or 104AR at any temperature from 0-50°C.

Panel Meters:
Voltmeter and ammeter indicate battery voltage and battery charge/discharge current.

Power Requirements:
115/230 volts ±10% vac, 50-1000 cps

Battery Supplied:
16 ampere hour vented nickel-cadmium

Output Connectors:
MS type female connectors at rear mate with 103AR/104AR, 113BR power cables.

External Battery Provision:
MS 3102E-14S-2S female connector, with cap, at rear.

Weight:
75 lbs. including battery, 25 lbs. without battery

Dimensions:
19 in. wide, 7 in. high, 14 in. deep (max. behind panel, including cable allowances)

Accessories Furnished:
Power cable, 6 feet long, with NEMA line plug and MS 3106A-10SL-3S plug for rear chassis power connector. Mating plug for external battery connector.

TENTATIVE DATA

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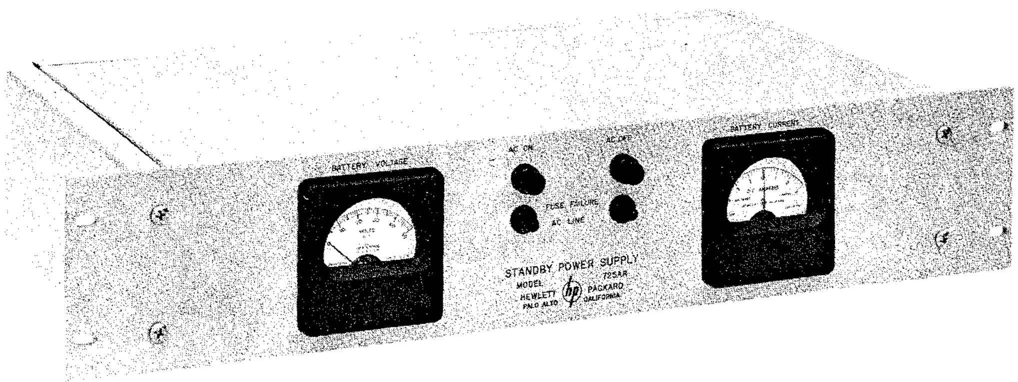
hp MODEL 725AR STANDBY POWER SUPPLY



ADVANTAGES

- Standby battery keeps frequency and time standard equipment in operation during power line failure
- Compact design; all solid-state components
- No switching between battery and load, or battery and charging circuitry
- Built in alarm circuits, provision for remote alarm
- Recharges internal battery automatically after power failure

USES

- Provides power for hp Models 103AR/104AR Quartz Oscillators and hp Model 113BR Frequency Divider and Clock
- Suitable as standby power supply for other equipment or systems requiring continuous operation from 24 volts dc

DESCRIPTION

Hewlett-Packard Model 725AR Standby Power Supply enables continued operation of primary frequency or time standards in the event of ac line failure. It also permits use of the standard at various locations, since the system can be kept in operation for 6 hours or more during transport.

Model 725AR is designed specifically to provide power for the hp 113BR Frequency Divider and Clock and for hp 103AR or 104AR Quartz Oscillators, or for other stable oscillators operating from 24 volts dc. The 725AR is designed to operate, with its standby battery floating across the regulated output, so that the battery automatically assumes the load in case of ac failure. Since no switching is employed between the battery and external load the transfer of load to and from the standby battery has no effect on the operation of the hp Frequency/Time Standard system. When ac power is restored, it reassumes the load and the battery is recharged automatically.

On special order, a model can be supplied to meet performance requirements of MIL-E-16400, class 4.

STANDBY BATTERY OPERATION

A 2 ampere-hour sealed nickel-cadmium standby battery fits inside Model 725AR. When the battery has its normal charge it will provide a minimum of 6 hours standby operation (at an average ambient temperature of 25°C) of an hp Model 113BR Frequency Divider and Clock and an hp Model 103AR or 104AR Quartz Oscillator. When the battery is discharged, a maximum of two weeks operation from the ac line brings the battery to normal charge. Model 725AR is also equipped with a connector for external batteries, if additional standby capacity is required, or if remote battery location is preferred.

ALARM SYSTEM

Front panel alarm lights show the operating condition of the system, indicating whether operating voltage is AC LINE or BATTERY. Additional lights show the existence of FUSE FAILURE on the ac line.

A DPDT relay (form C) is provided for operating remote alarms from an independent power source. These contacts may be wired to indicate the operating condition as AC LINE or BATTERY.

hp 725 EEM 4000

SPECIFICATIONS

Output Voltage:
24 ± 1 vdc

Rated Current (Total External Load):
300 ma, nominal*

Over Current Protection:
Current limiter provides short-circuit protection, eliminates need for load-fuses.

Alarm Indicators:
Panel lamps indicate OPERATING VOLTAGE as (1) AC LINE or (2) BATTERY. Additional lamps indicate AC LINE FUSE FAILURE.

Remote Alarm Provisions:
DPDT relay contacts (form C) provided at rear terminals for operating remote alarm from separate power system. Contacts rated at 3 amperes (resistive) at 115 volts ac or dc.

* Suitable for operating ℏ 113BR and 103AR or 104AR at any temperature from 0-50°C.

Panel Meters:
Voltmeter and ammeter indicate battery voltage and battery charge/discharge current.

Power Requirements:
115/230 volt ± 10% vac, 50-1000 cps

Battery Supplied:
2 ampere hour sealed nickel-cadmium

Output Connectors:
MS type female connectors at rear mate with 103AR/104AR, 113BR power cables.

External Battery Provision:
S3102E-14S-2S female connector, with cap, at rear

Weight:
20 lbs. including battery

Dimensions:
19 in. wide, 3-1/2 in. high, 12 in. deep. (max. behind panel, including cable allowances)

Accessories Furnished:
Power cable, 6 feet long, with NEMA line plug and MS 3106A-10SL-3S plug for rear chassis power connector. Mating plug for external battery connector.