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CHANGE 1

DEPARTMENT OF THE ARMY TECHNICAL BULLETIN

CALIBRATION PROCEDURE FOR FREQUENCY AND TIME MEASUREMENTS

Headquarters, Department of the Army, Washington, DC
11 September 2001

TB 9-4931-539-35, 4 August 1992, is changed as follows:

1. Remove old pages and insert new pages as indicated below. New or changed material is indicated by a vertical bar in the margin of the page.

Remove pages	**Insert pages**
1 and 2	1 and 2
11 and 12	11 and 12

2. File this change sheet in front of the publication for reference purposes.

By Order of the Secretary of the Army:

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REPORTING OF ERRORS

You can help improve this publication. If you find any mistakes or if you know of a way to improve the procedure, please let us know. Mail your letter or DA Form 2028 to: Commander, U. S. Army Aviation and Missile Command, ATTN: AMSAM-MMC-MA-NP, Redstone Arsenal, AL 35898-5230. A reply will be furnished to you. You may also send in your comments electronically to our e-mail address: ls-lp@redstone.army.mil or FAX 256-842-6546/DSN 788-6546.

SECTION I
GENERAL INFORMATION

1. Purpose. This information and guidance for personnel who are involved with frequency and time measurements. This covers frequency and time standardization information and the present frequency and time capabilities and techniques.

2. Applicability. This bulletin is applicable to all TMDE support activities (TSA), Army National Guard (ARNG), and Government owned contractor operated facilities (GOCO), to include the U.S. Army Primary Standards Laboratory (APSL).

3. Definitions

a. Accuracy. The accuracy of a frequency standard is the difference between its measured frequency and the U.S. Naval Observatory (USNO) time and frequency standard. Accuracy is usually expressed in parts in $10^{N.}$

b. Diurnal shift. Diurnal shift is a phase offset between eat local standard and a very low frequency (VLF) signal caused by a shift from a daylight propagation path to a night path. An opposite (approximately) equal phase offset will occur when propagation changes from a night path to a daylight path.

c. Global Positioning System (GPS). GPS is a worldwide, satellite-based radio navigation system developed by the U.S. Department of Defense (DOD).

d. Precise frequency. Signifies a frequency (time interval) requirement within 1 part in 10^N.

e. Precise time. Signifies a time requirement within 10 ms.

f. Retrace. Retrace describes the ability of a frequency standard to return to an original frequency after an offset period. For example, the quartz oscillator will retrace to less than 1 part in 10^8 of the original frequency within 45 minutes following a 24-hour off period. Fast warm-up quartz oscillators will achieve a stability of 5 parts in 10^{10} in less than 24 hours. However, the frequency must be adjusted to the accuracy needed. The exact frequency at which high stability oscillators will stabilize after an off period is not known and may be any value from the original frequency to the retrace specification.

g. Stability. The stability of a frequency standard is its frequency change. Stability is usually expressed in parts in 10^N/day for the time interval of interest.

h. Standards. Signify the reference values of time and time interval. These standards are determined by astronomical observation and by the operation of atomic clocks. They are disseminated by the transport of clocks, radio transmission, and other means.

i. Time. The designation of an instant on a selected time scale, astronomical or atomic. It is used in the sense of the time of day.

j. Time Interval. Indicates the duration of a segment of time without reference to when the time interval begins and ends. Time interval may be given in seconds of time.

SECTION II
GENERAL DISCUSSION

4. VLF Tracking System. Since frequency is the reciprocal of time, the atomic second is used as the standard for frequency. Radio station WWVB at Fort Collins, CO, transmits a standard 60 kHz carrier frequency directly traceable to NIST. This signal carries a basic accuracy of 2 parts in 10^{11} and is normally transmitted 24 hours a day over the continental U.S. In addition to WWVB, there are a number of other stations which transmit carrier frequencies with equal accuracy. These frequencies are listed in tables 1 and 2 below. Occasionally, due to poor reception caused by weather, sunspots, transmission path length, etc., the standard VLF signals cannot be suitably used. An alternative is the TIMESHARED OMEGA system which transmits repetitively on assigned time segments of a 10-second duration. Basic accuracy is to parts in 10^{11}.

5. System Components. A local frequency standard can be maintained to within a few parts in 10^{10} by phase comparison with a received VLF carrier transmission. This VLF transmission is picked up by the Model 599-700R Ferrite Loop Antenna and applied to the Model 599J/K VLF Tracking Receiver. Basic accuracy of the 599J/K is 2 parts in 10^{11}. The VLF receiver and phase comparator provide a precision measurement of relative phase between the transmitted VLF carrier frequency and the local time base reference (Model 105A or FS-323). The output of the phase comparator is used to drive a phase shifter for automatically locking the local time base reference with the selected VLF carrier. The phase of the local time base frequency is thus locked to the phase of the received VLF carrier signal. A strip chart recorder responds to error signals indicating slight phase deviation between the two signals and provides a visual indication to allow the operator to adjust the local standard. When the frequency of the local oscillator has been calibrated, it becomes the local standard for calibration of counters, oscilloscopes, etc. A frequency difference meter (Model 527E or FDM-2100) is connected between the local oscillator and the instrument under test and is used to determine the fractional frequency difference between the two. This provides a visual means for adjusting the TI to that of the standard.

Table 1. DOD VLF Radio Stations

Station And Location	Call Letters	Frequency (kHz)	Type Operation	Nominal Radiated Power (kW)	Maintenance Weekly Schedule
NRS(T) Cutler, ME USA 44° 38' 50" N 67° 15' 54" W	NAA	24.0	MSK	1000	Mon. 1400 to 2359 UT (universal time) (If holiday on Mon., maintenance will be performed on preceding Fri.) 1200 to 2000 UT 2d and 4th
NCS Japan Yosami, Japan 34° 58' 15" N 137° 01' 18" E	NDT	17.4	MSK	200	1st Thurs. And Fri. Of month 2300 to 0900 UT All others Thurs. And Fri. 2300 to 0700 UT
NRS(T) Jim Creek, WA USA 48° 12' 15" N 21° 55' 00" W	NLK	24.8	MSK	234	Thurs. 1600 to 2400 UT (During daylight savings time) 1500 to 2300 UT each Thurs. Scheduled off 2 Nov 1500 to 8 Nov 2359 UT
NAVCAMS EASTPAC Laualualei, HI 21° 25' 30" N 158° 09' 20" W	NPM	23.4	MSK	600	1800 to 0400 UT last Wed. And Thurs. Of month 1800 to 0200 UT all other Wed. And Thurs.
NRTF Annapolis, MD USA 38° 59' 30" N	NSS	21.4	MSK	1000	1200 to 2000 UT Testing 2000 to 2200 UT Tues., Operator training 1800 to 2000 UT 2d and 4th Thurs.
NCS H.E. HOLT NWC Australia 21° 49' 01" S 114° 09' 50" E	NWC	22.3	MSK	1000	Mon. 000 to 0800 UT
NIST BOULDER, CO USA	WWVB	60.0	VLF	15	No Scheduled Maintenance
Aquada P.R. NAU	NAU	28.5	MSK	100	1200 to 2000 Wed.
Rugby, England	GBR	16.0	FSK	750	1000 to 1400 UT Tues.

[1]May be used if no DOD stations are available.

6. Frequency Measurement. Use of the 599J/K receiver for frequency calibration of a local standard is simple and straightforward. Any relative frequency error between the local frequency standard and the received VLF carrier signal is observable as a phase drift on the MICROSECONDS digital counter and on the strip chart recorder. The rate of this phase drift can be directly interpreted as a fractional frequency error (FFE) in the local standard. The FFE for observed phase changes over various elapsed time intervals can be obtained using the conversion factors listed below:

1 min = 60 s = 6 x 10^7 µs
1 h = 3600 s = 3.6 x 10^9 µs
1 d = 8.64 x 10^4 s
= 8.64 x 10^{10} µs = 86400 s
1 µs/min = 1.667 x 10^{-8}
1 µs/h = 2.78 x 10^{-10}
1 µs/d = 1.16 x 10^{-11}

Table 2. DOD Omega VLF Radio Stations

Station	Letter	Coordinates[1]	Antenna	Operator
NORWAY	A	66 25 12.68 N 13 08 13.07 E	Valley span	NORWEGIAN TELECOMMUNICATION ADMINISTRATION (NTA)
LIBERIA	B	6 18 19.26 N 10 39 51.85 W	Grounded 1400' tower	LIBERIAN MINISTRY COMMERCE, INDUSTRY, AND TRANSPORTATION
KANEOHE HI	C	21 24 16.92 N 157 49 50.96 W	Valley span	U.S. COAST GUARD (USCG)
LA MOURE ND	D	46 21 57.40 N 98 20 08.22 W	Insulated 1400'tower	U.S. COAST GUARD (USCG)
LA REUNION ISL	E	20 58 26.90 S 55 17 23.62 E	Grounded 1400'tower	FRENCH NAVY
ARGENTINA	F	43 03 12.79 S	Insulated 1500' tower	ARGENTINE NAVY
AUSTRALIA ISL	G	38 28 52.42 S 146 56 07.06 W	Grounded 1400'tower	AUSTRALIAN DOT
JAPAN	H	34 36 53.06 N 129 27 13.12 E	Insulated 1500'tower	JAPANESE MARITIME SAFETY AGENCY (JMSA)

[1]WGS-84:

- 2 to 4 nautical mile accuracy, 95% confidence.
- 95% operating time for each station, including scheduled off air.
- Three station availability worldwide 95% of the time.
- No greater than +2 deviation of the phase transmitted signal from the synchronized mean.

The formula for calculating fractional frequency error is as follows:

$$FFE = \frac{\text{difference in microseconds} \times 10^{-6}}{\text{elapsed time in seconds}}$$

For example: If the MICROSECONDS counter reading is 5278.4 at 9:00 a.m. and 5240.1 at 1:30 p.m. of the same day, the elapsed time is 4 h and 30 min, or 16,200 s. The net phase difference is 5278.4 minus 5240.1, or +38.3 µs. The fractional frequency difference, then, is:

$$FFE \quad \frac{+38.3 \times 10^{-6}}{16{,}200} = +2.36 \times 10^{-9}$$

The decrease in the MICROSECONDS counter reading in the example above indicates that the local frequency standard is low in nominal frequency. Knowing this, you would increase the frequency of the local oscillator. Consequently, an increase in the MICROSECONDS counter reading would be indicative of an increase in nominal frequency of the local standard. A decrease in frequency would be required on the local oscillator. There are two methods for calculating the "difference in microseconds" portion of the FFE formula. Notice in the example above that the stop time was subtracted from the start time to obtain the difference. It is equally correct to compute the difference in microseconds by subtracting the start time from the stop time. The magnitude of the phase deviation will remain the same. Only the polarity of the FFE result will change. To alleviate confusion, use whichever method is preferred consistently and disregard the polarity sign in the FFE result. The computation of phase difference using the chart recorded is basically identical to that using the MICROSECONDS counter reading. The chart paper is broken down into a series of grids. Reading vertically, up and down, the right-hand side of the paper is numbered from 1 to 12. This numeric sequence is repetitious and represents a certain amount of elapsed time. The time lapse between numerals (Phase Tracking Rate) is dependent on the position of the SERVO TIME CONSTANT SEC switch. Reading the chart paper horizontally gives the phase deviation. Full scale can be either 10 or 100 μs, depending on the scale setting of the rear panel switch. Ideally, if there is no frequency deviation between the received VLF signal and the local oscillator over a specific time period, a straight line (track) would be produced indicating a zero phase shift (drift). Tracks to the left indicate that the local standard is low in frequency (-) while tracks to the right indicate that it is high in frequency (+). By observing the elapsed time and converting it to seconds and noting the phase deviation in microseconds, fractional frequency error can be calculated. (NOTE: Frequency comparisons should always be made during the daylight hours when VLF propagation is extremely stable.)

7. Adjusting the Local Oscillator. Once the FFE has been computed the data can be used to adjust the local oscillator if required. Adjustment is NOT necessary as long as the local standard is within ±5 parts in 10^{10}. There are two adjustments for both models, 105A and FS-323. These are the COARSE FREQUENCY ADJUST and the FINE FREQUENCY ADJUST. The COARSE FREQUENCY ADJUST is used to change the oscillator's frequency by large increments and is normally made only when the local oscillator is initially installed or has been repaired. Adjustment is accomplished by first setting the FINE FREQUENCY ADJUST control to 250 (midrange) and then connecting the output of the oscillator to an oscilloscope. Next, adjust the COARSE FREQUENCY ADJUST control for a stable display on the oscilloscope. The COARSE FREQUENCY ADJUST control is normally kept covered to prevent accidental adjustment or tampering. Control range of the COARSE FREQUENCY ADJUST is 1 part in 10^6. Ordinarily, the FINE FREQUENCY ADJUST control is the adjustment utilized to correct for FFE. It adjusts the local oscillator frequency by parts in 10^{10} with a maximum range of 500 parts in 10^{10}. To illustrate how the actual adjustment is made, use the previously computed FFE example of 2.36×10^{-9} Since the local standard is not within ±5 parts in 10^{-10}, an adjustment is required. The computed FFE is either subtracted from or added to the current FINE FREQUENCY ADJUST control setting. It will be added if the MICROSECONDS counter reading has decreased (indicating a decrease in nominal frequency of the local standard). It will be subtracted if the MICROSECONDS counter reading has increased (indicating an increase in the nominal frequency of the local standard). For instructional purposes, assume that the FINE

FREQUENCY ADJUST control setting is currently set at 265.2. This setting can be broken down as follows:

10^{-8}		10^{-9}	10^{-10}	10^{-11}
2	6	5	.2	

Because there was a decrease in the MICROSECONDS counter reading in our example, we will add the FFE result of 2.36 x 10^{-9} to the current FINE FREQUENCY ADJUST control setting. This will adjust for the phase deviation between the VLF carrier transmission and the local oscillator. The new control setting will be:

10-8		10-9	10-10	10-11
+2		6	5	.2
	2	3	.6	
2	8	8	.8	

If there had been an increase in the MICROSECONDS counter reading, it would have been necessary to subtract our FFE result from the current FINE FREQUENCY ADJUST control setting. The new control setting would be:

10-8		10-9	10-10	10-11
-2		6	5	.2
		2	3	.6
2	4	1	.6	

SECTION III
FREQUENCY CALIBRATION SYSTEM STANDARD OPERATING PROCEDURES

8. References. All U.S. Army measurements of time and time intervals and calibration will be referenced to the DOD standards for time and time interval, maintained by the USNO, or to acceptable international standards for overseas areas defined in table 1 or 2 above.

9. Radio Transmissions. Use the DOD controlled radio transmissions of time and frequency to the maximum extent practicable.

10. Traceability

a. By DOD directive 5160.51, 14 June 1985, all frequency measurements must be traceable to standards maintained by the USNO. Traceability of all U.S. Army calibration frequency standards is maintained by utilizing standard frequency transmissions.

b. The APSL will maintain traceability to the USNO by means of VLF radio signals or GPS. Each TSA shall be directly traceable to the USNO through its VLF capability. DOD VLF signals, DOD Omega signals or GPS will be used for frequency calibration. VLF stations can be received worldwide, but the convenience of their use will vary with diurnal shift and signal strength. Each location must be evaluated by the user to determine the most usable VLF signals.

c. International frequency standards may be used when applicable.

11. Capabilities

a. VLF Tracking Receiver. The VLF tracking receiver is capable of calibrating to 1 part in 10^{11} on a noon-to-noon basis when propagation conditions are good. Sources having a 1 MHz or 100 kHz output, minimum stability of 1 part in 10^{6} , and a voltage level of 0.5 to 5.0 V into 1000Ω may be used with the receiver. The receiver is a phase tracking system and is not directly comparable to the more commonly used, super heterodyne receivers. The VLF receiver compares the phase of the received signal to the phase of local 100 kHz or 1 MHz frequency source and produces an error signal. The error is recorded on a strip chart. The receiver will not operate without a local 100 kHz or 1 MHz source.

b. Quartz Oscillator. The quartz oscillator has a basic stability specification of ± parts in 10^{10} per day. Output frequencies are 100 kHz, 1 MHz, and 5 MHz. Front and back outputs may be used simultaneously.

c. Frequency Difference Meter (FDM). The FDM can be used to compare stable 100 kHz and 1, 2.5, 5 and 10 MHz sources to the quartz oscillator or other suitable crystal (or atomic) sources. The FDM compares an unknown frequency standard with a reference frequency standard and indicates the difference. The FDM indication is a relative reading. Therefore, the accuracy and stability of the reference must be considered in using the FDM. The comparison capability of the FDM is from ±10 parts in 10^{7} through ±10 parts in 10^{11} (direct reading). By making observations over a period of time the relative stability of an unknown standard can be calculated. Addition of the stability of the reference standard (which is available from VLF measurements) to the relative stability of the unknown frequency standard will yield the stability of the unknown standard.

d. Omega Gating Unit (OGU). The OGU enables the VLF receiver to track omega transmissions. Omega stations broadcast during assigned time segment of a 10 s period on several frequencies including 10.2 kHz and 13.6 kHz. The OGU is basically an electronic switch that enables reception only during a selected time segment. The OGU shall be installed with the VLF tracking receiver and used as propagation conditions permit.

e. VLF/MSK Converter. The VLF/MSK converter enables the VLF receiver to track a form of code known as MSK (minimum-shift-keying). This is a type of MSK in which the bit frequency is equal to twice the difference frequency. In consequence, if a bit is transmitted at frequency No. 1, then one bit at frequency No. 2, and a third at frequency No. 1 again, the phase of frequency No. 1 during the third bit will differ by 180 degrees from what it was during the first bit. Therefore, there is no coherent "carrier" at either of the two frequencies. By a process of frequency doubling, those transmissions at zero phase and those at 180 degrees are restored to equal phase at the second harmonic frequency. Phase tracking of the second harmonic with a VLF tracking receiver is then possible.

f. Atomic Standard. The cesium atomic beam controller oscillator is a primary frequency standard and does not require any other reference when used as a frequency standard. When used as a time standard, calibration is required. Calibration of a cesium standard that is used as a time reference can be coordinated through the U.S. Army Precise Time and Time Interval (PTTI) coordinator. The U.S. Army PTTI coordinator will obtain the calibration service required from the U.S. Observatory. To obtain this service, send a statement of calibration requirements and location where needed to: Director, U.S. Army TMDE Activity, ATTN: U.S. Army PTTI Coordinator, AMXTM-S, Redstone Arsenal, A1 35898-5400.

g. Global Positioning System (GPS). The GPS is a space based radio navigation system which provides position, velocity, and time worldwide. GPS should be fully implemented by the mid-1990's. The system will include 24 satellites. Each satellite will carry two rubidium and two cesium atomic standards. Each GPS satellite broadcasts two carrier frequencies called L1 and L2 (where L1 = 1575.42 MHz and L2 = 1227.6 MHz). A GPS based counter and frequency workstation have been planned to replace the VLF time and frequency method in use now. The system will provide higher accuracy and better worldwide coverage than the VLF system in use.

12. Frequency Calibration System

a. Standard Substitution. Calibration can be performed when necessary by:

(1) Substituting the crystal oscillator in a counter for the quartz oscillator.

(2) Substituting an oscilloscope for the frequency difference meter (an unknown signal can be synchronized with a known signal and the stability computed from the drift rate).

b. VLF Signal Use. A good discussion of VLF receiver operation is contained in the VLF receiver manual; however, the following points should be emphasized.

(1) All-daylight paths should be used for maximum accuracy (all-night paths may be used at lesser frequency). An all-daylight path is defined as one on which daylight falls from transmitter to receiver. In no case should adjustments to the quartz oscillator be performed during diurnal shift transitions.

(2) Phase plots should be repeatable from daylight to daylight, often in parts in 10^{11} Proper tracking can be checked at any time by advancing or retarding the phase serve approximately 2 to 5 µs from its equilibrium tracking position and observing whether or not the servo moves back to this position. It is recommended that the servo be checked by both advancing and retarding. If the plots are not repeatable (i.e., have wide variations), consider the possibility of “long way” propagation. “Long way” propagation means that the VLF receiver receives both a signal by the shortest route and a signal travels the "long way" around the world arriving 180 degrees from the direction of the shortest route. Check for "long way" propagation by switching frequencies and checking for repeatable phase plots. Fluctuations in phase plots are also caused by solar flares, local electrical interference, and local atmospheric interference.

(3) Locations in the continental U.S. should have little trouble with propagation. In overseas locations, technical literature is not available for defining the expected propagation nor can guidance be given to cover all cases. This data must be obtained by observation.

c. Oscillator Calibration. Standard practices for calibration of quartz oscillators, or (more generally) crystal oscillators, shall include:

(1) Warm up all oscillators for specified period in TB or use a minimum of 24 hours warm-up if period is unspecified.

(2) Set for a minimum frequency difference between the test instrument (TI) and the quartz oscillator. After 24 hours (of stabilization) check TI frequency stability.

(3) Oscillators with stability specifications equal to or better than the standard quartz oscillator shall be calibrated to full specifications using the VLF receiver and directly by substituting the TI for the standard quartz oscillator. The period for stability shall be 24 hours minimum.

13. Maintenance of Records

a. A frequency logbook will be maintained by all calibration activities that perform frequency/time calibrations.

NOTE

A frequency logbook is not required for the GPS Time and Frequency Calibration Workstation, AUTEK Systems Corporation Model 620.

(1) VLF tracking system users will include, as a minimum, the following information in the logbook:

(a) Starting date and time of monitored track.
(b) Starting MICROSECONDS setting of VLF tracking receiver.
(c) Current standard oscillator setting.
(d) Ending date and time of monitored track.
(e) Ending MICROSECONDS setting of VLF tracking receiver.
(f) Calculated FFE results.
(g) Resulting standard oscillator setting.

(2) Logbooks for other types of frequency monitoring systems will contain all pertinent data necessary to verify proper traceability.

(3) Logbook data will be retained for at least 3 years. Upon request, a copy of the logbook data will be forwarded to USATA.

By Order of the Secretary of the Army:

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