MIL-STD-188-115
31 March 1986

MILITARY STANDARD

INTEROPERABILITY AND PERFORMANCE STANDARDS FOR COMMUNICATIONS TIMING AND SYNCHRONIZATION SUBSYSTEMS

DEPARTMENT OF DEFENSE

SLHC/TCTS

NO DELIVERABLE DATA
REQUIRED BY THIS DOCUMENT

DEPARTMENT OF DEFENSE
WASHINGTON, DC 20301

INTEROPERABILITY AND PERFORMANCE STANDARDS
FOR COMMUNICATIONS TIMING AND SYNCHRONIZATION SUBSYSTEMS
MIL-STD-188-115

1. This military standard is approved and mandatory for use by all Departments and Agencies of the Department of Defense in accordance with OASD (C^3I) Memo; 16 Aug 1983, Subject: Mandatory Use of Military Telecommunication Standards in the MIL-STD-188 Series (see appendix A).

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Director, Joint Tactical Command, Control and Communications Agency, ATTN: C3A-SES, Fort Monmouth, New Jersey 07703-5513, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FOREWORD

1. Originally, Military Standard 188 (MIL-STD-188) covered technical standards for tactical and long haul communications, but later evolved through revisions (MIL-STD-188A, MIL-STD-188B) into a document applicable to tactical communications only (MIL-STD-188C).

2. The Defense Communications Agency (DCA) published DCA Circulars (DCAC) promulgating standards and engineering criteria applicable to the long haul Defense Communications System (DCS) and to the technical support of the National Military Command System (NMCS).

3. As a result of a Joint Chiefs of Staff (JCS) action, standards for all military communications are now being published in a MIL-STD-188 series of documents. The MIL-STD-188 series is subdivided into a MIL-STD-188-100 series covering common standards for tactical and long haul communications, a MIL-STD-188-200 series covering standards for tactical communications only, and a MIL-STD-188-300 series covering standards for long haul communications only. Emphasis is being placed on developing common standards for tactical and long haul communications published in the MIL-STD-188-100 series.

4. In many digital communications systems, the timing relationship of each particular pulse to other pulses in the same sequential stream is fundamental to interpreting the information contained in the pulses. If time division multiplexing, time division switching or time division multiple access systems are used, this time relationship is a determining factor as to whom the information belongs, as well as its meaning, i.e., particular time slots are assigned for particular purposes. The loss of proper timing can be catastrophic and cause all received information to be meaningless. Therefore, it is imperative that effective, survivable, economical system timing be provided for military digital communications.

5. Accurate time is required for certain systems to establish synchronization under jamming conditions to enhance reception or to avoid detection. Without accurate time, these systems would not be able to provide these capabilities.

6. This document provides mandatory system standards for planning, engineering, procurement and use of timing and synchronization capabilities for DoD digital communications systems and indicates design objectives for preferred network timing capabilities.

7. This document supersedes those applicable portions of MIL-STD-188-200.

CONTENTS

FIGURES

Page

TABLES

APPENDIXES

1 SCOPE

1.1 Purpose. The purpose of this document is to provide a standardized method of timing that will fully support Department of Defense (DoD) communications timing requirements during peace and war, as well as support new communications functions as the need arises.

The technical parameters promulgated by this document represent, in general, minimum interoperability and performance characteristics that may be exceeded in order to satisfy specific requirements. This document provides guidance required to achieve interoperability between existing and future communications facilities. In addition, emphasis has been placed on allowing maximum flexibility of system configurations to satisfy diverse user requirements. This document is not intended to be an engineering textbook or a reference handbook. However, this document does contain technical background information to explain how some of the standards were derived, why certain parameters were standardized, where these standards apply and how the standards are to be used.

This document does not apply to systems that do not have to interoperate with other systems. However, changing requirements and possible future needs and the benefits of standardization must be considered before making this determination.

This document is not a stand-alone, comprehensive, and engineering reference containing all the technical details required for the design of new equipment and facilities or the preparation of specifications. Consequently, design details such as size and weight limitations, cable assemblies and power supply requirements are not contained in this document.

NOTE 1: "Timing" is used here in a general sense which includes scheduling, regulating the rate and causing an action or event to occur at a desired instant relative to another action or event. Hence, synchronization is considered to be a special case of timing.

NOTE 2: "Time" is used in the sense of time-of-day (TOD).

NOTE 3: "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.

1.2 Application. This document is to be used in the planning, design, development, procurement and installation of all new DoD digital communications systems and those existing digital communications systems undergoing major modifications or upgrade. This document does not necessarily apply to leased commercial facilities, but such facilities should be selected to be compatible with the requirements contained in this document.

It is not intended that existing systems be immediately converted to Comply with the requirements of this standard. All design and Development of equipment or systems started after the effective date of This document shall satisfy the requirements of this document. This Document is in accordance with DOD directive (DODD) 5160.51, Precise Time and Time Interval (PTTI) Standards and Calibration Facilities for Use of Department of Defense Components and Federal Standard 1002 (FED-STD-1002), Time and frequency. Reference Information in Telecommunications Systems.

1.3 Objectives; The objectives of this document with respect to timing and synchronization are: (a.) to insure a high degree of interoperation of long haul and tactical equipment, subsystems and systems consistent with military requirements; (b.) to provide a degree of system performance acceptable to a majority of users of communications systems; and (c.) to achieve interoperability, performance and compataiblity in the most economical way.

1.4 System standards and design objectives. The parameters and other Requirements specified in this document are mandatory system standards (see appendix A) if the word “shall” is used in connection with the parameter value or requirement under consideration. Non-mandatory system parameters and design objectives are indicated as optional by the word “should” in connection with the parameter value or requirement under consideration “Will” is used to express a declaration of purpose or intent. For a definition of the “system standards” and “design objective”, see FED-STD-1037.

2 REFERENCED DOCUMENTS

2.1 Government documents. The following documents and the documents referenced in the cited documents (first tier) form a part of this standard to the extent specified. All others are for guidance and information only.

2.1.1 Specifications, standards, and handbooks. Unless otherwise specified, the following specifications, standards and handbooks of the issue listed in that issue of the Department of Defense Index of Specifications and Standards (DODISS) specified in the solicitation form a part of this standard to the extent specified herein.

Standards

Federal

FED-STD-1002	Time and Frequency Reference Information in Telecommunications Systems
FED-STD-1037	Glossary of Telecommunications Terms

Military

MIL-STD-188-114	Electrical Characteristics of Digital Interface Circuits
MIL-STD-461	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
DoD-STD 1399/441	Interface Standard for Shipboard Systems, Precise Time and Time Interval

2.1.2 Other Government documents, drawings, and publications. The following Government documents, drawings, and publications form a part of this standard to extent specified herein.

DODD 5160.51	Precise Time and Time Interval (PTTI) Standards and Calibration Facilities for Use by Department of Defense Components

Copies of specifications, standards, handbooks, drawings, and publications required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.

2.2 Order of precedence. In the event of a conflict between the text of this standard and the references cited herein, the text of this standard shall take precedence.

3 DEFINITIONS

3.1 Definition of terms. Definition of terms used in this document shall be as specified in FED-STD-1037. Those definitions of terms unique to timing and synchronization and not defined in FED-STD-1037 are provided in appendix B.

3.2 Abbreviations and acronyms. The abbreviations and acronyms used in this document are defined in FED-STD-1037. Those abbreviations and acronyms unique to timing and synchronization and not defined in FED-STD-1037 are provided in appendix C.

4 GENERAL REQUIREMENTS

4.1 Networks.

4.1.1 Timing and synchronization. All operations within each node of a network shall be timed from the nodal clock. Data shall be read into a retiming unit with the timing of the received signal and transferred out with timing determined by the nodal clock. In accordance with FED-STD-1002 and DODD 5160.51, whenever interoperability between telecommunications networks is dependent on time or frequency or time and frequency reference information, the time and frequency shall be referenced to (known in terms of) the existing standards of time and frequency maintained by the U.S. Naval Observatory (USNO) or any source traceable to Coordinated Universal Time (UTC) of the USNO. The accuracy of the time and frequency reference information with respect to UTC (USNO) or a UTC (USNO) traceable source shall be commensurate with individual design and interface requirements. This can be accomplished using internal and external timing and synchronization. Either internal or external timing shall be referenced to UTC (see DODD 5160.51 and FED-STD-1002) when available.

NOTE 1. The term "referenced to (known in terms of)" as used above identifies a common reference between networks, systems, facilities, etc., in order to achieve interoperability. For example, knowing the frequency accuracy of two networks does not necessarily indicate the relative frequency offset between the two networks unless the frequency accuracies are "referenced to (known in terms of)" the same (a common) frequency reference.

NOTE 2. FED-STD-1002 identifies the UTC (USNO) and UTC National Bureau of Standards (NBS) as the two reference sources for Federal Agencies. However, DODD 5160.51 identifies the USNO as the single DoD component responsible for uniform and standard time and time interval operations.

NOTE 3. Once interoperation is achieved, referring to a common reference external to the network(s) may not be required, since the network(s) could implement master-slave derived timing or some other scheme to maintain timing and synchronization. However, whenever timing or synchronization must be re-established, UTC is the common reference to be used.

4.1.1.1 Internal timing. The network should be designed to minimize dependence on any particular external timing system. The timing capability and any timing reorganization needed after link or node failure should occur automatically, where practicable. There are many methods to provide timing information for use by clocks throughout the

4.1.1.2 External timing. UTC (USNO) reference sources for timing and synchronization, if not available from within the network, shall be obtained from an external source whose timing is traceable to the master clock of the USNO (see appendix I), in accordance with FED-STD-1002 and DODD 5160.5. When external timing references are to be used as the primary means of timing for a network: the accuracy, the coverage, and the reliability of the overall (reference and acquisition) system should be specified.

4.1.1.3 Communications overhead for timing. In a multichannel network, communications overhead for achieving correct frame synchronization in continuously operating individual links, including all synchronization codes or time markers, shall not exceed two percent of the total communications capacity of any link. When the link is part of a digital communications network, the overhead requirements for the network synchronization shall be included in this same two percent of communications capacity.

4.1.2 Time-dependent networks. Communications networks requiring all elements of the network to be time-synchronized shall use as a common reference either UTC or whatever station is serving as master. Where a master reference is employed, its timing shall be referenced to UTC (USNO) to maximize the availability of qualified referenced sources (see appendix F). The nodes and the network shall be protected from the possible failure of the dissemination system(s) by a capability for independent time maintenance or self-organization or both of the network. In addition to an UTC traceable time reference, alternate means of initial clock setting or synchronization should be provided. Maintenance of time accuracy after the initial setting and between updates shall be by continuous operation of the nodal clock(s) and maintenance of frequency (rate) accuracy. When updating or rate correction is needed to maintain the required accuracy, all communications systems requiring precise time shall, when available, use timing traceable to UTC (USNO).

4.1.2.1 Time ambiguity. For the purpose of transferring time, the minimum period of time ambiguity for any transmission links in a communications network should be one minute.

4.2 Links.

4.2.1 Timing and synchronization. This section applies only to paths employing isochronous signals where the spacing between individual characters or frames are fixed. All point-to-point digital communications paths should either be provided with a timing capability making them compatible with digital communications networks or have the capability for convenient upgrading to satisfy such a requirement.

NOTE: Point-to-point transmission paths include transmission links that interconnect the individual nodes of a communications network.

4.2.1.1 Synchronization of receivers. Receivers shall be synchronized to the unit interval of the received signal by deriving timing information from the received mission bit stream unless there is a demonstrated need for a special capability provided by using a synchronization signal outside the mission bit stream. All receiving equipments shall be provided with the capability to synchronize to a local timing reference, or provide an error signal to a subservient clock for the purpose of synchronizing the subservient clock to the timing of the received signal. Equipment should be designed or selected to assure that synchronization can be directly achieved without the use of extended searches or prolonged sequences of search operations, for example frequency sweeping. An out-of-synchronization signal shall be provided by all equipments when they are not correctly synchronized. This does not restrict the use of automatic gain control signals or other types of signal processing.

4.2.1.2 Frame synchronization of receivers. Frame synchronization shall be provided by periodically inserting a frame synchronization signal or code into the transmitted data stream or as an alternative using a separate timing path. The preferred method is by insertion into the data stream.

4.2.1.3 Re-acquisition of frame synchronization. Re-acquisition of frame synchronization shall be accomplished without extended searches for framing errors that do not exceed four data unit intervals. Receiving equipment (including demultiplexing and decrypting equipment) should be designed so that whenever a framing error does not exceed four data unit intervals, the needed correction can be determined directly and automatically without a search mode. The number of data unit intervals should be increased to where it is virtually unnecessary to use a search mode after the initial acquisition when the equipment is first placed in operation.

4.3 Nodes. Major communications facilities frequently host a number of colocated nodes having precise time or frequency requirements. At such sites, the establishment of a precise time and frequency reference to serve all of the nodes shall be made available. The local reference shall have an interface that is compatible with all nodes that it might serve. The standardized interface described in 4.3.1.4 shall be provided by the reference.

4.3.1 Timing and synchronization. All timing generated within a node shall be derived from its principal clock to maintain a known phase and frequency relationship and shall be distributed to all locations where timing functions occur within the node. Timing from a major or minor node's principal clock shall be distributed to all locations where timing functions occur within the node. Timing at major nodes shall be made available as a reference to minor and access nodes. Each minor node shall also have the capability to operate in a free-running mode.

4.3.1.1 Clocks. Nodal clocks fall into one of four categories: principal clocks, alternate (backup) clocks, subservient clocks and other clocks. All principal and alternate clocks shall be capable of operating in a free-running mode when their timing references are not available. The free-running performance of the clocks, in combination with the capacity of the data buffers (variable storage buffers), shall allow slip-free operation. Clocks shall not require resynchronization in the free-running mode when used at all major communications facilities employing continuous mission bit streams for a minimum of 24 hours following initiation of the free-running period.

4.3.1.1.1 Principal clocks. Every node shall use a principal clock which shall provide the time, frequency, and timing source requirements for all the peripheral equipment at the node. All local functions that require precise time or frequency shall be referenced to this principal clock.

NOTE: The principal clock can be either a single clock or an ensemble of clocks providing a single output.

4.3.1.1.2 Alternate (backup) clocks. Major nodes shall be provided with at least one alternate (backup) clock. The alternate clock(s) shall derive timing from the principal clock in a manner to minimize timing errors or other disturbances when switching from the principal to the alternate clock(s). When available, the sources of reference for a node's alternate clock when it becomes the principal clock shall be the same as those for its principal clock (see appendix J).

NOTE: The alternate clock may be a member of the principal clock system or ensemble when such an arrangement is employed.

4.3.1.1.3 Subservient clocks. For those applications where a controlled (variable) timing offset relative to the principal clock or an alternate clock is required, a subservient clock may be used. Each subservient clock shall have the capability to advance or retard its timing relative to the principal clock in response to a control signal. If the reference from which the control signal is derived should be lost, the subservient clock shall be capable of retaining the best estimate of the required timing offset. A subservient clock, upon loss of the control signal from the receiver, shall be mesochronous to its associated principal clock or its alternate. This permits the subservient clock to use the long term stability of the principal clock.

4.3.1.1.4 Other clocks. All other clocks within a communications node shall derive their timing from the principal clock, its alternate, or a subservient clock.

4.3.1.1.5 Frequency accuracy. Provisions shall be made to maintain the frequency accuracy of the principal clock to satisfy the requirements of 4.3.1.1 during a free-running period.

NOTE: For long haul communications, during a controlled period of operation, (e.g., while referenced to UTC) the average frequency should be maintained accurate with respect to the UTC reference so that no buffer resetting is required due to clock error (see 5.2.4).

4.3.1.1.6 Frequency stability. As required by the communications timing system the frequency stability of the principal clock should be adequate to support all timing requirements at the node. For burst and other intermittent communications, the frequency stability of the principal clock shall be adequate for satisfactory measurement of elapsed time between the most infrequent clock updatings.

4.3.1.1.7 Adjustment (control). Clocks used as a frequency or timing reference for the communications equipment at any particular facility shall have the capability to have their output adjusted. Where cesium, rubidium or high quality quartz oscillators are used as principal clocks, the capability shall be provided for precise adjustment of the clock's output without disturbing the clock itself. The size of the adjustment shall be made available for use in determining the clock's future adjustments, should the clock be placed into a free-running mode.

4.3.1.1.8 Limit cycle. Nonlinear clock control functions that can result in any type of limit cycle for the clock frequency (phase) shall not be employed.

4.3.1.2 Local reference frequencies. When local reference frequencies other than the standard clock frequencies are required for timing in any facility referenced to a principal clock, those frequencies shall be derived from the principal clock (or its alternate) (see 5.2.1). Only local frequency sources with outputs coherent with the reference input shall be used to satisfy this requirement.

4.3.1.3 Data buffers. Data buffers shall be placed in all received bit streams of major nodes of a switched digital communications network. These buffers shall have a sufficiently large capacity to meet the requirements of 4.3.1.1 when operating with the node's principal clock in a free-running or independent mode.

4.3.1.4 Nodal distribution of timing. All systems within a node shall derive their timing from the principal clock at that node. All nodal principal and alternate clocks in multichannel switched networks shall be capable of synchronizing to an external signal. Timing from the nodal principal clock shall be distributed throughout the node. The timing distribution system shall be designed to accept sine wave and square wave inputs, only one of which is supplied at a time. The timing distribution output signal shall be an alternating, symmetrically shaped wave at the required rate. When the output waveform is a sine wave it shall be in accordance with 5.1.1.3. When the output waveform is a square wave, either balanced or unbalanced to ground, it shall be in accordance with the applicable voltage and waveshaping requirements of MIL-STD-188-114.

4.4 Timing at subscriber terminals and access central terminals. Not standardized at this time.

4.5 Electromagnetic compatability (EMC)/electromagnetic interference (EMI). Timing and synchronization subsystems shall comply with the requirements of MIL-STD-461.

NOTE: Additional information may be found in MIL-STD-462, MIL-HDBK-235, MIL-HDBK-237, MIL-HDBK-241, and MIL-HDBK-253.

5 DETAILED REQUIREMENTS

5.1 Networks.

5.1.1 Timing and synchronization. All principal and alternate clocks of a communications system shall be capable of accepting a timing reference from an external source, e.g., NAVSTAR GPS, Loran C, including the output of a portable clock.

5.1.1.1 Long haul network timing. Network timing within the digital Defense Communications System (DCS) will be referenced to UTC via clock systems using external reference at major nodes and referencing minor nodes to major nodes (see appendix H). The long haul system shall use internal timing references that are coordinated with UTC (USNO) when available.

5.1.1.2 Tactical network timing. Network timing for tactical switched digital communications networks shall be capable of using the independent clock technique for timing between major nodes of the network. Provisions shall be made for a node to derive timing from the modulation on a signal received from another node. However, every node shall be capable of operation using a free-running clock. Major nodes with continuous mission bit streams shall have sufficient buffering capability and clock stability to assure slip-free operation for at least 24 hours in a free-running mode. The long term phase stability of the principal clocks shall be sufficient to ensure that when operating independently, timing is maintained between received and transmitted signals within ±25 percent of the data unit interval for periods not less than 24 consecutive hours.

NOTE 1: This does not exclude the use of buffers to maintain the necessary synchronism.

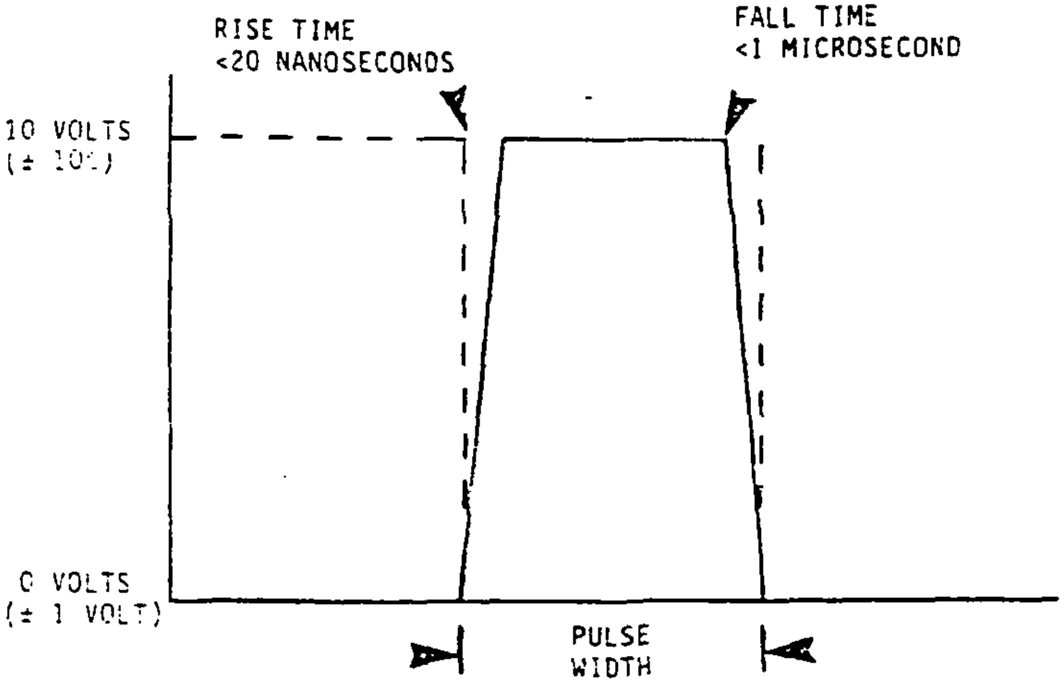
NOTE 2: The time period of 24 consecutive hours specified above does not apply to tactical single channel radio equipment. The length of time period, expected to be less than 24 consecutive hours for this type of equipment, is under consideration.

5.1.1.3 Outputs from timing reference sources. Outputs from timing reference sources shall meet the following:

(a.) The output frequencies shall be in accordance with 5.2.1.

(b.) The harmonic distortion for sine wave signals shall be at least 40 decibels (dB) below the rated output levels. The level of any signal component not a harmonic of the signal frequency shall be at least 60 dB below the rated output level.

(c.) For a one pulse-per-second reference, the reference source shall provide one pulse-per-second UTC with a pulse width of 20 microseconds ±5 percent. The rise time shall be less than 20 nanoseconds and the fall time shall be less than one microsecond. The pulse amplitude should be between 10 volts ±10 percent and 0 volts ±1 volt. This is illustrated in figure 1 and is in accordance with DoD-STD-1399-441.



PULSE WIDTH 20 MICROSECONDS ± 5 PERCENT

FIGURE 1. One pulse-per-second timing signal.

5.1.2 Time-dependent networks. Networks shall not be made continuously dependent upon external time-dissemination services. The capability shall be provided for each node to continue network operation after loss of all external dissemination service. Some degradation of capabilities after dissemination-service loss or failure may be acceptable; however, an alternative timing capability should be provided within the nodes or network.

5.1.2.1 Network time. Principal and alternate clocks shall have the ability to maintain network time from a designated internal source(s) when all external timing references are lost. Networks requiring independent maintenance of accurate time at the nodal level shall employ nodal clocks or ensembles capable of maintaining network time after loss of all external references.

5.1.2.2 Initial setting and maintenance of time. Provisions shall be made at each node for initially setting the nodal clock. Subsequent network interaction shall allow for additional time updates. Nodes that are intermittently connected to networks shall contain a clock of sufficient rate accuracy so that after initial setting and after quiescent periods (in a free-running mode, see 4.3.1.1), the clock remains within system tolerances such that the node can still transmit and receive information.

5.1.2.3 Time-dependent network clock outputs. Clocks (or clock systems) for time-dependent networks shall provide the following outputs:

(a.) The output frequency provided shall be in accordance with 5.2.1.

(b.) The harmonic distortion for sine wave outputs shall be at least 40 dB below the required output levels. The level of any signal component not a harmonic of the output reference shall be at least 50 dB below the required output level.

(c.) Nodal clocks shall provide a one pulse-per-second UTC as shown in figure 1.

(d.) A binary coded decimal (BCD) reference signal shall provide UTC TOD in hours, minutes and seconds. The leading edge of the BCD code (negative going transitions after extended high level) shall coincide with the on-time (positive going transition) edge of the one pulse-per-second signal to within ±1 millisecond (msec). Provisions shall be made for leap second adjustment. The time code shall be a 24 bit serial bit stream using international telegraph alphabet number 2 (ITA-2) code. The bit rate shall be a minimum of 50 bits per second. Rise and fall times shall be in accordance with MIL-STD-188-114. The time word starts with the most significant digit. (This time word provides TOD information, hours, minutes and seconds to within 1 msec)(see figure 2).

NOTE: For additional information, refer to DoD-STD-1399/441.

RATE: 50 BIT PER SECOND
BIT PULSE WIDTH: 20 msec

H = + 6V dc ± 1V
L = - 6V dc ± 1V

EXAMPLE: SELECTED TIME IS 12:34:56

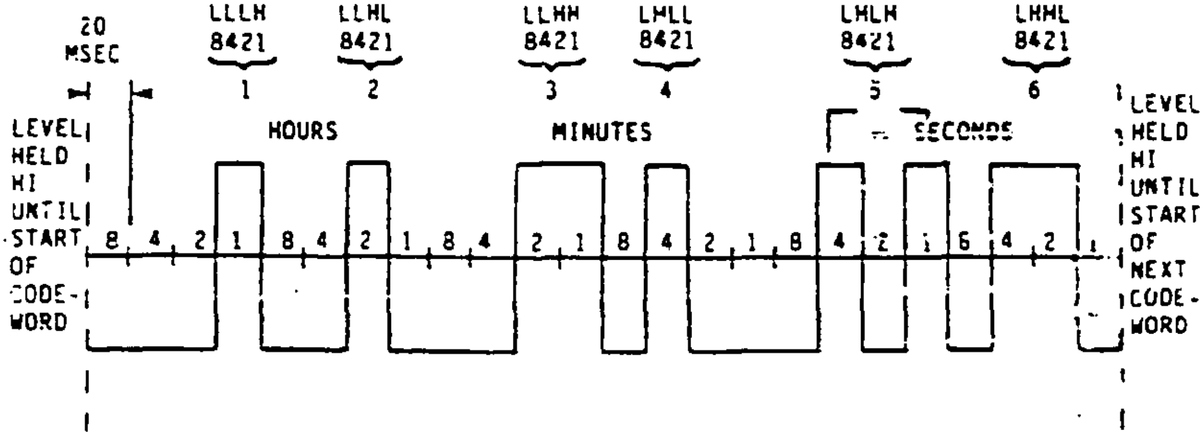


FIGURE 2. 24 bit BCD time code.

(e.) In addition to subparagraph (d.) the 24 bit TOD BCD time code may be immediately followed by 12 bits (three decimal digits) describing the day of the year (DOY) in hundreds, tens, and units of days (in that order) and followed by a high level held until the start of the next codeword. This results in a 36 bit BCD codeword.

(f.) As an alternative or in addition to subparagraph (e.) above, the BCD reference signal may be immediately followed by a four bits (one decimal digit) describing a figure of merit (FOM) of the time signal and immediately thereafter followed by a high level held until the start of the next codeword. This results in either a 28 bit or 40 bit BCD codeword. The meanings of the FOM digits are provided in the table I.

TABLE I. FOM character meanings.

BCD Character	Meaning
all bits high	No information
9	Greater than 10 ms of fault
8	1-10 ms
7	100 us - 1 ms
6	10 us - 100 us
5	1 us - 10 us
4	100 ns - 1 us
3	10 ns - 100 ns
2	1 ns - 10 ns
1	better than 1 ns
0	proper/nominal operation

5.2 Nodes. Principal and alternate clocks shall be provided to the node in accordance with 5.2.1 through 5.2.6. Waveform characteristics of all local frquency sources within the nodes in addition to the principal and alternate clocks are dealt with in 5.2.7 through 5.2.10.

5.2.1 Frequency output. The frequency of the nodal principal clock shall be 1 Megahertz (MHz), 5 MHz, or ($5x2^N$) MHz where N is an integer greater than zero; the preferred frequency being 5 MHz. For nodes requiring accurate time or for those nodes that will at some future date require accurate time, signals or readouts described in 5.1.2.3 shall be provided. A one second marker, described in 5.1.1.3(c), coherent with this frequency should be provided.

5.2.2 Waveform output. The clock output waveform shall be either a sine wave or square wave, the preferred waveform being a sine waveform. When the output waveform is a sine wave it shall be in accordance with 5.1.1.3. When the output waveform is a square wave, it shall be in accordance with applicable voltage and wave shaping requirements of MIL-STD-188-114.

5.2.3 Frequency stability. The stability of both principal and alternate clocks at major nodes should correspond to the fractional frequency fluctuation (square root of the two sample or Allan variance) values shown in table II.

TABLE II. The fractional frequency fluctuation for both principal and alternate clocks at major nodes.

Averaging time (s)	Fractional frequency fluctuation
1	$\leq 7 \times 10^{-11}$
10	$\leq 3 \times 10^{-11}$
100	$\leq 7 \times 10^{-12}$

5.2.4 Frequency accuracy and drift. As a minimum, a cesium beam principal or alternate clock shall have a frequency accuracy of at least 5×10^{-11} (with a design objective of 3×10^{-11}). All principal and alternate clocks shall have a drift rate not exceeding 1×10^{-11} per day (with a design objective of 1×10^{-11}, lifetime). This frequency drift includes the nonstatistical drift in frequency caused by the aging of resonance control devices.

5.2.5 Warm up characteristics. When principal and alternate clocks are turned on initially or after power off periods of at least 24 hours, the frequency reference shall be within 5×10^{9} of the final frequency after an elasped time of 15 minutes.

5.2.6 Settability. Long haul systems shall and tactical systems should provide the means to set the frequency and time of each nodes principal and alternate clocks to UTC when available.

5.2.7 Clocking signal period. A clocking signal period or cycle shall consist of one half-cycle of positive polarity (sense) and one half-cycle of negative polarity (sense). The duty cycle shall be 50 percent, ±1 percent (see note).

NOTE: In the binary sense, each clocking signal period or cycle is composed of two clock signal unit intervals and it follows that a clock signaling rate of 50 Hz is a clock modulation rate of 100 baud (Bd).

5.2.8 Phase relationship between clock and data signals. Subparagraphs 5.2.8.1 through 5.2.8.5 shall apply to all interconnected digital devices operated at baseband.

5.2.8.1 Direct clock control. In a direct clock control timing subsystem only one of the clocks at the two ends of a communications link shall be permitted to be adjusted to reduce timing differences between the clocks (see note 1). All data signal transitions emitted by a source under direct control of an external clocking signal shall occur on (be caused by) the negative to positive transitions of that clock signal (see note 2). The delay between the clocking signal transition and the resulting data signal transition should be a minimum, but in no case shall this delay exceed 12.5 percent of the duration of the data unit interval. For each equipment, once this delay is fixed in hardware, the delay shall be consistent within ±1 percent of the data unit interval for each clocking signal transition. These delay limits shall apply directly at the data source interface (see figure 3).

NOTE 1: This property allows closed loops to be avoided, i.e., it makes it possible to assure that a change in a clock cannot result in a signal passing around a closed path to influence the same clock again.

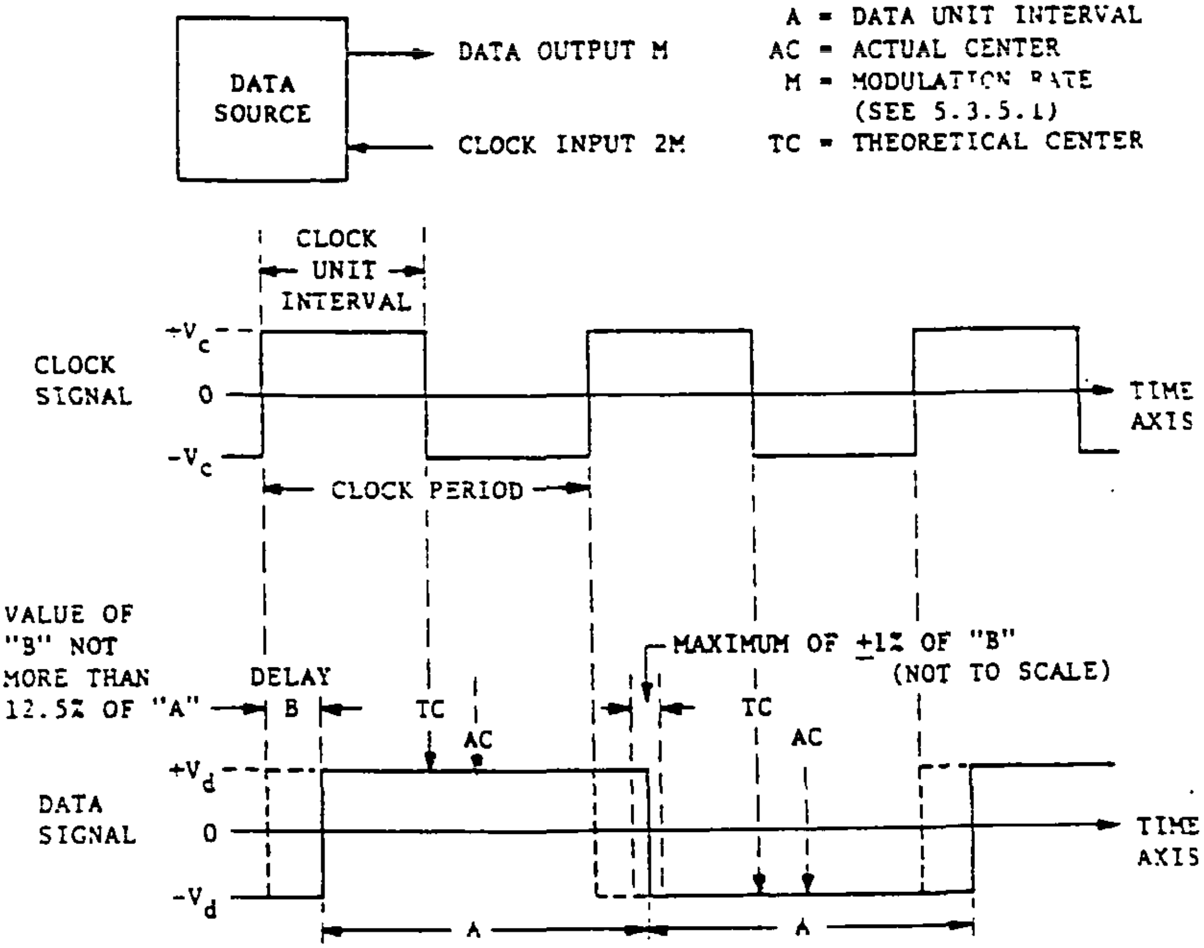


FIGURE 3. Phase relationship between clocking and data signals for direct clock control.

NOTE 2: Direct clock control means control of the data signal by a clocking signal with a modulation rate of twice the data modulation rate.

5.2.8.2 Indirect clock control. For indirect clock control (see note 1), the phase difference between an external clocking signal and a data signal shall be consistent within ±1 percent of the data unit interval at the applicable modulation rate, regardless of the absolute value of the phase difference (see note 2). If the modulation rate of an external clock is divided, within an equipment, to a clocking signal modulation rate of twice the data modulation rate, and then supplied as the equipment clock output, the data signal transitions shall coincide within ±1 percent of the data unit interval with the negative to positive transitions of the clocking output signal (see figure 4).

NOTE 1: Indirect clock control means control of the data signal by a clocking signal with a standard modulation rate greater than twice the data modulation rate (see figure 4).

NOTE 2: The absolute value of the phase difference between an external clock signal and a data signal is not specified for devices in which the external clock signal is related only indirectly to the data signal (see figure 4).

5.2.8.3 Sampling of data signals. Sampling of data signals at a sink interface under the control of an external clock signal shall occur on (be caused by) positive to negative clock signal transitions (see figure 5). For devices in which input data to a sink are sampled under the control of a clocking signal with a modulation rate that is not directly related to the data modulation rate, the phase relationship of the data signal to the clocking signal shall be maintained such that each data unit interval shall be sampled within ±1 percent of the theoretical center of the data unit interval. For start-stop devices using internal, low stability sampling sources, incoming data signals shall be sampled within ±12.5 percent of the data unit interval measured at the actual center of the data unit interval (see figure 3). Any distortion caused by this sampling method shall not be passed onto an output interface. The data signal shall be regenerated before it is retransmitted.

5.2.8.4 Intermittent data transmission. When a gated clocking signal is used for controlling intermittent data transmission, the data signal shall not change state except when requested by a negative to positive clocking signal transition. The quiescent state of the clocking signal shall be at a negative voltage. The quiescent state of the data signal shall be that state resulting from the last negative to positive clocking signal transition (see figure 6).

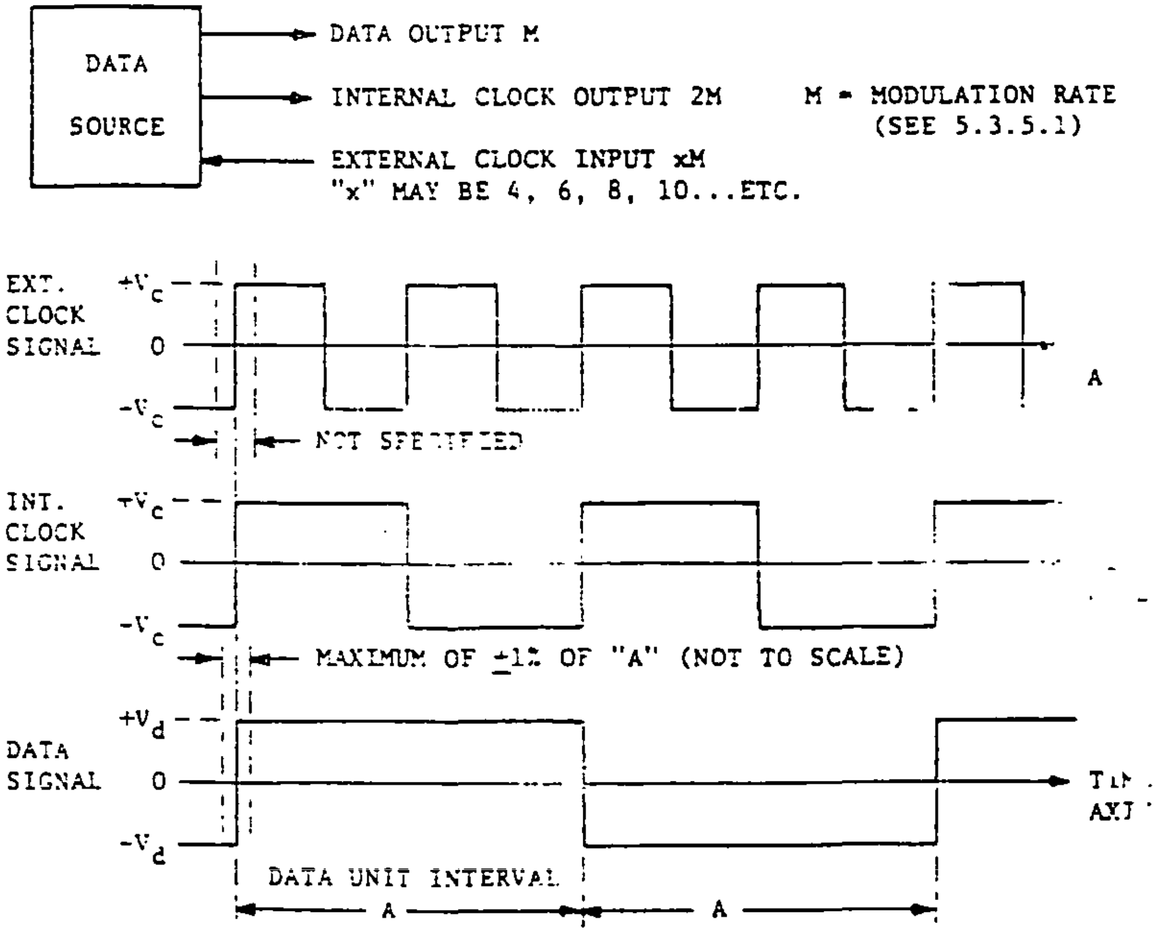


FIGURE 4. Phase relationship between clocking and data signals indirect clock control.

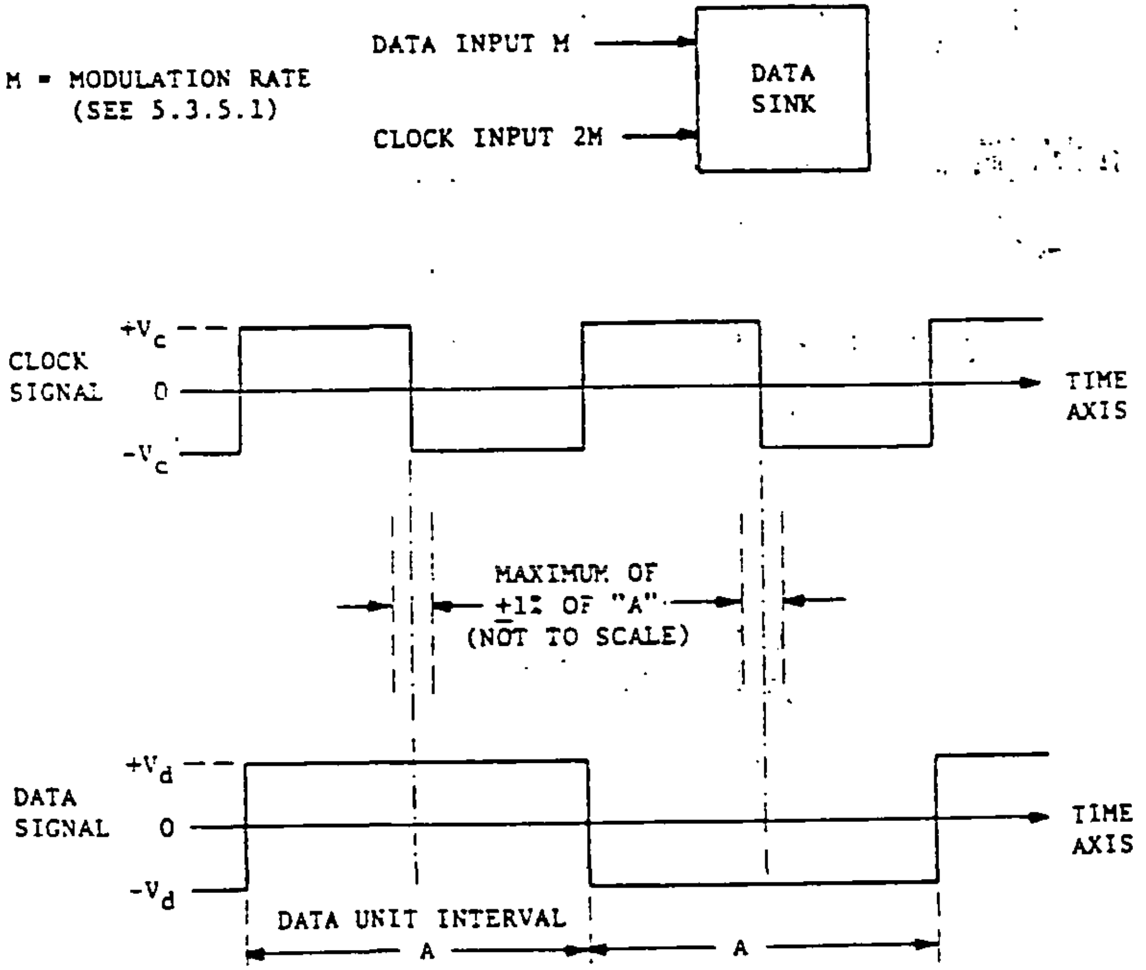
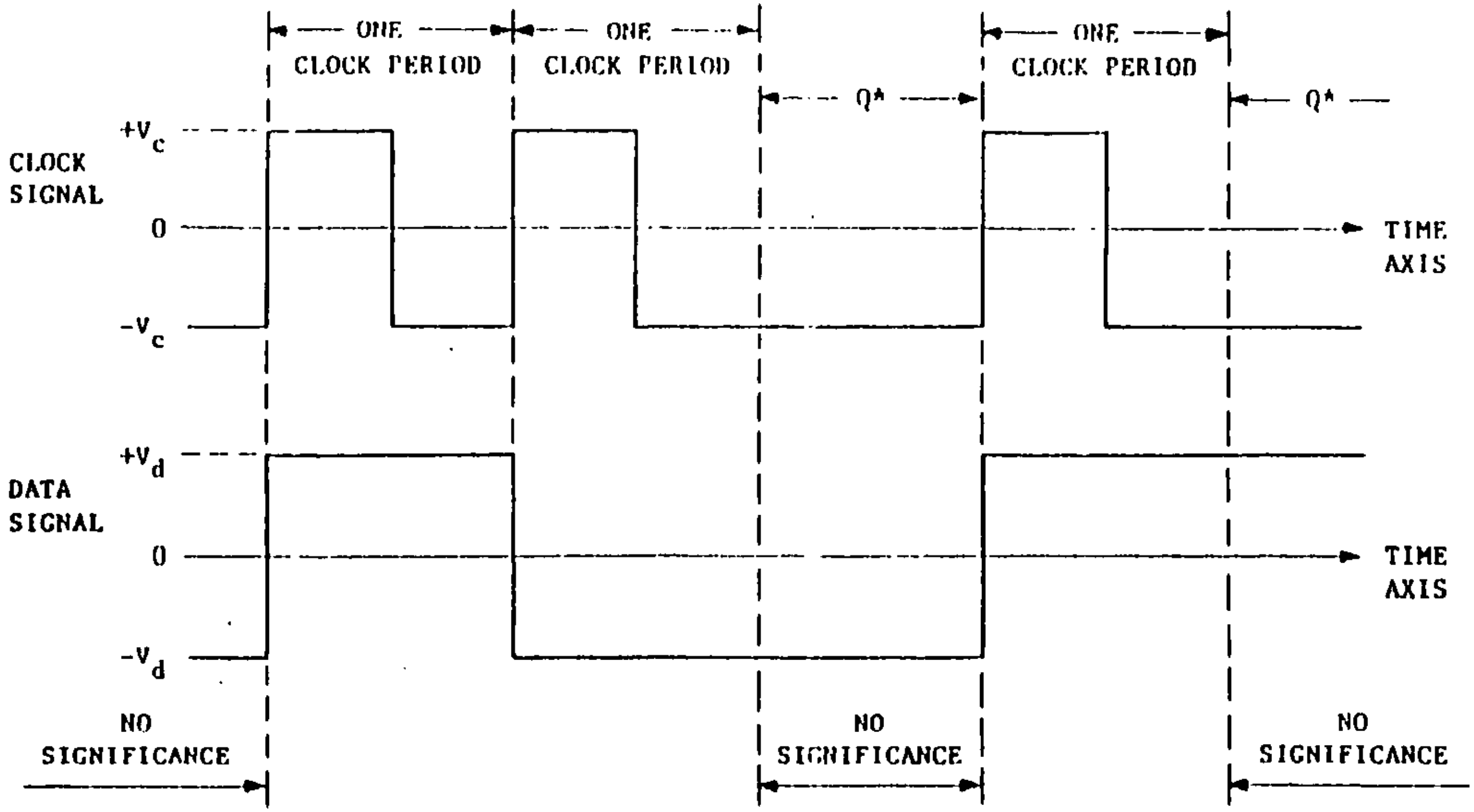


FIGURE 5. Phase relationship between clocking and data signals for sampling of data (direct clock control).



*Q is the quiescent state of the clock. (See 5.3.6.2.4.)

FIGURE 6. Phase relationship between clocking and data signals for intermittent data transmission (gated clock).

5.2.8.5 Start-stop signals. For synchronous devices transmitting start-stop signals and operating from an external clocking signal with a modulation rate that is directly related to the data modulation rate, data signal transitions shall be coincident with negative to positive clocking signal transitions within ±1 percent of the data unit interval (see note 1). For start-stop devices using internal, low stability sampling sources, incoming data signals shall be sampled within ±12.5 percent of the data unit interval, measured at the actual center of the data unit interval (see figure 3). Any distortion caused by this sampling method shall not be passed onto an output interface (see note 2). The data signal shall be regenerated before it is retransmitted.

NOTE 1: This mode is also referred to as isochronous operation.

NOTE 2: This mode is also referred to as asynchronous operation.

5.2.9 Local frequency source output rate. Local frequency sources used for bit rate control in multichannel switched systems shall be capable of providing, as required by the equipment supported, one or more of the following output frequencies coherent with the nodal clock: (a.) 8000N Hz where N can be any integer from 1 to 2000; (b.) 75 multiplied by 2^n Hz where n can be any integer from 0 to 9; (c.) 4000 Hz; (d.) 2000 Hz; and (e.) 50 Hz. For systems in which the local frequency source output is to be used with the one pulse-per-second nodal clock output, a positive-going transition of the clocking signal shall coincide with the on-time (positive-going transition) of the one pulse-per-second nodal clock output.

5.2.10 Local frequency source output waveform. The output waveform of local frequency sources used for bit rate control shall be either a sine wave or a square wave. When the output waveform is a sine wave, it shall be in accordance with 5.1.1.3. When the output waveform is a square wave, it shall be in accordance with applicable voltage and wave shaping requirements of MIL-STD-188-114. The output waveform of local frequency sources, not used for bit rate control, is left to the system designer.

APPENDIX A

MEMORANDUM FROM THE ASSISTANT SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING
16 AUGUST 1983
SUBJECT: MANDATORY USE OF MILITARY TELECOMMUNICATIONS STANDARDS IN THE MIL-STD-188 SERIES

This appendix contains information related to MIL-STD-188-115. Appendix A is a mandatory part of this standard.

THE UNDER SECRETARY OF DEFENSE
WASHINGTON, D.C. 20301

RESEARCH AND
ENGINEERING

16 AUG 1983

MEMORANDUM FOR ASSISTANT SECRETARY OF THE ARMY (INSTALLATIONS, LOGISTICS & FINANCIAL MANAGEMENT)
ASSISTANT SECRETARY OF THE NAVY (SHIPBUILDING & LOGISTICS)
ASSISTANT SECRETARY OF THE AIR FORCE (RESEARCH DEVELOPMENT & LOGISTICS)
COMMANDANT OF THE MARINE CORPS
DIRECTOR, DEFENSE COMMUNICATIONS AGENCY
DIRECTOR, NATIONAL SECURITY AGENCY

SUBJECT: Mandatory Use of Military Telecommunications Standards in the MIL-STD-188 Series

On May 10, 1977, Dr. Gerald Dinneen, then Assistant Secretary of Defense(C^3I), issued the following policy statement regarding the mandatory nature of the MIL-STD-188 series telecommunications standards:

"...standards as a general rule are now cited as 'approved for use' rather than 'mandatory for use' in the Department of Defense.

This deference to the judgment of the designing and procuring agencies is clearly appropriate to standards dealing with process, component ruggedness and reliability, paint finishes, and the like. It is clearly not appropriate to standards such as those in the MIL-STD-188 series which address telecommunication design parameters. These influence the functional integrity of telecommunication systems and their ability to efficiently interoperate with other functionally similar Government and commercial systems. Therefore, relevant military standards in the 188 series will continue to be mandatory for use within the Department of Defense.

To minimize the probability of misapplication of these standards, it is incumbent upon the developers of the MIL-STD-188 series to insure that each standard is not only essential but of uniformly high quality, clear and concise as to application, and wherever possible compatible with existing or proposed national, international and Federal telecommunication standards. It is also incumbent upon the users of these standards to cite in their procurement specifications only those standards which are clearly necessary to the proper functioning of the device or systems over its projected lifetime."

This statement has been reviewed by this office and continues to be the policy of the Department of Defense.

APPENDIX B

DEFINITION OF TERMS USED IN MIL-STD-188-115

This appendix contains general information in support of MIL-STD-188-115. Appendix B is not a mandatory part of this standard.

10 GENERAL

10.1 Scope. This appendix contains definitions of terms used in this document that are not defined in FED-STD-1037.

20 REFERENCED DOCUMENTS

Not applicable.

30 DEFINITIONS

Not applicable.

40 GENERAL REQUIREMENTS

Accuracy - Generally equivalent to the systematic uncertainty of a measured value relative to the true value (see random clock errors, time measurement tolerance).

Aging - The process whereby a frequency determining element (such as a quartz crystal or a rubidium cell) changes its frequency determining properties as a function of its age (not purely a time function but related to its environmental history). For example, a quartz crystal with a frequency of 100 kHz may age until its frequency becomes 100.01 kHz.

Alternate clock - A member of a set of redundant clocks which is not normally active in providing a time, phase, or frequency reference, but is held in reserve to take over the function of the principal clock if the principal clock should fail or some other contingency should arise. The term is used interchangeably with the term "backup clock".

Ambiguity - The characteristic or property whereby more than one possible interpretation, or measurement, or value satisfies the conditions stated. A clock which displays 3 hours 5 minutes could be indicating that time for either A.M. or P.M. or for any day. Further information is required to remove the ambiguity if it causes any problems. In a system where the additional information is already available, it is not necessary for it to be supplied by the clock (see time ambiguity).

Calibration - The process of identifying and measuring errors and either accounting for them or providing for their correction.

Closed loop-noise bandwidth - The integral, over all frequencies, of the absolute value of the closed loop transfer function of a phase lock loop. The closed loop-noise bandwidth when multiplied by the noise spectral density gives the output noise in a phase locked loop.

External timing reference - A timing reference obtained from a source external to the communications system such as one of the navigation systems, many of which are referenced to Coordinated Universal Time (UTC).

False lock - A condition where a phase lock loop locks to a frequency other than the correct frequency.

Fractional frequency fluctuation - Instantaneous fluctuations in the fractional frequency of an oscillator, usually expressed as a function of time.

Free-running capability - The capability of a normally synchronized oscillator that can operate in the absence of a synchronizing signal.

Frequency difference - The algebraic difference between two frequencies that can be of identical or different nominal values.

Hold-in frequency range - Maximum rate of change of frequency between the local oscillator (or clock) and the reference frequency of a phase lock loop for which the local oscillator (or clock) will slowly change frequency in a direction which will reduce the frequency difference and, if not interrupted will eventually reach the lock-in frequency and achieve phase lock.

Improved time reference distribution - A time reference distribution technique employing independence of clock error measurement and correction, and also permitting the time reference information for each node to be derived from a near optimum weight average of several paths between that node and the master node while still avoiding all closed loops.

Independence of clock error measurement and correction - A property by which a change in the time (phase) of a clock at a particular node (whether for clock correction or any other purpose) is not permitted to effect the measurement of the error in the clock at another node.

Independent clocks - A communications network timing subsystem using precise free-running clocks at the nodes for synchronization purposes. Variable storage buffers installed to accommodate variations in transmission delay between nodes are made large enough to accommodate small time (phase) departures among the nodal clocks that control transmission. Traffic is occasionally interrupted to reset the buffers.

Information - The meaning assigned to data by known conventions.

Internal timing references - A timing reference obtained from within the communications system.

Limit cycle - A closed curve in the state space of a closed loop control system to which the state trajectory either approaches asymptotically (stable) or from which it recedes (unstable) for all sufficiently close initial states.

Local clock - A clock located in close proximity to a particular communications station, node, or other facility with which it is associated. The same clock might be a remote clock relative to some other station, node, or facility.

Long term stability - Phase or frequency variations of a timing signal, clock, or oscillator which have frequency components (related to the rate of the variations rather than their magnitude) between 3 microhertz and 3 millihertz (period between 5.6 minutes and 3.86 days).

Loop filter - A filter located between the phase detector (or time discriminator) and the voltage controlled oscillator (or phase shifter) of a phase lock loop.

Loss of synchronization indication - An electrical signal or a visual or audible indication that a receiver or other device is not in synchronism with the signal that it is to process.

Major node - In a timing system for a communications network, a node which is connected to three or more other major nodes, or one which is designated a major node because of its unique location or function (see minor node).

Minor node - A node which is not designated as a major node. Minor nodes are normally connected to no more than two or three other nodes (see major node).

Nodal clock - The principal clock or alternate clock located at a particular node that provides the timing reference for all major functions at that node.

Nominal value - An assigned, specified or intended value of any quantity with uncertainty in its actual realization.

Offset - An intentional difference between the realized value and the nominal value.

Offset frequency - The amount by which an available frequency is intentionally offset from its nominal frequency. In the case of U.S. television networks, the offset is about 3000 parts in 10^{11}.

Overall accuracy - The total uncertainty comprising both systematic and random parts (see accuracy, random clock errors).

Phase detector - A circuit or instrument that detects the difference in phase (in degrees or microseconds) between corresponding points on two signals.

Phase error - Lack of direct proportionality of phase shift to frequency over the frequency range required for transmission.

Phase instability - Phase instability is expressed by the phase change within a given time interval.

Phase microstepper - A device which generates (in response to a digital control signal) subnanosecond (or picosecond) adjustments to the phase of a reference input signal. This can be accomplished either through regular phase progression (nanoseconds/second) for frequency corrections or by individual phase steps (nanoseconds).

Phase reference combining - A characteristic by which improved time reference distribution differs from other time reference distribution techniques. It statistically combines references from different paths for improved accuracy and stability.

Pull-in frequency range - Maximum frequency difference between the local oscillator (or clock) and the reference frequency of a phase lock loop for which the local oscillator will slowly change frequency in a direction which will reduce the frequency difference and, if not interrupted, will eventually reach the lock-in frequency and achieve phase lock.

Quartz clock - A clock containing a quartz oscillator which determines the precision of the clock for the measurement of time intervals (see quartz oscillator).

Quartz oscillator - An oscillator that uses the piezoelectric property of a quartz crystal which is caused to vibrate at a nearly constant frequency dependent on its size and shape. After a crystal is placed in operation, the frequency changes slowly as a result of physical changes. Quartz oscillators are used in most frequency control applications including atomic standards.

Random clock errors - Clock noise performance is frequently characterized in terms of five noise types, one of which will usually predominate in one part of the spectrum while another will predominate in another part of the spectrum.

Rubidium clock - A clock containing a rubidium standard which determines the precision of the clock for the measurement of time intervals (see quartz clock).

Rubidium standard - A secondary frequency standard in which a rubidium gas cell is used to reduce the drift of a quartz oscillator through a frequency lock loop. Because it is dependent on gas mixture and pressure in the cell, it must be calibrated. It has a drift typically 100 times less than the best quartz standard (see quartz oscillator).

Sampling - The process of obtaining a sequence of instantaneous values of a wave; at regular or intermittent intervals.

Secondary time standard - A time standard which periodically requires calibration.

Signal transition - A change from one signalling condition to another; for example, the change from positive to negative, mark to space, one to zero, etc.

Signal transit time - The time required for a signal to travel from one point to another. Signal transit time delay might refer to time required for a signal to travel between specific locations within the same piece of equipment or between specific locations in widely separated pieces of equipment. The particular locations should be identified when the term is used (see time delay).

Single ended - In a timing subsystem, the nodes at the two ends of a link do not exchange timing information with one another for the purpose of determining the difference between the two nodal clocks. Timing is obtained only from the difference between the time of the local clock and the timing of the received signal.

Spectral purity - The degree to which a signal is coherent, i.e., a single frequency with a minimum of sideband noise power.

Spurious modulation of timing signal - Phase or frequency variations of a timing signal, clock or oscillator which have frequency components (related to the rate of the variations rather than their magnitude) greater than 3 kHz.

Stability - The term is used interchangeably with "instability" for specifying the frequency or phase variations of oscillators and clocks.

Standard frequency - A frequency with a known relationship to a specified frequency standard.

Subservient clock - A clock which is mesochronous to an associated master clock, but which may have a controlled phase offset from its associated master. The controlled phase offset may be a function of time, such as that required to permit a subservient clock used with a communications receiver to follow variations in the phase of a received signal due to changing parameters in the propagation path while still maintaining a phase tolerance relationship to the nodal clock (see alternate clock).

Subservient oscillator - The difference between a subservient oscillator and a subservient clock is that the subservient oscillator does not have to identify particular cycles or particular time interval markers, i.e., it is only a source of frequency or phase modulo one cycle. The subservient oscillator is therefore somewhat less complex than a subservient clock. For many communications applications, either would satisfy the requirement. Some applications require a clock (see subservient clock).

Sweep acquisition - A technique whereby the frequency of the local oscillator is slowly swept past the reference frequency in order to assure that the pull-in range is reached (see pull-in frequency range).

Synchronous signals - Two signals are synchronous if their corresponding significant instants have a desired phase relationship (in a strict sense, if they occur simultaneously). The word synchronous describes a relationship between two or more things and cannot describe characteristics of a single signal.

Time ambiguity - A situation where more than one different time or time measurement can be obtained under the stated conditions.

Time delay - The time interval between the manifestation of a signal at one point and the manifestation or detection of the same signal at another point (see signal transit time).

Time division analog switching - Analog switching with common time-divided paths for simultaneous calls.

Time division digital switching - Digital switching with common time-divided paths for simultaneous calls.

Time interval - The duration between two instants read on the same time scale.

Time marker - A reference signal, often repeated periodically, enabling the assignment of numerical values to specific events on a time scale. Time markers can be used as references in establishing synchronization.

Time measurement tolerance - The maximum permissible departure of a time measurement from a correct time measurement.

Timing - A broad term which includes synchronizing as a special case. It implies: (a.) scheduling; (b.) making coincident in time or causing to occur in unison; (c.) setting the tempo or regulating the speed; (d.) ascertaining the length of time or period during which an action, process, condition, or the like continues; (e.) causing an action or event to occur at a desired instant relative to some other action or event; (f.) producing a desired relative motion between objects; (g.) causing an event to occur after a particular time delay; or (h.) determining the moment of an event.

Timing ambiguity - See time ambiguity.

Timing reference - A frequency reference for a clock to follow.

Timing signal - A signal used to aid the synchronization of interconnected equipment.

Tracking error - The deviation of a dependent variable with respect to a reference function.

Transit time - The time required for a signal to travel from one point to another. Sometimes it is also called propagation time delay. Propagation time delay might refer to time required for a signal to travel between specific locations within the same piece of equipment or between specific locations in widely separated pieces of equipment. The particular locations should be identified when the term is used (see time delay, signal transit time).

Uniform time scale - A uniform time scale is one that uses equal intervals for its successive scale intervals, where two intervals are said to be equal if it can be shown that equal processes took place during the two intervals.

Variable storage buffers - Digital data storage units in which a signal can be temporarily stored for purposes of correcting its timing. The signal is usually written into the buffer by one clock having incorrect timing and read out of the buffer by a different clock having correct (or nearly correct) timing. They are also called elastic buffers or simple buffers.

Voltage controlled oscillators - An oscillator whose frequency is a function of an input signal voltage.

Warm-up characteristics - The characteristics that need to be met when the output voltage or current has reached an equilibrium value after power turn on.

APPENDIX C

LIST OF ABBREVIATIONS AND ACRONYMS USED IN MIL-STD-188-115

This appendix contains general information in support of MIL-STD-188-115. Appendix C is not a mandatory part of this standard.

10 GENERAL

10.1 Scope. This appendix contains a list of abbreviations and acronyms used in this document that are not defined in FED-STD-1037.

20 REFERENCED DOCUMENTS

Not applicable.

30 DEFINITIONS

Not applicable.

40 GENERAL REQUIREMENTS

CNI	-	Communications, Navigation and Identification
DODD	-	Department of Defense Directive
DODISS	-	Department of Defense Index of Specifications and Standards
DoD-STD	-	Department of Defense Standard
FED-STD	-	Federal Standard
FOM	-	Figure of merit
ITA	-	International Telegraph Alphabet
MIL-STD	-	Military Standard
ms	-	Millisecond (10^{-3} seconds)
NAVSTAR-GPS	-	Navigation Satellite Timing and Ranging-Global Positioning System
SLHC	-	Standardization of Long Haul Communications (Standardization Area)
TBD	-	To be determined
TCTS	-	Tactical Communications System Technical Standards (Standardization Area)
TOD	-	Time-of-Day

APPENDIX D

DERIVATION OF BUFFER SIZE REQUIREMENTS

This appendix contains tutorial information in support of MIL-STD-188-115. Appendix D is not a mandatory part of this standard.

10 GENERAL

10.1 Purpose. The purpose of this appendix is to derive an equation to determine the buffer storage capacity as a function of the frequency variations resulting from clock instabilities.

10.2 Scope. This appendix is a tutorial on how to derive buffer sizes for independent clocks.

20 REFERENCED DOCUMENTS

Not applicable.

30 DEFINITIONS

For purposes of this appendix, the definitions of FED-STD-1037 and those found in appendix B shall apply.

40 GENERAL REQUIREMENTS

40.1 Relationship between timing errors and frequency differences. The first case is a step (or constant) frequency difference that exists between two independent frequency sources for some stipulated time duration as depicted below.

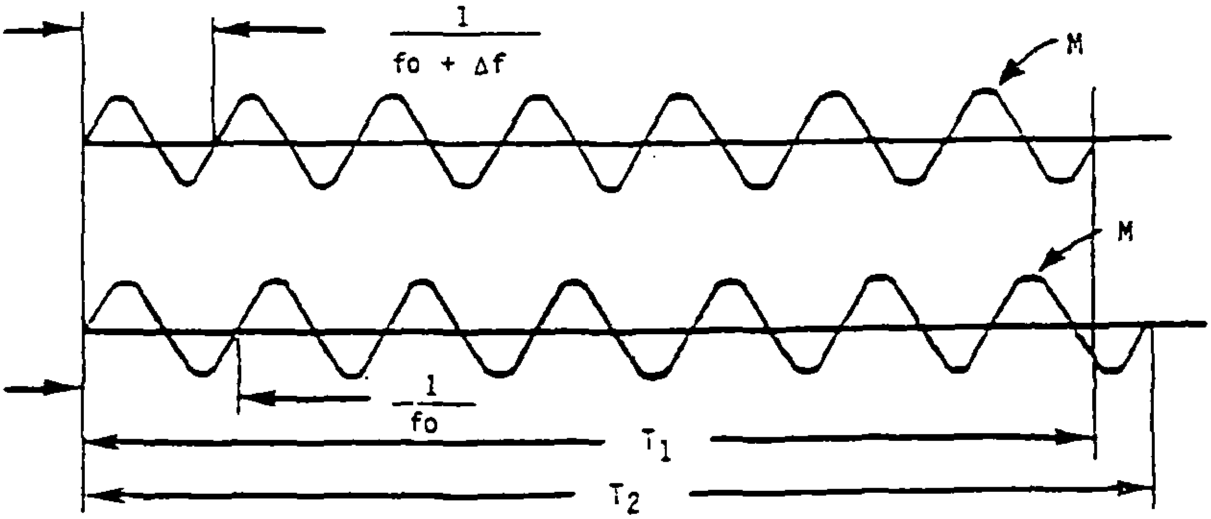


FIGURE D-7. Two independent frequency sources.

M is equal to the number of cycles. From the preceding figure it can be seen that

$$\Delta T = T_2 - T_1 , \tag{1}$$

$$\Delta T = \frac{M}{f_0} - \frac{M}{(f_0 + \Delta f)} , \tag{2}$$

$$\Delta T = M \frac{\Delta f}{f_0 \ (f_0 + \Delta f)} . \tag{3}$$

For $f_0 >> \Delta f$

$$\Delta T = M \frac{\Delta f}{f_0^{\,2}} = T_2 \frac{\Delta f}{f_0} . \tag{4}$$

If stability (S) is defined as the ratio of the maximum frequency change Δf to the initial frequency f_0 during some given time duration $T_0 = T_2$, then

$$S = \left. \frac{\Delta f}{f_0} \right|_{T_0} , \tag{5}$$

and

$$\Delta T = \frac{M}{f_0} S = T_2 S = T_0 S . \tag{6}$$

Equations (4) and (6) identify the timing error resulting when a step frequency difference exists between two independent sources for a time period, T. This represents the worst case and in general would not be a reasonable assumption. The approach employed above will now be expanded to obtain a general expression that may be applied to any form of oscillator frequency difference. This can be accomplished by considering the time dependence of the frequency to comprise frequency ramp segments as shown in figure D-8.

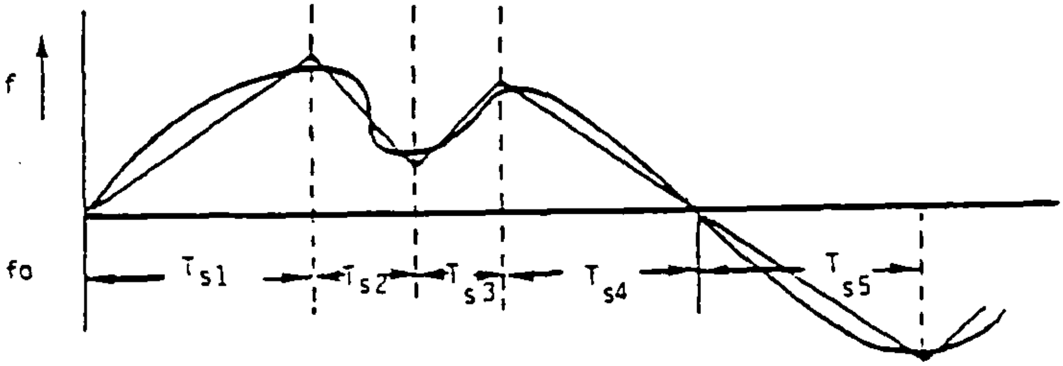


FIGURE D-8. Time dependence of the frequency.

The timing error for each segment may then be determined by quantizing each ramp frequency change into small frequency steps as illustrated below.

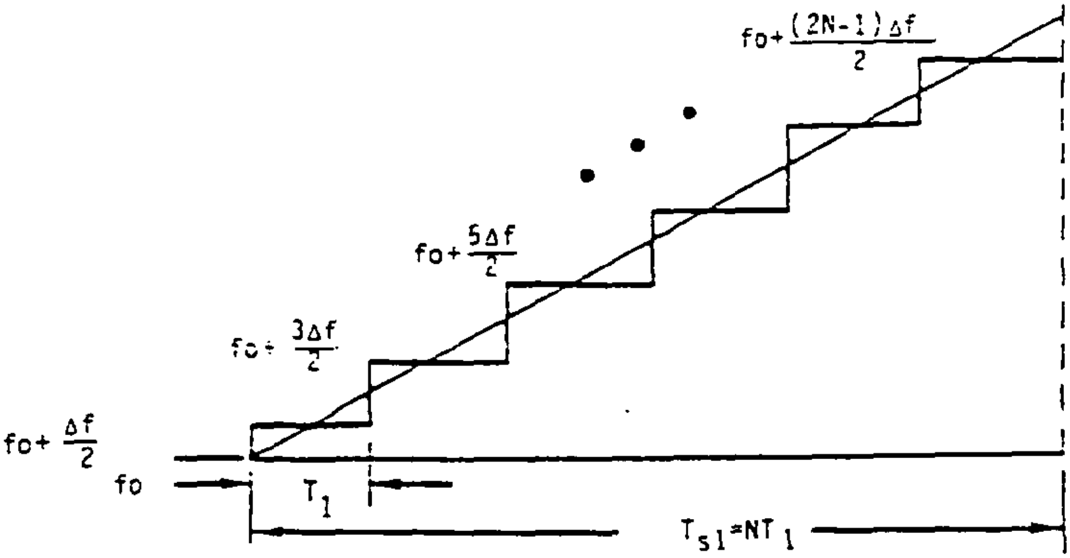


FIGURE D-9. Ramp frequency change.

The timing error associated with each subsegment is then readily identified by making use of the previous derivation for a step frequency change and considering each frequency ramp segment to comprise a group of constant step frequency changes as shown in figure D-9. Applying equation (4) to each subsegment then results in

$$\Delta T = \frac{T_1}{2}\,\frac{\Delta f}{f_0}\ , \tag{7}$$

$$\Delta T_1 = \frac{T_1}{2}\left(\frac{\Delta f}{f_0}\right)\ , \tag{8}$$

$$\Delta T_2 = \frac{3T_1}{2}\left(\frac{\Delta f}{f_0}\right)\ ,$$

$$\vdots$$

$$\Delta T_N = \frac{(2N-1)\,T_1}{2}\left(\frac{\Delta f}{f_0}\right)\ . \tag{9}$$

And the total timing error is simply the sum of the error produced in each subsegment.

$$\Delta T_{T1} = \Delta T_1 + \Delta T_2 + \text{-----} + \Delta T_N\ , \tag{10}$$

$$\Delta T_{T1} = \frac{T_1}{2}\cdot\left(\frac{\Delta f}{f_0}\right)[1 + 3 + 5 \text{ -----} + (2N-1)]\ . \tag{11}$$

The bracketed term on the right side of equation (11) is a simple arithmetic progression whose sum may be expressed in closed form as

$$S = \frac{N}{2}\,[2a + (N-1)d]\ , \tag{12}$$

where N = number of terms
a = first term
d = common difference

and we have

$$S = N^2, \tag{13}$$

hence

$$\Delta T_{T1} = \frac{T_1 N^2}{2} \left(\frac{\Delta f}{f_o}\right) . \qquad (14)$$

ΔT_{T1} would be positive or negative (i.e., the timing error would be advanced or retarded) depending on the sign of the instantaneous frequency difference relative to the reference frequency f_o.

A similar analysis applied to segment two would yield

$$\Delta T_{T2} = \frac{T_2 N^2}{2} \left(\frac{\Delta f}{f_o}\right) , \qquad (15)$$

or in general

$$\Delta T_{Ti} = \frac{T_i N^2}{2} \left(\frac{\Delta f}{f_o}\right) . \qquad (16)$$

Hence the total timing error over m frequency segments is given by

$$\Delta T_T = \sum_{i=1}^{m} \frac{T_i N^2}{2} \left(\frac{\Delta f}{f_o}\right) , \qquad (17)$$

where ΔT_T = total time error,
T_i = quantized time interval in (i)th time segment,
$N\Delta f$ = maximum frequency change in (i)th segment,
NT_i = total time duration of (i)th segment,
f_o = reference frequency.

Equation (17) may be applied to any anticipated or known oscillator frequency change to determine the timing errors introduced.

40.2 Derivation of the total error equation. When the frequency change or difference can be expressed as an integrable function, it is possible to derive a closed form equation which quantitatively establishes the time error associated with the frequency variation.

Equation (4) indicates that the timing error for a stipulated time interval ΔT is related to the frequency difference between two clocks as follows

$$\Delta\epsilon_T = \frac{\Delta f}{f_o} \Delta T \, , \qquad (18)$$

$$\Delta\epsilon_T = \frac{(f - f_o)}{f_o} \Delta T \, . \qquad (19)$$

This corresponds to the existence of a constant frequency difference during time interval ΔT. The total error is obtained by taking the sum of all incremental errors which occur during time interval ΔT. Taking the limit of this sum as the time increment approaches zero

$$\epsilon_T = \lim_{\substack{\Delta T \to 0 \\ n \to \infty}} \sum_{i = 1}^{n} \frac{(f - f_o)}{f_o} \Delta T_i \, , \qquad (20)$$

which from the fundamental theorem of integral calculus becomes

$$\epsilon_T = \int_0^T \frac{(f - f_o)}{f_o} dt \, , \qquad (21)$$

where $f - f_o = f_d$, the frequency variation which occurs during time interval ΔT. The above equation can be used to identify the timing error associated with any continuously varying and integrable frequency difference f_d.

40.2.1 Derivation of a closed form error equation for a step frequency difference.

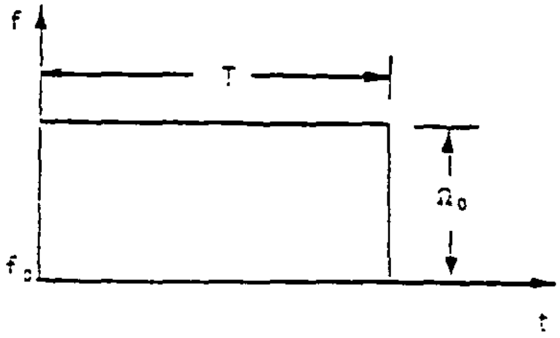


FIGURE D-10. Step frequency difference.

$$f_d = \Omega_0$$

$$\epsilon_T = \int_0^T \frac{\Omega_0}{f_0}\, dt$$

$$\epsilon_T = \frac{\Omega_0}{f_0} T \qquad (22)$$

40.2.2 Derivation of a closed form error equation for a ramp frequency difference.

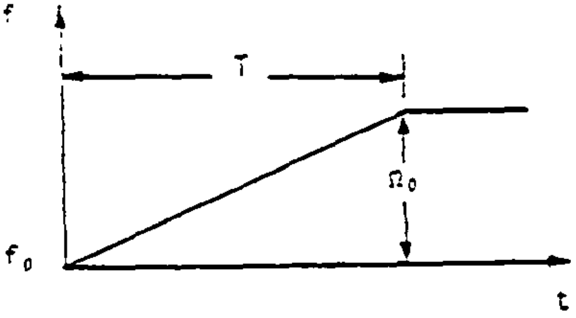


FIGURE D-11. Ramp frequency difference.

$$fd = \frac{\Omega_0}{T} t$$

$$T = \int_0^T \frac{\Omega_0}{f_0 T}\, tdt$$

$$\epsilon_T = \frac{\Omega_0}{f_0} \; \frac{T}{2} \qquad (23)$$

40.2.3 Derivation of a closed form error equation for a sinusoidal frequency difference.

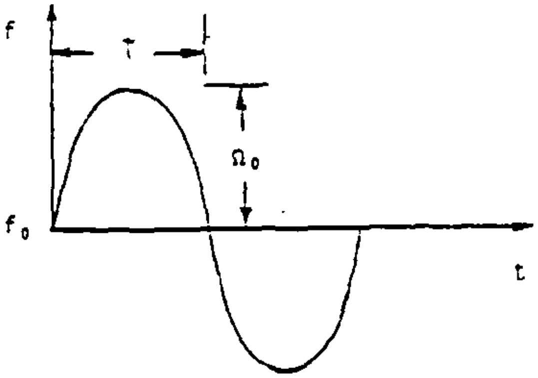


FIGURE D-12. Sinusoidal frequency difference.

$$fd = \Omega_0 \sin \left(\frac{\pi t}{T}\right)$$

$$\epsilon_T = \frac{\Omega_0}{f_0} \int_0^T \sin \left(\frac{\pi t}{T}\right) dt$$

$$\epsilon_T = \frac{2\Omega_0 T}{\pi f_0} \tag{24}$$

The required buffer storage (Q) is equal to twice the quantity of bits contained in a time duration equal to the timing ϵ_T, as shown below. The factor of two is required since buffers are reset to their mid-point to allow for both positive and negative time differences.

$$Q = \frac{2\epsilon_T}{t_r} = 2\epsilon_T f_r \quad , \tag{25}$$

where f_r = bit rate of incoming stream.

The following sections will use the derived equations to illustrate the buffer storage capacity required to accommodate the frequency variations resulting from clock instabilities and transmission media propagation characteristics.

50 DETAILED REQUIREMENTS

50.1 Example using a cesium clock. The long-term variation for a cesium atomic clock can be maintained to within ±3 x 10^{-12}. The total combined frequency difference between two independent cesium clocks would be 6 x 10^{-12}. By using equation (22) and equation (25), the required buffer size Q for a buffer reset interval "T" of 24 hours would be given by

$$Q=1x10^{-6}f_r. \tag{26}$$

The capacity requirements for the trunk group buffers at nodes equipped with cesium clocks would therefore be as given in table D-III.

TABLE D-III. The capacity requirements for the trunk group buffers at nodes equipped with cesium clocks.

Trunk group transmission rate (in kb/s)	Required buffer capacity (in bits)
16	1
32	1
64	1
128	1
512	1
1544	2
2048	3
20000	20

50.2 Example using a rubidium clock. Although a rubidium clock has excellent stability over a relatively short time period, such as 24 hours, its frequency variation over an extended period is cumulative. Consequently, periodic recalibration is required to avoid excessive buffer size requirements. The stability over 24 hours for a rubidium clock is 1 part in 10^{11}, therefore, during the first 24 hours after recalibration, the buffer storage required would be essentially the same as for the cesium clock which is typically 1 part in 10^{11} per month. Subsequent 24 hours periods, however, experience larger frequency differences due to the systematic (non-statistical) drift inherent in the rubidium clock which is typically 1 part in 10^{11} per month. This leads to the need for larger buffers during the subsequent 24 hour intervals. If a linear frequency drift is assumed, a frequency drift of 1 x 10^{-11} per month would correspond to a change of 3.3 x 10^{-13} per 24 hours. The maximum buffer requirement would occur during the 24 hour period just prior to recalibration. The frequency difference for that interval would be

$$f_d = \left[(2 \times 3.3 \times 10^{-13}N) + (2 \times 10^{-11})\right] f_0 , \tag{27}$$

where N = number of days between recalibration.

The factor of 2 is to account for the total possible frequency difference between the clocks.

A recalibration interval of 6 months (182 days) yields a buffer size requirement of

$$Q = 2.42 \times 10^{-5} f_r. \tag{28}$$

The capacity requirements for the trunk group buffers at nodes equipped with rubidium clocks would therefore be as shown in table D-IV.

TABLE D-IV. The capacity requirements for the trunk group buffers at nodes equipped with rubidium clocks.

Trunk group transmission rate (in kb/s)	Required buffer capacity (in bits)
16	1
32	1
64	2
128	4
512	14
1544	38
2048	50
20000	484

50.3 Example using line-of-sight (LOS) links. Frequency variations for LOS links are negligible.

50.4 Example using tropospheric links. Frequency variations associated with tropospheric systems have never been established but it is known that rapid phase changes are experienced. It will be assumed here that under the worst condition the phase can instantaneously change by a time interval corresponding to the maximum range difference which can occur over a tropospheric link. This is approximately 0.4 us for the parameters associated with a typical tactical tropospheric transmission link. The trunk group bit rates to be employed in the land-based systems comprised of multiplexing 32 kb/s channels with a maximum capacity of 72 channels. For the maximum size group, this corresponds to a transmitted bit rate of 2.304 Mb/s. This reduces to a buffer requirement of only ±1 bit, as follows

$$Q = 0.4\ (10^{-6}) \times 2.3\ (10^{6}) = .92. \tag{29}$$

50.5 Example using satellite links. The buffer storage requirement for a satellite link is rather large when the system timing is not made synchronous by eliminating the time variation associated with the Doppler effect. With stationary terminals, the Doppler effect results only from the relative motion of the satellite. For a satellite in synchronous orbit, the radial velocity change is sinusoidal with a period of 24 hours. The largest value of peak range rate occurs when the ground terminal latitude is 72 degrees and the orbital inclination of the satellite is 2.5 degrees. The maximum range rate, $\overline{V}$, in this situation is 20 meters/sec. The peak Doppler frequency which results from this radial velocity is given by

$$f_d = \frac{2\overline{V}f_c}{C} = \Omega_0 . \tag{30}$$

Combining equation (24) and equation (30) identifies the timing error as

$$\varepsilon_T = \frac{4\overline{V}T}{\pi C} , \tag{31}$$

and establishes a buffer storage requirement Q of

$$Q = \frac{8\overline{V}T}{\pi C}\ f_r , \tag{32}$$

where T = ½ period = 12 hours,
$\overline{V}$ = 20 m/s,
C = velocity of light,
= 3×10^{8} m/s .

Utilizing the known parameter values and accounting for the buffer requirement during the negative Doppler excursion results in

$$Q = 7.32\ (10^{-3}) \times f_r . \tag{33}$$

The buffer requirements for stationary ground terminals would be as shown in table D-V.

TABLE D-V. The buffer requirements for stationary ground terminals.

Trunk group transmission rate (in kb/s)	Required buffer capacity (in bits)
16	188
32	235
64	469
128	937
512	3758
1544	11303
2048	14992
20000	146400

The required storage is identified in terms of trunk group bit rates. A much larger overall storage requirement would occur if the available satellite bandwidth is shared by many trunk groups using TDMA. In this case, the storage requirement is dictated by the composite bit rate transmitted through the satellite and the total buffer storage requirement could be much greater than in table D-V.

The buffer requirements identified above are for a satellite link which does not incorporate any method for eliminating the Doppler effect on the transmitted bit rate. Several concepts exist which can be employed to partially or completely eliminate the time variations inherent in a satellite link.

(This page intentionally left blank)

APPENDIX E

ANALYSIS OF SYNCHRONIZATION PERFORMANCE

This appendix contains information related to MIL-STD-188-115. Appendix E is not a mandatory part of this standard.

10 GENERAL

10.1 Purpose. The purpose of this appendix is to illustrate the analysis of synchronization parameters that must be established to assure adequate synchronization performance.

10.2 Scope. This appendix is a tutorial on how to derive synchronization parameters.

20 REFERENCED DOCUMENTS

TRI-TAC Architecture for Tactical Switched Communications Systems, Annex F3 Network Timing.

30 DEFINITIONS

For purposes of this appendix, the definitions of FED-STD-1037 and those found in appendix B will apply.

40 GENERAL REQUIREMENTS

40.1 Analysis of synchronization performance. When timing sources are slaved to another clock, parameter values must be established to assure that adequate synchronization performance is realized.

To identify values for the hold-in range and the pull-in range parameters, it is necessary to determine the transient and noise performance of synchronizing loops. A second order (frequency correcting) loop will be assumed in order to facilitate the establishment of typical parameter values. A functional block diagram of a general second order loop synchronization system is shown in figure E-13. The closed loop transfer function is:

$$\frac{\theta_o}{\theta_i}(S) = \frac{w_o}{w_i}(S) = \frac{\text{Through Transfer Function}}{1 + \text{Loop Transfer Function}} \qquad (34)$$

$$= \frac{1 + mT_o S}{1 + mT_o S + (T_o/K) S^2} \qquad (35)$$

where T_0 = Time constant,
K = Total loop gain,

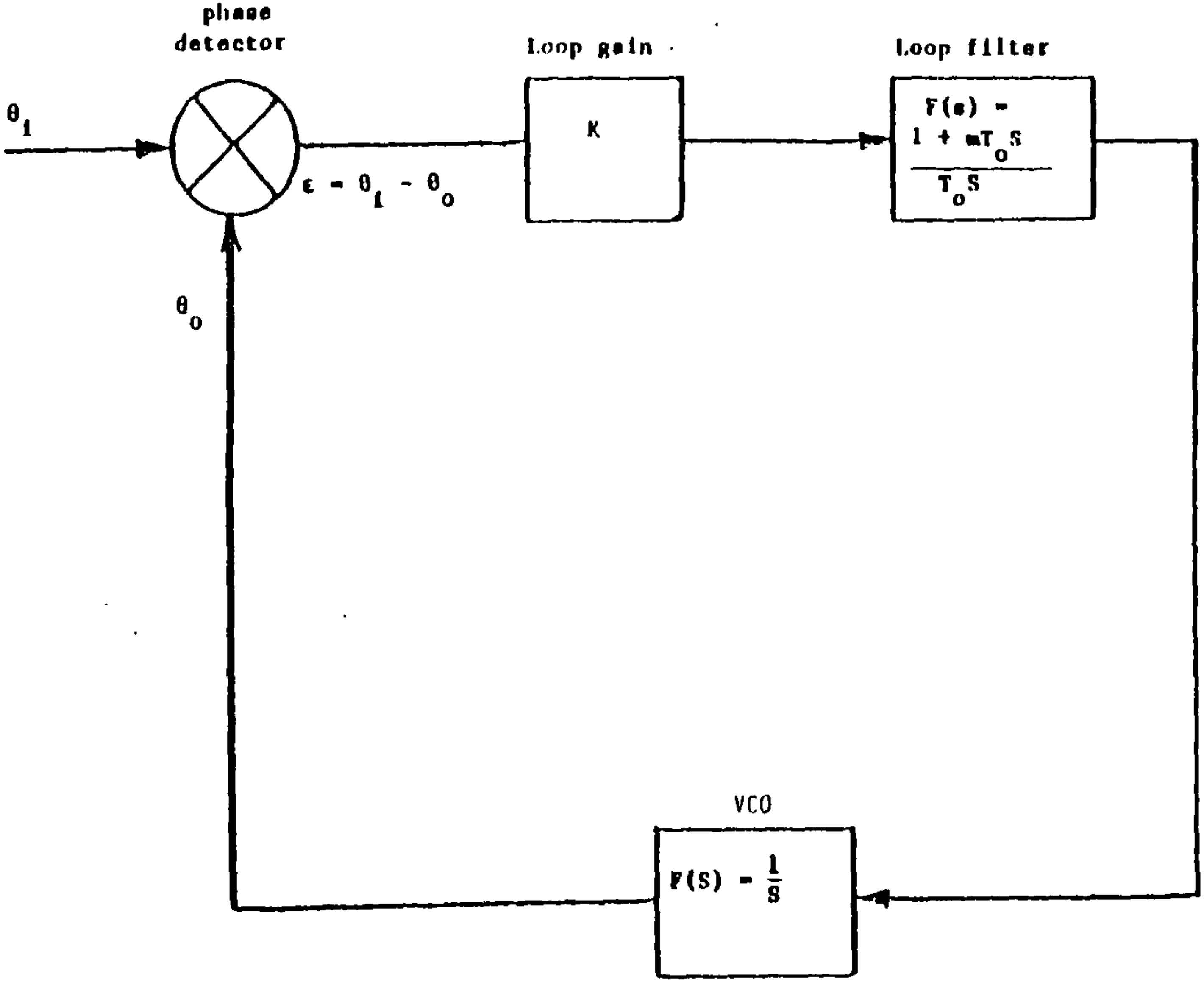


FIGURE E-13. Second order phase lock loop.

substituting $\omega_n = \sqrt{K/T_o}$ yields

$$\frac{\theta_o}{\theta_i}(S) = Y(S) = \frac{1 + mT_oS}{1 + mT_oS + (1/\omega_n)^2 S^2} \quad . \qquad (36)$$

The damping coefficient ξ is equal to

$$\xi = \sqrt{\frac{(m\ T_o)^2}{4/\omega_n^2}} = \frac{m\ T_o}{2/\omega_n} \quad , \qquad (37)$$

and putting ξ in equation (36) yields

$$Y\ (S) = \frac{1 + (2\xi/\omega_n)\ S}{1 + (2\xi/\omega_n)\ S + S^2/\omega_n^2} \quad . \qquad (38)$$

By using figure E-13, we can see that the tracking error is

$$\varepsilon(S) = \Theta_i(S) - \Theta_o(S) \quad . \qquad (39)$$

Combining equations (36) and (39) gives

$$\frac{\varepsilon(S)}{\Theta_i(S)} = 1 - Y(S) \quad , \qquad (40)$$

then combining equations (38) and (40) gives

$$\varepsilon\ (S) = \frac{(1/\omega_n)^2 S^2}{1 + (2\xi/\omega_n)S + (1/\omega_n)^2 S^2}\ \Theta_i(S) \quad . \qquad (41)$$

A damping ratio of .5 results in a minimum noise error and when ξ equals $1/\sqrt{2}$ or .707, it yields a minimum noise plus the transient error. However, when $\xi = 1$, this minimizes the transient error and simplifies the analysis with only a small difference in the overall loop performance. The total difference in the closed loop noise bandwidth between $\xi = .5$ and $\xi = 1$ is only 20 percent.

By letting $\xi = 1$

$$\varepsilon(S) = \frac{(1/\omega_n)^2 S^2}{1 + (2/\omega_n) S + (1/\omega_n)^2 S^2} \theta_i(S), \tag{42}$$

finally

$$\varepsilon(S) = \frac{S^2}{(S + \omega_n)^2} \Theta_i(S). \tag{43}$$

This establishes the transient performance of the loop for any input function $\Theta_i(S)$.

Identification of the closed loop bandwidth parameter ω_n establishes all the principal characteristics associated with a second order synchronizing system.

40.1.1 Hold-in range. There is no theoretical limit for the maximum hold-in range since the steady state tracking error for a constant frequency difference is zero in a second order loop. A continuously changing ramp frequency change, however, would result in a tracking error.

For an input ramp frequency change as shown in figure E-14

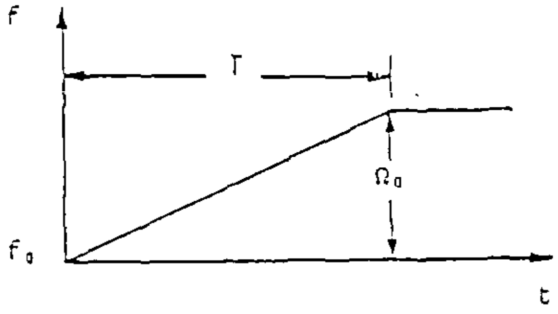


FIGURE E-14. An input ramp frequency.

$$\omega_i = \frac{\Omega_0}{T} t \tag{44}$$

$$\omega_i(S) = \frac{\Omega_\ell}{TS^2} , \qquad (45)$$

and

$$\Theta_i(S) = \frac{\Omega_\ell}{TS^3} . \qquad (46)$$

Recalling that

$$\epsilon(S) = \frac{(1/\omega_n)^2 S^2}{1 + (2\xi/\omega_n)S + (1/\omega_n)^2 S^2} \Theta_i(S) , \qquad (41)$$

setting $\xi = 1$ and combining equations (41) and (45)

$$\epsilon(S) = \frac{\Omega_\ell/T}{(S + \omega_n)^2 S} . \qquad (47)$$

From a table of Laplace transforms

$$\epsilon(t) = \frac{\Omega_\ell}{T\omega_n^2} [1 - (1 + \omega_n t)e^{-\omega_n t}] . \qquad (48)$$

$\epsilon(t)$ identifies the transient error output associated with a ramp frequency input from which the maximum transient error can be seen to occur at $t = \infty$ and is given by

$$\epsilon_{max} = \frac{\Omega_\ell}{T\omega_n^2} . \qquad (49)$$

The hold-in range must be sufficient to assure that the phase tracking error is less than $\pm\pi/2$ radians (or $\pm T/2$ for a pulse repetition frequency (PRF) locking loop system) for all frequency rate changes that could occur due to oscillator instability and propagation anomalies. The maximum frequency rate which would be accommodated occurs when the tracking error is $\pi/2$ radians. The maximum allowable rate of change of frequency is therefore given by

$$\left(\frac{\Omega_\ell}{T} \right)_{max} = \pi/2 \; \omega_n^2 \text{ rad/sec}^2. \qquad (50)$$

40.1.2 Pull-in range. To identify the pull-in range, it is necessary to establish the transient response for a step frequency difference input.

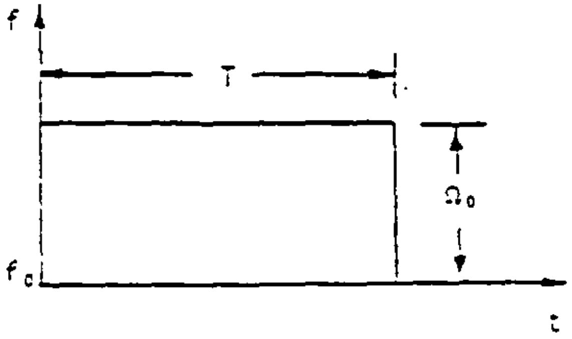


FIGURE E-15. A step frequency.

For a second order loop

$$\omega_i = \Omega_0 = \text{constant} ,$$

and (51)

$$\omega_i(S) = \frac{\Omega_0}{S} ,$$

and (52)

$$\theta_i(S) = \frac{\Omega_0}{S^2} .$$

(53)

Recalling that

$$\epsilon(S) = \frac{(1/\omega n)^2 S^2}{1 + (2\xi/\omega n)S + (1/\omega n)^2 S^2} \theta_i(S) , \tag{41}$$

and by setting $\xi = 1$

$$\epsilon(S) = \frac{S^2}{(S + \omega_n)^2} \theta_i(S) . \tag{43}$$

Combining equations (42) and (52)

$$\epsilon(S) = \frac{\Omega_0}{(S + \omega_n)^2} . \tag{54}$$

and from a table of Laplace transforms

$$\varepsilon(t) = \Omega_0 t\, e^{-\omega_n t} . \quad (55)$$

Equating the derivative of equation (55) to zero and solving for t identifies the time corresponding to the peak transient error as

$$t = \frac{1}{\omega n} , \quad (56)$$

which when substituted into equation (55) determines the peak transient error as

$$\varepsilon_{max} = 0.368 \frac{\Omega_0}{\omega_n} . \quad (57)$$

The pull-in range must be sufficient to assure that the phase tracking error is less than ± π/2 radians (or ± τ/2 for a PRF lock loop) for all step frequency differences that could occur due to oscillator instabilities and propagation anomalies. The maximum pull-in frequency is identified when $\varepsilon_{max} = \pi/2$ radians. The relationship between the maximum allowable frequency and the loop parameter for a carrier lock loop is given by

$$\Omega_{0max} = 4.27\ \omega n \text{ rad/sec} . \quad (58)$$

40.1.3 Acquisition time. In an uncoded synchronization loop, the acquisition time comprises the sweep time (if employed) plus several closed loop time constants. A coded system would require an acquisition time given by the code length (integration time) multiplied by the number of code bits contained in the code sequence. This assumes that all n bits are integrated. Initial integration could be over less than n bits to reduce the acquisition time. Another method for reducing acquisition time is to examine several subsequences of the code in parallel. In all cases, the closed loop time constant $1/f_n$ is the principal constraint. A number of alternatives exist for speeding up acquisition.

40.1.4 Flywheeling. In a perfect second order loop with an ideal filter, the tracking error is zero for a constant frequency difference between the synchronizing loop voltage controlled oscillator (VCO) and the input frequency. This condition implies that the loop has an infinite memory and that no timing error would accrue, provided the frequencies remained constant during a fade. This condition is easily illustrated by referring to the following equation

$$\varepsilon(t) = \Omega_o t e^{-\omega_n t}. \qquad (59)$$

For $t \rightarrow \infty$ (this generally corresponds to t equal to several loop time constants $1/f_n$), $\varepsilon = 0$ and removing the input would not have any effect on the synchronizing loop. Some implementation methods could involve a tracking error by virtue of the fact that they involve an approximate second order loop. Most methods for implementing a synchronization system involve a multiplier or its equivalent (such as a phase detector or time discriminator), a frequency or phase controlled oscillator or clock, and a filter. The important system transient characteristics such as locking time, holding time, frequency locking range, etc., depend on system loop parameters such as the effective loop filter transfer function, the loop gain and the order of control (i.e., 1st, 2nd, etc.) that is employed for the closed loop system. In general, a perfect second order velocity correcting system provides good performance and results in a zero error control voltage for a constant frequency difference.

Consider the following general second order loop synchronizing system, shown in figure E-16.

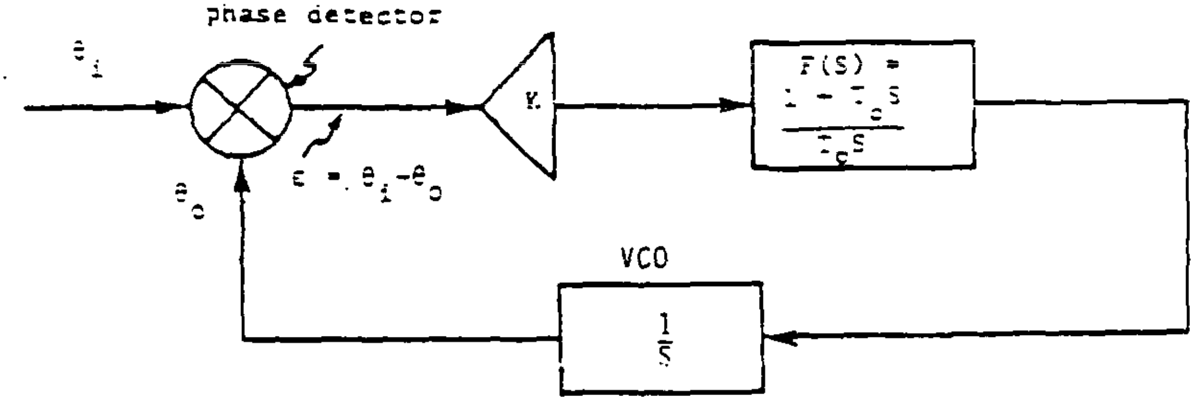


FIGURE E-16. A general second order loop synchronizing system.

The error control voltage is related to the input forcing function θ_i by

$$\frac{\varepsilon(s)}{\theta_i(s)} = 1 - \frac{\theta_o(s)}{\theta_i(s)} \qquad (60)$$

and we have from feedback analysis employing Laplace transform methods

$$\frac{\varepsilon(S)}{\theta_i(S)} = \frac{1}{1+(K/S)\,F(S)} , \tag{61}$$

or substituting for F (s)

$$\varepsilon(S) = \frac{T_o/K\,S^2\,\theta_i(S)}{1 + T_oS + (T_o/K)\,S^2} . \tag{62}$$

For a constant frequency difference input

$$\omega_i(S) = \frac{\Omega_o}{S_o} , \tag{52}$$

and

$$\theta_i(S) = \frac{\Omega_o}{S^2} , \tag{53}$$

hence

$$\varepsilon(S) = \frac{\Omega_o\,T_o/K}{1 + T_oS + (T_o/K)\,S^2} , \tag{63}$$

and by invoking the final limit theorem we see that

$$\varepsilon(\infty) = S\,\varepsilon(S)\Big|_{S=0} = 0 . \tag{64}$$

The error control voltage is removed for a constant frequency difference between the synchronizing system and the input frequency. This condition automatically holds the loop clock at that frequency difference during signal fades of any duration provided the free running frequency of the clock remains constant during the fade. This condition emphasizes the importance of short term stability. If the frequency difference between the oscillators remained constant during the fade, the loop would never lose synchronism in a fade situation no matter how many fades occurred. A perfect second order loop, however, is not easily implemented. One approach is to employ an electro-mechanical system utilizing a servo-motor driven capacitor to change the frequency of a VCO. An alternate approach is to utilize a passive filter with a large loop gain "K" to achieve an approximation to a second order loop. A functional block diagram of this concept is illustrated in figure E-17.

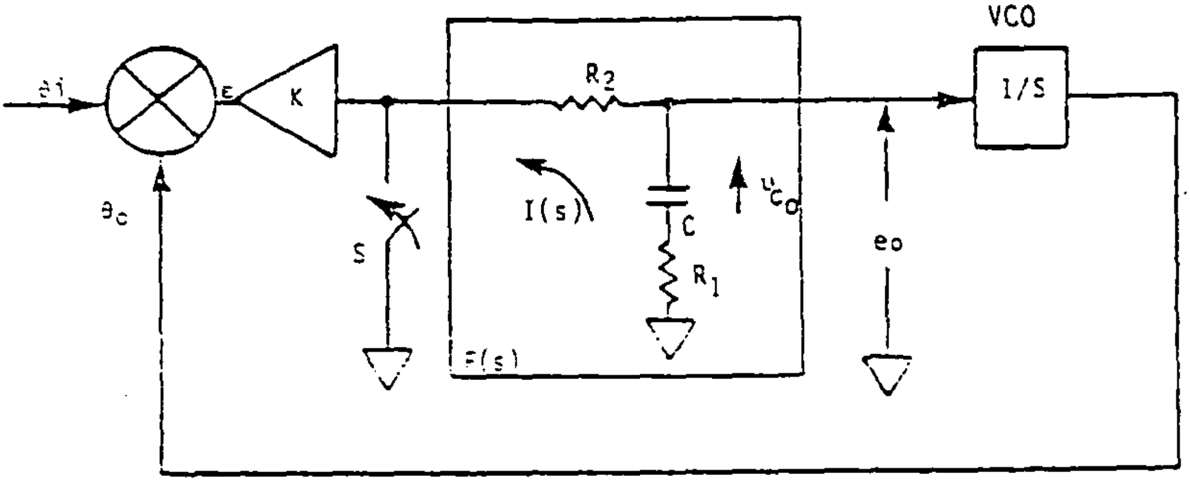


FIGURE E-17. Second order phase lock loop with a large loop gain.

For the filter

$$F(s) = \frac{1 + m T_2 S}{1 + T_2 S} , \qquad (65)$$

where $T_2 = (R_1 + R_2) C$

and $m = R_1/(R_1 + R_2)$

and since

$$\frac{\varepsilon(s)}{\theta_i(s)} = 1 - \frac{\theta_o(s)}{\theta_i(s)} , \qquad (60)$$

therefore

$$\frac{\varepsilon(s)}{\theta(s)} = 1 - \frac{(1 + mT2S)}{1 + (mT_2 + 1/K)S + (T_2/K)S^2} , \qquad (66)$$

$$\frac{\varepsilon(S)}{\theta_i(S)} = \frac{S(1/K+T_2/K\ S)}{1+(mT_2+1/K)S+(T_2/K)S^2} \qquad (67)$$

For a step frequency input, Ω_o,

$$\omega_i(S) = \frac{\Omega_o}{S}, \qquad (52)$$

and

$$\Theta_i(S) = \frac{\Omega_o}{S^2}, \qquad (53)$$

hence

$$\varepsilon(S) = \frac{\Omega_o(1/K+T_2/K\ S)}{S[1+(mT_2+1/K)S+(T_2/K)S^2]}, \qquad (68)$$

which results in

$$\varepsilon(\infty)=\Omega_o/K, \qquad (69)$$

where K = total loop gain in Hertz/radian.

When the input signal disappears during fades, the result is equivalent to shorting the input to the loop filter F(s). The oscillator control voltage then reduces to zero which returns the VCO frequency to its quiescent value.

The specific transients involved are readily identified since

$$\frac{e_o(S)}{\Theta_i(S)} = \frac{K\ F(S)}{1+(K/S)\ F(S)}, \qquad (70)$$

$$e_o(S) = \frac{S(1+mT2S)\ \theta_i(S)}{1+(mT_2+1/K)S+T_2/K\ S^2}, \qquad (71)$$

and for a step frequency input, Ω_o,

$$\Theta_i(S) = \frac{\Omega_o}{S^2}, \qquad (53)$$

which yields

$$e_0\ (\infty) = \Omega_0 = V_{C_0} \qquad (72)$$

When the input signal is removed, the switch S is closed with the capacitor, C, charged to Ω_0. Applying Laplace transform theory we have

$$I(S) = (R_1+R_2+\frac{1}{SC}) = \frac{\Omega_0}{S}\ , \qquad (73)$$

and

$$e_0(S) = I(S)\ R_2\ , \qquad (74)$$

$$e_0(S) = \Omega_0(\frac{R_2}{R_1+R_2})\ \frac{1}{S+\frac{1}{C\ (R_1+R_2)}}\ , \qquad (75)$$

and from a table of Laplace transforms

$$e_0(t) = \Omega_0(\frac{R_2}{R_1+R_2})\ e^{-\frac{t}{C(R_1+R_2)}}\ , \qquad (76)$$

which for $R_2 >> R_1$, results in

$$e_0(t) = \Omega_0 e^{-\frac{t}{C(R_1+R_2)}}\ . \qquad (77)$$

Equation (77) indicates that during a fade the oscillator frequency would initially retain the frequency difference between the input and the oscillator and then decay exponentially with an open loop time constant equal to C $(R_1 + R_2)$. The design of the synchronizing loop now becomes a compromise between the use of a sufficiently large loop gain K, a relatively narrow band effective closed loop bandwidth $\sqrt{K/T_2}$ and the retention of a large open loop time constant C $(R_1 + R_2)$ for holding the VCO frequency during signal fades.

For LOS and tropo transmission links, the mean duration of those fades that depress carrier-to-noise power ratios (C/N) to +5dB or lower is generally less than 10 seconds with the exception of UHF/LOS. In the case of UHF/LOS, the mean duration is less than 10 seconds for (C/N) $\leq$ -2dB. In essence, 10 seconds represents a reasonable expected fade duration for identifying the memory requirements for synchronization systems employed in terrestrial transmission links. The allowable relative frequency change Ω_o/f_o is given by

$$\frac{\Omega_o}{f_o} = \frac{\varepsilon_T}{T} \quad . \tag{78}$$

Assuming a maximum allowable timing error requirement of 10 percent of the pulse width of the maximum trunk bit rate of 4.608 Mb/s

$$\varepsilon_T = 0.1 \times \frac{1}{4.608(10^6)} \quad , \tag{79}$$

and

$$\frac{\Omega_o}{f_o} = \frac{2.17(10^{-8})}{T} \quad , \tag{80}$$

therefore

$$\frac{\Omega_o}{f_o} = 2.17 \times 10^{-9} \quad . \tag{81}$$

The short term stability of the oscillators in conjunction with the frequency variations associated with propagation conditions must be less than 2 parts in 10^9.

40.1.5 Threshold performance of synchronizing loops. The threshold obtained in a synchronizing loop depends on the type of loop implemented. The C/N threshold is determined for the various possible alternate synchronization approaches to enable an assessment of the relationship between fades, acquisition time, C/N threshold level, and stability. Available synchronization concepts include spectral line filtering, PRF lock loop synchronization (coherent video), and optimum coherent gated carrier loop synchronzation. Any specific implementation approach would correspond to one of these concepts.

40.1.5.1 Spectral line filtering system. Consider a system which synchronizes to a single spectral line of a digital input pulse train. A functional block diagram for this concept is illustrated in figure E-18.

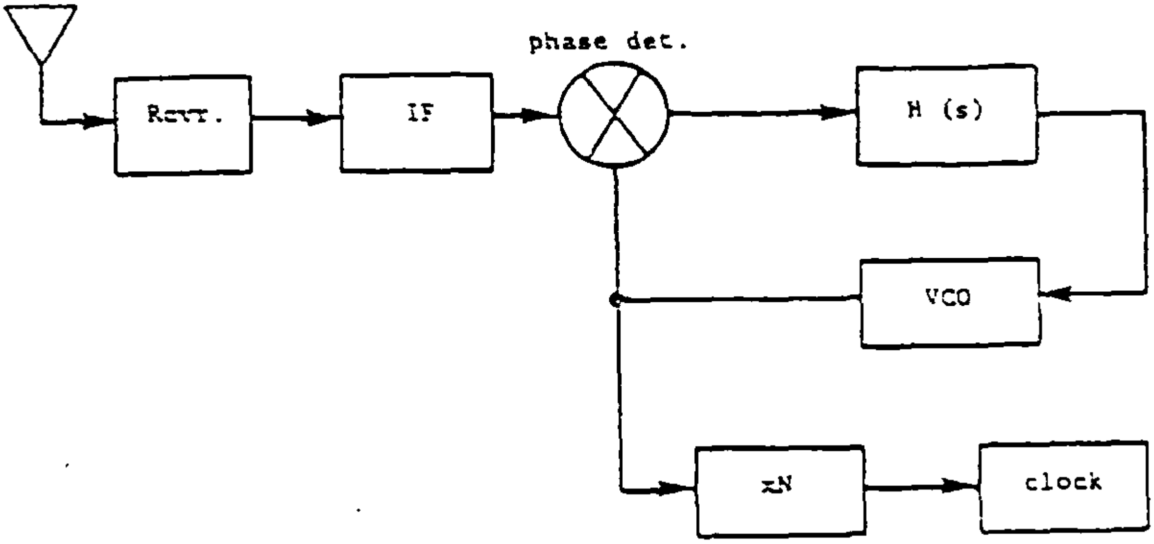


FIGURE E-18. A spectral line of a digital input pulse train.

A Fourier series analysis of a pulse train results in the following input spectrum depicted in figure E-19.

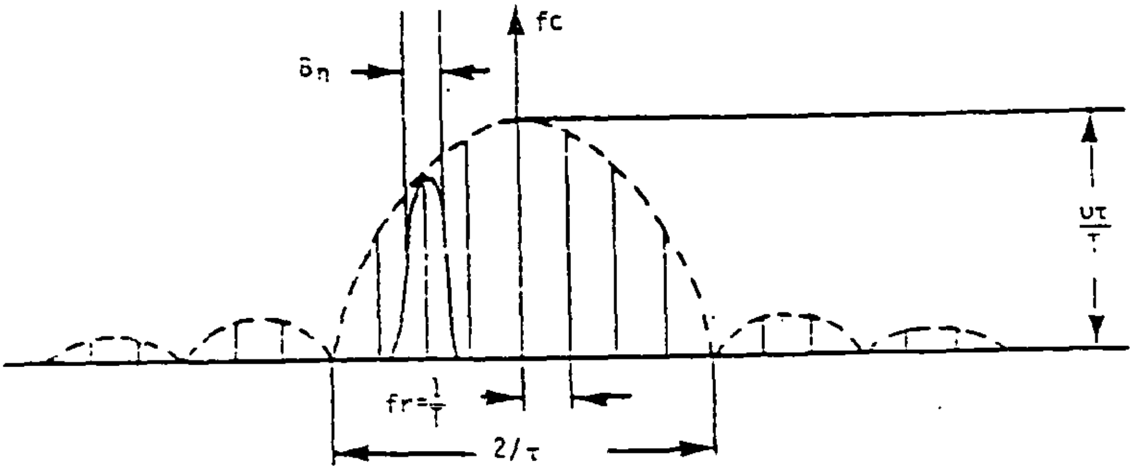


FIGURE E-19. A Fourier series analysis of a pulse train.

From figure E-19 it can be seen that the voltage for spectral lines close to the carrier is

$$V_r = \frac{V_t}{T} = V\frac{f_r}{B_i} , \tag{82}$$

and the received power per spectral line is then

$$P_r' = V_r^2 = (V\frac{f_r}{B_i})^2 , \tag{83}$$

$$P_r' = \frac{V^2}{M^2} = \frac{P_r}{M^2} , \tag{84}$$

where M = number of spectral lines in bandwidth B_i

$$M = \frac{B_i}{f_r} . \tag{85}$$

The output noise power N_o in the loop filter bandwidth B_n is given by

$$N_o = FKTB_n , \tag{86}$$

where FKT = noise power density.

Therefore, the received output $(S/N)_o$ power ratio is

$$(\frac{S}{N})_o = \frac{P_r'}{N_o} = \frac{P_r}{M^2 FKT\ B_n} , \tag{87}$$

and the input carrier-to-noise ratio $(C/N)_i$ is

$$(\frac{C}{N})_i = \frac{P_r}{FKT\ B_n} , \tag{88}$$

therefore by combining the equations (87) and (88) yields

$$(\frac{S}{N})_o = \frac{B_i}{M^2 B_n} (\frac{C}{N})_i . \tag{89}$$

Threshold occurs when the phase lock loop output root mean square (rms) noise phase jitter exceeds approximately 60 degrees or $\pi/3$ radians. This corresponds to 90 degrees or $\pi/2$ radians being exceeded too often for recovery of loop synchronization. The relationship between the output $(S/N)_o$ ratio and the output phase jitter ϕ_{NO} is given by

$$\phi_{NO} = \frac{\sqrt{N_o}}{\sqrt{2}\sqrt{S_o}}, \qquad (90)$$

where $\sqrt{N_o}$ = rms noise voltage,

$\sqrt{S_o}$ = rms signal voltage.

Combining equations (89) and (90) in conjunction with the fact that $B_n = \frac{1}{N t_r} = \frac{f_r}{N}$ and $B_i = Mf_r$ results in

$$\left(\frac{C}{N}\right)_i = \frac{M}{2N\phi^2_{N_O}}, \qquad (91)$$

which at threshold becomes

$$\left(\frac{C}{N}\right)_{it} = \frac{9M}{2\pi^2 N}, \qquad (92)$$

where N = number of pulses contained in the loop integration time.

40.1.5.2 PRF lock loop synchronization system. A video synchronization system is equivalent to coherently multiplying the input video pulses through the process of gating and then integrating over N pulses to enhance the output $(S/N)_o$ ratio. This coherent process is preceded by a non-linear envelope detector such as a square law detector. The non-linear operation degrades the (S/N) ratio which negates to some degree the improvement associated with the integration process occurring in the loop. The overall performance is in general superior to filtering out a single spectral line of the input signal. A functional block diagram of a PRF lock loop is shown in figure E-20.

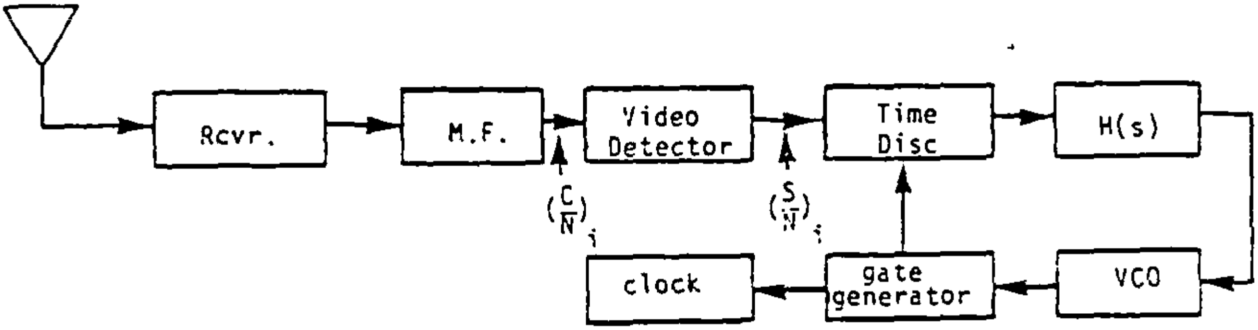


FIGURE E-20. A PRF lock loop.

The loop input signal-to-noise ratio $(S/N)_i$ is readily related to the receiver input signal-to-noise $(C/N)_i$ if a square law video detector is assumed to be utilized. In this case

$$\left(\frac{S}{N}\right)_i = \frac{\left(\frac{C}{N}\right)_i^2}{2\left[1+2\left(\frac{C}{N}\right)_i\right]} . \tag{93}$$

The noise components at the input to the loop are spread over $2B_i$ due to the mixing of noise terms. Additional filtering associated with the closed loop therefore reduces the noise by approximately

$$\frac{2\ B_i}{B_n M} , \tag{94}$$

where B_i = $\frac{1}{\tau}$ input receiver bandwidth,
B_n = closed loop noise bandwidth,
M = number of spectral lines contained in the input bandwidth B_i,
$B_n M$ = total effective closed loop noise bandwidth.

Since

$$M = \frac{B_i}{f_r} , \tag{95}$$

and

$$B_n = \frac{1}{Nt_r} = \frac{f_r}{N} , \tag{96}$$

where N = number of pulses integrated by the loop.

Combining equations (94), (95) and (96) results in

$$\frac{2B_i}{B_n M} = 2N . \tag{97}$$

This equation is an approximate relationship due to the fact that the noise is no longer white following the square law detector. It is, however; considered sufficiently accurate for the purpose of establishing the degree of noise reduction by the loop. The output $(S/N)_o$ is then given by

$$\left(\frac{S}{N}\right)_o = N \frac{\left(\frac{C}{N}\right)_i^2}{\left[1 + 2\left(\frac{C}{N}\right)_i\right]} . \tag{98}$$

To establish the threshold, it is necessary to relate the output noise time jitter to the output signal and noise. This is accomplished by identifying the time discriminator curve and the effect of noise on the loop output for a PRF synchronizing loop. A time discriminator which provides the necessary bipolar control for synchronizing is presented in the figure E-21.

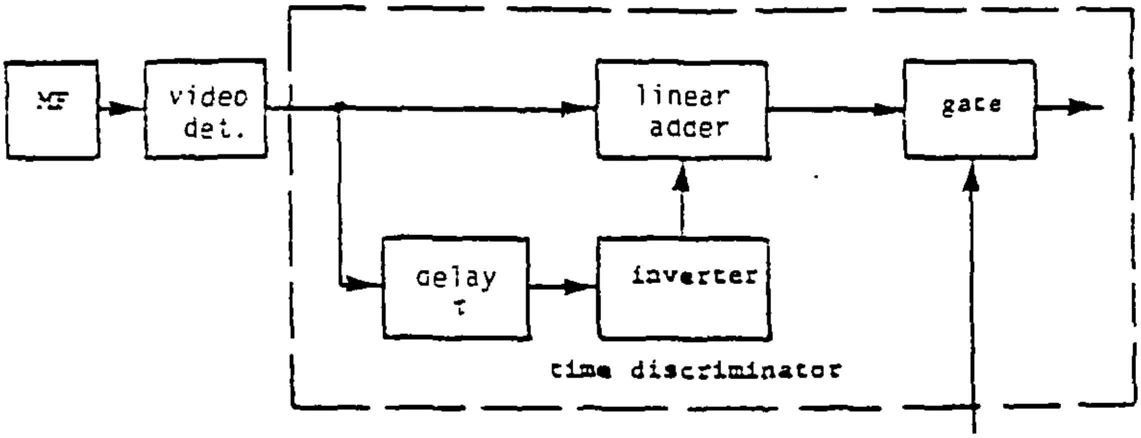


FIGURE E-21. A time discriminator.

The resulting discriminator curve is shown in figure E-22 along with the timing error δT_R introduced by noise.

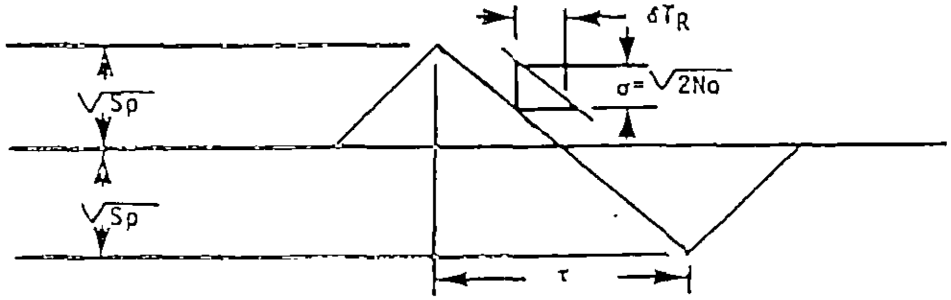


FIGURE E-22. A discriminator curve.

Referring to figure E-22

τ = input pulse width,
σ = output rms noise amplitude,
σ = $\sqrt{2N_o}$,

where $\sqrt{2}$ results from the summation of two uncorrelated noise sources in the error detector and

N_o = output noise power,
δT_R = output rms noise time jitter,
$\sqrt{S_p}$ = output signal peak voltage.

The output rms noise time jitter may be related to the output rms noise amplitude, the pulse width, and the output signal

$$\frac{2\sqrt{S_p}}{\tau} = \frac{\sigma}{\delta T_R} . \tag{99}$$

Since

$$\sqrt{S_p} = \sqrt{2S_o} , \tag{100}$$

where $\sqrt{S_o}$ = output rms signal voltage

then

$$\left(\frac{S}{N}\right)_o = \frac{\tau^2}{4\ \delta T_R^2} . \tag{101}$$

Combining equations (98) and (101) yields

$$\left(\frac{C}{N}\right)_i^2 - 2\beta\left(\frac{C}{N}\right)_i - \beta = 0 \quad , \tag{102}$$

where

$$\beta = \frac{\tau^2}{4N\ \delta T_R^2} \ . \tag{103}$$

Solving equations (102) and (103) for $\left(\frac{C}{N}\right)_i$ identifies the relationship between the output jitter and the input carrier-to-noise ratio

$$\left(\frac{C}{N}\right)_i = \frac{\tau^2}{4N\ \delta T_R^2}\left[1+\sqrt{1+\left(\frac{4N\ \delta T_R^2}{\tau^2}\right)}\right] . \tag{104}$$

The PRF loop reaches threshold when the output rms time jitter δT_R is equal to 1/3 the pulse width or $\tau/3$ yielding

$$\left(\frac{C}{N}\right)_{it} = \frac{9}{4N}\left[1+\sqrt{1+\frac{4N}{9}}\right] . \tag{105}$$

40.1.5.3 Optimum coherent gated carrier loop synchronization system.

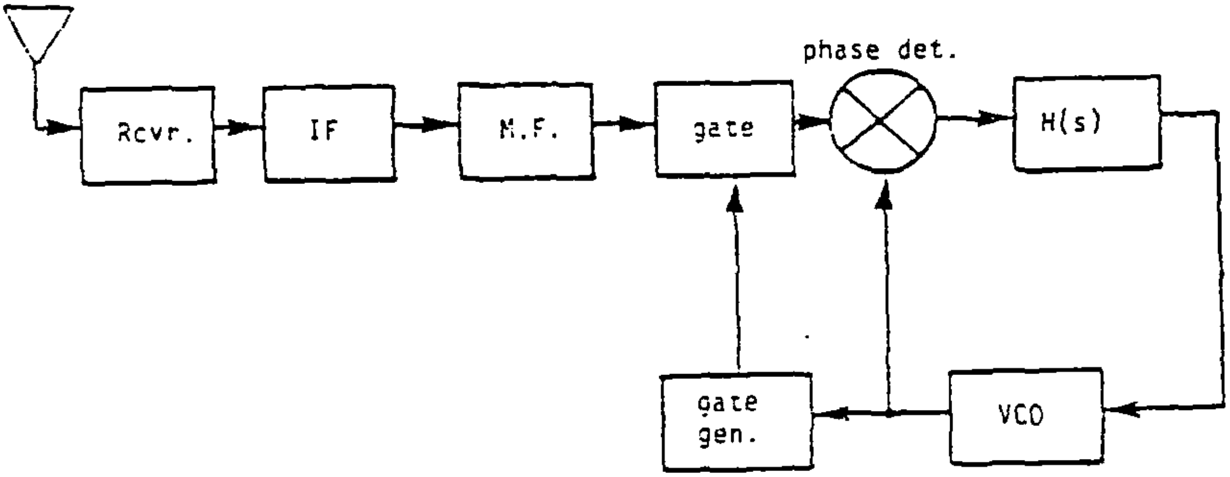


FIGURE E-23. An optimum coherent gated carrier loop synchronization system.

This system cross-correlation detects the input carrier pulse train with an identical carrier pulse train to optimally synchronize to the framing channel. All the signal energy is utilized for locking in this coherent detection system. Its implementation requires that the PRF be synchronous with the input carrier in order to keep the gate centered over the pulsed carrier input. Initial synchronization may be achieved with a separate PRF loop to center the gate over the carrier cycles. Upon synchronizing the gated carrier loop, the PRF loop would then be disengaged. The output rms signal-to-noise ratio for an optimum coherent detector is given by

$$\left(\frac{S}{N}\right)_o = \frac{E}{\eta} , \tag{106}$$

where E = received signal energy in joules,
η = FKT = noise power density in watts/Hz.

Since

$$E = P_r \tau N , \tag{107}$$

where P_r = received power,
τ = pulse width,
N = number of pulses integrated in loop,

and

$$B_i = \frac{1}{\tau} , \tag{108}$$

then

$$\left(\frac{S}{N}\right)_o = \frac{N P_r}{FKT B_i} , \tag{109}$$

or

$$\left(\frac{S}{N}\right)_o = N\left(\frac{C}{N}\right)_i . \tag{110}$$

The output rms signal-to-noise ratio $(S/N)_0$ is also related to the output noise phase jitter by

$$\emptyset_{N_o} = \sqrt{\frac{N_c}{2S_o}} \quad . \tag{111}$$

Combining equations (110) and (111) yields

$$\left(\frac{C}{N}\right)_i = \frac{1}{2N\emptyset^2_{N_o}} \quad , \tag{112}$$

which at threshold becomes

$$\left(\frac{C}{N}\right)_{it} = \frac{9}{2\pi^2 N} \quad . \tag{113}$$

40.1.5.4 Summary. Expressions have been derived which identify the threshold signal-to-noise ratio $(C/N)_{it}$ for three basic synchronization concepts. The results are tabulated below.

For a spectral line synchronization system

$$\left(\frac{C}{N}\right)_{it} = \frac{9M}{2\pi^2 N} \quad . \tag{114}$$

For a PRF lock loop synchronization system

$$\left(\frac{C}{N}\right)_{it} = \frac{9}{4N}\left[1+\sqrt{1+\frac{4N}{9}}\right] \quad , \tag{115}$$

For a gated carrier loop synchronization system

$$\left(\frac{C}{N}\right)_{it} = \frac{9}{2\tau^2 N} . \qquad (116)$$

An examination of the equations reveals that an optimum coherent system is better than one which filters out a single spectral line by the factor M, where M represents the number of spectral lines contained in the input bandwidth or equivalently the number of channels contained in a multichannel system. An optimum coherent gated carrier loop would have a threshold much lower than for a system which filtered out a single spectral line. The performance of a PRF lock loop system is essentially between that obtained for the other two approaches.

40.1.6 <u>Optimum synchronization loop design.</u> The following analysis establishes that an optimum design exists for a synchronized carrier loop which minimizes the transient plus noise errors to provide a minimum threshold carrier signal-to-noise ratio. As the closed loop noise bandwidth is reduced, the output noise is reduced which improves the threshold until the transient error approaches the maximum allowable total phase error. At some value prior to this, the threshold signal-to-noise ratio obtains its lowest possible values.

To facilitate the analysis, reference should be made to Section 7.1 of Annex F3, Network Timing, of the TRI-TAC document, Architecture for Tactical Switched Communications Systems. Equation (31) of that section establishes the transient performance of a critically damped second order synchronization phase lock loop for any input function $\theta_i(s)$.

$$\varepsilon(S) = \frac{S^2}{(S + \omega_n)^2}\,\theta_i(S) \qquad (43)$$

where S is the Laplace transform,

ω_n is the loop design parameter which establishes the transient and noise performance,

$\theta_i(S)$ = input phase as a function of S,

$\varepsilon(S)$ = output loop tracking error as a function of S.

The input rms noise jitter (ϕ_{N_i}) is related to the input signal and rms noise amplitude levels by the following equation

$$\phi_{N_i} = \frac{N_i}{\sqrt{2}\,S_i} \text{ radians ,} \qquad (117)$$

where N_i = rms noise voltage in the input bandwidth B_c,
S_i = rms signal voltage at the input.

The phase lock loop output noise jitter or phase noise is related to the input noise jitter or phase noise by

$$\phi_{N_o} = \phi_{N_i} \sqrt{\frac{\omega_{nt}}{B_c}} , \tag{118}$$

where ω_{nt} = total effective closed loop noise bandwidth,
B_c = carrier bandwidth at the input to the phase locked loop in radians/sec., and the input noise is assumed.

By definition

$$\omega_{nt} = \int_{-\infty}^{\infty} |Y(\omega)|^2 d\omega , \tag{119}$$

which for a second order critically damped loop is readily determined as

$$\omega_{nt} = 2.5 \pi \omega_n . \tag{120}$$

Combining equations (117), (118), and (120) results in

$$\left(\frac{S}{N}\right)_i = \sqrt{\frac{2.5 \pi \omega_n}{2B_c}} \cdot \frac{1}{\phi_{N_o}} , \tag{121}$$

where $\left(\frac{S}{N}\right)_i$ = input signal-to-noise ratio in input bandwidth, B_c.

The loop would lose synchronization when $\phi_{N_o} = \lambda\pi/2$ radians in the absence of transient errors which establishes the threshold signal-to-noise ratio for the loop. When the tracking error is accounted for, the loop would lose synchronization for

$$\phi_{N_o} = \lambda(\pi/2) - \epsilon_{max} , \tag{122}$$

where $\pi/2 \geq \lambda \geq \pi/3$ depending on the statistics of the noise perturbations
ϵ_{max} = maximum transient tracking error.

Substituting equation (122) into (121) yields

$$\left(\frac{S}{N}\right)_{it} = \sqrt{\frac{1.25\pi\omega_n}{B_c}} \cdot \frac{1}{\lambda(\pi/2)-\varepsilon_{max}} . \qquad (123)$$

If stable clocks are employed, then the frequency accuracy expressed as a maximum frequency difference can be considered as a constant step frequency difference during the acquisition time of the loop. In establishing a quantitative value, care should be exercised in relating the calibration and long term frequency stability to the frequency accuracy.

For a step frequency difference Ω_0

$$\omega_i = \Omega_0 = \text{constant} , \qquad (51)$$

hence

$$\theta_i\ (S) = \frac{\omega_i(s)}{S} = \frac{\Omega_0}{S^2} , \qquad (53)$$

therefore

$$\varepsilon\ (s) = \frac{\Omega_0}{(s+\omega_n)^2} , \qquad (54)$$

and from a table of Laplace transforms

$$\varepsilon\ (t) = \Omega_0 t e^{-\omega_n t} . \qquad (55)$$

Equating the derivation of equation (55) to zero and solving for "t" identifies the time corresponding to the peak transient error as

$$t = \frac{1}{\omega_n} , \qquad (56)$$

which when substituted into equation (55) determines the peak transient error ε_{max} as

$$\varepsilon_{max} = 0.368\ \frac{\Omega_0}{\omega_n} . \qquad (57)$$

Combining equations (117) and (57) then results in obtaining the threshold signal-to-noise ratio as a function of the loop design parameter ω_n

$$\left(\frac{S}{N}\right)_{it} = \sqrt{\frac{1.25\,\pi\,\omega_n}{B_c}} \cdot \frac{1}{\lambda\,\pi/2 - 0.368\,\Omega_o/\omega_n} \quad . \tag{124}$$

Let

$$\gamma = \sqrt{\frac{1.25\,\pi}{B_c}} \quad , \tag{125}$$

then

$$\left(\frac{S}{N}\right)_{it} = \frac{\gamma\,\omega_n{}^{3/2}}{(\lambda\,\pi/2)\,\omega_n - 0.368\,\Omega_o} \quad . \tag{126}$$

Equation (126) demonstrates that the threshold signal-to-noise ratio $(S/N)_{it}$ approaches infinity as $(\lambda\ \pi/2)\omega_n$ approaches $0.368\Omega_0$ and also as $\omega_n \rightarrow \infty$. Therefore, at least one minimum (optimum) value must exist between these extremes which is readily determined by equating its derivative to zero.

$$\frac{1}{\gamma}\ \frac{d\left(\frac{S}{N}\right)_{it}}{d\omega_n} = \frac{[(\lambda\ \pi/2)\omega_n - 0.368\Omega_o]\ \frac{3}{2}\,\omega_n{}^{1/2} - (\lambda\ \pi/2)\omega_n{}^{3/2}}{[(\lambda\ \pi/2)\omega_n - 0.368\Omega_o)^2} = 0 \quad , \tag{127}$$

from which

$$\omega_n(\mathrm{opt}) = \frac{2.2}{\pi\lambda}\ \Omega_o \quad . \tag{128}$$

Equation (128) is the desired result which indicates that the closed loop bandwidth parameter ω_n should be essentially equal to the frequency difference to obtain an optimum design which minimizes the transient plus noise error and results in a minimum threshold signal-to-noise ratio. The corresponding threshold $(S/N)_{it}$ ratio is readily determined by substituting equation (128) into equation (126)

$$\left(\frac{S}{N}\right)_{it(\mathrm{opt})} = 1.59\lambda^{-3/2}\left(\frac{\Omega_o}{B_c}\right)^{1/2} \quad . \tag{129}$$

If the phase noise or jitter is Gaussian, then phase lock is lost at 60 degrees or $\pi/3$ radians for which $\lambda = 2/3$. In this case equations (128) and (129) become

$$\omega_n(\mathrm{opt}) = 1.05\,\Omega_0 \quad , \tag{130}$$

and $$\left(\frac{S}{N}\right)_{it(opt)} = 2.92 \left(\frac{\Omega_o}{B_c}\right)^{1/2} \qquad (131)$$

Equation (129) is the desired result and utilizing it as a design equation yields an extremely low threshold signal-to-noise ratio as indicated by equation (129) or (131). It should be pointed out that the derivation does not take into account frequency variations due to propagation conditions involving Doppler frequencies such as would be experienced in a transceiver on a moving vehicle. It would apply to fixed installations such as the trunk links of a multichannel switched system (exclusive of satellite links).

As an illustration of what threshold values might be obtained, consider a stable quartz oscillator whose long term stability is 1×10^{-9} per day which was calibrated precisely against an atomic cesium primary standard. After 100 days, the frequency accuracy would be 1×10^{-7}. Assuming a carrier frequency of 10 MHz would then result in Ω_o=1Hz. For an rf bandwidth of 1 MHz, the threshold signal-to-noise ratio would be 2.92 (10^{-3}) = -25.4 db.

Care must be exercised in utilizing the derived optimum design equation since the threshold signal-to-noise ratio increases very rapidly as ω_n is made smaller than the design value. A practical design must account for the maximum anticipated change expected and should then allow a reasonable margin of safety to the expected value for Ωo.

APPENDIX F
ADVANTAGES AND DISADVANTAGES OF NETWORK INTERNAL TIMING METHODS

This appendix contains information in support of MIL-STD-188-115. Appendix F is not a mandatory part of this standard.

10 GENERAL

10.1 Purpose. The purpose of this appendix is to illustrate the advantages and disadvantages of network internal timing methods.

10.2 Scope. This appendix is a tutorial in network timing that are discussed in the standard.

20 REFERENCED DOCUMENTS

Not applicable.

30 DEFINITIONS

For the purpose of this appendix, the definitions of FED-STD-1037 and those found in appendix B will apply.

40 GENERAL REQUIREMENTS

Network timing and synchronization are critical design issues since some communications objectives reflect a need for automated digital systems which are specifically designed to accommodate both voice and non-voice traffic and to provide communications security on an end-to-end basis. For satisfactory system operation, stringent requirements must be satisfied with regard to the timing variations which are allowable both within and among the digital bit streams handled by the systems. Several different synchronous and asynchronous concepts could be employed to provide network timing. Independent stable clocks and bit stuffing represent two possible asynchronous concepts. Master-slave and frequency averaging represent two possible synchronous concepts. Basic operational requirements concerning network timing relate to the need for systems to accommodate time division multiplexing (TDM), digital switching, encryption, and to maintain bit count integrity (BCI). Precise timing is also required for obtaining end-to-end communications security, adequate electronic counter-countermeasure (ECCM), and an acceptable data transmission capability. In some systems, an accurate knowledge of time is required to acquire synchronization.

40.1 Advantages and disadvantages of the master-slave network timing method. The basic elements of most master-slave network timing systems (except for broadcast networks) include a modem, buffer, clock, and means to measure and correct clock errors. The modem is used to regenerate the incoming digital bit stream. The clock is used to provide a stable local timing signal. The buffer is used to absorb differences between the phase of the local clock and the incoming bit stream. The clock error corrections are based on filtered clock error information derived from the received signal(s). There are many different master-slave approaches. Nearly all digital communications systems employ some form of the basic master-slave approach. In some simple master-slave systems, clocks at nodes directly connected to the master clock are phase locked to the digital signal received from the master while other nodes not connected to the master are slaved to those nodes that are directly connected. This basic master-slave technique, unsupported by other master-slave system capability, is generally unsuitable to provide network synchronization for major nodes of a military communications system because of survivability problems (i.e., loss of nodes or links). However, it is a frequently used method for timing within a node and for minor nodes to get their timing from major nodes. More advanced master-slave systems can be provided that overcome the survivability disadvantages.

The primary advantage of the master-slave method is the long term accuracy that it provides when properly implemented. Even with the most simple master-slave approaches, the long term average variation rates of the individual clocks are very nearly identical to that of the network master. If the master is referenced to the United States Naval Observatory (USNO), every node in the network will have a long term average rate very nearly identical to that of the USNO. Therefore, when clocks are operating properly, it may be unnecessary to interrupt traffic to reset buffers anywhere in the network. In a worldwide network, disruptions due to a clock error at a particular node can cause some disruptions in other parts of the network even if their clocks or buffers are undisturbed. It is not convenient to reset buffers in such a network and it is unnecessary in normal operation, but such a capability could be provided to enhance survivability. In a survey conducted for DCA by several civilian wideband digital communications networks, none felt that their customers would accept an occasional interruption of traffic to reset the buffers if such an interruption could be avoided. All of them recommended the use of master-slave systems.

The simple master-slave technique is economical and convenient to implement with a simple phase locked loop, but if it is unsupported by a capability to reorganize itself to employ alternative masters and other enhancements, it posses some survivability problems. Such survivability problems can be overcome by preferred military survival implementations that provide automatic master-slave reorganization including selection of a new master whenever required. By providing the ability to measure and remove errors during normal operation and to predict and remove errors during a free-running period following a period of calibration, it can provide greater accuracy and uninterrupted operation for a longer period of time even in the free-running mode than can be provided by independent clocks.

Because a survivable military implementation of a master-slave method preferred for multichannel switched systems employs very loose coupling between the error measurement process and clock correction (in normal operation it might require more than a day to make a 10 microsecond correction), it maintains many of the qualities of independent clocks while providing the long term stability of phase locked systems. Jamming or interfering signals will not cause significant timing problems. If a single link serving a major node is interfered with, jammed or destroyed, another link will be providing the timing. If all links to a node are interfered with, jammed or destroyed, the relatively stable clocks will enter a free-running mode with highly accurate frequency and phase. This can provide free-running for longer periods of time before the need for buffer reset. Effects of malfunctions in links or nodes are automatically detected and do not propagate among major nodes of the network.

40.1.1 Referencing master-slave timing to UTC. If the master of a master-slave network is referenced to coordinated universal time (UTC), all of the nodes of this master-slave network are referenced to UTC. To provide for survivability, every major node of a master-slave network should be capable of automatically being selected as master for the entire network, or as master for any severed portion of the network. Although UTC is usually not essential for satisfactory operation of a network it enhances interfacing capabilities. A capability to provide a UTC reference to the master and those other nodes selected as most likely to ascend to master, should be provided. This reference can be provided by a variety of dissemination means, any of which could be used to provide a reference to UTC (USNO). A sizeable number of SATCOM stations, for example, are designated as precise time stations (PTS). A PTS participates with USNO to maintain time directly traceable to the USNO master clock through portable clock trips, satellite time transfers, or other means. These stations have a capability to provide time to many other parts of the Defense Communications System (DCS) and to colocate or interconnect tactical nodes.

With such a system providing an accurate reference to the master of a master-slave system that is accurately disseminated internally to the communications network, nodal clocks can be maintained accurately until they are required to maintain time accuracy in a free-running mode. The free-running mode is necessary for survivability in all systems, but it is particularly important for some time dependent systems. Survivability in a master-slave system can be maximized with an extended free-running capability and multiple means for updating to the Department of Defense (DoD) reference.

40.2 Advantages and disadvantages of the independent stable clock network timing method. The basic elements of the independent clock network timing approach include a modem, a buffer and a highly stable frequency standard or clock. The modem is used to regenerate the incoming digital bit stream. The independent clock is used to provide a stable local clock rate. The buffer is used to absorb phase differences caused by differences between the frequency of the local clock at the receiving node and the frequency which is associated with the incoming digital bit stream. Since the output of the buffer is controlled by the nodal clock, the incoming digital bit stream is retimed in accordance with the local clock.

The apparent basic clock frequency of the incoming digital bit stream can differ from that of the local nodal clock due to the inherent differences in the independent clocks at the two nodes and the propagation delay variations of the internodal transmission links. These factors, as well as the link transmission rate and the allowable buffer reset period, dictate the capacity requirement for the buffer. With the independent clock approach, network timing is established by employing an accurate frequency standard at each node to provide a stable local timing reference. This technique is inherently asynchronous since the frequency standards will vary slightly from node to node. The differences between the basic bit rates of the incoming trunk groups and that of the local timing source are accommodated through employment of buffers which are used to retime the incoming trunk traffic. To minimize the differences among timing sources, highly stable clocks are used to implement the independent clock approach.

The independent stable clock technique provides frequency stability which is not affected by system operation or by an external signal source; it is, therefore, immune to jamming signals. The approach is not susceptible to transient disturbances in the network frequency. Buffers must be employed on each internodal link to accommodate timing differences between the sending and receiving nodes and to accommodate frequency variations caused by the transmission media. The buffers must be periodically reset due to long-term accumulated phase differences. A drawback to this approach is the cost of providing the individual stable timing sources to each site, however these costs are reducing and represent a small fraction of the total cost of a multichannel communications node. A major advantage of the approach is that the effects of malfunctions in links and nodes are not propagated throughout the network.

40.3 Time-dependent networks. The use of a common reference by all networks will permit one to aid another and all to take advantage of the timing services offered by other systems whose timing is traceable to USNO. It will also make possible the use of a common clock facility by colocated nodes.

Passive time-dissemination does not require the user to radiate signals in order to acquire accurate time information. The use of external time-dissemination services traceable to USNO may be necessary in certain links or networks that, for operational or security reasons, are established or entered only at certain times.

A number of systems require precise time and must therefore continuously maintain accurate clocks. Some of these systems have a built-in capability to maintain traceability to the DoD Master Clock (USNO Master Clock), while others use external means or a combination of internal and external means for redundancy and survivability. Some systems employ redundant local atomic clocks (generally cesium) to provide an in-house capability that would survive prolonged losses of the dissemination means by which they are normally checked against the DoD Master Clock. They may also have alternate dissemination means available for access to other traceable UTC references both to increase their own survivability and to provide alternate links between the references and the DoD Master Clock. Some of these systems make their accurate time signals available to signals other colocated systems or nodes.

The issue of survivability is most important in a time-dependent system and requires that the timing and synchronization aspects of the system be identified and addressed as an integral part of the system architecture. Of particular importance are the free-running capability of each clock system and the availability of UTC reference sources. Redundancy is commonly employed in clock systems to ensure that the local time reference will not be lost during free-running. Major systems frequently contain clock ensembles with comparison means to identify a substandard or malfunctioning clock. The clocks of the ensemble normally run relatively independently of each other so that no clock or control system failure would seriously affect all of the clocks.

In time-dependent systems, loss of the accurate nodal time reference is generally of greater consequence than a temporary discontinuity in providing timing signals. Also, in time-dependent systems, the free-running performance requirements of the clock are generally more difficult to meet than the requirements for an accurate frequency alone. For these reasons, clock system design objectives for a time-dependent system may be different from those of a system whose only timing requirement is an accurate frequency. Compatible clock system designs should be used wherever the clock might at some time be required to serve the dual purpose of supplying an accurate frequency and acting as a time reference.

Intermittent or late entry into some networks can be greatly facilitated by a prior knowledge of network time whether time is obtained by time-dissemination or by other means. Navigation systems that disseminate time are frequently employed for time dissemination. They, along with other systems, make it possible (sometimes automatically) to correct for propagation time delays.

40.4 Timing for networks requiring accurate time. The bit-stream timing and synchronization of an UTC traceable time reference requires an accurate frequency standard, but not necessarily accurate time. However, for some networks accurate time (used in the sense of "epoch" or "occasion" of a non-recurring or rarely recurring event) is required. These networks are designed to resist jamming; reduce chances of intercept or spoofing; enhance reception of signals in noise; reduce or eliminate synchronization overhead; deny use of assets (such as satellites) to others; provide synergy with position-location, navigation, or intelligence systems; identify or authenticate; permit immediate or quick entry and reduce guard bands in time division multiple access (TDMA) systems; or provide combinations of these features. While some systems requiring precise time may normally operate continuously, a need for precise time is often to establish or re-establish a link or network or to bring new systems on line within the network. Therefore, the nodal clocks are often required to maintain accurate time whether the node is participating in network operations or not.

Although accurate frequency can be established and maintained at any location by using "primary" atomic standards, such as cesium beam devices, accurate time must be obtained initially from a reference outside the node and maintained locally with reference to an accurate local frequency (rate) standard until subsequently updated. Some means of time dissemination, either internal or external to the communications network, is required to coordinate the clocks in a time-synchronized link or network. The initial setting, which may also include a frequency (or rate) calibration, is accomplished through a time-dissemination or local distribution system. The reference for clock setting might be timing disseminated through a network, a portable clock, a clock of a colocated node or a common clock of colocated nodes, a navigation system, a special timing link, a time broadcast or certain communications links (including special synchronizing modes of the network) that can provide the required accuracy.

(This page intentionally left blank)

APPENDIX G
EXAMPLE OF NETWORK TIMING DISTRIBUTION BETWEEN TACTICAL NODES

This appendix contains tutorial information in support of MIL-STD-188-115. Appendix G is not a mandatory part of this standard.

10 GENERAL

10.1 Purpose. The purpose of this appendix is to illustrate, using an example, how timing is distributed throughout a tactical node.

10.2 Scope. This appendix, showing a timing subsystem, is intended to be a general tactical system level overview. A more detailed description of individual equipments or assemblages may be obtained by referencing appropriate equipment specifications.

20 REFERENCED DOCUMENTS

Not applicable.

30 DEFINITIONS

For purposes of this appendix, the definitions in FED-STD-1037 and those found in appendix B will apply.

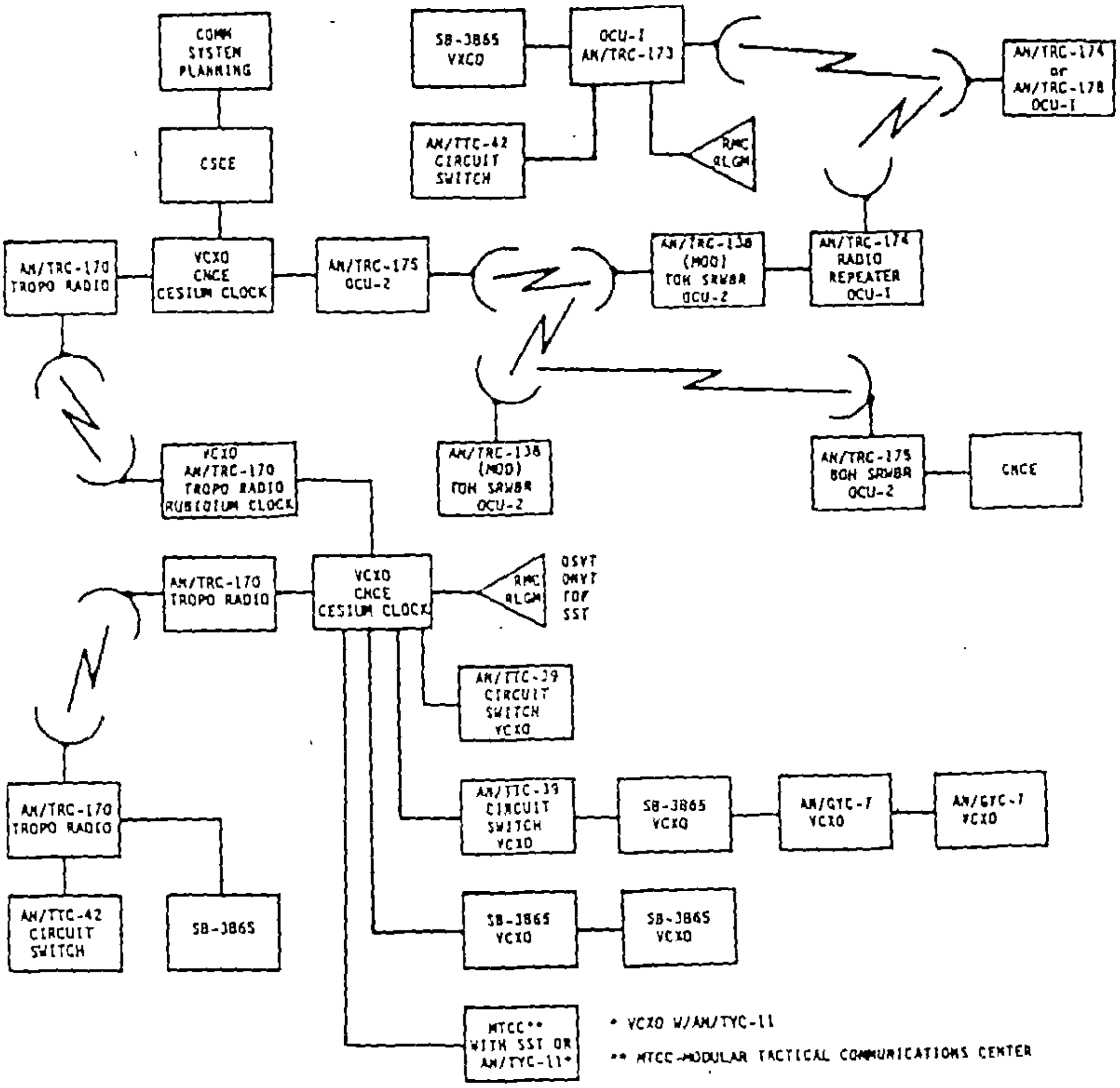
40 GENERAL REQUIREMENTS

40.1 Example of network timing distributions between tactical nodes. The timing subsystem developed for tactical switched communications networks is built around a highly accurate cesium beam standard located in the AN/TSQ-111, Communications Nodal Control Element (CNCE). Each CNCE normally operates its own timing system from its own internal cesium standard which drives a voltage controlled crystal oscillator (VCXO). This approach is generally referred to as an independent timing system. In this mode, the sending and receiving CNCE cesium based clocks will be set closely enough that filling or emptying of the receiving station's buffer should be infrequent. The necessity of interrupting traffic to reset buffers is expected to be once per day or less under normal conditions.

The CNCE does have a number of additional timing capabilities. The cesium beam standard will normally drive the internal VCXO. There is a second VCXO as backup. The VCXO can free-run if the cesium standard is lost. In addition, timing can be derived from either of two incoming transmission groups and used to slave the oscillator to the selected incoming group. These capabilities can be selected on a manual or automatic basis.

Below the CNCE equipped node, at subordinate or access nodes, tactical switches obtain timing from a VCXO, and in most cases the VCXO will have a backup unit. These switch associated VCXOs will normally derive their timing reference from and be slaved to an incoming conditioned diphase data transmission group which is traceable back to a cesium standard at a CNCE. All switch VCXOs however, do have the ability to free run, with reduced stability if the CNCE cesium clock fails, if connection to a CNCE is lost, or if the deployment is such that a CNCE is not available.

The tactical radio equipment will normally operate in a slaved mode. All such radios will derive timing from conditioned diphase data transitions in the traffic data stream. There are two potential exceptions to this rule. The AN/TRC-170 Tropo/LOS digital radio terminal system contains a rubidium source which can operate as a master timing source, driving an internal VCXO. The ability to free-run from a rubidium source or directly from the VCXO is available for a stand-alone situation where the AN/TRC-170 can provide direct access to subscribers or smaller digital switches with low stability timing sources, and without a CNCE or major switch in the system as a timing source. The AN/TRC-170 can also slave its VCXO to data coming from either the radio or cable side. The other exception concerns inventory analog Army radios which have been modified by addition of digital modems, multiplexers and orderwire control units (OCU). The OCUs have timing options which permit them to derive timing from a variety of sources. Preferably, these sources are traceable to a CNCE from which they can then be manipulated and distributed to satisfy the total timing requirements within the associated assemblage shelter. These OCUs can operate in a free-running mode if the external source is lost. However, this capability is primarily intended to service the secure digital voice orderwire for initial circuit lineup (no traffic) or restoral (again no traffic) and thus no external mode of operation. Buffers will retime data from other CNCE equipped nodes, adjust any minor differences between the two CNCEs cesium beam standards and feed the received data to the local CNCE processor at the local timing rate. The CNCE can also operate its timing system in several other modes which can be selected manually or automatically. If the local cesium beam fails, then the VCXO can be set to operate in a free-running mode. The cesium beam standard can be set to operate within 2 x 10^{-12} of the desired frequency. The VCXO, which would normally be slaved to the cesium beam standard, would in the case of free-running revert to a stability of $\pm 10^{-9}$ for a 24 hour period. Although stability would be reduced and buffer resets might be more frequent, the system would continue to function but in a degraded mode. Here it must be noted that all subordinate nodes or switches will have VCXOs and buffers, and they will normally operate slaved to the CNCE. When the CNCE timing sources are lost, then subordinate elements can also have their VCXOs reset to a free-running mode with a loss in stability comparable to that for the CNCE when it switches from cesium to VCXO free-running timing. The system will continue to function although in a degraded mode, with a more frequent need to interrupt traffic for buffer resets. For an example of network timing distribution between tactical nodes see figure G-24.



* VCXO W/AN/TYC-11

** MTCC-MODULAR TACTICAL COMMUNICATIONS CENTER

FIGURE G-24. Example of network timing distribution between tactical nodes.

APPENDIX H
NETWORK TIMING FOR THE DEFENSE COMMUNICATIONS SYSTEM (DCS)

This appendix contains tutorial information in support of MIL-STD-188-115. Appendix H is not a mandatory part of this standard.

10 GENERAL

10.1 Purpose. The purpose of this appendix is to describe the criteria and rationale used in planning the network timing and synchronization capability for the planned digital portion of the Defense Communications System (DCS). This timing and synchronization capability will be required for certain equipments, subsystems, and system interfaces.

10.2 Scope. This appendix gives general information on the functioning of network timing for the DCS.

20 REFERENCED DOCUMENTS

20.1 Appendix extraction. This appendix is excerpted from DCEC EP3-83.

20.2 Documents referenced in this appendix. JCS Master Navigation Plan (SM-256-83).

30 DEFINITIONS

For purposes of this appendix, the definitions of FED-STD-1037 and those found in appendix B will apply.

40 GENERAL REQUIREMENTS

40.1 Timing and synchronization configuration. The proposed configuration of the timing and synchronization subsystem consists of the station clock, clock distribution subsystem, and digital data buffer. A functional diagram of the station clock and the clock distribution subsystem is shown in figure H-25. For terrestrial nodes colocated with Defense Satellite Communications System (DSCS) sites, existing cesium beam standards used in the DSCS may be used as the primary reference for the DCS station clock. The two precision oscillators provided as backup will have an initial accuracy equal to the reference and a long term stability of ± 2 x 10^{-10}. For non-DSCS sites, Loran C will be used as the primary reference source for the station clock. Both the DSCS atomic clocks and the loran C navigational system have transmit frequency sources that are synchronized to universal coordinated time (UTC).

In order to satisfy the set of performance objectives for timing subsystem availability, station clock accuracy, station clock stability, mean time between outage (MTBO), mean time to repair (MTTR), mean time to timing slips (MTTS), and buffer lengths, the station clock has been specified to provide redundancy in the form of two precision oscillators in order to compensate for any loss of loran C due to equipment failure or signal loss. The station clock is also capable of accepting an external reference (such as a cesium beam standard) when available.

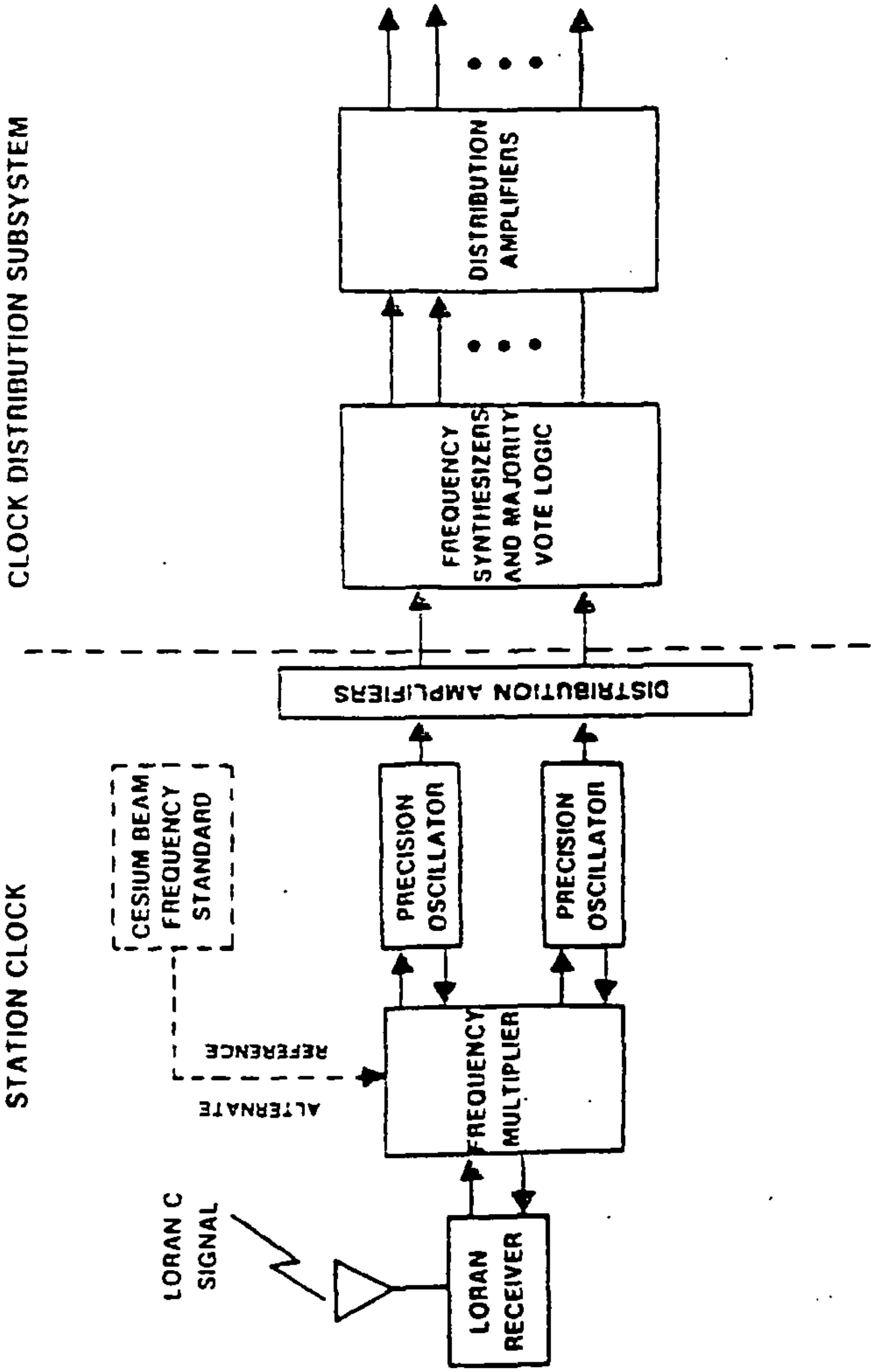


FIGURE H-25. DCS station and clock distribution subsystem.

40.1.1 Station clock. It should be noted that the JCS Master Navigation Plan (SM-256-83) proposes a phase out of the Loran system in favor of the NAVSTAR Global Positioning System (GPS) during the period 1987-1992. In the event that this planning is executed, available alternatives will be substituted to provide requisite UTC reference.

The station clock, as functionally depicted in figure H-26, will provide an accurate and stable source of frequency and time standards at rates of 1 MHz, 5 MHz, and 1 pps. The station clock has the option of being driven by the loran C receiver or by an external reference source (such as cesium beam standard), dependent upon the best available reference. In priority order, first choice will be the primary reference; second choice, the alternate reference; and third choice, the two oscillators. The selection of the loran C or the external reference source as the primary or alternate reference is an operator selectable function.

40.1.1.1 Loran C receiver. The loran C receiver provides automatic acquisition and tracking of operator selected loran C signals for use as a precise reference against which other frequency standards may be compared or controlled. After the Group Repetition Interval (GRI) and desired loran C station have been selected by the operator, no other intervention will be needed. The receiver will automatically acquire the selected station of the loran C chain and then automatically go into the tracking mode. Without intervention, the receiver will continue to track until the incoming signal fades beyond the sensitivity of the receiver or the operator takes action to halt the tracking process. In the event that this signal is lost, the receiver will automatically reacquire the ground wave of the initially selected station.

Using the loran C ground wave, the receiver will provide a 1 MHz signal output which tracks the long term accuracy of the loran C signal. The 1 MHz reference output will have an accuracy of at least 1 part in 10^{11} in one hour, 1 part in 10^{12} in one day, and 1 part in 10^{13} thereafter, maintained with respect to the received signal. The 1 pps reference output as provided by the receiver is tied to the received loran C signal. The 1 pps output is accurate to 1 microsecond with respect to the received signal. The 1 pps pulse, at least 20 microseconds wide, will be used as an unambiguous timing pulse.

40.1.1.2 Frequency multiplier. The frequency multiplier provides the functions of frequency synthesis, distribution, manual selection and failure mode operation and all necessary interfaces within the station clock, to include the loran C receiver, the external source, the primary and back up oscillators and the distribution amplifier.

Should the primary reference fail, the frequency multiplier will automatically switch to the alternate reference until it is manually

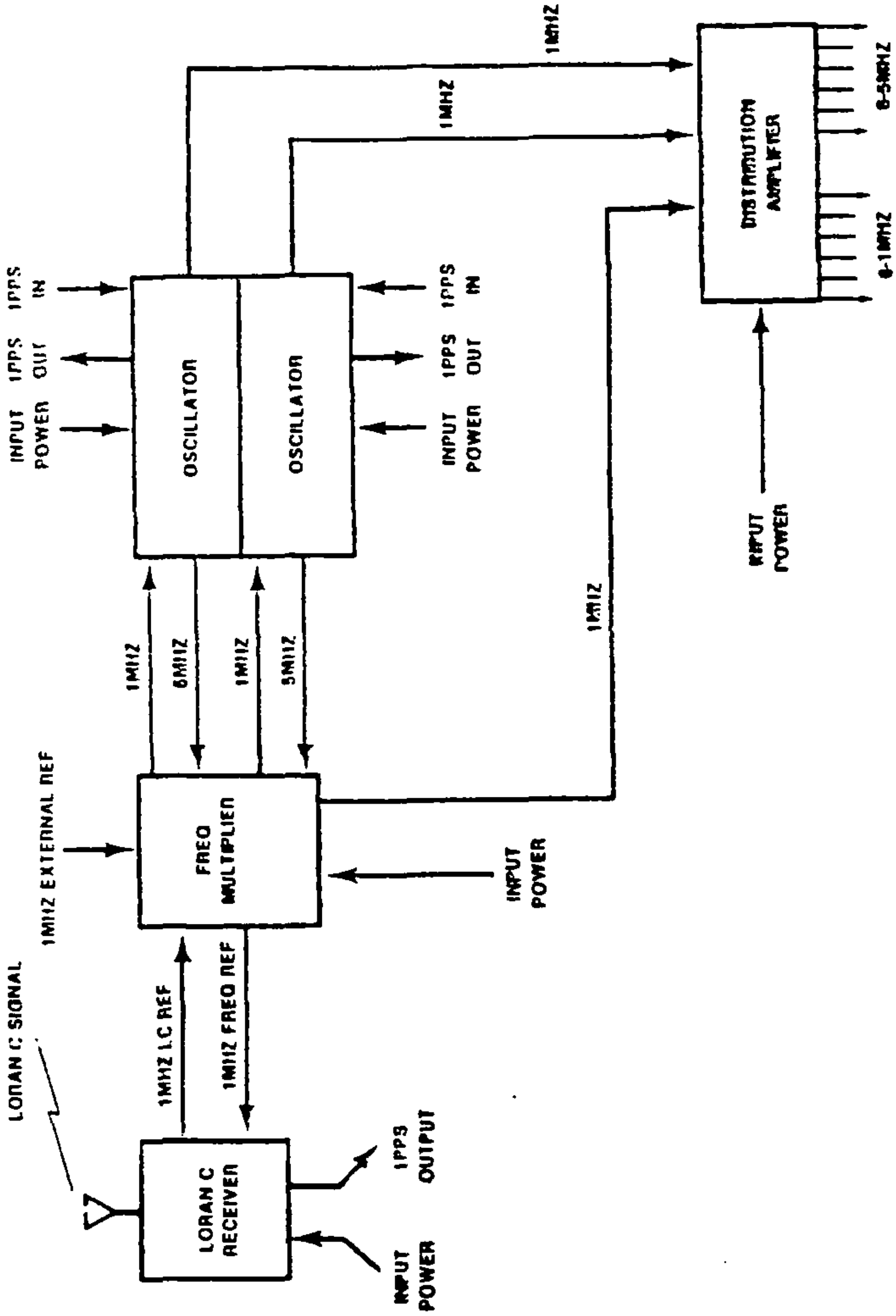


FIGURE H-26. Functional diagram of the station clock.

reset. Should both the primary and alternate references fail, all reference input signals to the oscillators will discontinue, and the oscillators will operate unlocked (not phase and frequency locked to the 1 MHz primary and alternate reference).

40.1.1.3 Oscillators. Two oscillators are provided as separate independent components. Each oscillator is locked to its respective input from the frequency multipler. Should the reference signal be lost, reacquisition of phase lock will be automatic after the reference signal is restored. The oscillators accept the reference input and provide outputs that assume the long term stability of the reference. Upon removal of the reference signal, the oscillators will continue to provide the output signals without immediate degradation greater than $1x10^{-12}$. Thereafter the oscillators will degrade in accuracy not more than $3.3x10^{-11}$ per day.

40.1.1.4 Distribution amplifier. The distribution amplifier provides the drive capability to interface the frequency multiplier and the oscillators' 1 MHz output signals to remote equipment. In addition to its use within the station clock, the distribution amplifier is also capable of indenendent operation. The distribution amplifier employs three separate synthesizers to synthesize the 5 MHz output signals. The distribution amplifier as a minimum provides six 5 MHz and six 1 MHz sine wave outputs.

40.1.2 Clock distribution subsystem (CDS). The CDS interfaces with the station clock to generate and distribute timing signals to transmission and user equipments. In order to meet DCS availability criteria, triple redundant frequency synthesis followed by majority vote logic is provided. Voting logic will select one of the three frequency synthesized outputs and provide the selected frequency rate to the distribution amplifier. The distribution amplifier then provides an individually isolated output to each equipment as required.

The principal functions of the CDS include

(a) accepting up to three independent frequency reference input signals,
(b) providing redundancy in generating synthesized clocking frequencies for the required families of rates (table H-VI),
(c) distributing these clocking signals to individual transmission and switching equipment, and
(d) providing alarm indications for failures.

A functional schematic of the CDS, depicting the interrelationship of its elements, is shown in figure H-27.

The CDS and the associated frequency sources will provide timing to some or all the transmission and switching subsystems located at a DCS

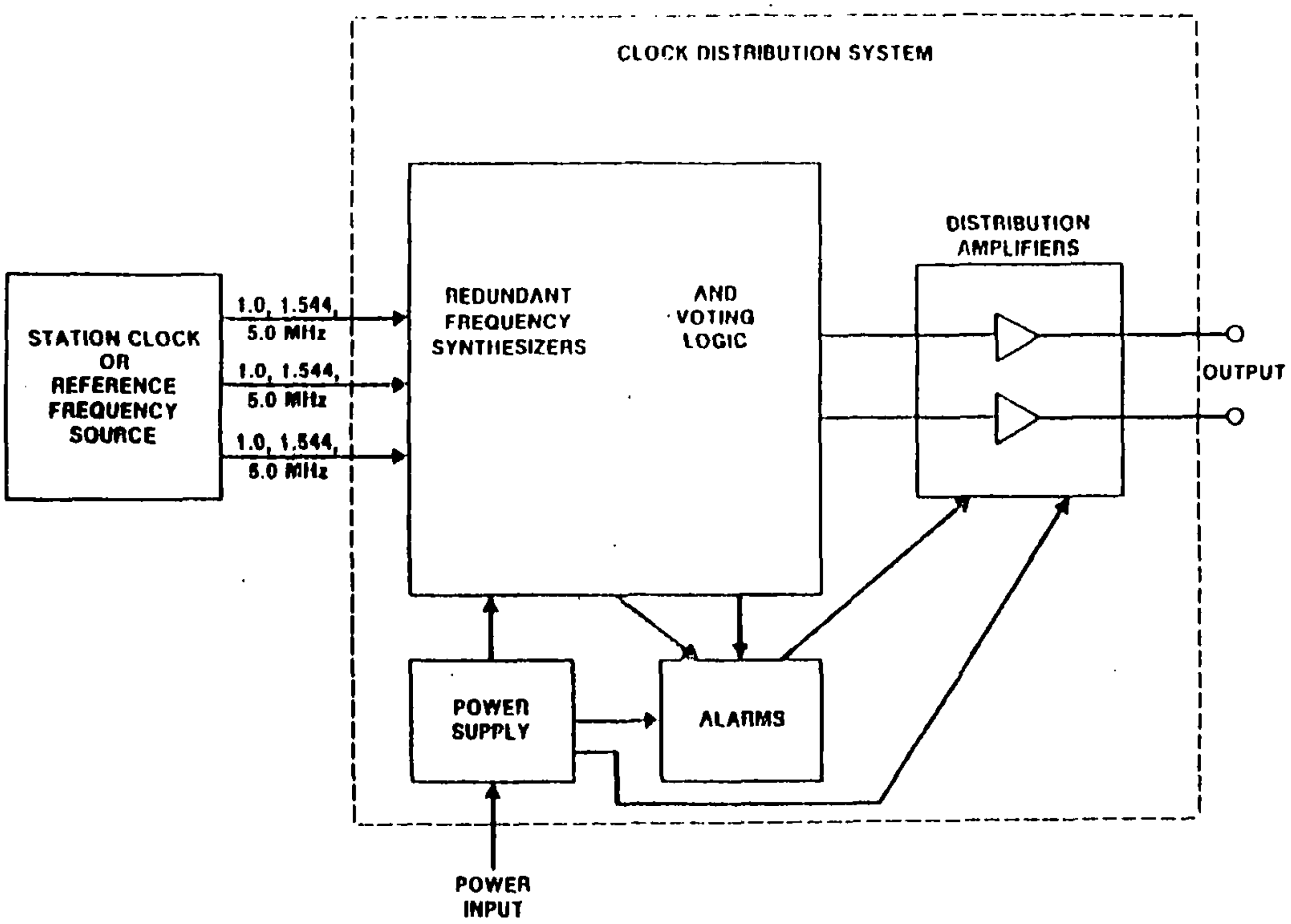


FIGURE H-27. Functional schematic of clock distribution subsystem.

TABLE H-VI. Clock frequency families.

Clock Rates		N Values
I.	75 (2^N) Hz family	N = 0 to 11
II.	600 (N) Hz family	N = 1 to 12
III.	8000 (N) Hz family	N = 1 to 8
IV.	2^N kHz family	N = 6 to 11
V.	192 (N) kHz family	N = 1, 2, 3, 8
VI.	1.544 (N) kHz family	N = 1 to 4
VII.	3.232 (N) MHz family	N = 1 to 4
VIII.	5.0 (N) MHz family	N = 1

communications node. The clock signals generated by the CDS will be applied to external clock inputs of the transmission and switching equipment consistent with the input interface parameters of each equipment.

The CDS frequency synthesizer accepts as inputs three 1 MHz or 5 MHz signals from the station clock or other frequency standard. The CDS also accepts as inputs three 1.544 MHz signals from external sources (e.g., AN/FCC-98). Simultaneous inputs of any combination of 1.544, 1, or 5 MHz cannot be used. When available, the frequency synthesizer of the clock distribution subsystem can also interface with cesium beam standards of the type used in the DSCS. The frequency synthesizer is capable of synthesizing all clock rates listed in table H-VI. For each generated family of clock rates specified in table H-VI, the redundant frequency synthesizers will provide outputs to the voting logic. The voting logic will then select one of these synthesizer outputs and provide the selected frequency rate to the distribution amplifier. The voting logic determines which (if any) of the frequency synthesizer outputs are in disagreement. If one frequency synthesizer is found to disagree with the other two synthesizers, its output is removed from the input to the distribution amplifier, and will require operator intervention for return to service. If all frequency synthesizers are found to disagree, the voting logic will lock to any one of the synthesizer outputs. If two or more of the frequency synthesizers are found to agree, the voting logic will select any one of the synthesizers which agree for output to the distribution amplifier.

Implementation of the network does not require that every node have a loran C receiver or other primary reference standard. The allowable implementation will be to provide these primary clock sources at major nodes, with minor nodes slaved (looped) to them.

The determination as to major versus minor node designation and hence the timing and synchronization configuration for each node is made using a number of specific criteria.

Specific criteria for major nodes are noted below.

(a) The widespread application of the Low Speed Time Division Multiplexer (LSTDM - AN/FCC-100) and its synchronous data channel capabilities require in most cases separate timing and synchronization capabilities,

(b) the introduction of digital troposcatter will require synchronization of associated equipment to include the MD-918 tropo modem and internal oscillators,

(c) with the DCS evolving toward an all digital communications system, there are timing and synchronization requirements for the application of digital switching. Therefore, major nodes within the Defense Switched Network (DSN) realm will consist of those colocated DSN/DCS sites not defined as terminating nodes,

(d) the interface of synchronous data channels between the terrestrial DCS and the DSCS will require synchronization of these two systems. Buffers, station clocks, and clock distribution subsystems may be required for satisfying these DSCS-terrestrial interface requirements, and

(e) timing and synchronization systems have been allocated at those repeater locations (which are more than through-routed repeaters) branching in three or more directions, in order to maintain the overall performance characteristics of the network.

Specific criteria for minor nodes are noted below.

(a) Where LSTDM's are located at terminating sites, looped timing will be used, and

(b) through-routed repeater locations are not provided separate timing and synchronization subsystems.

(This page intentionally left blank)

APPENDIX I
EXAMPLE OF TIME-DEPENDENT SYSTEMS AND TIME-DISSEMINATION SYSTEMS

This appendix contains general information related to MIL-STD-188-115. Appendix I is not a mandatory part of this standard.

10 GENERAL

10.1 Purpose. The purpose of this appendix is to illustrate typical time-dependent systems and time dissemination systems.

10.2 Scope. This appendix is a brief overview of time-dependent systems and time dissemination systems and is not all inclusive.

20 REFERENCED DOCUMENTS

"Navy Precise Time and Time Interval (PTTI) Requirements Analysis Final Report," NAVOBSY TS/PTTI SOP-81, "Operating Procedures for Precise Time and Time Interval Equipments."

30 DEFINITIONS

For purposes of this appendix, the definitions of FED-STD-1037 and those found in appendix B will apply.

40 GENERAL REQUIREMENTS

40.1 Examples of time-dependent systems. The following descriptions illustrate typical time-dependent systems and the means by which accurate time is obtained, maintained and, in some cases, provided to other systems or nodes.

NOTE: There are numerous Navy systems that require time accurate to 1 ms or better. The timing requirements of many of these systems are given in the "Navy Precise Time and Time Interval (PTTI) Requirement Analysis Final Report", published by the Space and Naval Warfare Systems Command (SPAWARS), and in a NAVELEX memorandum, both of which are classified. The Defense Communications Agency (DCA) and the Services also have systems with timing requirements of better than 1 ms. Some of these systems are classified.

40.1.1 SATCOM. In the DSCS SATCOM spread spectrum systems, the redundant local cesium clocks are traceable directly to the DoD Master Clock (USNO Master Clock) and serve as precise time stations (PTS). The SATCOM clocks are regularly checked through the inherent worldwide time dissemination capability of the spread spectrum links to the USNO and are occasionally compared with portable USNO cesium clocks. Dissemination (either portable clock or satellite-link) is accurate to the order of 100 ns, and the clocks are maintained within ±5 us of the USNO Master Clock. Adjustments that can change the time or rate (frequency) of the SATCOM clock are done manually according to a standard operating procedure and are performed only by direction of

USNO. The operation of the PTS network is specified in NAVOBSY TS/PTTI SOP-81. A PTS provides a point for local and transient clock checks for both time and frequency and performs a monitor and reference function for local transmission. In some cases, the accurate time and frequency are made available to other colocated systems, such as channel-packing, AUTODIN, crypto-systems, and LOS microwave links. The PTS may also monitor loran C, Navy Navigation Satellite System (TRANSIT), and other time dissemination facilities. The monitoring function is a part of the system by which USNO disseminates precise time, since the results are reported to USNO. At the same time, the monitoring adds to the redundancy of the PTS, because deviations in the local clock can be more effectively evaluated with larger amounts of independently acquired corroborative data. Since the SATCOM clocks are regularly rated and updated by USNO over an extended period of time, their performance histories are well known, and they have the capability to free-run for long periods without accumulating large time or frequency error. Therefore, the PTS system has a high degree of survivability, and degradation would be very gradual and small in the event of a loss of the link with USNO.

40.1.2 <u>HAVE QUICK.</u> The HAVE QUICK communications system for tactical aircraft communications employs rubidium clocks to maintain time accuracy. Thousands of these equipments are being procured. The clocks may be synchronized by sending synchronizing words between aircraft. The system will interface with the NAVSTAR Global Positioning System (GPS) for time setting and updating to the required accuracy. Interoperability among and within groups will be enhanced by the GPS connection.

40.1.3 <u>JTIDS.</u> The Tactical Digital Information Link J provides secure digital communications utilizing a formatted data standard to support high capacity, secure, non-nodal, jam resistant information distribution. The link will be capable of operating in the severe adverse electromagnetic environments anticipated in future military operations. TADIL J recognizes state-of-the-art advances in signal processing and integrated circuit technology to overcome the most severe limitations of the previous generations of TADILs with expected data rates one to two orders of magnitude higher than previous systems. At the same time it incorporates sophisticated spread-spectrum communications and forward error correction coding techniques which support very high anti-jam margins, and low probability of intercept/low probability of exploitation (LPI/LPE) characteristics in systems which conform to the TADIL J requirements.

40.1.4 <u>MILSTAR.</u> The MILSTAR communications system will have a precise time requirement. Details are not available at present.

40.1.5 VERDIN. The Navy VERDIN VLF/LF communications system (and likely some similar Air Force systems) has a precise time requirement. Submarines and shore stations employ cesium beam clocks that are required to free-run for extended periods.

40.1.6 TACAMO. TACAMO aircraft provide a survivable VLF/LF link with Navy units. The system requires precise time and alternate means are provided for time setting and updating.

40.1.7 Other systems. Other command, control, communications and intelligence systems of the three services require precise time. Included are a number of modems, crypto systems, sensor systems, etc., whose details or requirements are classified.

40.2 Examples of time dissemination systems. Described below are some of the time dissemination systems in current use. These systems are traceable to USNO and can be used for clock setting and updating within their accuracy and availability limits.

40.2.1 NAVSTAR-GPS. The NAVSTAR Global Positioning System (GPS) is a worldwide navigation and time dissemination system giving position to approximately 10 meters and time accurate to 100 ns. The full constellation of 18 satellites giving continuous worldwide service will be operational in 1987. Currently, there are four operating satellites that can be used by fixed stations and, under favorable conditions, by mobile users. The user equipment now under development will contain a standard precise time interface. The satellites are monitored by USNO, and updated regularly. Cesium and rubidium clocks are carried aboard the satellites, and a hydrogen maser clock is under development for maximum survivability in the event of loss of contact with the monitor and control stations. The satellites will be capable of operating autonomously for extended periods in the unlikely event of a loss of all the links with the master control station. While reception from four satellites is required for a full navigation and time determination, a fixed site in a known location can determine time to 100 ns accuracy from reception of one satellite. The ground segment employs high-performance redundant cesium clocks and plans to use hydrogen maser clocks currently under development.

40.2.2 Loran C. The low frequency loran C navigation system gives ground wave coverage of much of the Earth's surface, but there are large gaps. Accuracy of time dissemination in the ground wave areas is normally better than 1 us. In the larger areas covered only by sky wave propagation, the accuracy is considerably reduced and is subject to occasional propagation disturbances, including daily effects, but is usable for some applications. Since the inherent time ambiguities of the system are in the order of 5 ms, time must be known locally to that accuracy before precise time can be obtained.

The various links of the system are monitored by USNO and by PTSs to give traceability to USNO. The loran C transmitters employ cesium beam clocks that can free-run for extended periods without update. Individual transmitters of a chain maintain close coordination with the master station through a monitoring system, but the chain may deviate a few microseconds from UTC. Corrections for each chain are published regularly by USNO. In many areas, interference from low frequency stations must be rejected with notch filters. Susceptibility to jamming is a possible disadvantage. Individual transmitters are occasionally taken off the air for maintenance.

Timing from loran C is used in some cases either for monitoring the long term performance of local clocks or determining the drift rates of moderate stability oscillators. Under favorable conditions and using ground wave signals, frequency comparisons can be made to about $1x10^{-12}$ over a one day observation. Distortions of sky wave signals degrade frequency measurement capability by a factor of 100 or more.

40.2.3 OMEGA navigation system. The very low frequency OMEGA navigation system has nominal world wide coverage through a system of eight transmitters. Navigation is accomplished by making simultaneous phase comparisons of several transmitters. For timing, the system is useful mainly as a stable frequency source, since time ambiguity intervals are very small. While the system employs cesium beam clocks, daily and anomalous variations of the essentially sky wave propagation make interpretation of frequency comparisons difficult (as with sky wave Loran C), and phase comparisons are normally made over a period of a day or more. Daily phase values of OMEGA are published by USNO.

40.2.4 High frequency time broadcasts. High frequency time broadcasts are useful mostly for time dissemination to an accuracy of about 1 ms. Propagation is typically sky wave and unlike navigation system dissemination and two-way satellite dissemination, there is no inherent provision for determining propagation time. The propagation delay calculated from the best estimate of the radio path involves some uncertainty, especially when the path is long. The unambiguous time is useful, within the coverage areas of the high frequency stations, for moderate accuracy clock setting and updating or as a means of resolving the ambiguities of loran C. Coverage is variable and depends upon the frequency in use and the existing propagation conditions, as well as the state of interference from other broadcast services or intentional jamming. The broadcasts of the National Bureau of Standards (NBS) high frequency stations WWV and WWVH are traceable to USNO through the PTSs maintained by NBS in Colorado and Hawaii.

40.2.5 Portable clocks. Portable Clocks are used by USNO as one method of rating and updating clocks of PTSs and other facilities requiring precise time. The cesium clocks are set to UTC at the USNO master clock and transportable while running continuously to the facilities requiring calibration. Batteries are used when power mains are not available. The clocks are rechecked after the trips in a timing "closure" to verify proper portable clock operations and to prorate small deviations through the trip. Accuracy of portable clock trips is in the order of 100 ns.

Clock trips are also used to verify other time dissemination techniques, such as GPS and the SATCOM spread spectrum method, which have commensurate precision. As the number of valid techniques increases, the number of portable clock trips will be reduced. Portable clock trips, however, may remain as a backup dissemination method.

40.2.6 Other dissemination methods. A large number of dissemination methods have been developed for both specific and general application. Only a few will be mentioned here.

40.2.6.1 TV line-10. In the TV line-10 method, two or more facilities extract the same synchronization pulse from a cooperative or uncooperative television broadcast station in common view of the facilities and compare its timing with their local clocks. The technique requires the users to resolve the frame ambiguity of about 33 ms separately. The method also requires exchange of data between the users. Propagation time differences must be resolved by distance measurement, portable clocks, etc. Range is limited by the coverage of available television transmitters in common view. The method is subject to broadcast schedules and other factors that are not under control of the users.

40.2.6.2 Very long baseline interferometry (VLBI). VLBI is a dissemination method that is capable of very high precision. The technique involves simultaneous monitoring of extraterrestrial radiation sources at two or more user sites and a comparison of time marked data exchanged through some communications medium such as shipping of recordings between sites. Operationally, the technique is not generally employed for communications, but might be used in very precise comparisons of major timing facilities.

40.2.6.3 Other dissemination systems. A number of dissemination systems have been designed for specific applications. Some are piggyback systems that make use of existing communications systems, and others employ special links or broadcasts established specifically for timing. In the Hawaii PTTI test bed, for example, a specially designed spread spectrum modem and time-transfer unit have been used on an unused portion of a microwave line-of-sight (LOS) communications link to make timing comparisons to sub-microsecond accuracy. The pilot tone of the master station of another microwave LOS network was stabilized by the station's accurate frequency reference to provide an accurate standard frequency to the other stations of the network. The spread spectrum modem and time transfer unit were also used in two-way satellite communications links to provide accurate time to stations not equipped with spread spectrum communications modems of the types used in SATCOM time dissemination.

Time dissemination via fiber optics or LOS laser links has the potential for extremely high precision because of the large available bandwidth and has been used experimentally with good results. Some links have the capability to act as time dissemination media. Ordinarily, a channel of large bandwidth will support precise time transfers, but this is not necessarily the case with frequency hopping systems that hop slowly.

These techniques require some means, such as two-way transmission or independent measures, to determine the propagation time delay. The propagation delay may be measured and considered constant for some fixed links not involving variable distances or paths, but with satellite links or links involving mobile platforms, the propagation delay must generally be determined for each time transfer. Automatic methods are usually available to resolve the propagation delay when two-way circuits are involved. The "passive" navigation systems, such as GPS or loran C, can be used in a (one-way) broadcast mode to provide precise time dissemination to both mobile or fixed users. The advantage of a passive system is that the user is not required to emit a signal or use any of its communications capacity to exchange data or correct for propagation delay.

APPENDIX J
SUBSERVIENT OSCILLATORS

This appendix contains tutorial information in support of MIL-STD-188-115. Appendix J is not a mandatory part of this standard.

10 GENERAL

10.1 Purpose. The purpose of this appendix is to describe general principles of the operation of subservient oscillators.

10.2 Scope. This appendix is a tutorial on subservient oscillators and does not provide detailed descriptions, i.e., loop bandwidth.

20 REFERENCED DOCUMENTS

Not applicable.

30 DEFINITIONS

For the purpose of this appendix, the definitions of FED-STD-1037 and those found in appendix B will apply.

40 GENERAL REQUIREMENTS

With reference to figure J-28, the reference signal from the principal clock is

$$A_p \sin(\omega_p t+\theta_p), \qquad (132)$$

and the output from the controlled oscillator is

$$A_o \sin(\omega_o t+\theta_o). \qquad (133)$$

The 90 degree phase shift between the oscillator and the phase detector is added so that the output of the oscillator will be in phase with the reference signal from the principal clock under phase locked conditions. The phase detector is a product device so that its output is the product of its two inputs multiplied by a gain factor. Therefore, for these inputs to the phase detector, its output is

$$K_2 A_p A_o \sin((\omega_p+\omega_o)t + (\theta_p+\theta_o)) + K_2 A_p A_o \sin((\omega_p-\omega_o)t + (\theta_p-\theta_o)). \qquad (134)$$

The filter removes the sum frequency term leaving only the difference term to be applied to control the frequency of the voltage controlled oscillator, ω_o. If the natural frequency of the oscillator (the frequency when the control voltage is zero) is the same as the reference frequency, this output is proportional to $\sin(\theta_p - \theta_o)$ and it will increase ω_o temporarily to increase θ_o or it will decrease ω_o temporarily to decrease θ_p. When θ_o is equal to θ_p, there is no output from the phase detector so that the system should continue to operate with θ_o equal to θ_p. If there are any disturbances to θ_o (or θ_p), the

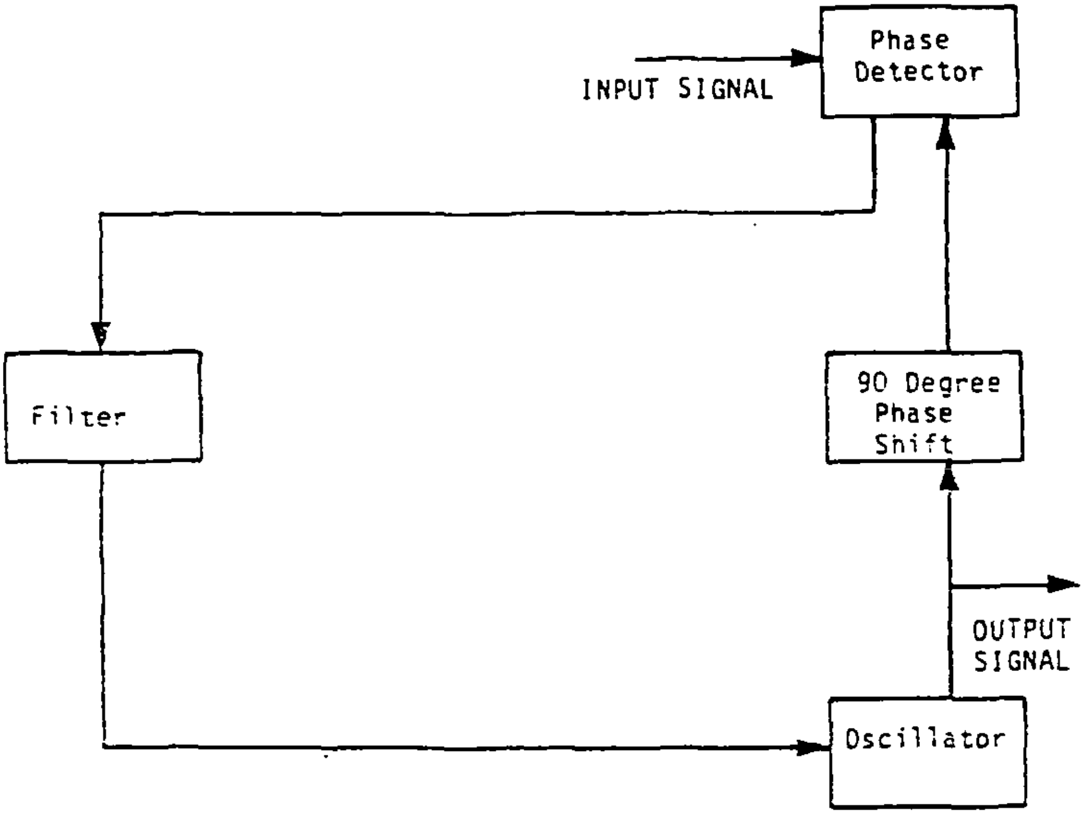


FIGURE J-28. Phased locked loop.

voltages from the phase detector will temporarily alter the frequency of the oscillator to reduce the difference between θ_p and θ_o.

The assumption that the natural frequency of the oscillator is the same as the reference frequency is not a good assumption. In practice an input control voltage must be applied to the voltage controlled oscillator to keep it on frequency while temporary variations in the control voltage are used to maintain the desired phase relationship. This can be accomplished by adding an integrator in the path between the output of the phase detector and the oscillator so that the output of the phase detector is integrated before being applied to control the oscillator. If there is a difference between the frequency of the oscillator and frequency of the reference signal and there is no control signal applied to the oscillator, the output of the phase detector will be a sine wave with a frequency equal to this difference. If this is applied to the oscillator as a control signal, it will distort the sine wave. The control signal will always change the oscillator frequency in a way to reduce the phase difference between the signals applied to the phase detector. During part of the phase detector output cycle, it will increase oscillator frequency and during another part, it will decrease the frequency. When $\sin(\omega_p-\omega_o)t$ is positive it increases ω_o to make the phase error smaller; but when $\sin(\omega_p-\omega_o)t$ is negative, it decreases ω_o to make the phase error smaller. At first thought, it might seem that these would cancel over the period of a full cycle. However, the portion of the cycle where $(\omega_p-\omega_o)$ is decreased is longer (because of its lower frequency) than portion of the cycle where $(\omega_p-\omega_o)$ is increased. With this distorted signal applied to the integrator, a voltage will accumulate that will cause the oscillator frequency to move toward the reference frequency until $(\omega_p-\omega_o)$ is equal to zero and phase lock is achieved with $\theta_p-\theta_o$ also equal to zero. Hence, in normal phase locked operation, there will always be a control voltage applied to the oscillator to keep it on frequency, but the input to the integrator will be zero. Whenever there is tendency for the oscillator to drift in-phase, an output from the phase detector will correct it.

Under phase locked conditions, the output of the phase detector is zero. If a d.c. voltage is added to this output, the input to the integrator must still be kept zero, so that the oscillator frequency is temporarily changed until there is an output from the phase detector that exactly cancels the added d.c. voltage. The oscillator continues to maintain phase lock with the reference signal but with a phase offset determined by the added d.c. voltage and the characteristics of the phase detector. This phase offset is the basis of the subservient oscillator that tracks one input signal when it is available but maintains the long term stability of the reference signal when that input signal is not available.

With reference to figure J-29, the loop at the top of the figure operates in the same manner as described in figure J-28 when the output from the hold circuit is zero. Any output from the hold circuit will cause a phase offset relative to the reference signal at point A. The signal to be tracked is applied at point B. When this signal is present, the holding mode of the hold circuit is disabled and the output of filter 2 is passed to the sum circuit through an inverter. The output of the oscillator is

$$A_o\sin(\omega_o t+\theta_o). \qquad (135)$$

The reference signal from the principal clock at point A is

$$A_p\sin(\omega_p t+\theta_p), \qquad (136)$$

and the signal to be tracked at point B is

$$A_t\sin(\omega_t t+\theta_t). \tag{137}$$

Therefore the output of the sum circuit at point C is

$$KA_pA_o\sin((\omega_p-\omega_o)t + (\theta_p-\theta_o)) - KA_pA_t\sin((\omega_p-\omega_t)t + (\theta_p-\theta_t)). \tag{138}$$

In a well controlled communications system, the signal to be tracked originating at the principal clock, has the same average frequency as the principal clock that is applied as reference at point A so that $\omega_p=\omega_t$. As shown earlier, the control system will drive the input to the integrator at point C to zero so that

$$A_o\sin((\omega_p-\omega_o)t + (\theta_p-\theta_o)) = A_t\sin(\theta_p-\theta_t). \tag{139}$$

If the input level of the signals to the phase detectors are maintained at the same level (or if phase detectors that are insensitive to the level of the input signal are used) and if under controlled conditions $\sin(\theta_p-\theta_o) = \sin(\theta_p-\theta_t)$ are both smaller than $\pm\pi/2$, then $\theta_o = \theta_t$ and the oscillator will track the desired signal. However, if either $(\theta_p-\theta_o)$ or $(\theta_p-\theta_t)$ exceeds $\pm\pi/2$ the oscillator might lock to an incorrect signal. This occurrence will be discussed in detail later. When the desired signal to track is not available, the hold circuit is activated maintaining the offset voltage input to the sum circuit at the last value obtained prior to loss of signal. The oscillator is locked to the reference signal from the principal clock with a phase offset determined by the voltage output of the hold circuit until the signal again becomes available.

There are various ways that phase detectors can be built to increase the phase angle that can exist between the input signals before ambiguities can occur. This is accomplished, for example, when time comparisons are used instead of the phase comparisons of periodic signals. Perhaps the most commonly applied method is by passing the inputs to the phase detectors through frequency dividers. This extends the range of the ambiguity by factor equal to the frequency division factor.

Another approach, for allowing the oscillator to track very large phase excursions (a very large number of cycles) relative to the principal clock while still maintaining a phase lock to the principal clock will be explained with reference to figure J-30 where the filters associated with each phase detector are assumed to be included in the phase detector to simplify the diagram. The operation will be explained in terms of the outputs of each of the phase detectors when a signal is present.

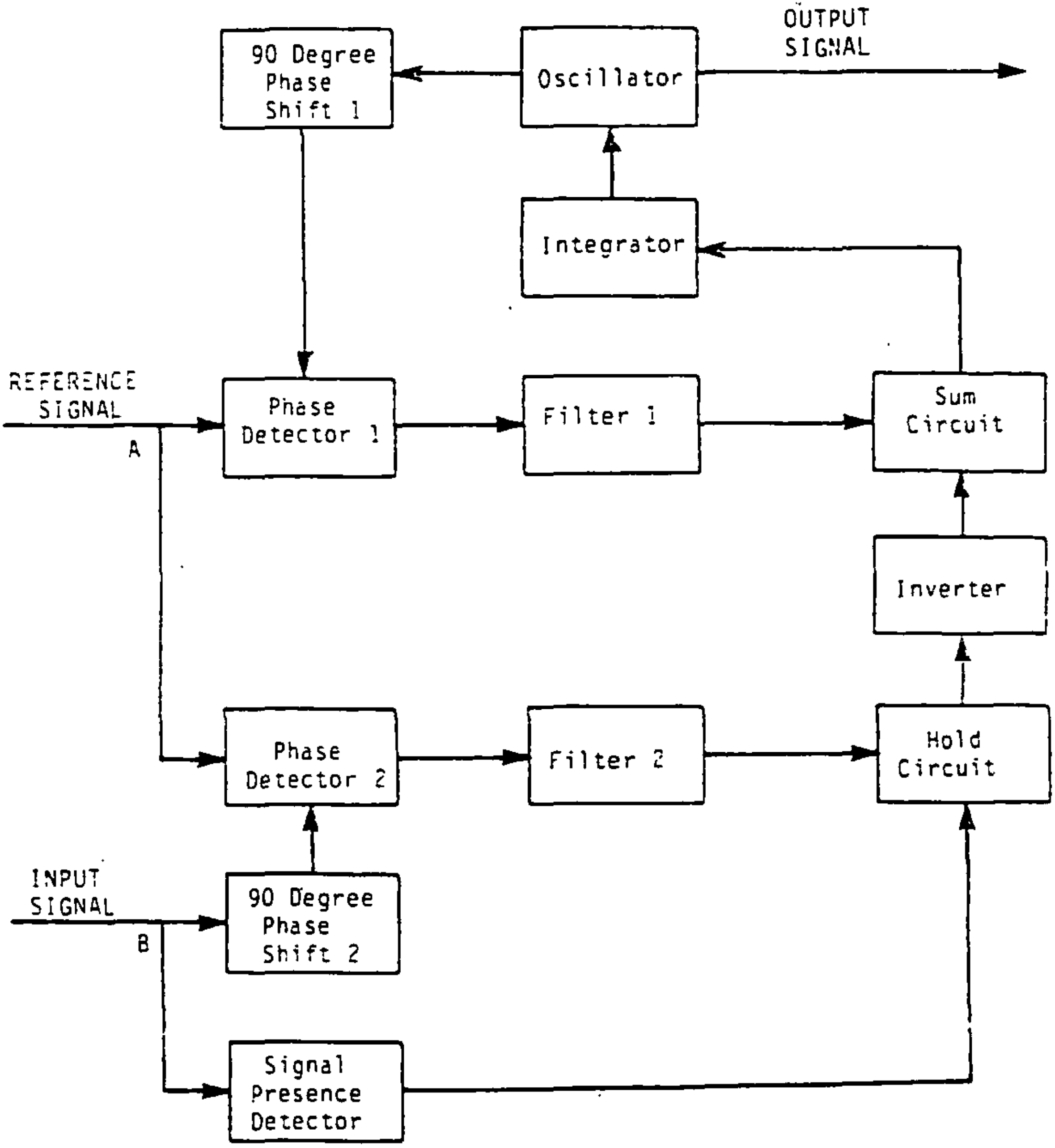


FIGURE J-29. Phased locked loops with two phase detectors.

The output of phase detector 1 is

$$\frac{-A_pA_t}{2}\cos(\omega_p-\omega_t)t+(\theta_p-\theta_t). \tag{140}$$

The output of phase detector 2 is

$$\frac{-A_pA_t}{2}\sin(\omega_p-\omega_t)t+(\theta_p-\theta_t). \tag{141}$$

The output of phase detector 3 is

$$\frac{-A_pA_o}{2}\cos(\omega_p-\omega_o)t+(\theta_p-\theta_t). \tag{142}$$

The output of phase detector 4 is

$$\frac{-A_pA_o}{2}\sin(\omega_p-\omega_o)t+(\theta_p-\theta_o). \tag{143}$$

Under locked conditions, the average frequencies of ω_p, ω_t, and ω_o will be the same and any variations from these frequencies, can be included in the values of θ. These frequencies will not be explicitly written for the outputs of phase detectors 5 and 6. This will simplify the notation.

The output of phase detector 5 is

$$\frac{A_p^2A_tA_o}{4}\sin(\theta_p-\theta_t)\cos(\theta_p-\theta_o). \tag{144}$$

The output of phase detector 6 is

$$\frac{A_p^2A_tA_o}{4}\cos(\theta_p-\theta_t)\cos(\theta_p-\theta_o). \tag{145}$$

The output of the sum circuit is

$$\frac{A_p^2A_tA_o}{4}\left[\sin(\theta_p-\theta_t)\cos(\theta_p-\theta_o)+\cos(\theta_p-\theta_t)\sin(\theta_p-\theta_o)\right], \tag{146}$$

where

$$K_1=\frac{A_p^2A_tA_o}{4}\sin(\theta_p-\theta_t), \tag{147}$$

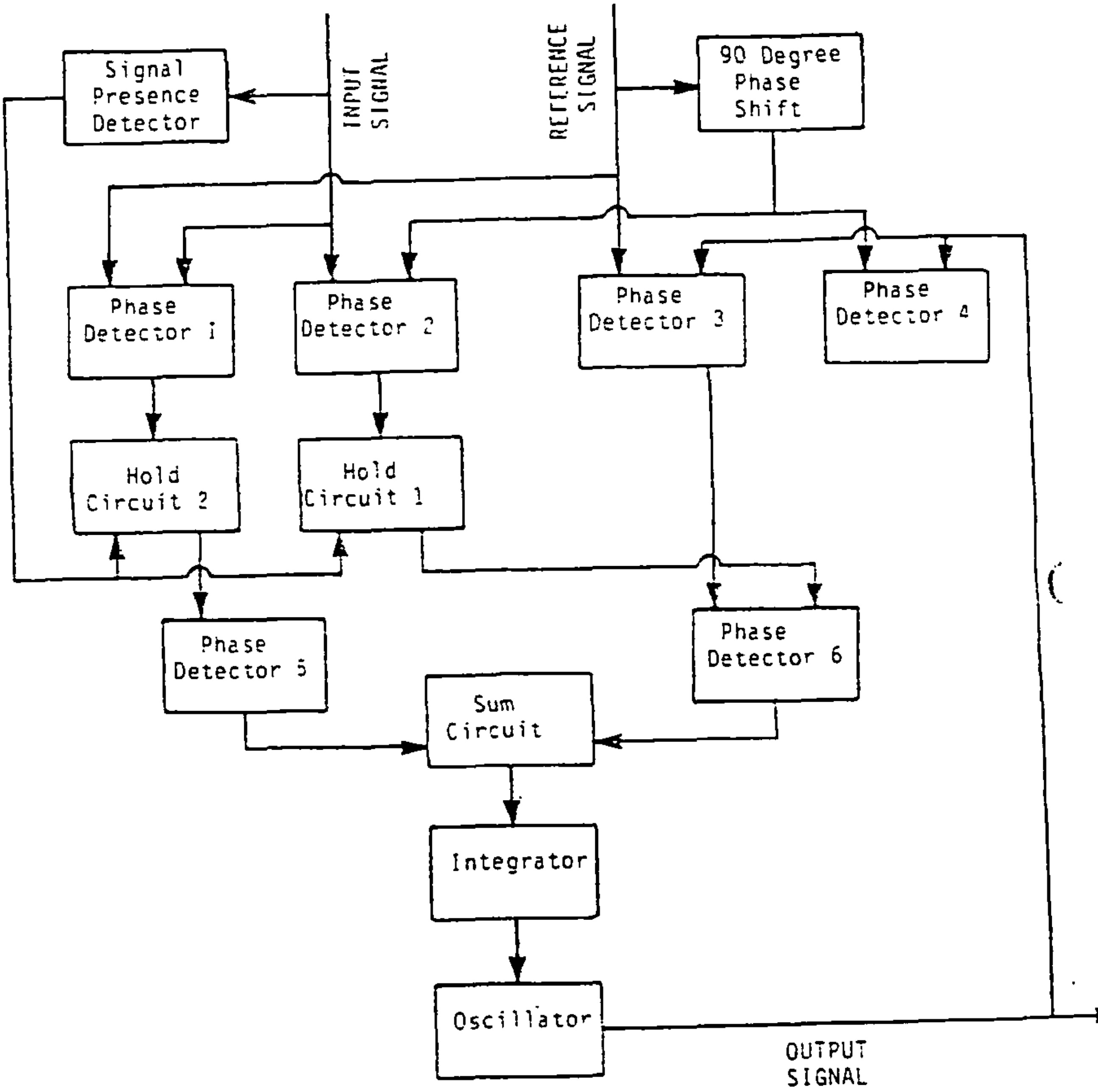


FIGURE J-30. Phased locked loops with six phase detectors.

and

$$K_2 = \frac{A_p^2 A_t A_o}{4} \cos(\theta_p - \theta_t), \qquad (148)$$

and

$$\tan^{-1} \frac{K_1}{K_2} = \theta_p - \theta_t + 180^\circ. \qquad (149)$$

The output of the sum circuit is applied directly to the integrator. When the system is phased locked, the input of the integrator is zero and $\sin(\theta_p - \theta_t) - (\theta_p - \theta_o)$ is zero. When θ_t changes, a corresponding change occurs in θ_o. When the signal is lost, the last values of K_1 and K_2 are maintained in the two hold circuits and the oscillator maintains a phase lock with the reference but with a fixed offset determined by K_1 and K_2. With this circuit, θ_t can be changed and an indefinite number of cycles and θ_o will follow it. However, when the signal is lost and K_1 and K_2 are fixed, θ_o will remain phase locked to the reference with an offset determined by the last value of $(\theta_p - \theta_t)$.

Another method of extending the range of a subservient oscillator over many cycles is closely related to the frequency division/phase method described earlier, except instead of using a frequency divider and phase detector, it uses a pseudo random generator and a correlator. This has the advantage of extending the ambiguity range while maintaining the resolution of the original system, but it has the disadvantage of more difficult initial acquisition of phase lock.

(This page is intentionally left blank)

APPENDIX K
JITTER

This appendix contains general information related to MIL-STD-188-115. Appendix K is not a mandatory part of this standard.

output signal transitions. The amplitude and frequency response of system timing recovery circuits can also affect jitter. To a first approximation, these circuits will remove input jitter frequency components outside their bandwidth and will pass or even amplify jitter within their bands.

Pattern dependent jitter can result from intersymbol interference caused by system response misalignments or when timing recovery circuits are required to process digital signals that contain periods of minimal or non-random signal transitions. Digital line codes that assure a more random-like pattern activity are often used, in part, to minimize these effects.

Another prevalent source of jitter termed waiting-time jitter arises when using certain types of multiplexing-demultiplexing processes employing pulse-stuffing. Input channels that are not synchronized to the same timing source can be multiplexed together. One common method uses positive justification, or pulse stuffing, of the input channels to a common frequency. A typical multiplexed digital signal consists of a number of channels that are TDM together into a single data stream. Groups of these bits are separated by overhead bits inserted periodically at the multiplexer which contain synchronization information, an indication of whether a pulse stuff occurred in individual channels, and other functions such as error-detection and auxiliary signaling channels. Pulse stuffing is accomplished using elastic stores in which the continuous channel input is written into a buffer, or data store, at the channel rate and read out of the store at the multiplexer channel rate into the TDM bit stream. Phase comparisons between the input and output timing indicate if a stuff bit is required. This pulse stuff and its subsequent removal at the demultiplexer can only occur in certain time slots which gives rise to the term waiting time jitter to describe the jitter caused by this process. In most systems, the ratio of the actual stuff rate dictated by the channel timing and multiplexer timing and the stuff opportunity rate dictated by the overhead structure are not rational, and frequency components of waiting time jitter can extend down to very low frequencies. This jitter is usually within the bandwidth of system components and can accumulate as systems are interconnected.

Other sources of jitter, such as the intrinsic phase noise of oscillators used as timing sources and in timing recovery phase locked loops, also add to the overall signal jitter although these levels are usually low.

The sources of jitter discussed are important to consider and usually occur in various degrees in digital systems. They can, in their extreme, cause performance degradations and make error-free connections between systems impossible.

40.1.2 Jitter tolerance. Most sources of jitter can be defined and usually controlled by proper system design, however, system components must be able to tolerate these jitter levels for proper system performance.

Most system components such as repeaters and demultiplexers have input timing recovery circuits that permit them to perform their functions. The tolerance to jitter of these circuits takes the form of figure K-31 which shows tolerance levels at which errors occur in bits, or unit intervals, of jitter versus the frequency of the jitter. Frequency components of input jitter greater than the bandwidth of the timing recovery system are not tracked, and acceptable input jitter variations are usually restricted to one bit or less as shown in the figure.

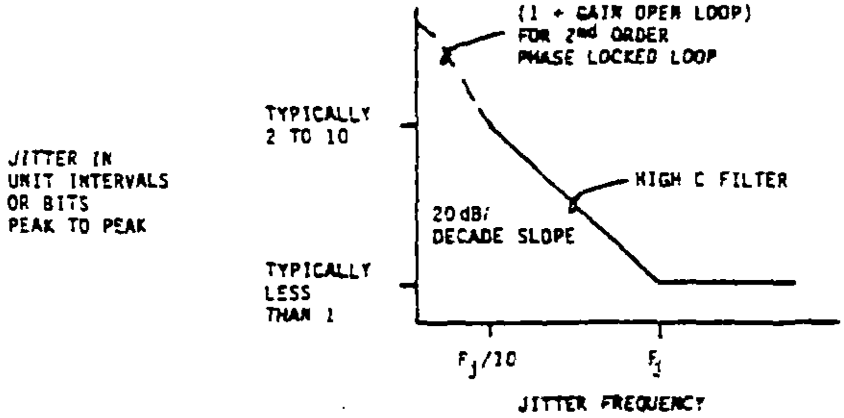


FIGURE K-31. Jitter tolerance for equipment with input timing recovery circuitry.

The recovered timing begins to follow jitter frequencies that are within the timing recovery bandwidth, and the tolerance to jitter increases for lower jitter frequencies. The jitter tolerance of components that have filters or phase locked loop timing recovery circuits at their input are shown in figure K-31.

For equipment that incorporates an elastic store for jitter reduction or clock smoothing, such as the demultiplexer channel output previously discussed, the jitter tolerance takes a form similar to figure K-32. For this case the tolerance to input jitter is the lower of the tolerance of the input signal timing recovery circuit or the tolerance of the very narrow phase locked loop of the elastic store. The tolerance of the elastic store's loop is increased from 1 bit peak-to-peak at high jitter frequencies by the addition of dividers, which permit the loop phase detector in the elastic store to tolerate greater input phase excursions without losing lock.

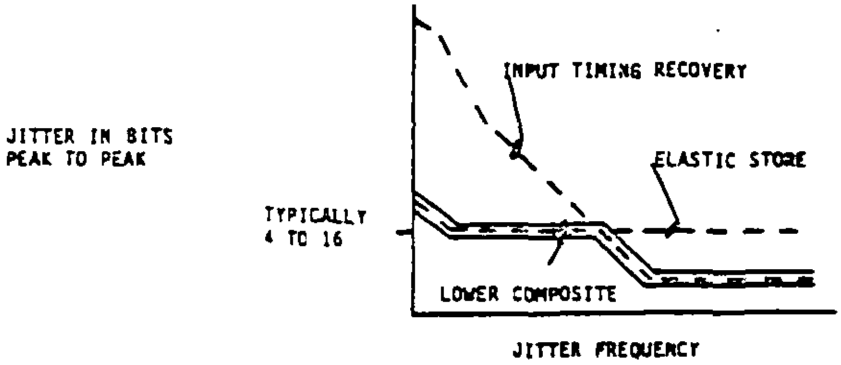


FIGURE K-32. Jitter tolerance for equipment with elastic store.

The exact characterization of jitter and its effect on performance in digital communications systems is often difficult at best, particularly when different digital links made of equipment from different manufacturers are interconnected. In this situation it is desirable to correlate pertinent jitter measurements with specific performance parameters. The following measurements are useful in characterizing jitter and assessing its effects on performance.

40.1.3 Jitter measurements. Both the magnitude and frequency content of jitter are usually important when determining jitter tolerance because of the frequency dependent characteristics of digital equipment. CCITT Recommendation O.171 defines the level and frequency ranges for jitter generating equipment that are applicable to most systems. Jitter tolerance measurements using selected bit pattern sequences or system-generated signals are also useful to assess pattern dependency effects.

40.1.4 Jitter magnitude. A measurement of peak-to-peak jitter is useful at the input to equipment such as demultiplexers and digital switches that have a jitter tolerance that is flat over a broad frequency range as shown in figure K-32.

40.1.5 Maximum jitter. A stored measurement of the maximum peak-to-peak jitter that occurs during a particular measurement period serves to verify the extremes of jitter excursions on digital signals. The limits of these measurements, to assure application to most systems, are also specified in CCITT Recommendation O.171.

40.1.6 Jitter threshold seconds. The number of seconds during which the peak-to-peak jitter exceeds a user selected threshold is recorded. This measurement is useful in characterizing the jitter of a system with the threshold set relative to a particular system tolerance level.

(This page intentionally left blank)

APPENDIX L

LORAN C, OMEGA, VLF TRANSMITTING STATIONS, AND TIME-SIGNALS EMITTED IN THE UTC SYSTEM

This appendix contains general information related to MIL-STD-188-115. Appendix L is not a mandatory part of this standard.

10 GENERAL

10.1 Purpose. The purpose of this appendix is to list loran C, OMEGA, and VLF transmitting stations and time-signals emitted in the UTC system.

10.2 Scope. This appendix gives lists of transmitting stations and time signals.

20 REFERENCED DOCUMENTS

Not applicable.

30 DEFINITIONS

Not applicable.

40 GENERAL REQUIREMENTS

40.1 Loran C, OMEGA, and VLF transmitting stations.

40.1.1 Loran C transmitting stations (100 kHz)

Central Pacific (4990)
- Johnston Island
- Upolo Point, Hawaii
- Kure, Midway Island

East Coast Canada (5930)
- Caribou, Maine
- Nantucket, Massachusetts
- Cape Race, Newfoundland, Canada
- Fox Harbour, Labrador, Canada

West Coast Canada (5990)
- Williams Lake, British Columbia, Canada
- Shoal Cove, Alaska
- George, Washington
- Port Hardy, British Columbia, Canada

Labrador Sea (7930)
- Fox Harbour, Labrador, Canada
- Cape Race, Newfoundland, Canada
- Angissoq, Greenland

Gulf of Alaska (7960)
- Tok, Alasaka
- Narrow Cape, Kodiak Island, Alaska
- Shoal Cove, Alaska

Norwegian Sea (7970)
- Ejde Faeroe Islands, Denmark
- Bo, Norway
- Sylt, Germany
- Sandur, Iceland
- Jan Mayen, Norway

Southeast USA (7980)
- Malone, Florida
- Grangeville, Florida
- Raymondville, Texas
- Jupiter, Florida
- Carolina Beach, North Carolina

Mediterranean Sea (7990)
- Sellia Marina, Italy
- Lampedusa, Italy
- Kargaharun, Turkey
- Estartit, Spain

Great Lakes (8970)
- Dana, Indiana
- Malone, Florida
- Seneca, New York
- Baudette, Minnesota

West Coast USA (9940)
- Fallon, Nevada
- George, Washington
- Middletown, California
- Searchlight, Nevada

Northeast USA (9960)
- Seneca, New York
- Caribou, Maine
- Nantucket, Massachusetts
- Carolina Beach, North Carolina
- Dana, Indiana

Northwest Pacific (9970)
- Iwo Jima, Japan
- Marcus Island, Japan
- Hokkaido, Japan
- Gesashi, Okinawa, Japan
- Yap Island, USA Trust

Icelandic (9980)
Sandur, Iceland
Angissoq, Greenland
Ejde, Faeroe Islands, Denmark

North Pacific (9990)
St. Paul, Pribilof Islands, Alaska
Attu, Alaska
Port Clarence, Alaska
Narrow Cape, Kodiak Island, Alaska

40.1.2 OMEGA transmitting stations. (Each station transmits four navigation frequencies -- 10.2, 13.5, 11 1/3, and 11.05 kHz. A fifth frequency, unique to each station, is also transmitted.)

Kaneohe, Hawaii	Unique frequency 11.8 kHz
Monrovia, Liberia	Unique frequency 12.0 kHz
Aldra, Norway	Unique frequency 12.1 kHz
La Reunion Island	Unique frequency 12.3 kHz
Tsushima Island, Japan	Unique frequency 12.8 kHz
Golfo Nuevo, Argentina	Unique frequency 12.9 kHz
Sale, Australia	Unique frequency 13.0 kHz
La Maure, North Dakota	Unique frequency 13.1 kHz

40.1.3 U.S. Navy VLF communications stations.

17.4 kHz, NDT, Yosami, Japan
21.4 kHz, NSS, Annapolis, Maryland
22.3 kHz, NWC, Exmouth, Australia
23.4 kHz, NPM, Lualualei, Hawaii
24.0 kHz, NAA, Cutler, Maine
24.8 kHz, NLK, Jim Creek, Washington
28.5 kHz, NAU, Aguadilla, Puerto Rico

40.2 Time-signals emitted in the UTC system. Table L-VII contains time-signals emitted in the UTC system.

TABLE L-VII. Time-signals emitted in the UTC system.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
BSF	Taiwan Rep. of China	5000	Between min 00-05, 10-15, 20-25, 30-35, 40-45, 50-55 from 0100-0900	Second pulses of 5 ms duration, Minute marker is pulse of 300 ms duration. During 29th and 59th min., Morse code and Chinese voice announcement of time. Second markers for DUT1 are pulses of 100 ms.
CHU	Ottawa Canada +45°18' +75°45'	3330 7335 14670	Continuous	Second pulses of 300 cycles of a 1 kHz modulation. Minute pulses are 0.5 s long. A bilingual (French-English) announcement of time is made each minute. DUT1: CCIR code by split pulses
DAM	Elmshorn Germany, F.R. +53°46' -9°40'	8638.5 16980.4 4625 8638.5 6475.5 12763.5	11 h 55 m to 12 h 6 m 23 h 55 m to 24 h 6 m from 21 Sept. to 20 Mar. 23 h 55 m to 24 h 6 m from 21 Mar. to 20 Sept.	New international system, then Second pulses from minutes 0.5 to 6.0 (Minute pulses prolonged). A1 type. DUT1: CCIR code by doubling after Minute pulses 1 to 5
DAN	Osterloog Germany, F.R. +53°38' -7°12'	2614	11 h 55 m to 12 h 6 m 23 h 55 m to 24 h 6 m	As DAM (see above)
DAO	Kiel Germany, F.R. +54°26' -10°8'	2775	11 h 55 m to 12 h 6 m 23 h 55 m to 24 h 6 m	As DAM (see above)

TABLE L-VII. Time-signals emitted in the UTC system. - Continued.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
DCF77	Mainflingen Germany, F.R. $+50^{\circ}1'$ $-9^{\circ}0'$	77.5	Continuous, except second Tuesday of every month from 4 h to 8 h	The Second marks are reduction to 1/4 of the carrier's amplitude of 0.1 s duration; the reference point is the beginning of the pulse modulation. The second 59 marker is omitted. DUT1: CCIR code by lengthening to 0.2 s
DGI	Oranienburg Germ. Dem. Rep. $+52^{\circ}48'$ $-13^{\circ}24'$	185	5 h 59 m 30 s to 6 h 00 m 11 h 59 m 30 s to 12 h 00 m 17 h 59 m 30 s to 18 h 00 m	A2 type Second pulses of 0.1 s duration for seconds 30-40, 45-50, 55-60. The last pulse is prolonged.
DIZ	Nauen Germ. Dem. Rep. $+52^{\circ}39'$ $-12^{\circ}55'$	4525	Continuous except from 8 h 15 m to 9 h 45 m for maintenance if necessary	A1 type Second pulses of 0.1 s duration. Minute pulses prolonged to 0.5 s. Hour pulses marked by prolonged pulses for seconds 58, 59, 60. DUT1: CCIR code by double pulse.
FFH	Chevannes France $+48^{\circ}32'$ $-2^{\circ}27'$	2500	Continuous from 8 h to 16 h 25m except Saturday and Sunday.	Second pulses of 5 cycles of 1 kHz modulation. Minute pulses prolonged to 0.5 s. DUT1: CCIR code by lengthening to 0.1 s.
FTA91	Saint-Andre-de-Corcy France $+45^{\circ}55'$ $-4^{\circ}55'$	91.15	At 8 h, 9 h, 9 h 30 m, 13 h 20 h, 21 h, 22 h 30 m.	A1 type Second pulses during the 5 minutes preceding the indicated times. Minute pulses are prolonged. DUT1: in Morse code.

TABLE L-VII. Time-signals emitted in the UTC system. - Continued.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
FTH42 FTK77 FTN87	Pontoise France +40°4' -2°7'	7428 10775 13873	At 9 h and 21 h At 8 h and 20 h At 9 h 30 m, 13 h, 22 h 30 m.	A1 type Second pulses during the 5 minutes preceding the indicated times. Minute pulses are prolonged. DUT1: In Morse code.
GBR	Rugby United Kingdom +52°22' +1°11'	16	At 3 h, 9 h, 15 h, 21 h	A1 type Second pulses during the 5 minutes preceding the indicated times. DUT1: CCIR code by double pulse.
HBG	Prangins Switzerland +46°24' -6°15'	75	Continuous	Interruption of the carrier at the beginning of each second, during 100 ms. The minutes are identified by a double pulse, the hours by a triple pulse. No transmission of DUT1.
IAM	Rome Italy +41°52' -12°27'	5000	10 m every 15 m from 7 h 30 m to 8 h 30 m and from 13 h to 14 h except Saturday afternoon and Sunday. Advanced by 1-hour in summer.	Second pulses of 5 cycles of 1 kHz modulation. Minute pulses of 20 cycles (Announcements and 1 kHz modulation, 5 m before the emission of time signals).
IBF	Torino Italy +45°2' -7°42'	5000	During 15 m preceding 7 h, 9 h, 10 h, 11 h, 12 h, 13 h, 14 h, 15 h, 16 h, 17 h, 18 h. Advanced by 1-hour in summer.	Second pulses of 5 cycles of 1 kHz modulation. These pulses are repeated 7 times at the minute. Voice announcement at the beginning and end of each emission. DUT1: CCIR code by double pulse.

TABLE L-VII. Time-signals emitted in the UTC system. - Continued.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
JG2AE	Koganei Japan +35°42' -139°31'	8000	From 20 h 59 m to 10 h 59 m.	Second pulses of 1600 Hz modulation. Minute pulses are preceded by a 600 Hz modulation. DUT1: CCIR code by lengthening.
JG2AS	Chiba Japan +35°38' -140°4'	40	From 23 h 30 m to 8 h (exc. Sunday) and from 8 h to 23 h 30 m on Monday. Interruptions during communications.	A1 type Second pulses of 0.5 sec. duration. Second 59 is omitted. No DUT1 code.
JJY	Koganei Japan +35°42' -139°31'	2500 5000 10000 15000	Continuous, except interruptions between minutes 25 and 34.	Second pulses of 8 cycles of 1600 Hz modulation. Minute pulses are preceded by a 600 Hz modulation. DUT1: CCIR code by lengthening.
LOL1	Buenos Aires Argentina -34°37' +58°21'	5000 10000 10000	11 h to 12 h, 14 h to 15 h, 17 h to 18 h, 20 h to 21 h 23 h to 24 h	Second pulses of 5 cycles of 1000 Hz modulation. Second 59 is omitted. Announcement of hours and minutes every 5 minutes, followed by 3 m of 1000 Hz and 440 Hz modulation. DUT1: CCIR code by lengthening.
LOL2		8030	1 h, 13 h, 21 h	A1 Second pulses during the 5 minutes preceding the indicated times. Minute pulses are prolonged. DUT1: CCIR code by lengthening.
LOL3		17180		

TABLE L-VII. Time-signals emitted in the UTC system. - Continued.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
LQB9	Planta Gral Pacheco Argentina -34°26' +58°37'	8167.5	22 h 5 m, 23 h 50 m	A1 Second pulses during the 5 minutes preceding the indicated times. Second 59 is omitted, second 60 is prolonged. After the emission, OK is transmitted if the emission is correct, NV if not correct. DUT1: CCIR code by omission of second markers.
LQC20		17551.5	10 h 5 m, 11 h 50 m	
MSF	*Rugby* United Kingdom +52°22' +1°11'	60	Continuous except for an interruption for maintenance from 10 h 0 m to 14 h 0 m on the first Tuesday in each month.	Interruptions of the carrier of 100 ms for the Second pulses, of 500 ms for the minute pulses. The signal is given by the beginning of the interruption. DUT1: CCIR code by double pulse.
		2500 5000 10000	Between minutes 0 and 5, 10 and 15, 20 and 25, 30 and 35, 40 and 45, 50 and 55	Second pulses of 5 cycles of 1 kHz modulation. Minute pulses are prolonged. DUT1: CCIR code by double pulse.
NBA	Balboa USA +9°3' +79°39'	24	Every even hour except 24 h and during Monday maintenance (12 h to 18 h)	Experimental FSK Second pulses on 24 kHz.
		147.85 5448.5 11080 17697.5	5 h, 11 h, 17 h, 23 h	CW Second pulses during the 5 minutes preceding the indicated times on the American Code time format. DUT1: by Morse Code, each minute between seconds 56 and 59.

TABLE L-VII. Time-signals emitted in the UTC system. - Continued.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
NDT	Yosami Japan +34°58' -137°1'	17.4	To be determined.	To be determined.
NPG	San Francisco USA +38°6' +122°16'	3268 6428.5 9277.5 12966	6 h, 12 h, 18 h, 24 h	CW Second pulses during 5 minutes preceding the indicated times on the American Code time format DUT1: by Morse Code, each minute between seconds 56 and 59.
NPM	Honolulu USA +21°25' +158°9'	4525 9050 13655 16457.5 22593	6 h, 12 h, 18 h, 24 h	CW Second pulses during 5 minutes preceding the indicated times on the American Code time format DUT1: by Morse Code, each minute between seconds 56 and 59.
NPN	Guam USA +13°27' -144°43'	4955 8150 13380 15925 21760	6 h, 12 h, 18 h, 24 h	CW Second pulses during 5 minutes preceding the indicated times on the American Code time format DUT1: by Morse Code, each minute between seconds 56 and 59.
NSS	Annapolis USA +38°59' +76°27'	21.4		Experimental FSK Second pulses on 21.4 kHz when transmissions resume.
		88 5870 8090 12135 16180	5 h, 11 h, 17 h, 23 h (on Tuesday 17 h the frequency 185 kHz replaces 88 kHz)	CW Second pulses during 5 minutes preceding the indicated times on the American Code time format.
		20225 25590	17 h, 23 h	DUT1: by Morse Code, each minute between seconds 56 and 59.

TABLE L-VII. Time-signals emitted in the UTC system. - Continued.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
NWC	Exmouth Australia -21°49' -114°9'	22.3	Keyed from 28 to 30 minutes after every other even hour beginning 0 h UTC	Experimental FSK Second pulses during the indicated times on the American Code time format. DUT1: by Morse Code, between seconds 56 and 58.
OLB5	Podebrady Czechoslovakia +50°9' -15°8'	3170	Continuous except from 5 h to 11 h on the first Wednesday of every month	A1 type, Second pulses No transmission of DUT1.
OMA	Liblice Czechoslovakia +50°4' -14°53'	50	Continuous except from 5 h to 11 h on the first Wednesday of every month	Interruption of the carrier of 100 ms at the beginning of every second, of 500 ms at the beginning of every minute. The precise time is given by the beginning of the interruption.
		2500	Between minutes 5 and 15, 25 and 30, 35 and 40, 50 and 60 of every hour except from 5 h to 11 h on the first Wednesday of every month	Pulses of 5 cycles of 1 kHz modulation (prolonged for the minutes). The first pulse of the 5th minute is prolonged to 500 cycles. No transmission of DUT1.
PPE	Rio de Janeiro Brazil -22°54' +43°13'	8721	0 h 30 m 11 h 30 m, 13 h 30 m, 19 h 30 m, 20 h 30 m, 23 h 30 m	Second ticks, of A1 type, during the 5 minutes preceding the indicated hours. The minute ticks are longer. DUT1: CCIR Code by double pulse.
PPR	Rio de Janeiro Brazil -22°59' +43°11'	435 8634 13105 17194.4	01 h 30 m, 14 h 30 m, 21 h 30 m	Second ticks, A1 type, during the 5 minutes preceding the indicated hours. The minute ticks are longer.

TABLE L-VII. Time-signals emitted in the UTC system. - Continued.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
RAT	Moscow USSR +55°19' -38°41'	2500	Between minutes 30 and 35, 41 and 45, 50 and 60 from 17 h 50 m to 24 h	Second pulses* at the beginning of the minute are prolonged to 0.5 s. DUT1 + dUT1 by Morse Code each hour between minutes 11 and 12.
		5000	Between minutes 30 and 35, 41 and 45, 50 and 60 from 1 h 30 m to 17 h	
RBU	Moscow USSR +55°19' -38°41'	66-2/3	Between minutes 0 and 5 from 0 h to 22 h 5 m	A1 type. Second pulses*. The pulses at beginning of the minute *are prolonged to 0.5 s. DUT1 +* dUT1: by Morse Code each hour between minutes 6 and 7.
RCH	Tashkent USSR +41°19' -69°15'	2500	Between minutes 15 and 20; 25 and 30, 35 and 40, 45 and 50 from 0 h to 3 h 50 m from 5 h 35 m to 9 h 30 m from 10 h 15 m to 13 h 30 m from 14 h 15 m to 24 h	Second pulses*. The pulses at the beginning of the minute are prolonged to 0.5 s. DUT1 + dUT1: by Morse Code each hour between minutes 51 and 52.
RID	Irkutsk USSR +52°46' -103°39'	5004	Between minutes 5 and 10, 15 and 20, 25 and 30, 51 and 60 from 0 h to 1 h 10 m from 13 h 51 m to 24 h	Second pulses*. The pulses at the beginning of the minute are prolonged to 0.5 s. DUT1 + dUT1: by Morse Code each hour between minutes 31 and 32.
		10004	Between minutes 5 and 10, 15 and 20, 25 and 30, 51 and 60 from 1 h 51 m to 13 h 10 m	

TABLE L-VII. Time-signals emitted in the UTC system. - Continued.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
RIM	Tashkent USSR +41°19' -69°15'	5000	Between minutes 15 and 20, 25 and 30, 35 and 40, 45 and 50 from 0 h to 1 h 30 m from 2 h 15 m to 3 h 50 m from 18 h 15 m to 24 h	Second pulses*. The pulses at the beginning of the minute are prolonged to 0.5 s. DUT1 + dUT1: by Morse Code each hour between minutes 51 and 52.
		10000	Between minutes 15 and 20, 25 and 30, 35 and 40, 45 and 50 from 5 h 35 m to 9 h 30 m from 10 h 15 m to 13 h 30 m from 14 h 15 m to 17 h 30 m	
RKM	Irkutsk USSR +52°46' -103°39'	10004	Between minutes 5 and 10. 15 and 20, 25 and 30, 51 and 60 from 0 h to 1 h 10 m, from 13 h 51 m to 24 h	Second pulses*. The pulses at the beginning of the minute are prolonged to 0.5 s. DUT1 + dUT1: by Morse Code each hour between minutes 31 and 32.
		15004	Between minutes 5 and 10, 15 and 20, 25 and 30, 51 and 60 from 1 h 51 m to 13 h 10 m	

TABLE L-VII. Time-signals emitted in the UTC system. - Continued.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
RTA	Novossibirsk USSR +55°04' -82°58'	4996	Between minutes 5 and 10, 15 and 20, 25 and 29, 35 and 39 from 0 h to 1 h 29 m from 18 h 5 m to 24 h	Second pulses*. The pulses at the beginning of the minute are prolonged. DUT1 + dUT1: by Morse Code each hour between minutes 45 and 46.
		9996	Between minutes 5 and 10, 15 and 20, 25 and 29, 35 and 39 from 3 h 5 m to 4 h 39 m from 14 h 5 m to 17 h 29 m	
		14996	Between minutes 5 and 10, 15 and 20, 25 and 29, 35 and 39 from 5 h 35 m to 9 h 29 m from 10 h 5 m to 13 h 29 m	
RWM	Moscow USSR +55°19' -30°41'	10000	Between minutes 30 and 35, 41 and 45, 50 and 60 from 1 h 30 m to 3 h from 17 h 50 m to 24 h	Second pulses*. The pulses at the beginning of the minute are prolonged to 0.5 s. DUT1 + dUT1 by Morse Code each hour between minutes 11 and 12.
		15000	Between minutes 30 and 35, 41 and 45, 50 and 60 from 3 h 50 m to 17 h	
RTZ	Irkutsk USSR +52°18' -104°18'	50	Between minutes 0 and 5 from 0 h to 22 h 5 m	A1 type second pulses*. The pulses at the beginning of the minute are prolonged. DUT1 + dUT1: by Morse Code each hour between minutes 6 and 7.

TABLE L-VII. Time-signals emitted in the UTC system. - Continued.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
VNG	Lyndhurst Australia -38°3' -145°16'	4500 7500 12000	9 h 45 m to 21 h 30 m Continuous except 22 h 30 m to 22 h 45 m 21 h 45 m to 9 h 30 m	Seconds markers of 50 cycles of 1 kHz modulation; 5 cycles only for Seconds markers 55 to 58; Seconds marker 59 is omitted; 500 cycles for Minute markers. During the 5th, 10th, 15th, etc. minutes, 5 cycles for Seconds markers 50 to 58. Identification by voice announcement during 15th, 30th, 45th, and 60th minutes. DUT1: CCIR code by 45 cycles of 900 Hz modulation immediately following the normal Seconds markers.
WWV	Fort Collins USA +40°41' +105°2'	2500 5000 10000 15000 20000 25000	Continuous	Pulses of 5 cycles of 1 kHz modulation. 59th and 29th second pulse omitted. Hour is identified by 0.8 second long, 1500 Hz tone. Beginning of each minute identified by 0.8 second long, 1000 Hz tone. DUT1: CCIR code by double pulse. Additional information on corrections.
WWVB	Fort Collins USA +40°40' +105°3'	60	Continuous	Second pulses given by reduction of the amplitude of the carrier. Coded announcement of the date and time and of the correction to obtain UT1. No CCIR code.

TABLE L-VII. Time-signals emitted in the UTC system. - Continued.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
WWVH	Kauai USA +21°59' +159°46'	2500 5000 10000 15000 20000	Continuous	Pulses of 5 cycles of 1200 Hz modulation. 59th and 29th seconds pulse omitted. Hour identified by 0.8 second long 1500 Hz tone. Beginning of each minute identified by 0.8 second long, 1200 Hz tone. DUT1: CCIR code by double pulse. Additional information on UT1 corrections.
YVTO	Caracas Venezuela +10°30' +66°56'	6100	12 h to 20 h 0 h 30 m to 1 h 30 m	Second pulses of 1 kHz modulation with 0.1 s duration. The minute is identified by a 800 Hz tone and a 0.5 s duration. Between seconds 52 and 57 of each minute, voice announcement of hour, minute and second.
ZUO	Olifantsfontein South Africa -25°58' -28°14'	2500 5000 10000	18 h to 4 h Continuous Continuous	Pulses of 5 cycles of 1 kHz modulation. Second 0 is prolonged. DUT1: CCIR code by lengthening.

OTHER TIME SIGNALS: BPV, XSG, Shanghai, China, P.R., Latitude: +31°12', Longitude: -121°26'. Characteristics and schedule not known.

* The information about the value and the sign of the DUT1 + dUT1 difference is transmitted after each minute signal by marking the corresponding second signals with additional impulses. In addition, it is transmitted in Morse Code as indicated.

APPENDIX M
TYPICAL CHARACTERISTICS OF FREQUENCY SOURCES

This appendix contains general information related to MIL-STD-188-115. Appendix M is not a mandatory part of this standard.

10 GENERAL

10.1 Purpose. The purpose of this appendix is to show the characteristics of three different frequency sources.

10.2 Scope. This appendix compares the three frequency sources in tabular form.

20 REFERENCED DOCUMENTS

Not applicable.

30 DEFINITIONS

Not applicable.

40 GENERAL REQUIREMENTS

Table M-VIII gives the characteristics of three frequency sources.

TABLE M-VIII. Characteristics of frequency sources.

CHARACTERISTICS	KIND OF OSCILLATOR		
	CRYSTAL	CESIUM	RUBIDIUM GAS CELL
BASIC RESONATOR FREQUENCY	10 kHz TO 100 MHz	9,192,631,770 Hz	6,834,682,608 Hz
OUTPUT FREQUENCIES PROVIDED	10 kHz TO 100 MHz	1, 5, 10 MHz TYPICAL	1, 5, 10 MHz TYPICAL
RESONATOR Q	10^4 TO 10^6	10^7 TO 10^8	10^7
RELATIVE FREQUENCY STABILITY SHORT-TERM, 1 SECOND	10^{-6} TO 10^{-12}	5×10^{-11} TO 5×10^{-13}	2×10^{-11} TO 5×10^{-12}
RELATIVE FREQUENCY STABILITY, LONG-TERM, 1 DAY	10^{-6} TO 10^{-12}	10^{-13} TO 10^{-14}	5×10^{-12} TO 3×10^{-13}
PRINCIPAL CAUSES OF LONG-TERM INSTABILITY	AGING OF CRYSTAL, AGING OF ELECTRONIC COMPONENTS, ENVIRONMENTAL EFFECTS	COMPONENT AGING	LIGHT SOURCE AGING, FILTER & GAS CELL AGING, ENVIRONMENTAL EFFECTS
TIME FOR CLOCK TO BE IN ERROR 1 MICROSECOND	1 S TO 10 DAYS	1 WEEK TO 1 MONTH	1 TO 10 DAYS
FRACTIONAL FREQUENCY REPRODUCIBILITY	NOT APPLICABLE MUST CALIBRATE	1×10^{-11} TO 2×10^{-12}	1×10^{-10}
FRACTIONAL FREQUENCY DRIFT	1×10^{-9} TO 1×10^{-11} PER DAY	5×10^{-13} PER YEAR	1×10^{-11} PER MONTH
PRINCIPAL ENVIRONMENTAL EFFECTS	MOTION, TEMPERATURE, CRYSTAL DRIVE LEVEL	MAGNETIC FIELD, ACCELERATIONS, TEMPERATURE CHANGE	MAGNETIC FIELD, TEMPERATURE CHANGE, ATMOSPHERIC PRESSURE

Custodians:	Preparing Activity:
Army - SC	JT
Navy - EC	
Air Force - 90	
DCA - DC	
NSA - NS	

Review Activities:

Army - SC, CR, SATCOMA
Navy - EC, MCDEC, USNO, NRL
Air Force - RADC
NSA - T25
DCA - DC
NCS - TS

User Activities:

Army
Navy
Air Force
DCA
NSA

Project No.: SLHC-1150

INSTRUCTIONS: In a continuing effort to make our standardization documents better, the DoD provides this form for use in submitting comments and suggestions for improvements. All users of military standardization documents are invited to provide suggestions. This form may be detached, folded along the lines indicated, taped along the loose edge *(DO NOT STAPLE)*, and mailed. In block 5, be as specific as possible about particular problem areas such as wording which required interpretation, was too rigid, restrictive, loose, ambiguous, or was incompatible, and give proposed wording changes which would alleviate the problems. Enter in block 6 any remarks not related to a specific paragraph of the document. If block 7 is filled out, an acknowledgement will be mailed to you within 30 days to let you know that your comments were received and are being considered.

NOTE. This form may not be used to request copies of documents, nor to request waivers, deviations, or clarification of specification requirements on current contracts. *Comments submitted on this form do not constitute or imply authorization* to waive any portion of the referenced document(s) or to amend contractual requirements.

(Fold along this line)

(Fold along this line)

DEPARTMENT OF THE ARMY

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

BUSINESS REPLY MAIL

FIRST CLASS PERMIT NO 12062 WASHINGTON D C

POSTAGE WILL BE PAID BY THE DEPARTMENT OF THE ARMY

Director
Joint Tactical Command
Control and Communication Agency
ATTN: C3A-SES
Fort Monmouth, NJ 07703-5513

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

(See Instructions – Reverse Side)

1. DOCUMENT NUMBER

2. DOCUMENT TITLE

3a. NAME OF SUBMITTING ORGANIZATION

4. TYPE OF ORGANIZATION *(Mark one)*

☐ VENDOR

☐ USER

☐ MANUFACTURER

☐ OTHER *(Specify)*: ______

b. ADDRESS *(Street, City, State, ZIP Code)*

5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional

b. WORK TELEPHONE NUMBER (Include Are Code) – Optional

c. MAILING ADDRESS *(Street, City, State, ZIP Code)* – Optional

8. DATE OF SUBMISSION *(YYMMDD)*

(TO DETACH THIS FORM, CUT ALONG THIS LINE.)

DD FORM 82 MAR 1426

PREVIOUS EDITION IS OBSOLETE.