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MIL-STD-188-110D
29 December 2017

SUPERSEDING
MIL-STD-188-110C
w/CHANGE 1
3 JANUARY 2012

# DEPARTMENT OF DEFENSE INTERFACE STANDARD

## INTEROPERABILITY AND PERFORMANCE STANDARDS FOR DATA MODEMS

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# FOREWORD

1. This Military Standard is approved and mandatory for use by all Departments and Agencies of the Department of Defense (DoD) in accordance with Joint Technical Architecture (JTA) Version 6, dated 3 October 2003.

2. This document contains technical standards and design objectives for minimum interface and performance standards pertinent to voice frequency band modulators-demodulators (modems) which operate in both long-haul and tactical communications systems. The terms "system standard" and "design objective (DO)" are defined in FED-STD-1037. In this document, the word "shall" identifies mandatory system standards. The word “should” identifies DOs that are desirable but not mandatory.

3. Comments, suggestions, or questions on this document should be addressed Air Force Sustainment Center – Oklahoma City/AFLCMC/LZPES, 3001 Staff Drive, Suite 1AB81A, Tinker AFB, OK 73145, or emailed to ocalc.dsp@us.af.mil. Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at https://assist.dla.mil.

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# 1. SCOPE

## 1.1 Scope.

This document establishes mandatory technical standards and design objectives (DO) that are necessary to ensure interoperability and to promote performance among data modulators-demodulators (modems) used in the voice frequency (VF) band of long-haul and tactical communications systems. This document also provides guidance to the designers of new data modems that incorporate characteristics not yet standardized by specifying the technical characteristics of data modems currently in the inventory. The purpose of this guidance is to ensure attainment of minimum acceptable performance and maximum interoperability between existing and future data modems with specified transmission channel conditions.

## 1.2 Applicability.

These standards are mandatory within the Department of Defense (DoD) in the design, development and engineering of new communications facilities for both narrowband and wideband long-haul and tactical systems. In some cases, reference is made to other documents that provide standards for specific applications. It is not intended that existing systems be immediately converted to comply with the requirements of these standards. New systems, and those undergoing major modification or rehabilitation, conformance to these standards is subject to current procurement regulations. This document is applicable to the design and development of new data modems with standard data signaling rates up to and including 240,000 bits per second (bps) used in long-haul and tactical communications systems. This document is not applicable to high frequency (HF) data modems used in the Tactical Digital Information Link (TADIL) A. The HF data modem standards for TADIL A are published in MIL-STD-188-203-1.

## 1.3 Application guidance.

Requirements in this document, if applied as intended, ensure the interoperability and performance of data modems having the same or similar functions. The variety of data modems is limited to that which are essential to effectively support the missions of the military forces. It is not intended that the standards contained in this document inhibit advances in communications technology. Such advances are encouraged by including DOs that should be used if economically feasible. Additionally, standardizing parameter values but not the technology that may be used to meet these parameter values facilitates such advances. Minimum performance requirements for the high frequency (HF) serial (single-tone) modem waveforms are specified in Table XVI and Appendices B, C, D, and F. The specified values shown represent HF modem performance under ideal test conditions. To identify the minimum acceptable performance available to users, many factors, including operational test and evaluation must be considered.

## 2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3 or 4 of this standard. This section does not include documents cited in other sections of this standard or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 or 4 of this standard, whether or not they are listed.

2.2 Government documents.

2.2.1 Specifications and standards, and handbooks. The following specifications and standards form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the solicitation or contract.

INTERNATIONAL STANDARDIZATION AGREEMENTS

| | |
|---|---|
| STANAG 4198 | Parameters and Coding Characteristics That Must Be Common to Assure Interoperability of 2400 BPS Linear Predictive Encoded Digital Speech |
| STANAG 4285 | Characteristics of 1200/2400/3600 bps Single Tone Modulators/Demodulators for HF Radio Links |
| STANAG 4415 | Characteristics of a Robust, Non-hopping Serial Tone Modulator/Demodulator for Severely Degraded HF Radio Links |
| STANAG 4529 | Characteristics of Single-Tone Modulators/Demodulators for Maritime HF Radio Links with 1240 Hz bandwidth |
| STANAG 4481 | Minimum Technical Standards for Naval HF Shore-To-Ship Broadcast Systems |
| STANAG 4591 | The 600 Bit/s, 1200 Bit/s, and 2400 Bit/s NATO Interoperable Narrow Band Voice Coder |
| STANAG 5066 | Profile For HF Radio Data Communications |

FEDERAL STANDARDS

| | |
|---|---|
| FED-STD-1035 | Coding, Modulation and Transmission Requirements for Single Channel Medium and High Frequency Radiotelegraph Systems Used in Government Maritime Mobile Telecommunications |
| FED-STD-1037 | Glossary of Telecommunication Terms |

DEPARTMENT OF DEFENSE STANDARDS

| | |
|---|---|
| MIL-STD-188-141 | Interoperability and Performance Standards for Medium and High Frequency Radio Equipment |
| MIL-STD-188-148 | (S) Interoperability Standard for Anti-Jam (AJ) Communications in the High Frequency Band (2-30 MHz) (U) |

(Copies of these documents are available online at http://quicksearch.dla.mil.)

2.2.2 Other Government documents and publications.
The following other Government documents and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues are those cited in the solicitation.

DEPARTMENT OF DEFENSE (DoD)

| | |
|---|---|
| DoD JTA | Joint Technical Architecture |

(Copies of this document is available online at http://www.acq.osd.mil/osjtf/pdf/jta-vol-I.pdf )

2.3 Order of precedence.
In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless specific exemption has been obtained.

# 3. DEFINITIONS

## 3.1 Terms.

Definitions of terms used in this document are specified in FED-STD-1037. For the purposes of this standard, definitions are provided for the following terms, some of which have been repeated, from FED-STD-1037 for the convenience of the reader.

Automatic link establishment (ALE). The capability of an HF radio station to make contact, or initiate a circuit, between itself and another specified radio station, without operator assistance and usually under processor control.

> NOTE: ALE techniques include automatic signaling, selective calling, and automatic handshaking. Other automatic techniques that are related to ALE are channel scanning and selection, link quality analysis (LQA), polling, sounding, message store and forward, address protection, and anti-spoofing.

Balanced to ground. Pertaining to electrical symmetry with respect to a common ground.

Clear-to-send (CTS) signal. The control signal generated by the transmitting modem on the CTS connection to denote a state of readiness for transmission. The CTS signal is a response to the request-to-send (RTS) signal from the transmitting device

Code rate. The ratio of the number of information symbols (k) to the total number of encoded symbols (n) in a code (i.e., the ratio of k/n).

Dead time. In hopping, the portion of a hop dwell period in which no transmission occurs.

Dwell period. The maximum amount of time a transmission occurs on a particular frequency.

Galois field. An arithmetic system, containing a set of symbol elements with two operations (and their inverses) for combining pairs of elements.

In-band diversity combining. A combining of two or more signals which uses frequencies within the bandwidth of the information channel and carries the same information received with the objective of providing a single resultant signal that is superior in quality to any of the contributing signals.

Mode. An available format in a data modem supporting multi-waveform capability.

Narrowband. At HF radio frequencies (1.5 - 30 MHz) the nominal voice frequency (VF) bandwidth allocated for single channel radio (i.e., 3 kHz).

Nominal bandwidth. The widest band of frequencies, inclusive of guard bands, assigned to a channel.

Occupied bandwidth. The width of a band of frequencies that contains 99% of the total mean power of a given emission.

Preamble code. A short sequence of symbols at the beginning of a coded sequence used to achieve synchronization.

Request-to-send (RTS) signal. The control signal generated by the transmitting terminal on the RTS connection to denote a request for transmission.

Secure voice. A voice communication that is protected against compromise through the use of an encryption system.

Transmission level point (TLP). A point in a transmission system at which the ratio, in decibels, of the power of the test signal at that point to the power of the test signal at a reference point, is specified.

Unbalanced to ground. Pertaining to electrical asymmetry with respect to a common ground.

NOTE: Frequently, the term "unbalanced" describes a circuit, one side of which is grounded.

Wideband. At HF radio frequencies (1.5 - 30 MHz) a bandwidth larger than 3 kHz.

3.2 Abbreviations and acronyms.
Abbreviations and acronyms used in this document are defined below. Those that are also found in FED-STD-1037 have been included for the convenience of the reader.

| | |
|---|---|
| ABCA | American, British, Canadian, Australian (armies) |
| AJ | anti-jamming |
| ALE | automatic link establishment |
| ANC | automatic node controller |
| ANDVT | Advanced Narrowband Digital Voice Terminal |
| ANSI | American National Standard Institute |
| ARQ | Automatic repeat request |
| Bd | Baud |
| BER | Bit error ratio |
| bps | Bits per second |

| | |
|---|---|
| BW | Bandwidth |
| CTS | Clear to send |
| CTX | Clear to transmit |
| CVSD | Continuously variable slope delta (modulation) |
| dB | Decibel(s) |
| dBm | dB referred to one milliwatt |
| dBm0 | Noise power in dBm referred to or measured at 0 TLP |
| DCD | Data carrier detect |
| DCE | Data circuit-terminating equipment |
| DCS | Defense Communications System |
| DISA | Defense Information Systems Agency |
| DISAC | Defense Information Systems Agency Circular |
| DO | Design objective |
| DoD | Department of Defense |
| DODISS | Department of Defense Index of Specifications and Standards |
| DPSK | Differential phase shift keying |
| DSN | Digital Switched Network |
| DTE | Data terminal equipment |
| EIA | Electronic Industries Association |
| EMI | Electromagnetic interference |
| EOM | End of message |
| FCC | Federal Communications Commission |
| FDM | Frequency-division multiplexing |

| | |
|---|---|
| FEC | Forward error correction |
| FED-STD | Federal Standard |
| FSK | Frequency-shift keying |
| GF | Galois field |
| HF | high frequency |
| Hz | Hertz |
| ISB | independent sideband |
| ITU | International Telecommunication Union |
| JCS | Joint Chiefs of Staff |
| kHz | kilohertz (1,000 hertz) |
| km | kilometer (1,000 meters) |
| LF | low frequency |
| log | Logarithm |
| LQA | link quality analysis |
| LSB | least significant bit |
| MF | medium frequency |
| MGD | modified-Gray decoder |
| MHz | megahertz (1,000,000 hertz) |
| MIL-STD | military standard |
| MM | maritime mobile |
| modem | modulator-demodulator |
| ms | millisecond(s) |
| MSB | most significant bit |

| | |
|---|---|
| NATO | North Atlantic Treaty Organization |
| NMCS | National Military Command System |
| PCM | pulse-code modulation |
| PSK | phase-shift keying |
| PSN | public switched network |
| PTT | push-to-talk |
| QAM | quadrature amplitude modulation |
| QDPSK | quadrature differential phase-shift keying |
| QSTAG | Quadripartite Standardization Agreement |
| RA | receive audio |
| RATT | radio teletypewriter system |
| RC | receive clock |
| RCE | radio communications equipment |
| RD | receive data |
| rms | root-mean-square |
| RS | receive (HF radio) signal |
| RTE | radio terminal equipment |
| RTS | request to send |
| RTX | request to transmit |
| s | second(s) |
| (S) | SECRET |
| SNR | signal-to-noise ratio |
| STANAG | Standardization Agreement (NATO) |

| | |
|---|---|
| sync | Synchronization |
| TA | transmit audio |
| TT | tactical terminal |
| TC | transmit clock |
| TADIL | tactical digital information link |
| TD | transmit data |
| TDM | time-division multiplexing |
| TIA | Telecommunications Industries Association |
| TLP | transmission level point |
| TS | transmit (HF radio) signal |
| TX | Transmit |
| (U) | UNCLASSIFIED |
| UHF | ultra high frequency |
| VP | voice frequency |
| VHF | very high frequency |
| VLF | very low frequency |
| 0 TLP | zero transmission level point(s) |

# 4. GENERAL REQUIREMENTS

## 4.1 Functional employment.

Data modulators-demodulators (modems) are employed in long-haul and tactical communications systems and subsystems. Delineation between long-haul and tactical communications systems can be found in Federal Standard (FED-STD)-1037. Data modems employ a variety of techniques for converting digital signals into quasi-analog signals for transmission over analog channels. Various modulation techniques have been standardized and no single optimum technique has been found for all applications. This section covers general requirements for both long-haul and tactical data modems operating over voice frequency (VF) and radio channels. A representative list is given in Table I with the modulation types and data rates noted for each channel category listed. This Table also provides a cross-reference to section 5 requirements. (Additional modulation types and data rates for HF modems are specified in the Appendices.)

NOTE: Very low frequency (VLF) radio modems are not standardized.

**TABLE I. Reference list for modem applications.**

| CHANNEL | MODULATION TYPE | DATA RATE (BPS) | REFERENCE PARAGRAPH |
|---|---|---|---|
| MM RADIO (3 KHZ) | FSK | $\leq$ 150 | 5.1.1 |
| HF RADIO (3 KHZ) | FSK | $\leq$150 | 5.1.2 |
| HF RADIO (3 KHZ) | PSK | 75-4800 | 5.3.2 |

## 4.2 Common parameters.

All data modems shall comply with the applicable requirements of 4.2.1 through 4.2.5.

### 4.2.1 Modulation and data signaling rates and tolerance.

The modulation rates expressed in baud (Bd) and the data signaling rates expressed in bits per second (bps) at the standard interfaces shown on Figure 1 shall be as listed below (as appropriate for each application listed in Table I).

a. 50 Bd or bps (optional, for legacy use only)

b. 75 X $2^m$ Bd or bps, up to and including 9600 Bd or bps, where m is a positive integer 0, 1, 2, … 7.

NOTE: The data signaling rate is expressed in bps; the modulation rate is expressed in Bd. Data signaling rates in bps and modulation rates in Bd are the same only for binary signaling. Data signaling rates in bps relate to modulation rates in Bd through the following equation:

Data signaling rates (bps) = k x modulation rates (Bd)

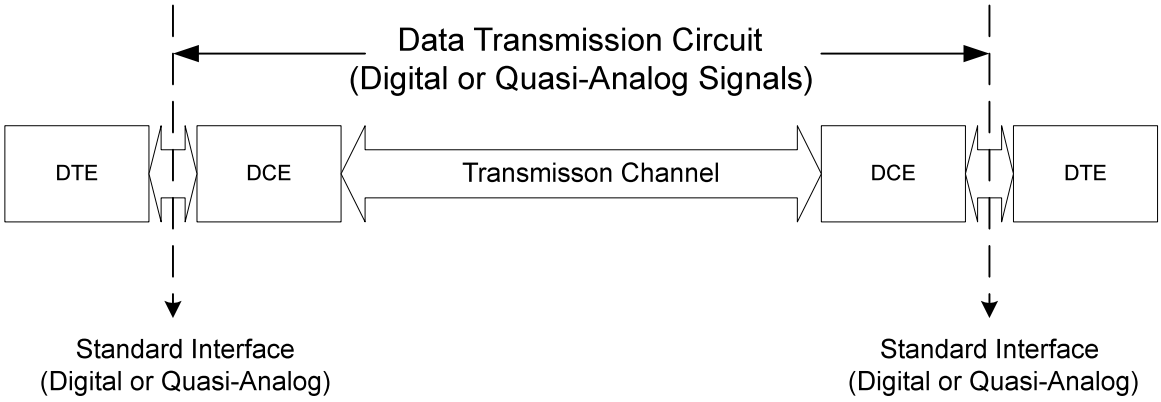
where $k = \log_2 M$ is the number of binary digits per modulation symbol, and M is the number of modulation symbols.

Except where specified otherwise, signaling rates shall not deviate from the nominal values by more than 10 parts per million (±0.001%).

4.2.2 Logic and signaling sense for binary signals.
For data and timing circuits, the signal voltage with respect to signal ground shall be negative to represent the MARK condition and positive to represent the SPACE condition. The significant conditions and other logic and signal states shown in Table II shall apply to telegraph and data transmission. An alternative capability shall be provided to interface with equipment that accepts positive mark and negative space signals.

**TABLE II. Logic and signal sense for binary signals.**

| Application | Condition | Condition |
|---|---|---|
| Voltage to signal ground | Negative (-) | Positive (+) |
| Conventional term | Mark | Space |
| Binary digit value | One (1) | Zero (0) |
| Timing signal state | Off | On |
| FSK signal state | Lower frequency | Higher frequency |




Notes:
1. DTE= Data Terminal Equiment
   DCE = Data Circuit - Terminating Equipment.

2. DTE and DCE may include data adapters, modems, error control algorithm, encryption devices, control units and other equipment, as required.

3. DTE and DCE can be combined in a single unit device.

4. The transmission channel may inhclude nodes and single or multichannel transmission equipments.

5. Modulation rates and data signaling rates at the standard interface are specified in 4.2.1.

**FIGURE 1. Standard interface between data terminal equipment and data circuit terminating equipment.**

4.2.3 Digital interface characteristics.
A synchronous serial interface shall be provided. The electrical characteristics of the digital interface at the modulator input and the demodulator output shall be in accordance with the applicable requirements of EIA-422 for balanced signals and EIA-423 for unbalanced signals.

4.2.4 Terminal impedance for quasi-analog signals.

4.2.4.1 Modems used in single-channel radio subsystems.
For modems used with radio equipment of single-channel radio subsystems, the modulator shall meet all other requirements of this standard when operating into a load of 150 ohms, unbalanced to ground, or 600 ohms balanced to ground. The terminal impedance at the demodulator input shall be balanced to ground (nominally 600 ohms, but a range of 300 to 1200 ohms is permitted).

NOTE: A terminal impedance balanced to ground is recommended for equipment (radios, data modems, etc.) operating in an environment that has a high electromagnetic interference (EMI) level, such as in aircraft, ships, and tanks. Measurements have shown that an electrical noise-rejection improvement of up to 20 dB can be achieved for balanced terminations, compared with unbalanced terminations.

4.2.4.2 Quasi-analog signal levels.
Standards for the quasi-analog signal levels of modulators and demodulators are documented in MIL-STD-188-141. The quasi-analog signal level at the modulator output shall be adjustable from at least -18 dB referred to one milliwatt (dBm) to +3 dBm. The demodulator shall be capable of operating, without degradation of performance, with a received quasi-analog signal level ranging from at least -35 dBm to +3 dBm The difference in FSK output levels between the MARK and SPACE binary signals shall be less than 1 dB.

4.2.5 Clock equipment, control, and timing.
All data modems shall have the capability to accept external timing signals. The clock is the device which provides the time base for controlling operation of digital equipment. An equipment clock provides the peculiar needs of its equipment and in some cases may control the flow of data at its equipment interface. A master or station clock, regardless of its physical location, controls two or more equipments which are linked together as a system. The following subparagraphs, 4.2.5.1 through 4.2.5.3 are primarily concerned with master or Station clocks.

4.2.5.1 Transmission modes.
All future communications equipment requiring a stable clock or precise character interval control shall make provisions for operating from station clocks. During periods when the sending equipment has no traffic to send, an idle pattern or all "ones" may be transmitted

4.2.5.2 Clock characteristics.

4.2.5.2.1 Modulation rates.
The standard clock modulation rates for compatibility with modulation or data signaling rates shall be two times the standard rates specified in subparagraph 4.2.1.

4.2.5.2.2 Modulation rate stability.
The stability of synchronized or clock timing supplied in all synchronous digital transmission, switching, terminal, and security equipment shall be sufficient to ensure that synchronization is maintained within ±25 percent of the unit interval between transmitted and received signals for periods of not less than 100,000 consecutive seconds.

4.2.5.2.3 Modulation rate phase adjustment.
Means shall be provided in all digital transmission, switching, terminal, and security equipment so that, at the applicable modulation rates, a shift in phase of the incoming data stream with relation to the clocking pulse shall be possible over a period of three unit intervals (i.e., a shift of

1.5 unit intervals early or late from theoretical center of the unit interval at the applicable modulation rate).

4.2.5.2.4 Output signal.
The output of the clock shall be an alternating symmetrically-shaped wave at the required clock modulation rate. In the case of an unbalanced digital interface, the clock output signal shall comply with the voltage and wave-shaping requirement of subparagraphs 4.3.1.3.3.4 and 4.3.1.3.3.5, respectively. In the case of a balanced digital interface, the clock output signal shall comply with the voltage requirements of subparagraph 4.3.1.3.4.4 and shall contain no points of inflection prior to reaching the maximum amplitudes. When the clock is quiescent, the clock signal state shall be negative.

4.2.5.2.5 Clock period.
A clock period or cycle is defined as having one half-cycle of positive polarity (sense) and one half-cycle of negative polarity (sense). The duty cycle shall be 50 percent ±1.0 percent. Thus, in the binary sense, each clock period or cycle is composed of two clock unit intervals, and it follows that a clock rate of 50 Hz is a clock modulation rate of 100 Bd.

4.2.5.3 Clock/data phase relationship.
Arrangements which may be used to supply clock pulses to sources and sinks are shown in subparagraph 4 3.1.6.3.1. Typical standard arrangements are shown from which one may be selected to meet a specific application. For those digital devices operated at dc baseband which are interconnected by metallic wire (or other equipment which provides in effect the same function as a metallic wire), the following clock/data phase relationships apply if, and only if, interface circuit lengths permit. It is noted that, due to signal propagation delay time differences over different dc wire circuits or dc equivalent circuits at data modulation rates higher than 2400 Bd, there may be a significant relative clock/data phase shift which must be adjusted in accordance with subparagraph 4.3.1.6.2.3. Practical operating experience indicates that typical multiple pair paper cable or polyvinyl chloride (PVC) insulated exchange grade telephone cable may be expected to function at modulation rates of 4800 Bd data/ 9600 Bd clock at distances up to 3000 cable feet without any need for concern over relative pulse shift or noise if the standard low level digital interface is applied to both clock and data signals in accordance with subparagraph 4 3.1.3.

All data transition emitted by a source under direct control of an external clock shall occur on (be caused by) negative to positive transitions of that clock. The design objective is a minimum delay between the clock transition and the resulting data transition, 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, it shall be consistent within ±1 percent of itself for each clock transition. These delay limits shall apply directly at the driver interface.

Sampling of the data signal by the external clock at a sink interface shall occur on (be caused by) positive to negative clock transitions.

When the clock is used for controlling intermittent data transmission, data may not change state except when requested by a negative to positive clock transition. The quiescent state of the clock

shall be at negative voltage. The quiescent state of the data shall be that state resulting from the last negative to positive clock transition.

The phase relationship between external clock and data *is* not specified for devices in which the external clock is related only indirectly to the source data; for example, to maintain synchronism between a data source and data sink for a signal with a constant modulation rate. However, whatever the phase delay, it shall be consistent to within +/- 1 percent at the data unit interval at the applicable modulation rate. If the clock at twice the modulation rate at the same data is also supplied as an output, then data transitions shall coincide within +/- 1 percent of the data unit interval with the negative to positive transitions of the output clock (see Figure 4. 3-9). Direct control means control of the data by a clock signal at twice the modulation rate of the data. Indirect control means use of a clock at some higher standard modulation rate; e.g., 4, 8, 128 times the modulation rate.

4.3 Federal maritime interoperability requirements.
Ship-to-ship and shore-to-ship medium frequency (MF) and high frequency (HF) radio teletypewriter system (RATT) operation shall be in accordance with the requirements of FED-STD-1035. Extreme care must be used to ensure that this document is tailored to select only the provisions applicable to a given design task.

4.4 Data link protocol (optional).
When an ARQ protocol is used it shall be in accordance with STANAG 5066.

# 5. DETAILED REQUIREMENTS

## 5.1 Frequency shift keying (FSK) modems for single-channel radio equipment.

Non-diversity FSK modems used primarily with single-channel (3 kHz) radio equipment shall comply with the applicable requirements of 4.2, 4.3, 5.1.1, and 5.1.2.

NOTE: The waveform requirements in this paragraph apply when backward compatibility and interoperability are necessary.

Table III shows characteristic frequencies of the various FSK modems for different radio channels.

**TABLE III. Characteristic frequencies of FSK data modems for single-channel radio equipment.**

| Channel | Mark frequency (Hz) | Center frequency (Hz) | Space frequency (Hz) |
|---|---|---|---|
| MM radio | 1615 | 1700 | 1785 |
| HF radio | 1575 | 2000 | 2425 |

### 5.1.1 Narrow-shift FSK modem.

For single-radio operation with binary narrow-shift FSK modulation, a shift of 170 hertz (Hz) shall be used with the characteristic frequencies given in Table III. The tolerance of each characteristic frequency shall be ± 4 Hz.

### 5.1.2 Wide-shift FSK modem.

For single-channel telegraph operation over high frequency (HF) radio links operating under 150 baud (Bd), the use of FSK with an 850-Hz shift is not consistent with the requirement that the U.S. operate its HF communication services in accordance with International Telecommunication Union (ITU) recommendations. However, where 850-Hz wide-shift FSK is used, the characteristic frequencies given in Table III shall apply. The tolerance of each characteristic frequency shall be ±4 Hz.

## 5.2 FSK data modems for voice frequency (VF) channel operation (withdrawn).

## 5.3 HF data modems.

The serial (single tone) transmit waveform described in this paragraph establishes the minimum essential interoperability and performance requirements for new HF modems.

### 5.3.1 General requirements.

5.3.1.1 Capability.
The HF modems shall be capable of modulating and demodulating serial binary data into/from a serial (single-tone) waveform. This waveform is transmitted received over HF radio operating in either fixed-frequency or frequency-hopping modes of operation. The minimum acceptable performance and joint service interoperability shall be at 75, 150, 300, 600, 1200, and 2400 bps using the fixed-frequency phase shift keying (PSK) serial waveform specified herein. Uncoded serial tone modem operation at 4800 bps is a design objective (DO). Note that this is a less robust mode of operation at 4800 than that capability specified in Appendix C.

5.3.1.2 Voice digitization.
When integrated within the data modem, voice digitization functions shall be in accordance with North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 4198 or STANAG 4591.

5.3.1.3 Optional modes.
As a DO, the modem should be expandable to include one or more of the following optional modes:

a. NATO mode. If included, this mode shall be in accordance with STANAG 4285 and 4481.

b. Binary FSK mode. If included, this mode shall be in accordance with 5.1. This mode is not recommended for new systems.

c. Medium data rate mode (3200 – 9600 bps). If included, this mode shall be in accordance with Appendix C. Note that in NATO documents (AC/322-D/17) data rates from 1200 through 9600 bps are termed “Medium Data Rate.”

d. Wideband HF mode (up to 48 kHz channels). If included, this mode shall be in accordance with Appendix D.

e. Multiple channel mode (including two independent sideband, or 2-ISB mode). If included, this mode shall be in accordance with Appendix F.

f. Robust 75 bps mode. If included, this mode shall be in accordance with STANAG 4415.

g. Frequency-hopping mode. If included, this mode shall be in accordance with the PSK serial (single-tone) waveform contained herein and the data training and timing format provided in MIL-STD-188-148.

h. NATO narrowband mode. When narrowband operation (1240 Hz channels) is required, it shall be in accordance with STANAG 4529.

5.3.1.4 Interface requirements.

5.3.1.4.1 Line-side data characteristics.
Line-side data interfaces shall be in accordance with 4.2.3.

5.3.1.4.2 LAN interface (DO).
If an additional Ethernet LAN interface is provided (see Joint Technical Architecture, 2.3.2.2.2.1: Local Area Network (LAN) Access), the modem should be capable of performing both line side and Remote Control (see 5.3.1.5) interface functions over the LAN including transport of user data, in accordance with Appendix A.

5.3.1.4.3 Equipment side characteristics (informative).
Modems shall be designed to provide the required performance (see 5.3.2.5) using the single-channel bandwidth and characteristics as given in MIL-STD-188-141.

5.3.1.4.4 Transmit override.
When operating in other than full duplex mode, data presented for transmission at the line-side or LAN interface shall cause the modem to commence transmit operation, overriding any reception of data on the equipment side. An option may be provided to disable transmit override, so that CTS is delayed after the assertion of RTS until a reception in progress is complete.

5.3.1.4.5 Buffering in synchronous serial mode.
When transferring line-side data in the synchronous mode, the modem shall transmit all user data that occur after the assertion of CTS by the modem and before the de-assertion of RTS by the DTE. At the receive end of the link, all of the bits that occur in this interval shall be delivered by the modem to the DTE. Transmission and reception of user bits that fall outside this interval is not precluded.

5.3.1.5 Remote control interface.
A remote control interface is mandatory for all new procurements of HF data modems.

5.3.1.5.1 Electrical interface.
The electrical interface for remote control of the modem shall comply with the specified industrial or military interface standard.

5.3.1.5.2 Optional modem control driver.
As an option a software remote control driver shall be supplied for installation in a remote control unit that provides an open, documented Application Programming Interface (API) to communications software.

5.3.2 Serial (single-tone) mode.

5.3.2.1 General.
This mode shall employ M-ary phase-shift keying (PSK) on a single carrier frequency as the modulation technique for data transmission. Serial binary information accepted at the line-side input is converted into a single 8-ary PSK-modulated output carrier. The modulation of this output carrier shall be a constant 2400-symbols-per-second waveform regardless of the actual throughput rate. The rate-selection capability shall be as given in 5.3.1.1. Selectable interleaver

settings shall be provided. This waveform (signal structure) has four functionally distinct, sequential transmission phases. These time phases are:

a. Synchronization preamble phase.
b. Data phase.
c. End-of-message (EOM) phase.
d. Coder and interleaver flush phase.

NOTE: Unless otherwise specified, the included serial (single-tone) waveform requirements apply to both the fixed-frequency and frequency-hopping modes of operation.

5.3.2.2 Sequencing of time phases.
Figure 2 illustrates the functional block diagram for fixed-frequency and frequency-hopping operation.

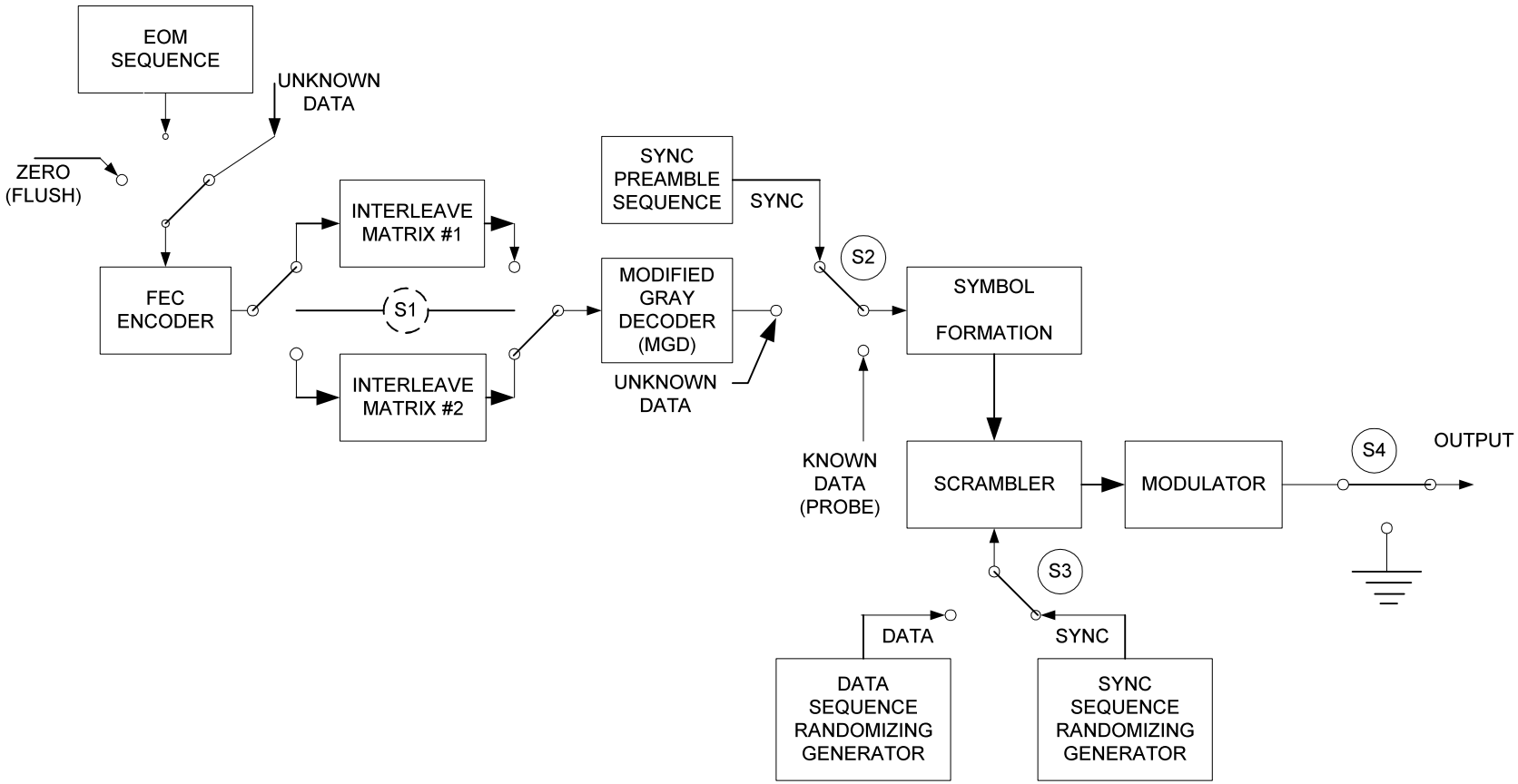



**FIGURE 2. Serial (single-tone) waveform functional block diagram**

5.3.2.2.1 Synchronization (sync) preamble phase.
The duration of the sync preamble phase shall correspond to the exact time required to load the selected interleaver matrix when an interleaver is present, with one block of data. During this phase, switch S1 (see figure 2) shall be in the UNKNOWN DATA position and the encode and load interleave functions shall be active as the modem begins accepting data from the data terminal equipment (DTE). Switches S2 and S3 shall be in the SYNC position. The transmitting modem shall send the required sync preamble sequence (see 5.3.2.3.7.2) to achieve time and frequency sync with the receiving modem. The length of the sync preamble sequence pattern shall be 0.6 s for the zero interleaver setting (this requires that a 0.6 s buffer be used to delay data traffic during the sync preamble transmission), 0.6 s for the short interleaver setting, and 4.8 s for the long interleaver setting. For radio frequency hopping operation, S4 and the data fetch controller shall provide the required traffic dead time at the beginning of each hop by disabling the modem output. The dead time shall be equal to the duration of 96 symbols. Switch S4 shall be placed in the through position during fixed-frequency operation. Referring to figure 3, the sequence of events for synchronous and asynchronous operation is as follows:

a. For fixed-frequency, full-duplex data operation, upon receipt of the message request-to-send (RTS) signal from the DTE, the modem shall simultaneously perform the following;

(1) Return to the DTE a clear-to-send (CTS) signal,

(2) Begin loading the interleaver with data traffic, and

(3) Commence sending the special sync preamble pattern described in 5.3.2.3.7.2 and 5.3.2.3.8.2.

b. For fixed-frequency half-duplex (one-way reversible) data operation using radio equipment without automatic link establishment (ALE) capability, the radio set transmitter shall be keyed first, then the sequence of events shall be identical to that given for fixed-frequency full-duplex operation.

c. Fixed-frequency half duplex data operation using ALE radio equipment shall incorporate a method of delaying the data CTS signal until radio link confirmation. In an example of this operation, upon receipt of the RTS signal from the user data terminal, the controller first initiates and confirms linking with the called station. During this link confirmation period, the RTS signal is controlled and delayed in the controller until the link is confirmed. After link confirmation, the controller sends the RTS signal to the modem. (In effect, the delaying of the RTS signal provides the needed delay of the data CTS signal.) Upon receipt of the RTS signal from the controller, the modem shall simultaneously perform the following:

(1) Key the radio,

(2) Return to the DTE a CTS signal,

(3) Begin loading the interleaver with data traffic, and

(4) Commence sending the special sync pattern described in 5.3.2.3.7.2 and 5.3.2.3.8.2.

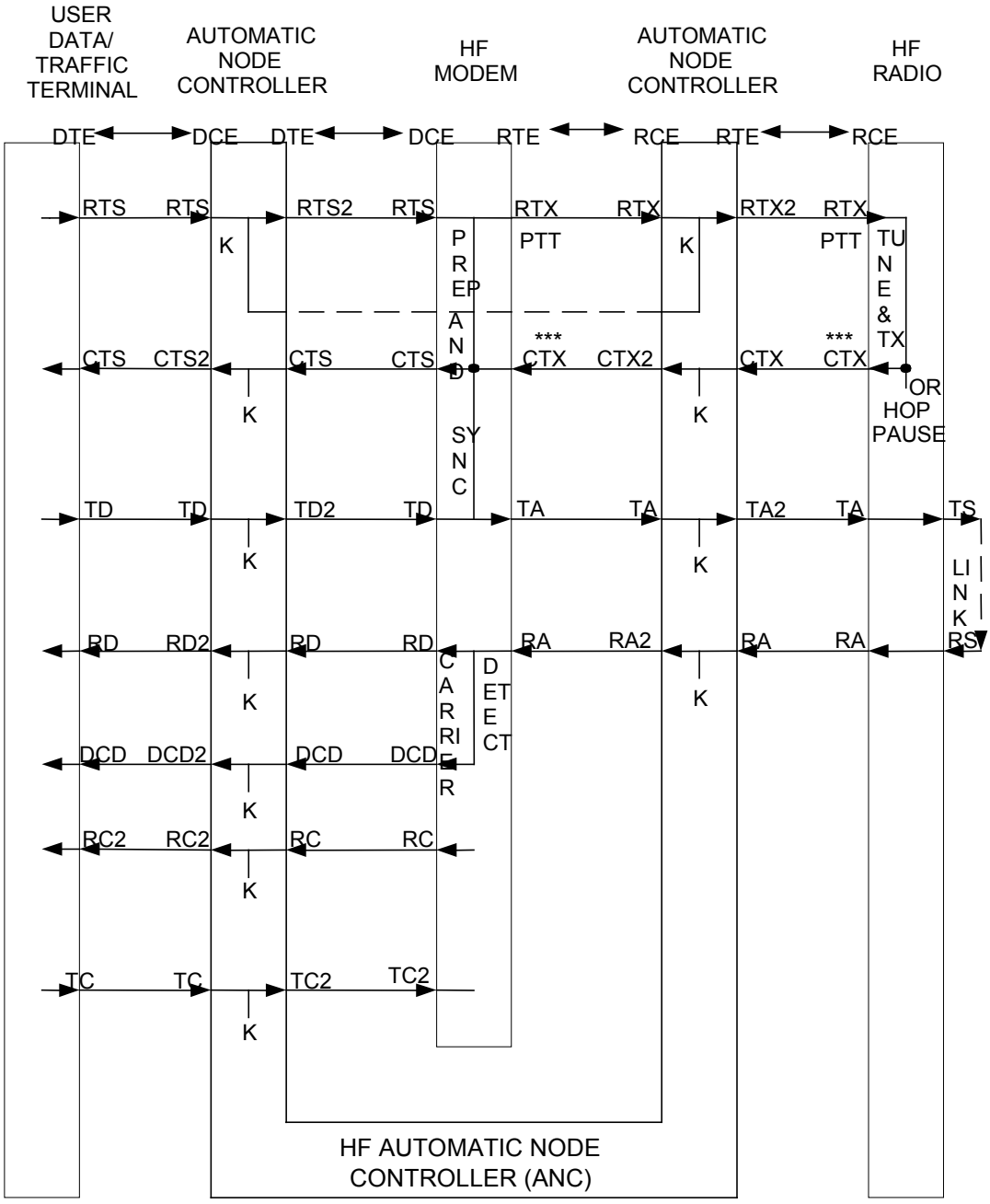



**FIGURE 3. An example of equipment interface block diagram.**

LEGEND:
* * * INDICATES A NECESSARY INTERFACE WHICH IS NOT PRESENTLY DEFINED AND REQUIRED IN PRESENT EQUIPMENTS AND STANDARDS, AND MUST BE INCORPORATED.

| | |
|---|---|
| ANC | AUTOMATIC NODE CONTROLLER |
| AND | LOGICAL AND, ALL (AVAILABLE) INPUTS MUST BE TRUE TO OBTAIN A TRUE OUTPUT |
| CTS | CLEAR TO SEND |
| CTS2 | CTS CONTROLLED THROUGH ANC |
| CTX | CLEAR TO TRANSMIT (TRANSMITTER TUNED AND ON) |
| CTX2 | CTX CONTROLLED THROUGH ANC |
| DCD | DATA CARRIER DETECT (RECEIVED DATA CARRIER DETECTION) |
| DCD2 | DCD CONTROLLED THROUGH ANC |
| DCE | DATA CIRCUIT-TERMINATING EQUIPMENT |
| DTE | DATA TERMINAL EQUIPMENT |
| HOP PAUSE | COMMAND TO PAUSE (TRANSMIT DATA) WHILE RADIO CHANGES FREQUENCY |
| K | INDICATES HF AUTOMATIC NODE CONTROLLER (ANC) CONTROL, WHICH MAY ALSO INCLUDE MONITORING AND/OR INJECTION. |
| LINK | HF RADIO LINK, INCLUDING DISTANT STATION AND PROPAGATION |
| OR | LOGICAL OR, SOME (AVAILABLE) INPUTS MUST BE TRUE TO OBTAIN A TRUE OUTPUT |
| PREP | PREPARATION TO ACCEPT AND SEND DATA, AND KEY TRANSMITTER |
| PTT | PUSH TO TALK (KEY TRANSMITTER ON) |
| RA | RECEIVE AUDIO |
| RA2 | RA CONTROLLED THROUGH ANC |
| RC | RECEIVE CLOCK |
| RC2 | RC CONTROLLED THROUGH ANC |
| RCE | RADIO COMMUNICATIONS EQUIPMENT |
| RD | RECEIVE DATA |
| RD2 | RD CONTROLLED THROUGH ANC |
| RS | RECEIVE (HF RADIO) SIGNAL |
| RTE | RADIO TERMINAL EQUIPMENT |
| RTS | REQUEST TO SEND |
| RTS2 | RTS CONTROLLED THROUGH ANC |
| RTX | REQUEST TO TRANSMIT |
| RTX2 | RTX CONTROLLED THROUGH ANC |
| SYNC | SYNCHRONIZATION FOR DATA TRANSMISSION |
| TA | TRANSMIT AUDIO |
| TA2 | TA CONTROLLED THROUGH ANC |
| TC | TRANSMIT CLOCK |
| TC2 | TC CONTROLLED THROUGH ANC |
| TD | TRANSMIT DATA |

| | |
|---|---|
| TD2 | TD CONTROLLED THROUGH ANC |
| TS | TRANSMIT (HF RADIO) SIGNAL |
| TUNE | TUNING OF THE TRANSMITTER AND ANTENNA SYSTEM BEFORE TRANSMIT |
| TX | TRANSMIT (HF RADIO ON AND READY TO SEND DATA) |

**FIGURE 3. An example of equipment interface block diagram - Continued.**

d. For frequency-hopping data operation, the modem shall, upon receipt of the RTS signal from the DTE input device, simultaneously perform the following:

(1) key the radio,

(2) return a data CTS signal to the DTE,

(3) commence loading the interleaver, and

(4) wait for the radio clear-to-transmit (CTX) signal. In no case shall the radio CTX signal occur later than 2.4 seconds after receipt of the data CTS signal. This requires, in addition to an interleaver buffer, a buffer of at least 2.45 times the highest data rate used.

NOTE: This additional buffer shall be bypassed during fixed-frequency operation.

Upon receipt of the radio CTX, the transmitting modem shall then commence sending the sync pattern as given in 5.3.2.3.7.2 and 5.3.2.3.8.2, and will use the data framing and timing format in MIL-STD-188-148.

NOTE: The interleaver fetch and modified Gray decoding functions are not active during this phase. All received data prior to entry into the data phase must be buffered by the modem. The radio CTX signal can originate from either the radio set itself or, if using ALE radio equipment, an ALE controller.

5.3.2.2.2 Data phase.
During the data phase, the transmit waveform shall contain both message information (UNKNOWN DATA) and channel probes (KNOWN DATA), that is, training bits reserved for channel equalization by the distant receive modem. Function switches S1 and S3 (figure 2) are in the UNKNOWN DATA and DATA position, respectively, and switch S2 toggles between the UNKNOWN DATA (modified Gray decoder (MGD) output) and the KNOWN DATA (probe) positions. The probe shall consist of zeros, D1, and D2 (D1 and D2 are defined in 5.3.2.3.7.1.2). The period of dwell in each switch position shall be as follows:

a. For frequency-hopping operation, the dwell is a function of bit rate and time duration of the hop. MIL-STD-188-148 gives the required timing of switches S2 and S4 during each hop time as a function of data rate and dead time.

b. For fixed-frequency operation, the period of dwell shall be a function of bit rate only. At 2400 and 4800 bps, there shall be a 32-symbol duration in the UNKNOWN DATA position followed by a 16-symbol duration in the KNOWN DATA position. At 150, 300, 600, and 1200 bps, the two durations shall be 20 symbols in each position. At 75 bps, switch S2 shall remain in the UNKNOWN DATA position. Data transfer operation shall be terminated by removal of the RTS signal by the input DTE.

NOTE: In all cases, switch S2 is placed in the UNKNOWN DATA position first, following the end of the sync preamble phase.

5.3.2.2.3 EOM phase.
When the last UNKNOWN DATA bit prior to the absence of the RTS signal has entered the forward error correction (FEC) encoder, S1 (figure 2) shall be switched to the EOM position. This shall cause a fixed 32-bit pattern (see 5.3.2.3.1) to be sent to the FEC encoder. Function switches S2 and S3 (and also S4 in frequency-hopping operation) shall continue to operate as established for the data phase.

5.3.2.2.4 FEC coder and interleaver flush phase.
Immediately upon completion of the EOM phase, S1 (figure 2 shall be switched to the FLUSH position causing input of flush bits (see 5.3.2.3.2) to the FEC encoder.

5.3.2.3 Functional descriptions.
The following subparagraphs provide figure 2 block descriptions.

5.3.2.3.1 EOM sequence.
The eight-digit hexadecimal number, 4B65A5B2 shall represent the EOM sequence. The bits shall be transmitted with the most significant digit first. Thus the first eight bits are, left to right, 0100 1011.

5.3.2.3.2 Interleaver flush
If an interleaver is used, the duration of the flush phase shall be 144 bits (for coder flush) plus enough bits to complete transmission of the remainder of the interleaved matrix data block (see 5.3.2.3.4 for data block size) containing the last coder flush bit. Flush bits shall be set to "0". If the interleaver is in a bypass (0.0 s) state, only the coder flush bits are transmitted.

NOTE: This causes the transmission of enough flush bits to allow effective flushing of the FEC decoder and the deinterleaver at the receiving modem.

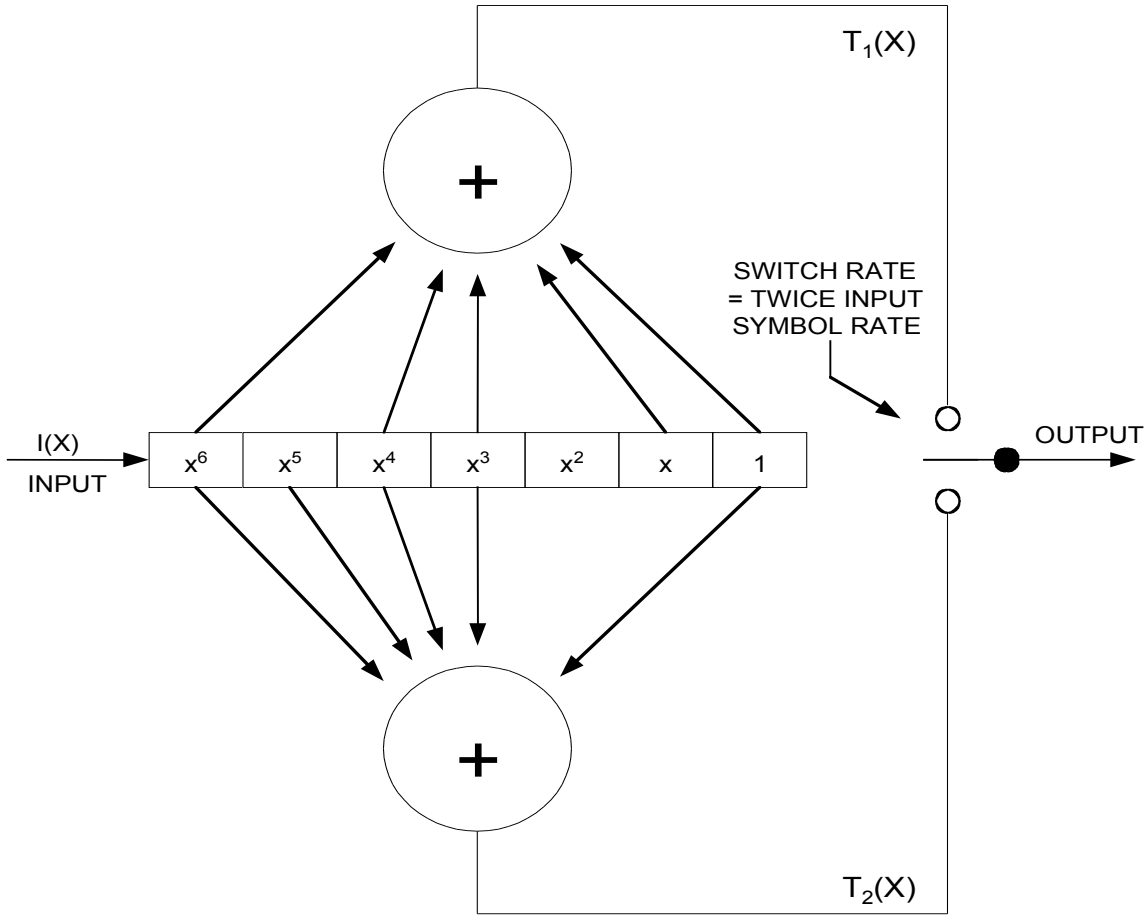
5.3.2.3.3 FEC encoder.
The FEC encoder shall be used for data rates up to and including 2400 bps. The FEC encoder block diagram for frequency-hopping and fixed-frequency operation is shown on figure 4.

a. For frequency-hopping operation, the FEC encoder function shall be accomplished by a constraint length 7 convolutional coder with repeat coding used at the 75, 150, and 300 bps rates. The two summing nodes on the figure represent modulo 2 addition. For each bit input to

the encoder, two bits shall be taken as output from the encoder, the upper output bit $T_1(x)$ being taken first. For the 2400 bps rate, every fourth bit (the second value of $T_2(x)$ shall be omitted at the interleaver output to form a punctured rate 2/3 convolutional rate. At all other rates, the convolutional coder shall be rate 1/2. Coded bit streams of 3600, 2400, and 1200 bps shall be generated for the input data rates of 2400, 1200, and 600 bps, respectively. For the 300, 150, and 75 bps input data rates, a 1200 bps coded bit stream shall be generated by repeating the pairs of output bits the appropriate number of times. The bits shall be repeated in pairs rather than repetitions for the first, $T_1(x)$, followed by repetitions of the second $T_2(x)$. Error correction coding for frequency-hopping operation shall be in accordance with Table IV.

**TABLE IV. Error correcting coding, frequency hopping operation.**

| Data rate (bps) | Effective Code rate | Method for achieving the code rate |
|---|---|---|
| 2400 | 2/3 | Rate 2/3 punctured convolutional code |
| 1200 | 1/2 | Rate 1/2 code |
| 600 | 1/2 | Rate l/2 code |
| 300 | 1/4 | Rate l/2 code repeated 2 times |
| 150 | 1/8 | Rate 1/2 code repeated 4 times |
| 75 | 1/16 | Rate 1/2 code repeated 8 times |




CONSTRAINT LENGTH = 7
GENERATOR POLYNOMIALS:

FOR $T_1$ $X^6+X^4+X^3+X+1$
FOR $T_2$ $X^6+X^5+X^4+X^3+1$

**FIGURE 4. FEC encoder block diagram.**

b. For fixed-frequency operation, the FEC encoder function shall be accomplished by a single rate 1/2 constraint length 7 convolutional coder with repeat coding used at 150 and 300 bps. The two summing nodes shall operate as given for frequency-hopping operation; that is, for each bit input to the encoder, two bits shall be taken as output from the encoder. Coded bit streams of 4800, 2400, and 1200 bps shall be generated for input data rates of 2400, 1200, and 600 bps, respectively. For 300-bps and 150-bps input data rates, repeating the pairs of output bits the appropriate number of times shall generate a 1200-bps coded bit stream. The bits shall be repeated in pairs rather than repetitions for the first, $T_1(X)$, followed by repetitions of the second $T_2(X)$. At 75 bps, a different transmit format (see 5.3.2.3.7.1.1) is used and the effective code rate of 1/2 shall be employed to produce a 150-bps coded stream. Error correction coding for fixed-frequency operation shall be in accordance with Table V.

**TABLE V. Error-correcting coding, fixed frequency operation.**

| Data rate (bps) | Effective code rate | Method for achieving the code rate |
|---|---|---|
| 4800 | (no coding) | (no coding) |
| 2400 | 1/2 | Rate 1/2 |
| 1200 | 1/2 | Rate 1/2 code |
| 600 | 1/2 | Rate1/2 code |
| 300 | 1/4 | Rate l/2 code repeated 2 times |
| 150 | 1/8 | Rate 1/2 code repeated 4 times |
| 75 | 1/2 | Rate 1/2 |

c. For 4800-bps fixed-frequency operation, the FEC encoder shall be bypassed.

5.3.2.3.4 Interleave load.
The interleaver, when used, shall be a matrix block type that operates upon input bits. The matrix size shall accommodate block storage of 0.0, 0.6, or 4.8 s of receiving bits (depending on whether the zero, short, or long interleave setting is chosen) at all required data rates. Because the bits are loaded and fetched in different orders, two distinct interleave matrices shall be required.

NOTE: This allows one block of data to be loaded while the other is being fetched. The selection between the long and short interleaves is contained in the transmitted sync pattern (5.3.2.3.7.2). The short interleaves shall be switch selectable to be either 0.0 s or 0.6 s (see 5.3.2.3.7.2.1).

To maintain the interleave delay at a constant value, the block size shall be scaled by bit rate. Table VI lists the interleaver matrix dimensions (rows and columns) that shall be allocated for each required bit rate and interleave delay.

NOTE: For frequency-hopping operation at rates of 300, 150, and 75 bps, the number of bits required for a constant time delay is the same as that for 600 bps due

to repeat coding. For fixed-frequency operation, repeat coding is used with only the 300-bps and 150-bps rates.

Unknown data bits shall be loaded into the interleaver matrix starting at column zero as follows: the first bit is loaded into row 0, the next bit is loaded into row 9, the third bit is loaded into row 18, and the fourth bit into row 27. Thus, the row location for the bits increases by 9 modulo 40. This process continues until all 40 rows are loaded. The load then advances to column 1 and the process is repeated until the matrix block is filled. This procedure shall be followed for both long and short interleave settings.

NOTE: The interleaver shall be bypassed for 4800-bps fixed-frequency operation.

For fixed-frequency operation at 75 bps only, the following changes to the above description shall apply:

a. When the interleaver setting is on long, the procedure is the same, but the row number shall be advanced by 7 modulo 20.

b. When the interleaver setting is on short, the row number shall be advanced by 7 modulo 10. If the short interleaver is selected and the short interleaver setting is 0.0 s, the interleaver shall be bypassed.

**TABLE VI. Interleaver matrix dimensions.**

| Bit rate (bps) | Long interleaver | | Short interleaver | |
|---|---|---|---|---|
| | Number of rows | Number of columns | Number of rows | Number of columns |
| 2400 | 40 | 576 | 40 | 72 |
| 1200 | 40 | 288 | 40 | 36 |
| 600 | 40 | 144 | 40 | 18 |
| 300 | 40 | 144 | 40 | 18 |
| 150 | 40 | 144 | 40 | 18 |
| 75H | 40 | 144 | 40 | 18 |
| 75N | 20 | 36 | 10 | 9 |

NOTE: H = frequency-hopping operation, N = fixed-frequency operation.

5.3.2.3.5 Interleave fetch.
The fetching sequence for all rates shall start with the first bit being taken from row zero, column zero. The location of each successive fetched bit shall be determined by incrementing the row by one and decrementing the column number by 17 (modulo number of columns in the interleaver matrix). Thus, for 2400 bps with a long interleave setting, the second bit comes from row 1, column 559, and the third bit from row 2, column 542. This interleaver fetch shall continue until the row number reaches the maximum value. At this point, the row number shall be reset to zero, the column number is reset to be one larger than the value it had when the row

number was last zero and the process continued until the entire matrix data block is unloaded. The interleaver fetch process shall be the same for frequency-hopping and fixed-frequency operation except as follows:

a. For frequency-hopping operation (as stated in 5.3.2.3.3), the puncture process at 2400 bps shall occur during the fetch routine by omitting every fourth bit from the interleaver output.

b. For fixed-frequency operation at the 75-bps rate, the interleaver fetch is similar except the decrement value of the column number shall be 7 rather than 17.

The bits obtained from the interleaver matrix shall be grouped together as one, two, or three bit entities that will be referred to as channel symbols. The number of bits that must be fetched per channel symbol shall be a function of bit rate as given in Table VII.

**TABLE VII. Bits-per-channel symbol.**

| Data rate (bps) | Number of bits fetched per channel symbol |
|---|---|
| 2400 | 3 |
| 1200 | 2 |
| 600 | 1 |
| 300 | 1 |
| 150 | 1 |
| 75H | 1 |
| 75N | 2 |

NOTE: H = frequency-hopping operation, N = fixed-frequency operation.

5.3.2.3.6 Modified-Gray decoder.
At 4800 and 2400 bps, the channel bits are effectively transmitted with 8-ary channel symbols. At 1200 bps and 75 bps (fixed frequency), the channel bits are effectively transmitted with 4-ary channel symbols.

NOTE: The purpose of decoding the bits from the interleaver matrix (through the MGD) is to guarantee that only one bit is in error when symbol errors involving adjacent phases are made at the receiving demodulator.

Modified Gray decoding of the 2400 bps, 4800 bps (tribit), and 75 bps (fixed frequency) 1200 bps (dibit) channel symbols shall be in accordance with Tables VIII and IX respectively. When one-bit channel symbols are used (600-150 bps, and 75 bps (frequency-hopping operation)) the MGD does not modify the unknown data bit stream.

**TABLE VIII. Modified Gray decoding at 2400 bps and 4800 bps.**

| Input bits | | | |
|---|---|---|---|
| First bit | Middle bit | Last bit | Modified Gray decoded value |
| 0 | 0 | 0 | 000 |
| 0 | 0 | 1 | 001 |
| 0 | 1 | 0 | 011 |
| 0 | 1 | 1 | 010 |
| 1 | 0 | 0 | 111 |
| 1 | 0 | 1 | 110 |
| 1 | 1 | 0 | 100 |
| 1 | 1 | 1 | 101 |

**TABLE IX. Modified-Gray decoding at 75 bps (fixed frequency) and 1200 bps.**

| Input bits | | |
|---|---|---|
| First bit | Last bit | Modified-Gray decoded value |
| 0 | 0 | 00 |
| 0 | 1 | 01 |
| 1 | 0 | 11 |
| 1 | 1 | 10 |

5.3.2.3.7 Symbol formation.
The function of symbol formation is one of mapping the one, two, or three bit channel symbols from the MGD or from the sync preamble sequence into tribit numbers compatible with transmission using an 8-ary modulation scheme. The mapping process is discussed separately for data and preamble transmissions.

5.3.2.3.7.1 Symbol formation for data transmission.
Channel symbols shall be fetched from the interleaver only during the portion of time that unknown symbols are to be transmitted. For all frequency-hopping and fixed-frequency operation data rates, the output of the symbol formation shall be scrambled with pseudo-random three bit numbers. This scrambled waveform shall appear to be 8-ary tribit numbers regardless of operational throughput bit rates. The relationship of tribit numbers (0-7) to the transmitted phase of the waveform is further defined in 5 3.2.3.9.

5.3.2.3.7.1.1 Unknown data.
At all frequency-hopping operation rates and rates above 75 bps for fixed-frequency operation, each one, two, or three bit channel symbol shall map directly into one of the 8-ary tribit numbers as shown on the state constellation diagram, figure 5. When one bit channel symbols are used (600-150 bps, and 75 bps (frequency-hopping)), the symbol formation output shall be tribit numbers 0 and 4 At the 1200-bps rate, the dibit channel symbol formation shall use tribit numbers 0, 2, 4, and 6. At the 4800-bps and 2400-bps rates, all the tribit numbers (0-7) shall be

used for symbol formation. At 75 bps fixed-frequency operation, the channel symbols shall consist of two bits for 4-ary channel symbol mapping. Unlike the higher rates, no known symbols (channel probes) shall be transmitted and no repeat coding shall be used. Instead, the use of 32 tribit numbers shall be used to represent each of the 4-ary channel symbols. The mapping that shall be used is given in Table X. The mapping in Table Xa shall be used for all sets of 32 tribit numbers with the exception of every 45th set (following the end of the sync pattern) if short interleave is selected, and every 360th set (following the end of sync pattern) if long interleave is selected. These exceptional sets, every 45th set for short interleave and every 360th set for long interleave, shall use the mappings of Table Xb. In any case, the resultant output is one of four orthogonal waveforms produced for each of the possible dibits of information. As before, these values will be scrambled later to take on all 8-phase states.

NOTE: Each set consists of 32 tribit numbers. The receive modem shall use the modification of the known data at interleaver boundaries to synchronize without a preamble and determine *the* correct date rate and mode of operation.

5.3.2.3.7.1.2 Known data.
During the periods where known (channel probe) symbols are to be transmitted, the channel symbol formation output shall be set to 0 (000) except for the two known symbol patterns preceding the transmission of each new interleaved block.. The block length shall be 1440 tribit channel symbols for short interleave setting and 11520 tribit channels symbols for the long interleave setting. When the two known symbol patterns preceding the transmission of each new interleaver block are transmitted, the 16 tribit symbols of these two known symbol patterns shall be set to Dl and D2, respectively, as defined in Table XI of 5.3.2.3.7.2.1 and Table XIII of 5.3.2.3.7.2.2. The two known symbol patterns are repeated twice rather than four times as they are in Table XIII to produce a pattern of 16 tribit numbers. In cases where the duration of the known symbol pattern is 20 tribit symbols, the unused last four tribit symbols shall be set to 0 (000).

NOTE: When zero interleaver setting is selected, the pattern associated with the 0.6 s block is used. When 4800 bps operation is selected, the pattern associated with the short interleaver setting is selected.

**TABLE X. Channel symbol mapping for 75 bps.**

| Channel symbol | Tribit numbers |
|---|---|
| a. Mapping for normal sets | |
| 00 | (0000) repeated 8 times |
| 01 | (0404) repeated 8 times |
| 10 | (0044) repeated 8 times |
| 11 | (0440) repeated 8 times |
| b. Mapping for exceptional sets. | |
| 00 | (0000 4444) repeated 4 times |
| 01 | (0404 4040) repeated 4 times |
| 10 | (0044 4400) repeated 4 times |
| 11 | (0440 4004) repeated 4 times |

5.3.2.3.7.2 Sync preamble sequence.

5.3.2.3.7.2.1 General.
The waveform for synchronization is essentially the same for all data rates. The synchronization pattern shall consist of either three or twenty four 200 millisecond (ms) segments (depending on whether either zero, short, or long interleave periods are used). Each 200-ms segment shall consist of a transmission of 15 three bit channel symbols as described in 5.3.2.3.7.2.2. The sequence of channel symbols shall be 0, 1, 3, 0, 1, 3, 1, 2, 0. Dl, D2, C1, C2, C3, 0.

The three bit values of Dl and D2 shall designate the bit rate and interleave setting of the transmitting modem. Table XI gives the assignment of these values.

NOTE: The D1, D2 combinations 5,6 and 5,7 are reserved for application-specific use.

If a demodulator receives any D1, D2 combination that it does not implement, it shall not synchronize but shall continue to search for synchronization.

NOTE: The short interleave can be selected to either 0.0 (bypassed) or 0.6 s. The short interleave generally should be set to 0.6 s. If the 0.0s interleave is selected, coordination with the distant terminal must be made before transmitting data. An automatic feature of selection between the 0.0 s and 0.6 s interleaver for both transmitter and receiver is a DO.

The three count symbols C1, C2, and C3 shall represent a count of the 200 ms segments starting at 2 for the zero and short sync (interleave) setting cases and 23 for the long sync (interleave) case. The count in either case shall start at the value established by the sync case setting and count down each segment to zero. The values shall be read as a six-bit word (C1,

C2, C3), where C1 contains the most significant two bits. The two bit values of each C (C1, C2, C3) shall be converted to three bit values. Adding a “1” before the two-bit value does this so that this "1" becomes the most significant bit. This conversion shall be as shown in Table XII.

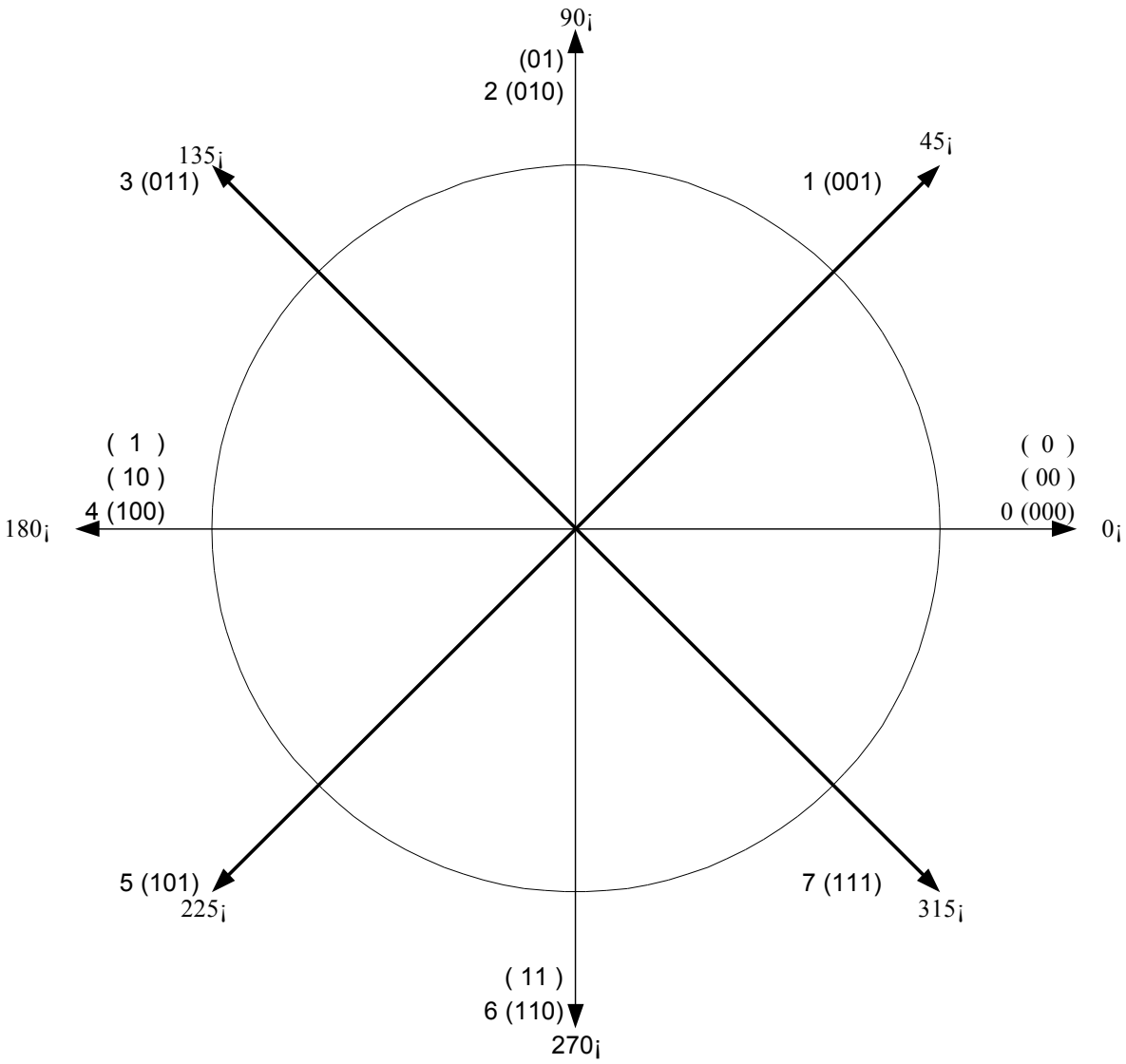
NOTE: The converted count of 23 (010111) would have values of 5, 5, and 7 for C1, C2, and C3, respectively.

**TABLE XI. Assignment of designation symbols D1 and D2.**

| | Short interleave | | Long interleave | |
|---|---|---|---|---|
| Bit rate | D1 | D2 | D1 | D2 |
| 4800 | 7 | 6 | reserved | reserved |
| 2400 (Digital voice). | 7 | 7 | reserved | reserved |
| 2400 (Data) | 6 | 4 | 4 | 4 |
| 1200 | 6 | 5 | 4 | 5 |
| 600 | 6 | 6 | 4 | 6 |
| 300 | 6 | 7 | 4 | 7 |
| 150 | 7 | 4 | 5 | 4 |
| 75 | 7 | 5 | 5 | 5 |

**TABLE XII. Conversion of two bit count value to three bit symbol.**

| Two-bit count value | Three-bit sync symbol |
|---|---|
| 00 | 4 (100) |
| 10 | 5 (101) |
| 01 | 6 (110) |
| 11 | 7 (111) |




LEGEND:
0¡...315¡ = PHASE (DEGREES)
0 ...7 = TRIBIT NUMBERS
(000) ... (111) = THREE BIT CHANNEL SYMBOLS
(00) ... (11) = TWO BIT CHANNEL SYMBOLS
(0) ... (1) = ONE BIT CHANNEL SYMBOLS

**FIGURE 5. State constellation diagram**

5.3.2.3.7.2.2 Preamble pattern generation.
The sync preamble pattern shall be a sequence of channel symbols containing three bits each (see 5.3.2.3.7.2.1). These channel symbols shall be mapped into thirty two tribit numbers as given in Table XIII.

NOTE: When the two known symbol patterns preceding the transmission of each new interleaves block are transmitted, the patterns in Table XIII are repeated twice rather than four times to produce 8 pattern of 16 tribit numbers.

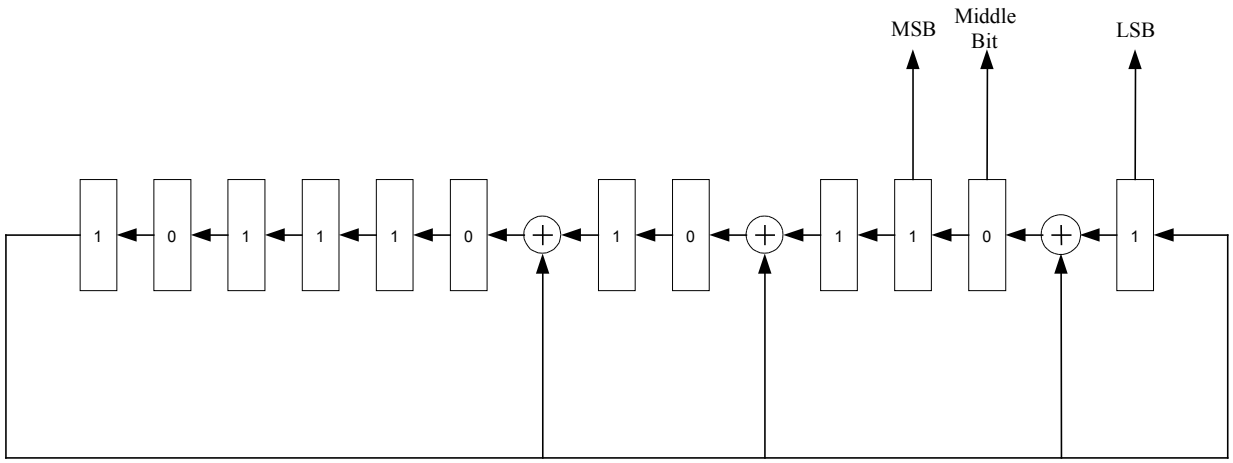
**TABLE XIII. Channel symbol mapping for sync preamble.**

| Channel Symbol | Tribit Numbers |
|---|---|
| 000 | (0000 0000)repeated 4 times |
| 001 | (0404 0404) repeated 4 times |
| 010 | (0044 0044) repeated 4 times |
| 011 | (0440 0440) repeated 4 times |
| 100 | (0000 4444) repeated 4 times |
| 101 | (0404 4040) repeated 4 times |
| 110 | (0044 4400) repeated 4 times |
| 111 | (0440 4004) repeated 4 times |

5.3.2.3.8 Scrambler.
The tribit number supplied from the symbol formation function for each 8-ary transmitted symbol shall be modulo 8 added to a three bit value supplied by either the data sequence randomizing generator or the sync sequence randomizing generator.

5.3.2.3.8.1 Data sequence randomizing generator.
The data sequence randomizing generator shall be a 12 bit shift register with the functional configuration shown on figure 6. At the start of the data phase, the shift register shall be loaded with the initial pattern shown in figure 6 (101110101101 (binary) or BAD (hexadecimal)) and advanced eight times. The resulting three bits, as shown, shall be used to supply the scrambler with a number from 0 to 7. The shift register shall be shifted eight times each time a new three bit number is required (every transmit symbol period). After 160 transmit symbols, the shift register shall be reset to BAD (hexadecimal) prior to the eight shifts.

NOTE: This sequence produces a periodic pattern 160 transmit symbols in length.




NOTES:
1. Initial settings shown
2. Shifted 8 times between outputs

**FIGURE 6. Randomizing shift register functional diagram**

5.3.2.3.8.2 Sync sequence randomizing Generator.
The following scrambling sequence for the sync preamble shall repeat every 32 transmitted symbols:

7 4 3 0 5 1 5 0 2 2 1 1 5 7 4 3 5 0 2 6 2 1 6 2 0 0 5 0 5 2 6 6

where 7 shall always be used first and 6 shall be used last. The sequences in 5.3.2.3.8.1 and this paragraph shall be modulo 8 added to the output of the symbol formation function.

5.3.2.3.9 PSK modulation.

a. The eight-phase modulation process shall be achieved by assigning the tribit numbers from the scrambler to 45-degree increments of an 1800-Hz sinewave. Thus, 0 (000) corresponds to 0 degrees, 1 (001) corresponds to 45 degrees, 2 (010) corresponds to 90 degrees, etc. Figure 5 shows the assignment and pattern of output waveform generation.

NOTE: Since the transmit channel symbol duration is less than one cycle of the 1800-Hz carrier, the waveforms controlling the sine and cosine components must be filtered to prevent severe aliasing.

b. Clock accuracy for generation of the 1800-Hz carrier shall be within ±1 Hz.

5.3.2.4 Waveform summary.
For frequency-hopping and fixed-frequency operation, tables XIV and XV summarize the data phase characteristics of the transmitted formats that shall be used for each bit rate.

NOTE: 4800 bps is not applicable to the frequency-hopping operation.

**TABLE XIV. Frequency-hopping operation waveform characteristics.**

| Information rate | Coding rate | Channel rate | Bits/channel symbol | 8-Phase channel symbol | Hop format |
|---|---|---|---|---|---|
| 2400 | 2/3 | 3600 | 3 | 1 | * |
| 1200 | 1/2 | 2400 | 2 | 1 | * |
| 600 | 1/2 | 1200 | 1 | 1 | * |
| 300 | 1/4 | 1200 | 1 | 1 | * |
| 150 | 1/8 | 1200 | 1 | 1 | * |
| 75 | 1/16 | 1200 | 1 | 1 | * |

*See MIL-STD-188-148 (S).

**TABLE XV. Fixed-frequency operation waveform characteristics.**

| Information rate | Coding rate | Channel rate | Bits/channel symbol | 8-Phase symbols/ channel symbol | No. of unknown 8-phase symbols | No. of known 8-phase symbols |
|---|---|---|---|---|---|---|
| 4800 | No coding | 4800 | 3 | 1 | 32 | 16 |
| 2400 | 1/2 | 4800 | 3 | 1 | 32 | 16 |
| 1200 | 1/2 | 2400 | 2 | 1 | 20 | 20 |
| 600 | 1/2 | 1200 | 1 | 1 | 20 | 20 |
| 300 | 1/4 | 1200 | 1 | 1 | 20 | 20 |
| 150 | 1/8 | 1200 | 1 | 1 | 20 | 20 |
| 75 | 1/2 | 150 | 2 | 32 | All | 0 |

5.3.2.5 Performance requirements.
The measured performance of the serial (single-tone) mode, using fixed-frequency operation and employing the maximum interleaving period, shall be equal to or better than the coded BER performance in Table XVI. Performance verification shall be tested using a baseband HF simulator patterned after the Watterson Model in accordance with Appendix E. The modeled multipath spread values and fading (two sigma) bandwidth (BW) values in Table XVI shall consist of two independent but equal average power Rayleigh paths. For frequency-hopping operation, an additional 2 dB in signal-to-noise ratio (SNR) shall be allowed.

**TABLE XVI. Serial (single-tone) mode minimum performance.**

| User bit rate | Channel Paths | Multipath (ms) | Fading (Note l) BW (Hz) | SNR (Note 2) (dB) | Coded BER |
|---|---|---|---|---|---|
| 4800 | 1 Fixed | - | - | 17 | 1.0 E-3 |
| 4800 | 2 Fading | 2 | 0.5 | 27 | 1.0 E-3 |
| 2400 | 1 Fixed | - | - | 10 | 1.0 E-5 |
| 2400 | 2 Fading | 2 | l | 18 | l.0 E-5 |
| 2400 | 2 Fading | 2 | 5 | 30 | 1.0 E-3 |
| 2400 | 2 Fading | 5 | 1 | 30 | 1.0 E-5 |
| 1200 | 2 Fading | 2 | 1 | 11 | 1.0 E-5 |
| 600 | 2 Fading | 2 | 1 | 7 | 1.0 E-5 |
| 300 | 2 Fading | 5 | 5 | 7 | 1.0 E-5 |
| 150 | 2 Fading | 5 | 5 | 5 | 1.0 E-5 |
| 75 | 2 Fading | 5 | 5 | 2 | 1.0 E-5 |

NOTE: Both signal and noise powers are measured in a 3-kHz bandwidth.

When testing a modem embedded with a radio, so that only radio frequency (RF) signals are available for testing, the RF signals must be downconverted to baseband for processing by the channel simulator, and the result upconverted to RF for the receiver. In this case, the built-in radio filters will affect the performance of the modems. Therefore, when testing embedded modems, the SNR values specified in Table XVI shall be increased by 1 dB.

5.3.3 Frequency hopping mode (optional).
See MIL-STD-188-148 (S).

5.3.4 Robust serial tone mode for severely degraded HF links (optional).
The optional robust serial tone mode shall employ the waveform specified above for 75 bps operation, and shall meet the performance requirements of STANAG 4415.

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use.
This standard contains requirements to ensure interoperability and minimum performance of new long-haul and tactical data modulators-demodulators (modems). These modems are intended for use in dedicated point-to-point circuits, public switched network (PSN) circuits,

and in single purpose systems such as medium frequency (MF) and high frequency (HF) radio; however, other radio systems employ this standard.

6.2 Acquisition requirements.
Acquisition documents should specify the title, number, and date of this standard.

6.3 Subject term (key word) listing.

Asynchronous
DPSK
Error-correcting code
Fallback Operation
Fixed-frequency
Frequency hopping
FSK
Full-duplex
Modified gray decoder
Half-duplex
HF data modems
In-band signaling
Interleaving
Modulator/demodulator
PSK
QAM
Quasi-analog signals
Randomizing generator
Scrambler
Serial (single tone)
Synchronous
16-tone DPSK mode
39-tone parallel mode

6.4 Changes notations.
The margins of this standard are marked with vertical lines to indicate the modifications generated by this change. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

# LAN INTERFACE

TABLE OF CONTENTS

**PARAGRAPH** **PAGE**

# A.1 SCOPE.

## A.1.1 Scope.
This appendix describes the requirements for an optional local area network (LAN) interface for radio data modems.

## A.1.2 Applicability.
This appendix is a non-mandatory part of MIL-STD-188-110D.

# A.2 APPLICABLE DOCUMENTS.
None.

# A.3 DEFINITIONS.
See section 3.

# A.4 GENERAL REQUIREMENTS.

## A.4.1 Protocol overview.
This interface is designed to enable a Data Terminal Equipment (DTE) to interact with a modem via a data network. Only one DTE at a time can control the modem using this interface. Attempts by a second DTE to establish a connection shall be rejected by the modem.

Two protocols are specified here: a TCP-based protocol for higher-performance networks, and a UDP-based protocol for data networks that experience long delays or non-negligible packet loss rates. Both protocols shall be supported in all implementations of this appendix.

## A.4.2 TCP port number.
Both the TCP-based and UDP-based protocols require the DTE to establish a TCP connection through the Ethernet interface of the modem. The TCP port number on the modem shall be configurable (port 3000 is suggested). After the connection is established the DTE and modem shall exchange control and data packets in accordance with the requirements of section 5 of this appendix.

## A.4.3 Full duplex threads.
Both the modem and the DTE device may send packets asynchronously on this interface, i.e., without prompting from the other device. Therefore, a separate thread blocked only on socket input port must be employed in each device to prevent system failure.

## A.4.4 Byte order.
Unless otherwise specified, all multi-byte fields shall be sent in network byte order i.e., most-significant byte first.

## A.5 DETAILED REQUIREMENTS.

### A.5.1 TCP socket interface.

#### A.5.1.1 Packet format.

Each packet exchanged between the DTE and the modem shall consist of an 8-byte header, optionally followed by a variable-length payload and a 16-bit CRC computed on the payload data (see Figure A-1). The total packet length shall be less than or equal to 4096 bytes. Therefore at most 4086 payload bytes may be sent in a single packet.


**Figure A-1. Packet Format**

##### A.5.1.1.1 Packet header format.

Each packet shall begin with a header consisting of the following fields (see Figure A-2):

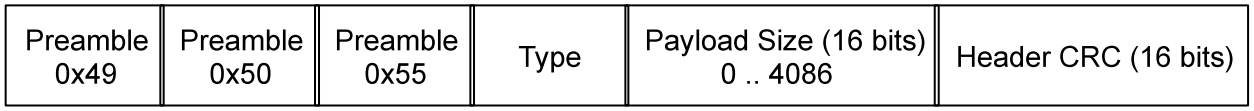



**Figure A-2. Packet Header Format**

The header shall begin with a three-byte Preamble containing the fixed values 0x49, 0x50, 0x55.

A 1-byte Type field shall follow the Preamble. The following meanings are assigned to the Type field values specified. Unused values shall not be sent, and shall result in an Error (0xFF) response if received.

**Table A-I: Packet Type Byte Values**

| Byte Value | Packet Type Name | Description |
|---|---|---|
| 0x00 | DATA | Data type packet (see A.5.1.1.3) |
| 0x01 | CONNECT | Initial Socket Connection packet (see A.5.1.1.2) |
| 0x02 | CONNECT ACK | Initial Socket Connection Acknowledgement packet (see A.5.1.1.2) |
| 0xFF | ERROR | Packet format or protocol error (see Section A.5.1.2.3) |

The Type field shall be followed by a 2 byte Payload Size field, which indicates the number of bytes in the packet payload (exclusive of Payload CRC). Valid values for this field range from 0 to 4086 bytes.

The header shall be concluded with a 2 byte Header CRC, following the Payload Size field. The Header CRC shall be computed (see A.5.3) for the preceding 6 header bytes only.

A.5.1.1.2 CONNECT and CONNECT ACK payload format.
Both CONNECT and CONNECT ACK packets shall have a one (1) byte version number payload. The version number may be used by the DTE and modem to differentiate among protocol format variations. The version number shall be set to 12 for devices that implement the protocol described in this appendix.

A.5.1.1.3 DATA Mode packet payload format.
If the payload size is zero in a DATA mode packet, no payload bytes are sent following the header. If the payload size is non-zero, the 8 byte header shall be followed by the number of payload bytes specified in the header Payload Size field, which are in turn followed by a 16-bit Payload CRC. The Payload CRC shall be computed (see A.5.3) for the payload bytes only.

The first byte of the payload shall be a Payload Command (see A.5.1.1.4). The format of the remainder of the payload field varies, depending on the Payload Command (see Table A-II).

A.5.1.1.4 Payload command Field.
The valid Payload Commands for use within DATA packets are specified in Table A-II. Unused values shall not be sent, and shall result in an Error response if received.

**Table A-II: Payload Commands**

| Command | Command Byte | Arguments (in the remaining payload bytes) | Details | Sent by |
|---|---|---|---|---|
| Data Transfer | 0x00 | Packet order byte<br>Packet ID<br>Data to be sent over the air | A.5.1.1.5 | both |
| Transmit Arm | 0x01 | none | | DTE |
| Transmit Start | 0x02 | none | | DTE |
| Request Tx Status | 0x03 | none | | DTE |
| Tx_Data_NAK | 0x04 | Cause<br>Packet ID | A.5.1.1.6 | modem |
| Tx_Status | 0x05 | modem TX state and buffer status | A.5.1.1.7 | modem |
| Abort_reception | 0x06 | none | | DTE |
| Carrier Detect | 0x08 | Carrier State<br>Receive Data Rate Info | A.5.1.1.8 | Modem |
| Transmit Setup | 0x09 | Transmit Data Rate Info | A.5.1.1.9 | Modem |
| Initial Setup | 0x0A | Data Socket Setup Parameters<br>Sync/Async Setup<br>Version | A.5.1.1.10 | Modem |
| Connection Probe | 0x0B | None | | Both |

A.5.1.1.5 Data transfer payloads: (sent to/from modem from/to DTE) .
Between 0 and 4072 bytes of over-the-air data may be sent to/from the modem using a data transfer payload. If N is the number of data bytes to be sent, the 14 + N information bytes of a data transfer payload shall be formatted as shown in Figure A-3.

| Payload Command (0x00) | Packet Order (1 byte) | Packet ID (12 bytes) | Data (0 to 4072 bytes) |
|---|---|---|---|

**Figure A-3. Data Transfer Payload Format**

A.5.1.1.5.1 Packet order byte.
The packet order byte shall take one of the following 4 values:

**Table A-III: Packet Order Byte Values**

| Byte Value | Order Type Name | Description |
|---|---|---|
| 1 | FIRST ONLY | The first packet of a multi-packet transmission |
| 2 | FIRST AND LAST | The only packet of a transmission |
| 3 | CONTINUATION | A continuation packet of a multi-packet transmission |
| 4 | LAST | The last packet of a multi-packet transmission |

The packet order byte of first packet of complete over-the-air transmission/reception must be either FIRST_ONLY or FIRST_AND_LAST. If only entire transmission/reception fits within a single packet, that packet may be sent with the packet order byte set to FIRST_AND_LAST. Otherwise, the packet order byte must be FIRST_ONLY for the first packet.

Each additional packet sent/received must have packet packet order set to either CONTINUATION if more data is to follow or LAST if this is the last data packet.

Packets with no data bytes are accepted, e.g. to notify transmitter of data termination with LAST set.

A.5.1.1.5.2 Packet ID field.
The Packet ID field shall contain a unique 12-byte identifier for each Data Transfer packet sent. This value is used only in acknowledgements (see A.5.1.1.6).

A.5.1.1.6 Transmitted data packet NACK payload.
Sent from modem to DTE only.

This message shall be sent by the modem in response to an unaccepted data packet from the DTE. Note that packets that fail CRC checks shall be silently dropped by the DTE or Modem (no NACK packet shall be generated).

| Payload Command (0x04) | Cause (1 byte) | NACKed Packet ID (12 bytes) |
|---|---|---|

**Figure A-4. NACK Payload Format**

The Cause byte shall take one of the following values:

**Table A-IV: NACK Cause Byte Values**

| Byte Value | Cause for NACK | Description |
|---|---|---|
| 0 | TRANSMIT QUEUES NOT ARMED | Modem transmit queues are not in armed or started state |
| 1 | TRANSMIT UNDERRUN | Modem transmitter underrun, transmitter is currently in a forced drain state |
| 2 | MISSING FIRST PACKET | Modem transmitter has not received a previous data packet marked as a "FIRST"-type data packet for the current transmission. |
| 3 | MULTIPLE FIRST PACKET | More than one packets received for current transmission marked as a "FIRST"-type data packet |

The NACKed packet ID shall contain the Packet ID of the data packet that caused the NACK command to be sent by the modem.

A.5.1.1.7 Transmitter status payload.
Sent from modem to DTE only.

Sent by modem in response to a Request Tx Status packet from the DTE or unsolicited when the modem transmitter's queues and/or status changes.

| Payload Command (0x05) | Transmitter State (1 byte) | Serial FIFO Space (32 bits) | Serial FIFO Fill (32 bits) | FIFO Critical Milliseconds (32 bits) | FIFO Critical Bytes (32 bits) |
|---|---|---|---|---|---|

**Figure A-5: Transmitter Status Payload Format**

The Transmitter State byte shall take one of the values shown in Table A-V according to the current state of the Modem transmitter.

**Table A-V: Transmitter State Byte Values**

| Byte Value | Command Name | Description |
|---|---|---|
| 1 | FLUSHED | Modem Transmitter flushed (Idle) |
| 2 | QUEUES ARMED AND PORT NOT READY | Modem Transmitter is ready to queue data bytes from DTE but is not ready to accept request to start transmission |
| 3 | QUEUES ARMED AND PORT READY | Modem Transmitter is ready to queue data bytes and is ready to accept request to start transmission |
| 4 | STARTED | Modem Transmitter has started processing the serial data |
| 5 | DRAINING OK | Modem transmitter is in a drain phase in response to a "LAST"-type data packet |
| 6 | DRAINING FORCED | Modem transmitter is in a forced drain phase in response to a data underrun condition. |

The Serial FIFO Space field shall indicate the space in bytes available in the transmitter serial FIFO.

The Serial FIFO Fill field shall indicate the space in bytes used in the transmitter serial FIFO.

The FIFO Critical Milliseconds field shall indicate the time in milliseconds before the modem goes into a forced drain state if no more data is sent to the modem by the DTE.

The FIFO Critical Bytes field shall indicate the number of bytes that the DTE must send to the modem to prevent the modem from going into a forced drain state.

A.5.1.1.8 Carrier detect payload.
Sent from modem to DTE only.

This packet shall be sent by the modem in response to any change in the state of the receiver. This packet shall also be sent by the modem to the DTE after the initial connection handshake and after a non-destructive configuration change.

| Payload Command (0x08) | Carrier State (1 byte) | Rx Data Rate in bits/s (32 bits) | Rx Blocking Factor in bits (32 bits) |
|---|---|---|---|

**Figure A-6: Carrier Detect Payload Format**

**Table A-VI: Carrier State Byte Values**

| Byte Value | State Name | Description |
|---|---|---|
| 0 | NO CARRIER | Modem receiver is Idle |
| 1 | CARRIER DETECTED | Modem has synchronized on a preamble or is processing data from the air. This state indicates CARRIER_DETECTED or RECEIVING state from Figure A-10. |

The Rx Data Rate field shall indicate the data rate in bits per second of the received signal.

The Rx Blocking Factor field shall indicate the chunk size in bits of the received signal. This value is tied to the interleaver length of the receive signal of most waveforms. Data shall be transferred to the DTE in data chunks equal to this value.

A.5.1.1.9 Transmit setup payload.
Sent from modem to DTE only.

Sent by modem in response to a change in the state of the transmitter. This packet shall be sent by the modem to the DTE after the initial connection handshake and after a non-destructive configuration change.

| Payload Command (0x09) | Tx Data Rate in bits/s (32 bits) | Tx Blocking Factor in bits (32 bits) |
|---|---|---|

**Figure A-7: Transmit Setup Payload Format**

The Tx Data Rate field shall indicate the data rate in bits per second of the transmitted signal.

The Tx Blocking Factor field shall indicate the chunk size in bits of the transmitter signal. This value is tied to the interleaver length of the transmitter of most waveforms. Data shall be read from the transmit buffers in data chunks equal to this value.

A.5.1.1.10 Initial setup payload.
Sent from modem to DTE only, as part of the initial connection exchange (see A.5.1.2.1). This packet contains information about the configuration of the data socket, and shall be formatted as shown in Figure A-8.

| Payload Command (0x0A) | Round-Trip Time in milliseconds (32 bits) | | Minimum Socket Latency in milliseconds (32 bits) | | | |
|---|---|---|---|---|---|---|
| Maximum Socket Latency in milliseconds (32 bits) | | Sync Flag (1 byte) | Async Data Bits (1 byte) | Async Stop Bits (1 byte) | Async Parity (1 byte) | Async Data Mode (1 byte) |

**Figure A-8: Initial Setup Payload Format**

The Round-Trip Time field shall indicate the Ethernet link round-trip time in milliseconds as calculated by the Modem during the initial connection probe exchange (see A.5.1.2).

The Minimum Socket Latency field shall indicate the minimum allowed socket latency value in milliseconds as configured on the modem. This value may be used by the modem for pre-buffer calculations instead of the Round-Trip Time value if it is greater than the Round-Trip Time.

The Maximum Socket Latency field shall indicate the maximum allowed socket latency value in milliseconds as configured on the modem. The connection may be dropped by the modem if the Round-Trip Time is greater than the Maximum Socket Latency.

**Table A-VII: Synchronous Flag Byte Values**

| Byte Value | State Name | Description |
|---|---|---|
| 0 | ASYNCHRONOUS | Operate socket in asynchronous mode. When in this mode, the modem shall convert the data stream into an asynchronous bit stream (see A.5.2.6.8.2) |
| 1 | SYNCHRONOUS | Standard synchronous socket mode of operation. When this mode is enabled, the four following bytes shall be set to 0 |

**Table A-VIII: Async Setup Fields Byte Values**

| Byte Value | Data Bits Field | Stop Bits Field | Parity Field |
|---|---|---|---|
| 0 | 5 DATA BITS | 1 STOP BIT | NO PARITY BIT |
| 1 | 6 DATA BITS | 2 STOP BITS | EVEN PARITY BIT |
| 2 | 7 DATA BITS | (reserved) | ODD PARITY BIT |
| 3 | 8 DATA BITS | (reserved) | (reserved) |

**Table A-IX: Async Data Mode Field**

| Byte Value | State Name | Description |
|---|---|---|
| 0 | STANDARD MODE | Sends all start, stop and parity bits over the air |
| 1 | DATA ONLY MODE | Sends only the data bits over the air |

A.5.1.2 TCP socket interface protocol.

A.5.1.2.1 Initial Connection Operation
Immediately after the Data terminal (DTE) device establishes a TCP-streaming connection to the modem, both the modem and DTE shall each send a CONNECT packet with version number set to 12 (see A.5.1.1.2). If the CONNECT packet is not received within 3 seconds of the socket

establishment, the entity that timed out (DTE or modem) shall terminate the TCP connection by closing the TCP socket.

After receiving a correct CONNECT packet, the modem or DTE shall validate the version numbers by immediately sending a CONNECT_ACK packet with version number set to 12 (see A.5.1.1.2). If the CONNECT_ACK packet is not received within 3 seconds of the CONNECT packet transmission, the entity that timed out (DTE or modem) shall terminate the TCP connection.

If the version is not 12 for any of the above packets, the TCP connection shall be terminated by the DTE or modem. The modem shall terminate the TCP connection if any timeout (as stated above) or packet failures occur during the initial connection phase.

Once the connection is established, the modem shall send a CONNECTION_PROBE packet to the DTE. The DTE shall immediately respond to the packet with another CONNECTION_PROBE packet. If the modem does not receive a CONNECTION_PROBE from the DTE within 6 seconds of the CONNECTION_PROBE transmission, it shall terminate the TCP connection.

The modem shall then send the following packets to the DTE:

1. Initial Setup Packet: The modem takes the time taken between the transmission of the CONNECTION_PROBE and the reception of the CONNECTION_PROBE from the DTE and saves it in the Round-Trip Time field. The rest of the settings are obtained from the Modem Data Socket configuration (user configured using a mechanism beyond the scope of this Appendix.)
2. Transmit Setup Packet: The data rate and blocking factor fields are obtained from the waveform configuration (user configured).
3. Transmit Status Packet: The state shall be set to FLUSHED and all other fields except for “Serial FIFO space” shall be set to 0
4. Carrier Detect Packet: If the modem is not currently receiving, the payload shall indicate NO CARRIER with all other fields set to 0. If the modem was receiving when the socket was established, the payload shall indicate CARRIER DETECTED and the Receive Rate and Receive Blocking Factor fields shall indicate the detected received waveform parameters.

#### A.5.1.2.2 Connection Keep-Alive

After successful completion of the Initial Connection protocol (see A.5.1.2.1), when no packet (status, control or data) has been sent for a period of 2 seconds (by the DTE or modem), a keep-alive packet shall be sent. The keep-alive packet shall be a DATA type packet (see A.5.1.1.3) with no payload (0 bytes).

When any DATA type packet (including the 0 byte keep-alive packet) is received by the DTE or Modem, a timeout timer is reset. If this timeout timer reaches 30 seconds, the TCP connection is terminated by the entity (DTE or modem) whose timeout has reached 30 seconds.

A.5.1.2.3 Error Handling

Any packet received by the DTE or Modem that fails the header or payload CRC check shall be silently dropped as if the packet was never received.

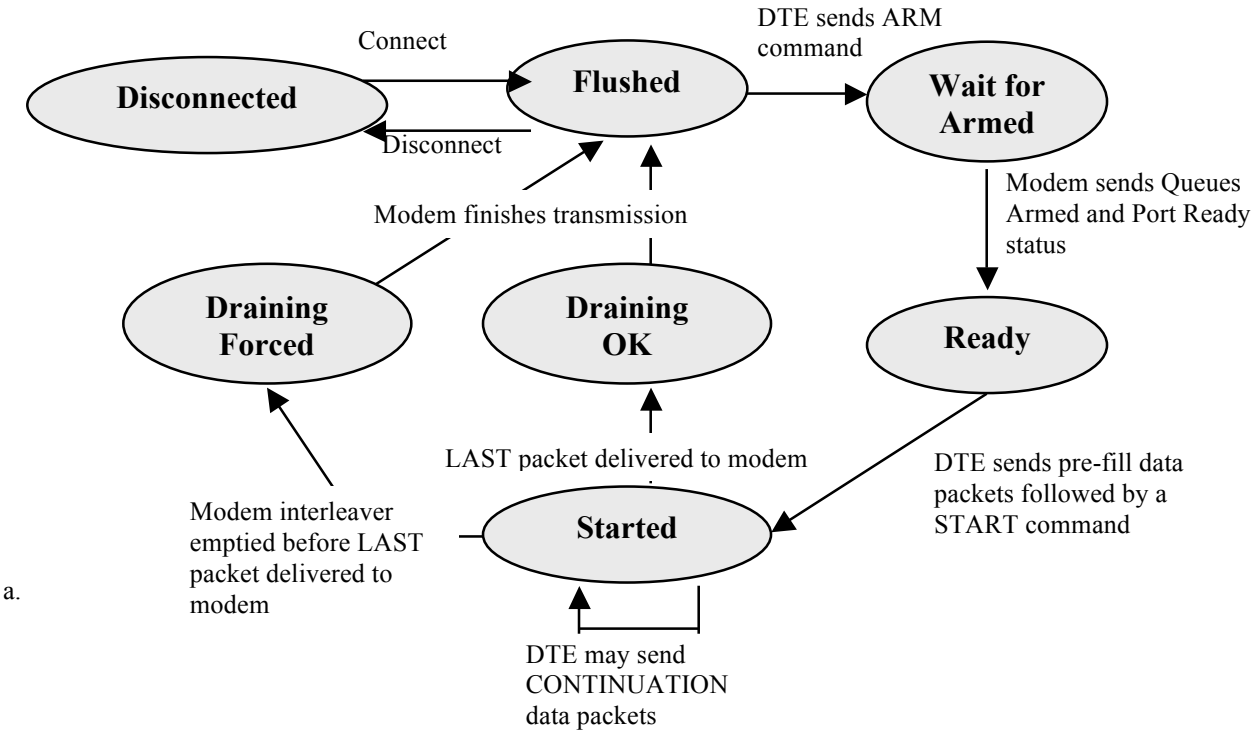
In the event of a protocol error for which a response is not specified elsewhere in this appendix (e.g., receipt of a reserved or unimplemented command, or receipt of a payload-bearing packet before the initial connection has been established), an ERROR type packet (see A.5.1.1.1) shall be returned by the receiving device, and that device shall terminate the TCP connection by closing the TCP socket.

A.5.1.2.4 Modem Configuration Changes

Modifying the modem configuration while the data socket connection is established may cause the modem to terminate the TCP connection. When this happens, the DTE should detect the TCP socket closure, re-establish the TCP connection and perform a new initial connection handshake.

A.5.1.2.5 Full Duplex Modem Transmitter operation

The Initial Connection handshake must be successfully completed before data can be sent from the DTE to the modem.




a.

**Figure A-9: Sending Modem States**

The sending process from the DTE to the modem shall proceed as follows:

1. Before sending a TRANSMIT_ARM command packet to the modem, the DTE should wait until it receives a transmit status packet from the modem indicating a FLUSHED state. If a TRANSMIT_ARM command packet is sent when the modem is not in the FLUSHED state, the modem shall send a Transmit Status Packet to the DTE indicating the modem's current state.
2. The DTE sends a TRANSMIT_ARM packet to the modem to arm the modem's transmit queues.
3. The modem shall respond with a transmit status packet of either (see A.5.1.1.7) QUEUES_ARMED_AND_PORT_NOT_READY or QUEUES_ARMED_AND_PORT_ READY if the packet is accepted. Otherwise, repeat from step 1.
4. The DTE sends at least three blocking factors of data packets to pre-fill the modem's interleaver queue (waveform and Ethernet link jitter dependent). Data packets shall be sent

using proper packet order as described in A.5.1.1.5. The DTE may send fewer than three blocking factors of data packets if a FIRST_AND_LAST or a LAST packet is sent.

5. The DTE sends a TRANSMIT_START packet after receiving a transmit status packet with QUEUES_ARMED_AND_PORT_READY state to start the transmission.
6. If the transmission has started, the modem shall respond with a transmit status packet with state STARTED.
7. The DTE should wait for a TRANSMIT_STATUS packet to arrive from the modem. If the state of the packet is not STARTED, the DTE should wait at least 10 milliseconds and repeat step 5. This may happen when the modem is in receive-master half-duplex mode (see A.5.1.2.7).
8. When the modem is in the STARTED or DRAINING state, it shall send transmit status packets to the DTE indicating the number of queued bytes and number of spaces for bytes in the modem's transmitter's queue at least every 2 seconds.
9. At any time, the client may request a transmit status packet by sending a Request Tx Status packet.
10. Data packets that are in transit to the modem are not included in the calculation of the queue size. Packets shall not be inserted into the queue if the number of free bytes in the queue is less than the maximum packet data size. This shall cause the TCP socket on the DTE to block until the modem's queue frees up.
11. If the critical bytes parameter of the transmit setup packet is non-zero, the modem shall receive from the DTE at least that number of bytes before the critical milliseconds parameter expires, or the modem shall transition into a DRAINING_FORCED state. This shall cause the modem to send a TRANSMIT_UNDERRUN Tx Data NACK packet to the DTE.
12. When the modem is in the STARTED state, if a packet is processed with the packet order set to ORDER_FIRST_AND_LAST or ORDER_LAST, and if the modem transmitter has not transitioned into a DRAINING_FORCED state, transmit status packets shall be issued with the DRAINING_OK state.
13. After the modem transmitter has finished sending all the user data to the DTE, the modem transmitter shall transition into the FLUSHED state.

While in any states shown in Figure A-9, if the TCP connection is terminated by either the DTE or the modem (from an error or a timeout), the modem transmitter shall immediately transition into the DISCONNECTED state.

A.5.1.2.6 Full Duplex Modem Receiver Operation

The Initial Connection handshake must be successfully completed before data can be sent from the modem to the DTE.

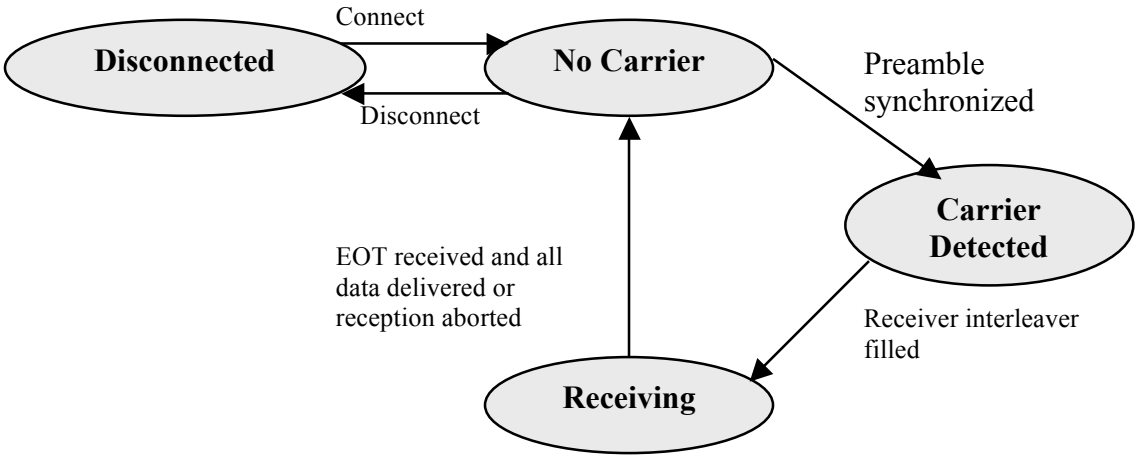



**Figure A-10: Receiving Modem States**

The receiving process at the DTE shall proceed as follows:

1. When the modem receiver is in a sync-acquire phase, at least one Carrier Detect packet shall be sent to the DTE with the carrier state set to NO_CARRIER. The data rate and blocking factor shall be set to 0.
2. When the modem receiver has fully detected a preamble, the modem shall issue a Carrier Detect packet with the carrier state set to CARRIER_DETECTED. The data rate and blocking factor shall be set to the detected values of the received waveform.
3. Once data is available, the modem shall begin sending data packets (first packet's order is either FIRST_AND_LAST for single packet or FIRST_ONLY).
4. If available, any additional data packets shall be sent with the CONTINUATION order flag set.
5. In a multi-packet transfer, the last packet (potentially zero data bytes) shall be marked as LAST packet.
6. When the modem is in the RECEIVING state, to cancel a reception and force the modem to return to the sync-acquire phase, the DTE may send an ABORT_ RECEPTION packet to the modem. This shall force the modem to send a LAST packet and transition into the NO_CARRIER state until it can resynchronize on the stream.
7. Once an end of message condition has been detected on the modem receiver a Carrier Detect packet shall be sent to the DTE with state set to NO_CARRIER. The data rate and blocking factor shall be set to 0. This may happen before or after the last data packet is delivered to the DTE.

While in any states shown in Figure A-10, if the TCP connection is terminated by either the DTE or the modem (from an error or a timeout), the modem receiver shall immediately transition into the DISCONNECTED state.

A.5.1.2.7 Half Duplex Operation.
In addition to the Full-Duplex receiver and transmitter operation described in A.5.1.2.5 and A.5.1.2.6, half-duplex operation shall also be supported. In half-duplex mode, the modem shall only be able to receive or transmit at any one time (not both at the same time). In addition, the modem shall also support the following two modes of operation when operating in half-duplex mode:

1. Transmitter Master
2. Receiver Master

A.5.1.2.7.1 Half Duplex Transmitter Master
When in half-duplex transmitter master mode, the modem shall prioritize the transmitter operation.

If a reception is currently in progress (CARRIER_DETECTED or RECEIVING states from Figure A-10), and the transmitter is in the FLUSHED state (see Figure A-9), the DTE may send a TRANSMIT_ARM command and initiate a transfer as shown in A.5.1.2.5. Once the modem is transitioned into the STARTED state, the modem receiver shall immediately return to the NO CARRIER state (see Figure A-10), which shall abort the reception. The modem shall then send a LAST data packet to the DTE and send a Carrier Detect packet with state set to NO_CARRIER to the DTE.

While the modem transmitter is in the STARTED, DRAINING_OK or DRAINING_FORCED states (Figure A-9), the modem receiver shall remain in the NO_CARRIER state (Figure A-10).

A.5.1.2.7.2 Half Duplex Receiver Master
When in half-duplex receiver master mode, the modem shall prioritize the receiver operation if a transmission is not currently in progress.

If a reception is currently in progress (CARRIER_DETECTED or RECEIVING states from Figure A-10), and the transmitter is in the FLUSHED state (see Figure A-9), the DTE may send a TRANSMIT_ARM command to the modem. While the modem reception is in progress, the modem shall transition into the QUEUES_ARMED_AND_PORT_NOT_READY state and remain in that state until the modem receiver transitions into the NO_CARRIER state.

While the modem is in the QUEUES_ARMED_AND_PORT_NOT_READY state, the DTE may send data packets to be queued onto the modem but may not send a TRANSMIT_START command to the modem. If the DTE sends a TRANSMIT_START command to the modem, the modem shall send another Transmit Status packet with state set to QUEUES_ARMED_AND_

PORT_NOT_READY to the DTE. In this case, once the modem receiver transitions into the NO_CARRIER state, the modem shall send a Transmit Status packet with state set to QUEUES_ARMED_AND_PORT_READY to the DTE. The DTE may then send a TRANSFER_STARTED command to the modem and perform a data transfer as shown in A.5.1.2.5.

The receiver master mode shall only prevent the modem from transitioning into the STARTED state while the receiver is in the CARRIER_DETECTED or RECEIVING state. Once the modem transmitter is in the STARTED, DRAINING_OK or DRAINING_FORCED states (see Figure A-9), the modem receiver shall remain in the NO_CARRIER state (see Figure A-10).

A.5.1.2.8 Data Socket Modes

The TCP data socket interface (TDSI) supports both synchronous and asynchronous operation. The differences between the two data modes are explained in this section. The mode of operation is specified by the modem and is sent to the DTE during the connection handshake.

A.5.1.2.8.1 Synchronous

While the TDSI is in the synchronous mode of operation the data shall be transferred from the DTE to the modem at the specified data rate to prevent the modem from going into a TRANSMIT_UNDERRUN state. The data is also not byte-synchronized in this mode of operation, which means that the DTE shall perform bit-synchronization to byte-align the received data stream.

A.5.1.2.8.2 Asynchronous

The asynchronous mode of operation supports two sub-modes of operation:

1. Standard Mode: All asynchronous data bits are transmitted over the air
2. Data Only Mode: Only the data bits are transmitted over the air

A.5.1.2.8.2.1 Asynchronous Standard Mode (Send-All)

When the Async Data Mode is set to STANDARD MODE, the sending modem shall convert the data stream into an asynchronous bit stream (adding start bits, stop bits and parity bits) with the specified settings before sending the data over the air. The receiving modem shall decode the received asynchronous stream from the air and convert it to a standard data stream before sending it to the DTE.

In this mode, the DTE does not have to keep a steady data stream to the modem. If the modem's transmit queues are emptied, it shall transmit stop bits over the air until more data is available for transmission up to a user specified keep-alive time. If no data is received by the modem for a period longer than the keep-alive time, the modem shall transition into a TRANSMIT_UNDERRUN state.

Data is always exchanged in the data packets using 8-bit byte alignment. If the ASYNC DATA BITS parameter is set to N DATA BITS, where N is less than 8, the least significant N bits of each 8-bit data bytes of the Data Payload shall be used for the OTA stream.

A.5.1.2.8.2.2 Asynchronous Data-Only Mode
When the Async Data Mode is set to DATA ONLY MODE, only the data bits are transmitted over the air. In this mode, the ASYNC DATA BITS shall be 8 DATA BITS and the ASYNC

PARITY shall be NO PARITY. Since no control bits are sent over the air, the data shall be transferred from the DTE to the modem at the specified data rate to prevent the modem from going into a TRANSMIT_UNDERRUN state.

The difference between asynchronous DATA ONLY MODE and synchronous is that for async mode, the modem receiver does not need to buffer data at the start of a reception before sending it to the DTE. The data is sent directly to the DTE as it is decoded from the waveform. For the synchronous mode, the modem shall buffer the data to keep the constant data rate specified by the receiving waveform before starting the data stream to the DTE.

A.5.2 UDP socket interface (UDSI).

A.5.2.1 Control connection.
UDP packets shall not be exchanged between the DTE and modem until a TCP Remote Control Interface (RCI) connection is established from the DTE to the modem. The RCI connection shall be used by the modem to obtain the DTE source address and port number that will be used for the UDP data stream. The protocol used for the RCI is beyond the scope of this appendix.

A.5.2.2 UDP socket interface packet format.
Each UDP packet exchanged between the DTE and the modem shall consist of a 4-byte header, optionally followed by a variable-length payload. A 16 bit CRC shall be appended to the end of each packet. The total packet length, including the 2 byte CRC, shall be less than or equal to 1226 bytes; at most 1220 payload bytes may be sent in a single packet.

| Packet Header (4 bytes) | Payload (0 to 1220 bytes) | Packet CRC (16 bits) |
|---|---|---|

**Figure A-11: UDSI packet format**

The payload length may be inferred from the packet type (see Table A-X). The Packet CRC shall be computed (see A.5.3) for the Packet Header bytes and Payload Bytes (if present).

A.5.2.3 UDP socket interface packet header format.
Each packet shall begin with a header consisting of the following fields:

| Version (4 bits) | Packet Type (4 bits) | Session Identification (24 bits) |
|---|---|---|

**Figure A-12: Packet Header Format**

The header shall begin with a 4-bit version number set to 1. Only packets with the version number field set to 1 shall be processed.

A 4-bit Packet Type field shall follow the Preamble. Valid values for the Packet Type field values are listed in Table A-X. Values not specified in Table A-X shall not be sent, and shall result in an Error response if received.

**Table A-X: Packet Type Byte Values**

| Packet Type | Packet Type Name | Description | Details | Payload Size | Sent By |
|---|---|---|---|---|---|
| 1 | PING REQUEST | Connection Keep-Alive | | 0 bytes | Both |
| 2 | PING REPLY | Connection Keep-Alive Reply | | 0 bytes | Both |
| 3 | STATUS REQUEST | Force the transmission of a modem status packet | | 0 bytes | DTE |
| 4 | STATUS REPLY | Transfer, error, state, link quality, modem buffer and tx and rx waveform data rate info | A.5.2.4.1 | 32 bytes | Modem |
| 5 | ENCODED DATA | FEC Encoded Data Packet | A.5.2.4.2 | 16 bytes + data | Both |
| 6 | ENHANCED ENCODED DATA | FEC Encoded Data Packet with data rate information | A.5.2.4.3 | 20 bytes + data | Modem |
| 7 | MODEM COMMAND REQUEST | Reliable Modem Command Request | A.5.2.4.4 | 4 bytes | DTE |
| 8 | MODEM COMMAND ACK | Modem Command Request Acknowledgement | A.5.2.4.5 | 4 bytes | Modem |

The Packet Type field shall be followed by a pseudo-random 24-bit Session Identification number, which shall be selected by the initiating device before the initial connection exchange. When the modem configuration changes the modem may increment this number, thus notifying the DTE that a new session has started. The DTE may also change this number to force a resynchronization on the modem side.

A.5.2.4 Packet types.

A.5.2.4.1 Status reply payload.
(Sent from modem to DTE only.) This message shall be sent by the modem when the state of any field changes or if a Status Reply packet has not been sent for 500 milliseconds. The DTE may also request a transmission of this packet from the modem by sending a STATUS_ REQUEST packet.

| | | | | |
|---|---|---|---|---|
| Packet Sequence Number (16 bits) | Current Transfer Identification (16 bit) | Reserved (16 bits) | Error Vector (8 bits) | Status Vector (8 bits) |
| Packets Dropped (16 bits) | Jitter (16 bits) | Transmit Queue Fill (32 bits) | | |
| Transmit Queue Space (32 bits) | | OTA Receive Bit Rate (24 bits) | | MSB of next field |
| OTA Receive Blocking Factor (24 bits) | OTA Transmit Bit Rate (24 bits) | | OTA Transmit Blocking Factor (24 bits) | |

**Figure A-13: Status Reply Payload Format**

Packet Sequence Number (16-bit number sent in network byte order): The modem shall increment the sequence number of the status packet for every successive packet. The Packet sequence number shall be computed modulo 65536 so that 0xFFFF, when incremented by 1 shall become 0. This shall be used by the DTE to detect out-of-order and duplicate status packets. The DTE shall calculate the modulo 65536 difference between the packet sequence number and the last received status sequence number. If this difference is less than zero when treated as a signed 16 bit value, the DTE shall ignore the status packet. This results in packets being ignored if the sequence number falls within the 0xFFFF/2 values previous to the last received sequence number. The DTE shall always accept the first status packet.

Current Transfer Identification (16-bit number sent in network byte order): The transfer ID shall be used by the DTE to identify which transfer the status packet pertains to, when sending many short transfers over a long latency network.

The modem shall set the current transfer identification number of the status packet to the transfer ID of the current transmission.

Reserved: This field shall be set to 0

The Error Vector shall be a bit field formatted as follows:

| Reserved (bits 7-5) | Not in Control (bit 4) | Rx Underrun (bit 3) | Rx Overrun (bit 2) | Tx Underrun (bit 1) | Tx Overrun (bit 0) |
|---|---|---|---|---|---|

**Figure A-14: Error Vector Format**

When the modem is not in an error state all bits in this vector shall be 0. The reserved bits shall always be 0. The following table provides a description of the error bits:

**Table A-XI: Error Vector Bit Values**

| Bit | Bit Name | Description |
|---|---|---|
| 0 | TX OVERRUN | When set to 1, The modem's transmit buffers have overflowed. This happens when the DTE sends data to the modem too fast. The transfer will be terminated and the modem's transmitter will return to the FLUSHED state |
| 1 | TX UNDERRUN | When set to 1, The modem's transmitter buffers have emptied unexpectedly. This happens when the DTE does not send data fast enough to the modem. The transfer will be terminated and the modem's transmitter will return to the FLUSHED state |
| 2 | RX OVERRUN | When set to 1, The modem's receive buffers have overflowed. This should not happen during normal operation |
| 3 | RX UNDERRUN | When set to 1, The modem's receive buffers have emptied unexpectedly. This should not happen during normal operation |
| 4 | NOT IN CONTROL | When set to 1, The modem has received data from the DTE but the DTE does not have "Control Mode" enabled on the RCI connection. No data will be accepted by the modem |

The Status Vector shall be a bit field formatted as follows:

| Reserved (bit 7) | Receiver State (bits 6-5) | Carrier Detect (bit 4) | Transmitter State (bits 3-1) | In Control (bit 0) |
|---|---|---|---|---|

**Figure A-15: Status Vector Format**

The reserved bits shall always be 0.
The following table provides a description of the status bits:

**Table A-XII: Status Vector Bit Values**

| Bit(s) | Bit Name | Description |
|---|---|---|
| 6-5 | RECEIVER STATE | 2-bit value (MSB is bit 6): Reflects the current state of the modem receiver (see Table A-XIII) |
| 4 | CARRIER DETECT | When set to 1, the modem's receiver has synchronized on a preamble or is processing data from the air |
| 3-1 | TRANSMITTER STATE | 3-bit value (MSB is bit 3): Reflects the current state of the modem transmitter (see Table A-XIV) |
| 0 | In Control | When set to 1, the modem has received the "Control Mode" request from the DTE on its RCI connection. The client may now send data to the modem |

**Table A-XIII: Status Vector Receiver State Values**

| Bit Value | Status Name | Description |
|---|---|---|
| 00 | FLUSHED | Modem Receiver is flushed (Idle) |
| 01 | STARTED | Modem Receiver has started processing user data |

**Table A-XIV: Status Vector Transmitter State Values**

| Bit Value | Status Name | Description |
|---|---|---|
| 000 | FLUSHED | Modem Transmitter flushed (Idle) |
| 001 | QUEUEING | Modem Transmitter has started receiving data from the DTE but has not started OTA transmission yet |
| 010 | STARTED | Modem Transmitter has started OTA transmission |
| 011 | DRAINING | Modem Transmitter is in a drain phase in response to a "Last" type data packet, an underrun condition or an unrecoverable data error (too many missed packets) |

Packets Dropped (16-bit number sent in network byte order): The number of packets that have been missed (dropped) by the modem for the current transmission. Packets are dropped either because of a network error (packet error) or because the packet arrives late. The dropped packets are recovered by the modem (using FEC) unless the modem transmitter has unexpectedly changed to a DRAINING state. This value may be used by the DTE as an Ethernet link quality value.

Jitter: The Ethernet packet jitter in milliseconds as seen by the modem for the current transmission. This value shall be the standard deviation of: the inter-packet arrival time minus the expected arrival time (uses the packet timestamp for calculations). This value is calculated over a window of 100 packets and is based on the standard deviation of the difference between the time of reception of a packet and the timestamp in the packet.

Transmit Queue Fill: Space in bytes used in the transmitter serial queue.

Transmit Queue Space: Space in bytes available in the transmitter serial queue.

OTA Receive Bit Rate: Over-the-air data rate in bits per second of the received signal.

OTA Receive Blocking Factor: Chunk size in bits of the received signal. This value is tied to the interleaver length of the receive signal of most waveforms. Data shall be written to the DTE in data chunks equal to this value.

OTA Transmit Bit Rate: Over-the-air data rate in bits per second of the transmitter waveform.

OTA Transmit Blocking Factor: Chunk size in bits of the transmitter waveform. This value is tied to the interleaver length of the transmit signal of most waveforms. Data shall be written to the DTE in data chunks equal to this value.

Encoded data payload.
Between 0 and 1200 bytes of FEC/interleaved data may be sent to/from the modem using an encoded data payload (see A.5.2.5 for more information on the FEC/Interleaver scheme). If N is the number of data bytes to be sent, the 16 + N information bytes of a data packet shall consist of:

<table>
<tr><td colspan="3">Transfer Identification<br>(16 bits)</td><td colspan="2">Packet Sequence Number<br>(16 bits)</td></tr>
<tr><td>Control Vector<br>(8 bits)</td><td>FEC<br>Type<br>(4 bits)</td><td>Inter-<br>leaver<br>Type<br>(4 bits)</td><td>FEC N Value<br>(8 bits)</td><td>FEC K Value<br>(8 bits)</td></tr>
<tr><td colspan="3">Data Length<br>(16 bits)</td><td colspan="2">Reserved<br>(16 bits)</td></tr>
<tr><td colspan="5">Timestamp<br>(32 bits)</td></tr>
<tr><td colspan="5">Data<br>(0 to 1200 bytes)</td></tr>
</table>

**Figure A-16: Encoded Data Payload Format**

Transfer Identification (16-bit number sent in network byte order): A pseudo-random number shall be selected and maintained for the duration of a transfer. This number shall be incremented every time a new transfer is started. The transfer identification number shall be computed modulo 65536 so that 0xFFFF, when incremented by 1 shall become 0.

Packet Sequence Number (16-bit number sent in network byte order): Each successive encoded data packet has an incremented sequence number associated to it. The packet sequence number shall be computed modulo 65536 so that 0xFFFF, when incremented by 1 shall become 0. This number is initialized to 0 for each new transfer. This is used by the DTE and modem to detect duplicate data packets and reorder out-of-order packets.

The Control Vector is a bit field as follows:

| Reserved (bits 7-3) | Holdoff Flag (bit 2) | Last Inter-leaver Set (bit 1) | First Inter-leaver Set (bit 0) |
|---|---|---|---|

**Figure A-17: Control Vector Format**

The reserved bits shall always be 0. The following table provides an explanation of the control bits:

**Table A-XV: Control Vector Bit Values**

| Bit | Bit Name | Description |
|---|---|---|
| 2 | HOLDOFF FLAG | May be used by the DTE to affect the modem's auto-prebuffer handling (default 0 for auto-prebuffer handling). See A.5.2.6.5. |
| 1 | LAST INTERLEAVER SET | When set to 1, this packet belongs to the last interleaver set of a transfer. An interleaver set is defined as N packets, where N is the FEC N value. |
| 0 | FIRST INTERLEAVER SET | When set to 1, this packet belongs to the first interleaver set of a transfer |

FEC Type (4-bits): The UDP data socket currently only supports the "Reed Solomon with Erasures" (see A.5.2.5) FEC Type, which is type 1. Only packets with FEC Type set to 1 shall be accepted.

Interleaver Type (4-bits): The UDP data socket currently only supports the "Standard FEC-matched byte-wise Interleaver" Interleaver Type, which is type 1. Only packets with Interleaver Type set to 1 shall be accepted.
FEC *N* Value (8-bits): The total number of bytes per FEC codeword.

FEC *K* Value (8-bits): The number of user bytes per FEC codeword.

Data Length (16-bit number sent in network byte order): The number of data bytes stored in the Encoded Data Payload packet (immediately following the Timestamp bytes).

Reserved: This field shall be set to 0

Timestamp field shall indicate the A timestamp in milliseconds taken at the source just before the packet is sent to the UDP socket. The timestamp may be calculated from the system time as follows:

```
struct timeval tv;
unsigned int nTimestamp;

gettimeofday(&tv, NULL);`
nTimestamp = ((tv.tv_sec % 3600) * 1000000) + tv.tv_usec;
```

A.5.2.4.3 Enhanced encoded data payload.
(Sent from modem to DTE only) Between 0 and 1200 bytes of FEC/interleaved data may be sent to/from the modem using an enhanced encoded data payload (see A.5.2.5 for more information on the FEC/Interleaver scheme). If *N* is the number of data bytes to be sent, the 20 + *N* information bytes of a data packet consist of:

<table>
<tr><td colspan="3">Transfer Identification<br>(16 bits)</td><td colspan="2">Packet Sequence Number<br>(16 bits)</td></tr>
<tr><td>Control Vector<br>(8 bits)</td><td>FEC<br>Type<br>(4 bits)</td><td>Inter-<br>leaver<br>Type<br>(4 bits)</td><td>FEC N Value<br>(8 bits)</td><td>FEC K Value<br>(8 bits)</td></tr>
<tr><td colspan="3">Data Length<br>(16 bits)</td><td colspan="2">Data Bit Rate<br>(24 bits)</td></tr>
<tr><td>LSB of Data Bit Rate</td><td colspan="4">Data Blocking Factor<br>(24 bits)</td></tr>
<tr><td colspan="5">Timestamp<br>(32 bits)</td></tr>
<tr><td colspan="5">Data<br>(0 to 1200 bytes)</td></tr>
</table>

**FigureA-18: Encoded Data Payload Format**

The Enhanced Encoded Data Payload has all the same fields as the Encoded Data Payload. Extra fields are provided to supply data rate information. The modem shall send an interleaver set of Extended Encoded Data packets at the start of each transfer and continue with Encoded Data packets if required.

See A.5.2.4.2 for descriptions of the following fields:

- Transfer Identification
- Packet Sequence Number
- Control Vector
- FEC Type
- Interleaver Type
- FEC *N* Value
- FEC *K* Value
- Data Length
- Timestamp

Data Bit Rate (24-bit number sent in network byte order): Data rate in bits per second of the received data stream. This value shall not change for the remainder of the transfer.

Data Blocking Factor (24-bit number sent in network byte order): Chunk size in bits of the received signal. This value is tied to the interleaver length of the receive signal of most waveforms. Data shall be written to the DTE in data chunks equal to this value. This value shall not change for the remainder of the transfer.

Modem command request payload.
(Sent from DTE to Modem only) This packet may be sent by the DTE to instruct the modem to execute a particular command. Since this command is reliable, if the DTE does not get a Modem Command ACK packet in response to a Modem Command Request, it shall re-send the command. See A.5.2.6.7.

| Packet Sequence Number (16 bits) | Command (8 bits) | Reserved (8 bits) |
|---|---|---|

**FigureA-19: Modem Command Request Payload Format**

Packet Sequence Number (16-bit number sent in network byte order): Each successive encoded Modem Command Request packet shall have an incremented sequence number associated to it. This number shall be initialized to 0 for the first command sent. If a packet is retransmitted, it shall keep the same sequence number as when it was initially transmitted.

The following table shows the list of commands that shall be supported by the protocol:

**Table A-XVI: Command Byte Values**

| Byte Value | Command Name | Description |
|---|---|---|
| 1 | ABORT RECEPTION | Force the modem to return to the Sync-Acquire phase. This will cause the modem to issue a LAST packet and switch to a FLUSHED state until it can resynchronize to the stream |

The modem shall ignore command request packets with unsupported command values.

Reserved: This field shall be set to 0

A.5.2.4.5 Modem command acknowledgement payload.
(Sent from Modem to DTE only) This packet shall be sent by the modem in response to a Modem Command Request packet.

| Packet Sequence Number<br><br>(16 bits) | Reserved<br><br>(16 bits) |
|---|---|

**Figure A-20: Modem Command Acknowledgement Payload Format**

Packet Sequence Number (16-bit number sent in network byte order): The sequence number of the Modem Command Request that is being acknowledged

Reserved: This field shall be set to 0

A.5.2.5 Data FEC and interleaving.
A Reed Solomon code is used to encode data so that data from late or missing data packets can be reconstructed by the receiver, whether it is Modem or DTE. Data to be sent are used to fill the data portion of an interleaver block and RS parity symbols are used to fill the remainder of the interleaver block.

The interleaver block is shown pictorially below, where the M * N symbols of the interleaver block are composed of rows consisting of RS encoded data with N-K parity symbols for each K data symbols. Note that the RS symbol size used, 4 bits, is one nibble or one half of a byte, so that in the diagram below, the cells with diagonal stripes represent the lower nibble of each byte. Data is written into the interleaver in rows. That is, the first row of the interleaver shown below, which contains the first Reed Solomon codeword is formed from the upper nibble of the first K data bytes. The second row of the interleaver, containing the second Reed Solomon codeword is formed using the lower nibbles of the first K data bytes. Data is transmitted, one interleaver at a time, with data being read out in columns. The precise details are described in this section.

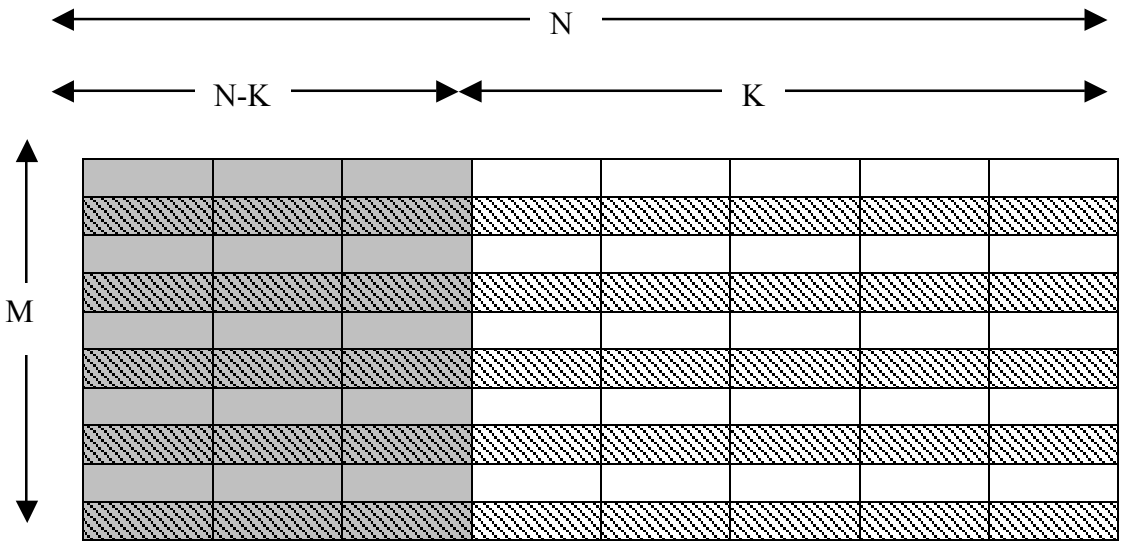



**Figure A-21: FEC Interleaver**

To allow the Modem or DTE to recover from late data packets or data packet losses, the UDSI shall provide forward error correction coding using Shortened Reed-Solomon (RS) error correction coding with erasures using 4-bit symbols, whose generator polynomial is:

$$g(x) = x^4 + a^{l3}\, x^3 + a^6 x^2 + a^3 x + a^{10};$$

where a is a non zero element of the Galois field (GF)($2^4$) formed as the field of polynomials over GF(2) modulo $x^4 + x + 1$.

For each data stream, an appropriate set of shortened N, shortened K and L parameters is chosen to maximize error recovery while minimizing the amount of pre-buffering, delay and overhead that is added by using the FEC and Interleaving scheme. The parameters are dependent on the Data Rate and Blocking Factor (tied to the waveform interleaver) of the waveform using the following formula:

**Table A-XVII: FEC Coding Length Table**

| Data Rate (bps) | N | K | Shortened N | Shortened K |
|---|---|---|---|---|
| 50 to 2400 | 15 | 11 | 6 | 2 |
| 3200 to 28800 | 15 | 12 | 7 | 4 |
| 32000 to 76800 | 15 | 12 | 8 | 5 |

$$L = \min\left(ceil\left(\frac{B}{K*8}\right), 1200\right) * N$$

Where L = Interleaver Length in bytes
B = Blocking Factor in bits
N = FEC N (total bytes per code)

**Figure A-22: Interleaver Length Calculation**

The shortened N value (stored in the data packets as FEC N) is the length in RS Symbols (or nibbles as the symbol size used is 4 bits or one nibble) of each RS codeword (This also translates to the number of data packets in an interleaver set).

The shortened K value (stored in the data packets as FEC K) is the number of user nibbles stored in each RS codeword.
L is the total number of bytes (data and parity) stored in an interleaver set of packets. (L / N) translates to the number of bytes stored in each packet.

The resulting Reed-Solomon codes are spread across N packets. Data packets that are late or lost are flagged as erasures. Using erasures, N-K packet losses may be recovered per interleaver. The user data length of each packet shall be equal to the interleaver length L / N.

A.5.2.5.1 FEC and interleaving example.
Assuming the data stream consists of the bytes {ABCDEFGHIJKLMNOP} the N, K is (7, 4) and L is 14 bytes, the FEC shall be applied to the data stream to as follows:

**Table A-XVIII: Reed-Solomon Table**

| | Byte | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| 1st Interleaver | 1st RS codeword | X | X | X | A | B | C | D |
| | 2nd RS codeword | x | x | x | a | b | c | d |
| | 3rd RS codeword | X | X | X | E | F | G | H |
| | 4th RS codeword | x | x | x | e | f | g | h |
| 2nd Interleaver | 5th RS codeword | X | X | X | I | J | K | L |
| | 6th RS codeword | x | x | x | i | j | k | l |
| | 7th RS codeword | X | X | X | M | N | O | P |
| | 8th RS codeword | x | x | x | m | n | o | p |

where capital letters have been used to denote the upper (most significant) nibble of each byte, lower case letters have been used to denote the lower (least significant) nibble of each byte, and upper and lower case X have been used to denote the RS parity symbols constructed from the

data symbols in that row. In the example above the byte stream `ABCD` is shown as the following set of 4-bit nibbles: `AaBbCcDd`

The first RS codeword, stored in the most significant 4 bits of each byte, is created from the most significant 4 bits of each user byte (denoted by uppercase letters) resulting in `{XXXABCD}`
The second RS codeword, stored in the least significant 4 bits of each byte, is created from the least significant 4 bits of each user byte (denoted by lowercase letters) resulting in `{xxxabcd}`

L bytes of RS encoded data are then segmented into an "interleaver set" of N packets. As such, each data packet shall contain L / N bytes of data (14 / 7 = 2). The first four rows of Table A-XVIII are shaded to outline the 14 bytes that will be inserted in the first interleaver set of packets. The first black box containing Xx and Xx shows the set of 2 bytes that will be inserted in the first data packet. See Table A-XIX for an example showing how the first 7 enhanced encoded data packets shall be created, including the pertinent header information:

**Table A-XIX: FEC and Interleaving Example 1**

| Data Packet Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Transfer ID | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Packet Sequence | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| First Interleaver Set | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Last Interleaver Set | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Data Length | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Data | XxXx | XxXx | XxXx | AaEe | BbFf | CcGg | DdHh |

The above packets shall be transmitted to the DTE or modem and the remaining data is encoded in the same manner:

**Table A-XX: FEC and Interleaving Example 2**

| Data Packet Number | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|
| Transfer ID | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Packet Sequence | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| First Interleaver Set | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Last Interleaver Set | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Data Length | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Data | XxXx | XxXx | XxXx | IiMm | JjNn | KkOo | LlPp |

Assuming packets 2, and 5 and 6 are late or lost at the receiver, the receiver shall replace the missed code bytes with erasures. In this case since the code length is (7,4), up to 7 – 4 = 3 packets may be lost per interleaver set.

The data received from the First Interleaver Set would look as follows:
Codeword pair 1 = `{Xx??XxAa???Dd}`
Codeword pair 2 = `{Xx??XxEe???Hh}`

Where the "?" nibbles from the lost packets and are marked as erasures before running each codeword through the RS decoder.

Codeword pair 1 shall be decoded as `{AaBbCcDd}` and Codeword pair 2 as `{EeFfGgHh}`.

A.5.2.5.2 End of message detection.

The following EOM string shall be used to delineate the end of the user data portion of a data stream:

```
{0x4B, 0x65, 0xA5, 0xB2, 0x26, 0xD2, 0xD3, 0x69}
```

The above string of bytes shall be appended to the end of the user data stream. The bytes shall be added before running the FEC encoder and Interleaver (i.e. the EOM bytes are also FECed). Any remaining bytes (to fill the rest of the last interleaver) shall be padded with `0x00`. Note that the EOM string may span multiple interleaver sets. Upon reception, the EOM string and following padding bytes shall be detected and removed from the data stream.

A.5.2.6 Protocol operation.

A.5.2.6.1 Initial connection operation.
Since UDP is a connectionless protocol, no connection is required before the data terminal (DTE) can send UDP data to the modem. However, the DTE shall establish a control connection, and obtain write lockout of the modem before sending data. The modem shall use the source address of the control connection to ensure that UDP data is only sent to, and received from a single DTE.

A.5.2.6.2 Connection keep-alive.
As a means to detect network failures, keep-alive ping packets shall be regularly sent from the DTE or the modem. Ping packets shall be sent to the modem at a rate of once every five seconds. The keep-alive packet shall be a PING REQUEST type packet (see A.5.2.1) with no payload (0 bytes).

When any PING REPLY type packet is received by the DTE or Modem, a timeout timer shall be reset. If the timeout timer reaches 30 seconds, the modem shall ignore any further data sent by the DTE and shall abort the current transmission. The modem shall only accept further data sent by the DTE once a PING REPLY is received, or the DTE sends data with a new session ID.

A.5.2.6.3 Error handling.
Packets received containing error(s) in the header or payload CRC shall be ignored. Packets of unrecognized type or incorrect format shall be ignored. Duplicate packets shall also be ignored.

Both the modem and DTE are responsible for re-ordering the packets they receive, and discarding packets that arrive late (after the interleaver set has been decoded).

The modem shall decode interleaver sets as they come, replacing any missing packets with erasures. If an interleaver set is unable to be decoded by the modem, an end of message will be sent over the air and the modem will transition to a DRAINING state.

Likewise, the DTE shall determine a maximum time to wait for a packet before considering it lost. This timeout shall be calculated as the amount of time to transmit the user data of the interleaver over the air ((FEC K * L * 8 bits/byte) / over air data rate (bps)), plus the expected latency of the UDP socket, plus the maximum expected jitter of the UDP socket. If the packet is considered lost, the DTE shall replace it with an erasure before performing the FEC decoding.

A.5.2.6.4 Modem configuration changes.
Modifying the modem configuration while the data socket is in use may cause the current transmission to be terminated. When this happens, the modem shall update its session ID, and return to a flushed transmitter state.

A.5.2.6.5 Modem transmitter operation.
The DTE must gain control of the modem before it can successfully send data.

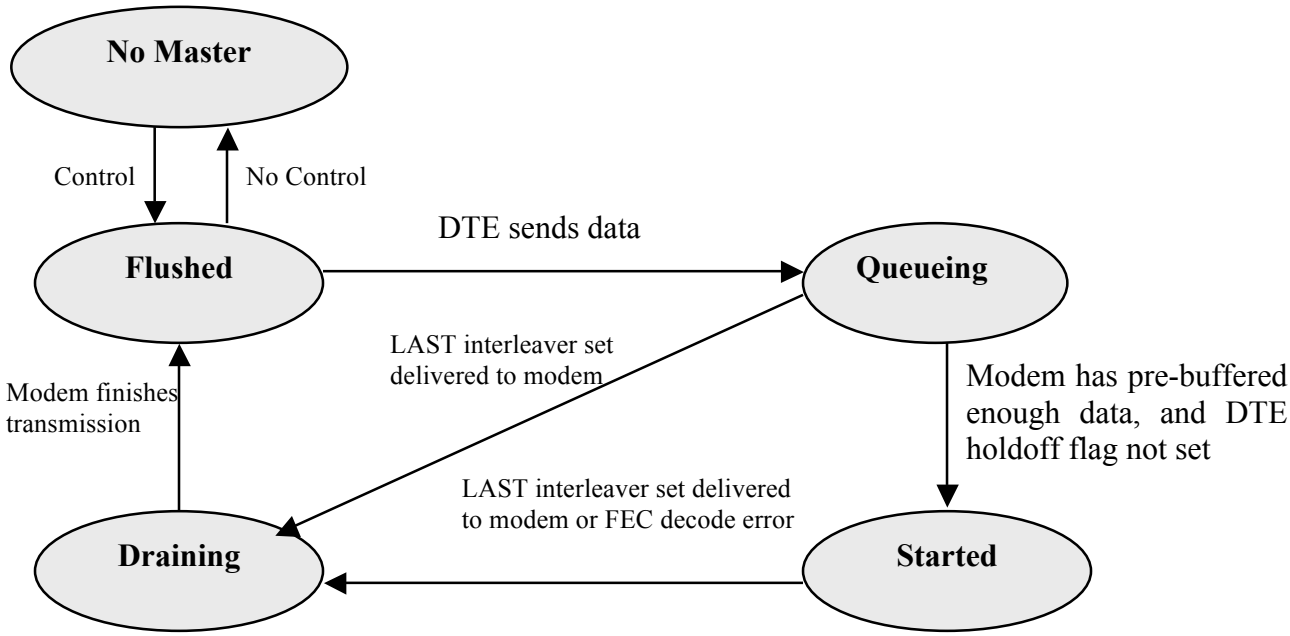



**Figure A-23: Sending Modem States**

The sending process from the DTE to the modem shall proceed as follows:

1. Before sending commands, the DTE must wait until it receives a modem transmit status packet from the modem indicating a FLUSHED state.

2. The Modem will transition to a QUEUEING state when it begins to receive data from the DTE.

3. The modem will automatically detect when it has enough data queued, and will begin to transmit. At this point, the modem will transition to a STARTED state. The DTE may prevent the modem from automatically starting by setting the hold off flag in the control vector of the encoded data packets. The modem will remain in a queueing state until this flag is cleared (in which case automatic pre-buffer detection resumes) or the last interleaver set is received by the modem (in which case the modem will transition to a draining state).

4. When the last interleaver set is received by the modem, it will transition into a DRAINING state.

5. When the modem is in the STARTED or DRAINING state, it shall periodically send status packets to the DTE indicating the number of queued bytes and number of spaces for bytes in the udp receive buffer. The udp receive buffer is a packet based buffer, so all packets are considered to be of max length (1200) for the purposes of the queued/space bytes calculation. The DTE shall use longer interleavers and lower N/K ratios at higher data rates. See Table A-XXI for a list of recommended FEC settings.

6. At anytime, the client may request a status packet by sending a Status Request packet.

7. Data packets that are in transit to the modem are not included in the calculation of the queue size. Packets will not be inserted into the queue if there is no remaining space in the queue. In this case the packet will be dropped.

8. The data sent from the DTE to the modem shall be paced such that the amount of user data sent to the modem over a given period of time is equal to the amount of data the modem is capable of sending over air in the same period of time.

9. If the modem is unable to decode data due to insufficient packets, or too much packet loss, it will force an end of transmission and transition to a DRAINING state.

10. After the transmitter has finished sending all the radio data, the modem transmitter will transition into the FLUSHED state.

**Table A-XXI: Recommended FEC Settings**

| Data Rate (bps) | FEC N | FEC K | Interleaver |
|---|---|---|---|
| 50 | 6 | 2 | 1 |
| 75 | 6 | 2 | 1 |
| 150 | 6 | 2 | 1 |
| 300 | 6 | 2 | 2 |
| 600 | 6 | 2 | 4 |
| 1200 | 6 | 2 | 8 |
| 1800 | 6 | 2 | 12 |
| 2400 | 6 | 2 | 15 |
| 3200 | 7 | 4 | 10 |
| 3600 | 7 | 4 | 12 |
| 4800 | 7 | 4 | 15 |
| 6400 | 7 | 4 | 20 |
| 7680 | 7 | 4 | 24 |
| 8000 | 7 | 4 | 25 |
| 9600 | 7 | 4 | 30 |
| 12800 | 7 | 4 | 40 |
| 14400 | 7 | 4 | 45 |
| 16000 | 7 | 4 | 50 |
| 19200 | 7 | 4 | 60 |
| 24000 | 7 | 4 | 75 |
| 25600 | 7 | 4 | 80 |
| 28800 | 7 | 4 | 90 |
| 32000 | 8 | 5 | 32 |
| 38400 | 8 | 5 | 39 |
| 48000 | 8 | 5 | 48 |
| 51200 | 8 | 5 | 52 |
| 64000 | 8 | 5 | 64 |
| 76800 | 8 | 5 | 77 |
| 80000 | 8 | 5 | 80 |
| 96000 | 8 | 5 | 96 |
| 128000 | 8 | 5 | 128 |
| 192000 | 8 | 5 | 192 |
| 256000 | 8 | 5 | 256 |
| 384000 | 8 | 5 | 384 |

A.5.2.6.6 Modem receiver operation.
The DTE must gain control of the modem before the modem can send data to the DTE.

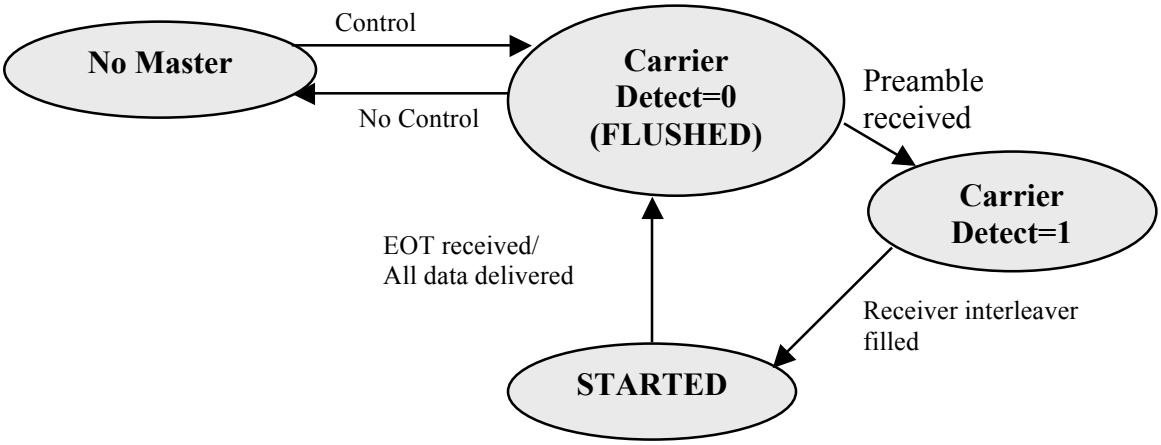



**Figure A-24: Receiving Modem States**

The receiving process at the DTE shall proceed as follows:

1. When the modem receiver is in a sync-acquire phase, status reply packets shall be sent to the DTE with the carrier detect flag set to 0.
2. When the modem receiver has fully detected a preamble, the modem shall issue a status reply packet with the carrier detect flag set to 1.
3. Once data is available, the modem shall begin sending data packets. The first interleaver shall be sent using ENHANCED ENCODED DATA packets indicating the rate and blocking factor for the reception. This interleaver set shall have the first interleaver flag set to 1. Any subsequent interleaver sets shall be sent using ENCODED DATA packets. The last interleaver set will have the last interleaver flag set to 1.
4. Once an end of message condition has been detected on the modem receiver a status reply packet shall be sent to the DTE with the carrier detect packet set to 0. This may happen before or after the last data packet is delivered to the DTE.
5. When the modem completes processing the received data, it shall send a status reply packet to the DTE indicating that the receiver is in a FLUSHED state. This may happen before or after the last data packet is delivered to the DTE.

A.5.2.6.7 Modem commands.
The DTE may send commands to the modem using a modem command request packet at any time to affect its operation. Currently the only supported command is the receiver abort command. When the modem receives a command, it shall send a modem command ack indicating that it has processed the command. Because the UDP protocol is unreliable, the DTE

may be required to retransmit commands using a pre-determined timeout with an exponential back off.

A.5.2.6.8 Data socket modes.
The UDP data socket supports a synchronous and asynchronous operation. The differences between the two data modes are explained in this section. The modem and DTE must be configured to use the same mode.

A.5.2.6.8.1 Synchronous.
The synchronous mode of operation is the standard mode of operation. The data must be transferred from the DTE to the modem at the specified data rate to prevent the modem from dropping packets or terminating the transmission due to a FEC decode error. The data is also not byte-synchronized in this mode of operation, which means that the DTE must perform bit-synchronization to byte-align the received data stream.

A.5.2.6.8.2 Asynchronous.
The asynchronous mode of operation with the Async Data Mode set to STANDARD MODE will cause the modem to convert the data stream into an asynchronous bit stream (adding start bits, stop bits and parity bits) with the specified settings before sending the data over the air. The modem will also decode the received asynchronous stream from the air, stripping the start, stop and parity bits from the data stream before sending it to the DTE.

In this case, the DTE does not have to keep a steady data stream to the modem. If the modem's transmit queues are emptied, it will transmit stop bits over the air until more data is available for transmission.

Data is always exchanged in the data packets using 8-bit byte alignment. If the ASYNC DATA BITS parameter is set to 5 DATA BITS, the least significant 5-bits of each 8-bit data bytes of the Data Payload will be used for the OTA stream.

When the Async Data Mode is set to DATA ONLY MODE, only the data bits are transmitted over the air. In this mode, the ASYNC DATA BITS must be 8 DATA BITS and the ASYNC PARITY must be NO PARITY. Since no control bits are sent over the air, the data must be transferred from the DTE to the modem at the specified data rate to prevent the modem from going into a TX_UNDERRUN state.

The difference between asynchronous DATA ONLY MODE and synchronous is that for async mode, the modem receiver does not need to buffer data at the start of a reception before sending it to the DTE. The data is sent directly to the DTE as it is decoded from the waveform. For the synchronous mode, the modem must buffer the data to keep the constant data rate specified by the receiving waveform before starting the data stream to the DTE.

A.5.3 CRC computation.

The 2 byte CRCs for the header and the optional payload portions shall be computed as follows, using the polynomial ($x^{16} + x^{15} + x^{12} + x^{11} + x^8 + x^6 + x^3 + x^0$).

The 16 bit CRC word is initially set to 0. Bits are consecutively shifted and combined into the CRC, starting with the least significant bit of the first byte, until all the bits are shifted in. After shifting all the data into the shift register, the 16 bit CRC to be transmitted consists of the contents of the 16 bit shift register. This CRC shall be sent most-significant byte first.

The following C code can be used to calculate the CRC value using the above polynomial:

```
unsigned short CalculateCRC16(unsigned char* pData, unsigned short nBytes)
{
    unsigned short nCrc, i;
    unsigned char  bit, j;

    nCrc = 0x0000;

    for ( i = 0; i < nBytes; i++ ) {
        for ( j = 0x01; j; j <<= 1 ) {
            bit = (((nCrc & 0x0001) ? 1 : 0) ^ ((pData[i] & j) ? 1 : 0));
            nCrc >>= 1;
            if ( bit ) nCrc ^= 0x9299; /* polynomial representation */
        }
    }
}
```

Any packet received by the DTE or Modem that fail the header or payload CRC check shall be silently dropped as if the packet was never received.

39-TONE PARALLEL MODE

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## B.1 SCOPE

### B.1.1 Scope.
This appendix describes the 39-tone parallel mode.

### B.1.2 Applicability.
This appendix is optional, and not recommended for new systems; however, when the 39-tone parallel mode is used, it shall be implemented in accordance with this appendix.

## B.2 APPLICABLE DOCUMENTS
This section is not applicable to this appendix.

## B.3 DEFINITIONS
See section 3.

## B.4 GENERAL REQUIREMENTS
The mode specified herein uses 39 orthogonal subcarrier tones in the audio frequency band with quadrature differential phase shift keying (QDPSK) modulation for bit synchronous data transmission. In the transmit direction, this mode (see figure B-1) (1) accepts UNKNOWN serial binary data at its line side data input port, (2) performs forward error correction (FEC) encoding and interleaving, and (3) converts the resulting bit stream into QDPSK data tones at the modulator output port. The modulation rate of the modulator output is constant for all data rates. In-band diversity of varying degrees is used at data rates below 1200 bits per second (bps). A means is provided for synchronization of the signal element and interleaved data block timing. A 40th unmodulated tone is used for correcting frequency offsets introduced by Doppler shift or radio equipment instability. In a like manner, the receive direction (1) accepts QDPSK data tones at its input, (2) converts them into the transmitted serial bit stream, (3) performs deinterleaving and FEC decoding, and (4) makes the resulting data stream available at its line-side output port.

## B.5 DETAILED REQUIREMENTS

### B.5.1 Characteristics.
In this section, detailed requirements are given for the waveform characteristics for which knowledge is needed to achieve over-the-air interoperability. These characteristics are error correction coding, interleaving, synchronization, modulator output signal, in-band time/frequency diversity, and asynchronous data operation.

### B.5.2 Error-correcting coding.
All UNKNOWN input data shall have redundant bits added to it, prior to modulation, for the purpose of correcting errors introduced by the transmission medium. The added bits shall be computed by a shortened Reed-Solomon (15,11) block code, whose generator polynomial is:

$$g(x) = x^4 + a^{l3}\, x^3 + a^6 x^2 + a^3 x + a^{10};$$

where a is a non zero element of the Galois field (GF)($2^4$) formed as the field of polynomials over GF(2) module $x^4 + x + 1$.

For input signaling rates of 2400 bps, the code shall be shortened to (14,10). Otherwise, the code shall be shortened to (7,3).

B.5.3 Interleaving.
The mode shall perform block interleaving for the purpose of providing time separation between contiguous symbols of a code word. Selectable interleaving degrees for the data rates is shown in Table B-I shall be provided. For a data signaling rate of 2400 bps, the selection shall consist of eight degrees. At data signaling rates below 2400 bps, four degrees for each bit rate shall be provided as shown in Table B-I. The input data stream shall be loaded into the interleaver buffer as described by figures B-2 and B-3.

B.5.4 Synchronization.
A means shall be provided whereby the receive demodulator process achieves time alignment with both signal element and code word timing. Frame synchronization shall be acquired within 680 milliseconds (ms). The transmit sequence of events is shown on figure B-4.

B.5.4.1 Preamble.
Prior to the transmission of data, a three part preamble shall be transmitted. Part one shall last for 14 signal element periods and consist of four equal amplitude unmodulated data tones of 787.5, 1462.5, 2137.5, and 2812.5 hertz (Hz). Part two shall last for 8 signal element periods and consist of three modulated data tones of 1125.0, 1800.0, and 2475.0 Hz. The three data tones of part two shall be advanced 180 degrees at the boundary of each data signal element. Part three shall last for one signal element period and consist of all 39 data tones plus the Doppler correction tone. This last part establishes the starting phase reference for subsequent signal element periods. During all parts of the preamble, the transmitted level of the composite signals shall have a root-mean-square (rms) value within ±1 decibel (dB) of the rms value of the modulator output (39-tone) levels occurring during subsequent data transmission. The tone phases at the onset of each part of the preamble, along with their normalized amplitudes, shall be in accordance with Table B-II.

B.5.4.2 Extended preamble.
To improve the probability of synchronization and signal presence detection in low signal-to-noise ratio situations, the ability to select an extended preamble shall be provided. Part one of the extended preamble shall last for 58 signal element periods, part two shall last for 27 signal element periods, and part three shall last for 12 signal element periods. In parts one and two, the data tones shall be as described in the nonextended preamble given above. In part three, the phase of each data tone shall be set at the onset of each signal element to the phase that it had at the onset of the first signal element in this part.

NOTE: When operating with the extended preamble, the minimum doppler correction shall be ±20 Hz and frame synchronization shall be acquired within 2.5 seconds (s).

B.5.4.3 Data block synchronization.
A set of interleaved code words is known as a super block. Block synchronization (framing) is the process whereby a receiving demodulator locates super block boundaries. This synchronization process must occur before proper deinterleaving and decoding can commence. Framing shall be established and maintained by periodically inserting into the encoded unknown data bit stream a known pseudo-random sequence. The required sequence is defined by the primitive polynomial $f(x) = x^9 + x^7 + x^6 + x^4 + 1$, when used in the feedback shift register configuration shown in figure B-5.

The first insertion of the block framing sequence shall start on the first signal element following the synchronization preamble. Upon transmission of the last bit of the sequence, the first bit of the first super block shall be transmitted without interruption. Thereafter, the framing sequence shall be inserted each time the number of super blocks specified in Table B-III has been transmitted. Upon transmission of the last bit of the framing sequence, transmission of data bits shall resume without interruption.

The number of framing bits to be transmitted per insertion varies with data rate and interleaving degree, and is specified in Table B-III. However, the final bit of the framing sequence shall always be the first space bit that follows a contiguous block of nine MARK bits. Equivalently, the final sequence bit shall be the bit generated by the shift register when its present state is 111111111 (binary) or 511 (decimal).

B.5.5 Modulator output signal.
The modulator output shall contain 39 QDPSK data tones (see Table B-IV). The 39 data tones shall be simultaneously keyed to produce a signal element interval of 22.5 milliseconds (ms) for each data tone. The composite modulator output shall have a constant modulation rate of 44.44 baud (Bd) for all standard input data signaling rates from 75 to 2400 bps. At input signaling rates less than 2400 bps, information carried on data tones 1 through 7 shall also be carried on data tones 33 through 39. The modulator shall also provide the required special preamble tone combinations used to initiate synchronization and Doppler correction.

During data transmission, the unmodulated Doppler correction tone shall be 6 dB ±1 dB higher than the normal level of any data tone. All tone frequencies shall maintain an accuracy of ±0.05 Hz. At the onset of each signal element, every data tone shall experience a phase change relative to its phase at the onset of the previous signal element. The modulator shall partition the bit stream to be transmitted into 2 bit symbols (dibits) and map them into a phase change of the appropriate data tone according to Table B-V.

B.5.6 In-band diversity.
Two selectable methods of in-band diversity for data rates of 75 - 600 bps shall be incorporated in each modem as follows: a modern method containing both time and frequency diversity, and a frequency-only diversity method for backward compatibility with older modems. The

requirements given for these methods in the following subparagraphs apply to diversities of order d, where d = 1200/(data signaling rate).

B.5.6.1 Time/frequency diversity.
Disregarding the redundant data carried on data tones 33 through 39, 64 bits, equally partitioned into d data words, shall be transmitted during each 22.5 ms signal element. Each data word and its d-1 copies shall be transmitted on 32/d unique data tones in d different signal elements. If data word i is being transmitted in a given signal element, the other data words that are to be transmitted in the same signal element are given by i - k(16/d), where k ranges from l through d-1 (see Table B-VI).

B.5.6.2 Frequency diversity.
In-band diversity shall be characterized by transmitting a data word and its (d-1) copies in one signal element (e.g., 22.5 ms time interval). This characterization is according to the tone/bit assignments shown in Table B-VII.

B.5.7 Asynchronous data operation.
In addition to bit synchronous data transmission, an asynchronous mode shall also be supported. When operating in the asynchronous mode, the modulator shall accept source data in asynchronous start/stop character format, and convert it to bit synchronous data prior to FEC encoding. Conversely, after FEC decoding, the demodulator shall convert bit synchronous data back into asynchronous format. Also, before FEC encoding, SPACE bits shall replace the start, stop, and parity bits. After FEC decoding, the start, stop, and parity bits shall be re-generated before placing the characters in the output data stream.

Otherwise, the mode operates as specified in B.5.1 through B.5.6.2 above.

B.5.7.1 Character length.
A means shall be provided whereby the modulator will accept, and the demodulator will generate, any of the data characters shown in Table B-VIII.

B.5.7.2 Data signaling rate constraint.
A means shall be provided whereby the selected data signaling rate of the modem is constrained to not exceed the nominal bit rate of the data input source.

B.5.7.3 Data-rate adjustment.
A means shall be provided whereby differences between data signaling rates of the data input source and the modem are accommodated with no loss of data or introduction of extraneous data in the demodulated output.

B.5.7.3.1 Input data source rate greater than modem rate.
The modem shall maintain a control path to the data source for the purpose of stopping the flow of data into the modulator. When the modem senses that continued flow of input data will result in data loss, it shall cause the data source to suspend the transfer of data. Upon sensing that the threat of data loss has passed, the modem shall allow the transfer of data to resume.

B.5.7.3.2 Input data source rate less than modem rate.
When the modem senses that it is about to exhaust its supply of source data, it shall insert a special "null" character into the source data bit stream prior to encoding. The null character shall be formed by making each of its bits a SPACE, and the start, stop, and parity bits a MARK. The demodulator shall recognize this bit pattern as a null character, and discard it from its data output.

B.5.7.4 End-of-message (EOM) indication.
Upon reception of the source's final data character, the modulator shall insert a series of EOM characters into the source data bit stream prior to encoding. The EOM character shall be formed by making each of its bits a MARK. The number of EOM characters inserted shall range from a minimum of ten to the number greater than ten required to fill a super block. The demodulator shall use the arrival of the EOM characters to terminate its data output.

B.5.7.5 Asynchronous mode interleaving and block framing.
The degree of interleaving, and the framing sequence length used in the asynchronous mode, vary with data signaling rate and character length. With each data rate and character length, four selectable interleaving degrees shall be provided as shown in tables B-IX, B-X, and B-XI, along with the corresponding framing sequence length.

B.5.7.6 Bit packing.
An integral number of data characters shall be transmitted between framing sequence transmissions. Therefore, the number of bits encoded will not always equal the number of bits received from the data source. In such cases, the modulator shall insert into the source data a number of fill bits equal to the difference between the number of bits encoded and the number of bits received (see tables B-IX, B-X, and B-XI). The fill bits shall be located in the bit stream so that they are the first bits encoded, thereby permitting the remainder of the data transmission to carry an integral number of data characters.

## B.6 PERFORMANCE REQUIREMENTS

The minimum performance of the 39-tone mode employing soft decision decoding and maximum interleaving, as measured using a baseband HF simulator patterned after the Watterson Model for channel simulation in accordance with Appendix E, shall be as shown in Table B-XII.

When testing a modem embedded with a radio, so that only radio frequency (RF) signals are available for testing, the RF signals must be down-converted to baseband for processing by the channel simulator, and the result up-converted to RF for the receiver. In this case, the built-in radio filters will affect the performance of the modems. Therefore, when testing embedded modems, the SNR values specified in Table B-XII shall be increased by 2 dB.

**TABLE B- I. Selectable interleaving degrees.**

| Data rate (bps) | 75 | 150 | 300 | 600 | 1200 | 2400 | |
|---|---|---|---|---|---|---|---|
| Interleaving degree | 1 | 1 | 1 | 1 | 1 | 1 | 36 |
| | 4 | 9 | 17 | 33 | 63 | 9 | 72 |
| | 12 | 25 | 47 | 99 | 189 | 18 | 144 |
| | 36 | 81 | 153 | 297 | 567 | 27 | 288 |

**TABLE B- II. Normalized tone amplitudes and initial phases.**

| Preamble part number | Tone freq (Hz) | Function | Normalized amplitude | Initial phase (degrees) |
|---|---|---|---|---|
| 1 | 787.50 | Data tone 3 | 3 | 0.0 |
| 1 | 1462.50 | Data tone 15 | 3 | 103.7 |
| 1 | 2137.50 | Data tone 27 | 3 | 103.7 |
| 1 | 2812.50 | Data tone 39 | 3 | 0.0 |
| 2 | 1125.00 | Data tone 9 | 4 | 0.0 |
| 2 | 1800.00 | Data tone 21 | 4 | 90.0 |
| 2 | 2475.00 | Data tone 33 | 4 | 0.0 |
| 3 | 393.75 | Doppler | 2 | 0.0 |
| 3 | 675.00 | Data tone 1 | 1 | 0.0 |
| 3 | 731.25 | Data tone 2 | 1 | 5.6 |
| 3 | 787.50 | Data tone 3 | 1 | 19.7 |
| 3 | 843.75 | Data tone 4 | 1 | 42.2 |
| 3 | 900.00 | Data tone 5 | 1 | 73.1 |
| 3 | 956.25 | Data tone 6 | 1 | 115.3 |
| 3 | 1012.50 | Data tone 7 | 1 | 165.9 |
| 3 | 1068.75 | Data tone 8 | 1 | 225.0 |
| 3 | 1125.00 | Data tone 9 | 1 | 295.3 |
| 3 | 1181.25 | Data tone 10 | 1 | 14.1 |
| 3 | 1237.50 | Data tone 11 | 1 | 101.3 |
| 3 | 1293.75 | Data tone 12 | 1 | 199.7 |
| 3 | 1350.00 | Data tone 13 | 1 | 303.8 |
| 3 | 1406.25 | Data tone 14 | 1 | 59.1 |
| 3 | 1462.50 | Data tone 15 | 1 | 185.6 |
| 3 | 1518.75 | Data tone 16 | 1 | 317.8 |
| 3 | 1575.00 | Data tone 17 | 1 | 101.3 |
| 3 | 1631.25 | Data tone 18 | 1 | 253.1 |
| 3 | 1687.50 | Data tone 19 | 1 | 56.3 |
| 3 | 1743.75 | Data tone 20 | 1 | 225.0 |
| 3 | 1800.00 | Data tone 21 | 1 | 45.0 |
| 3 | 1856.25 | Data tone 22 | 1 | 236.3 |
| 3 | 1912.50 | Data tone 23 | 1 | 73.1 |

| Preamble part number | Tone freq (Hz) | Function | Normalized amplitude | Initial phase (degrees) |
|---|---|---|---|---|
| 3 | 1968.75 | Data tone 24 | 1 | 281.3 |
| 3 | 2025.00 | Data tone 25 | 1 | 137.8 |
| 3 | 2081.25 | Data tone 26 | 1 | 5.6 |
| 3 | 2137.50 | Data tone 27 | 1 | 239.1 |
| 3 | 2193.75 | Data tone 28 | 1 | 123.8 |
| 3 | 2250.00 | Data tone 29 | 1 | 19.7 |
| 3 | 2306.25 | Data tone 30 | 1 | 281.3 |
| 3 | 2362.50 | Data tone 31 | 1 | 194.1 |
| 3 | 2418.75 | Data tone 32 | 1 | 115.3 |
| 3 | 2475.00 | Data tone 33 | 1 | 45.0 |
| 3 | 2531.25 | Data tone 34 | 1 | 345.9 |
| 3 | 2587.50 | Data tone 35 | 1 | 295.3 |
| 3 | 2643.75 | Data tone 36 | 1 | 253.1 |
| 3 | 2700.00 | Data tone 37 | 1 | 222.2 |
| 3 | 2756.25 | Data tone 38 | 1 | 199.7 |
| 3 | 2812.50 | Data tone 39 | 1 | 185.6 |

**TABLE B- III. Framing sequence insertion intervals and lengths.**

| Data rate (bps) | Interleaving degree | Insertion interval (super blocks) | Insertion interval (bits) | Sequence length (bits) |
|---|---|---|---|---|
| 75 | 1 | 567 | 15876 | 252 |
| 75 | 4 | 234 | 26208 | 416 |
| 75 | 12 | 75 | 25200 | 400 |
| 75 | 36 | 16 | 16128 | 256 |
| 150 | 1 | 576 | 16128 | 256 |
| 150 | 9 | 100 | 25200 | 400 |
| 150 | 25 | 36 | 25200 | 400 |
| 150 | 81 | 8 | 18144 | 288 |
| 300 | 1 | 567 | 15876 | 252 |
| 300 | 17 | 54 | 25704 | 408 |
| 300 | 47 | 18 | 23688 | 376 |
| 300 | 153 | 4 | 17136 | 272 |
| 600 | 1 | 567 | 15876 | 252 |
| 600 | 33 | 30 | 27720 | 440 |
| 600 | 99 | 10 | 27720 | 440 |
| 600 | 297 | 2 | 16632 | 264 |
| 1200 | 1 | 567 | 15876 | 252 |
| 1200 | 63 | 14 | 24696 | 392 |
| 1200 | 189 | 6 | 31752 | 504 |
| 1200 | 567 | 1 | 15876 | 252 |
| 2400 | 1 | 144 | 8064 | 256 |
| 2400 | 9 | 16 | 8064 | 256 |
| 2400 | 18 | 12 | 12096 | 384 |
| 2400 | 27 | 9 | 13608 | 432 |
| 2400 | 36 | 7 | 14112 | 448 |
| 2400 | 72 | 3 | 12096 | 384 |
| 2400 | 144 | 1 | 8064 | 256 |
| 2400 | 288 | 1 | 16128 | 512 |

NOTE: Insertion interval does not include framing sequence bits.

**TABLE B- IV. Data-tone frequencies and bit locations.**

| Tone freq(Hz) | Function | Bit locations 2400 bps | | 1200 bps | |
|---|---|---|---|---|---|
| 393.75 | Continuous Doppler | | | | |
| 675.00 | Data tone 1 | 1 | 2 | 1 | 2 |
| 731.25 | Data tone 2 | 3 | 4 | 3 | 4 |
| 787.50 | Data tone 3 | 5 | 6 | 5 | 6 |
| 843.75 | Data tone 4 | 7 | 8 | 7 | 8 |
| 900.00 | Data tone 5 | 9 | 10 | 9 | 10 |
| 956.25 | Data tone 6 | 11 | 12 | 11 | 12 |
| 1012.50 | Data tone 7 | 13 | 14 | 13 | 14 |
| 1068.75 | Data tone 8 | 15 | 16 | 15 | 16 |
| 1125.00 | Data tone 9 | 17 | 18 | 17 | 18 |
| 1181.25 | Data tone 10 | 19 | 20 | 19 | 20 |
| 1237.50 | Data tone 11 | 21 | 22 | 21 | 22 |
| 1293.75 | Data tone 12 | 23 | 24 | 23 | 24 |
| 1350.00 | Data tone 13 | 25 | 26 | 25 | 26 |
| 1406.25 | Data tone 14 | 27 | 28 | 27 | 28 |
| 1462.50 | Data tone 15 | 29 | 30 | 29 | 30 |
| 1518.75 | Data tone 16 | 31 | 32 | 31 | 32 |
| 1575.00 | Data tone 17 | 33 | 34 | 33 | 34 |
| 1631.25 | Data tone 18 | 35 | 36 | 35 | 36 |
| 1687.50 | Data tone 19 | 37 | 38 | 37 | 38 |
| 1743.75 | Data tone 20 | 39 | 40 | 39 | 40 |
| 1800.00 | Data tone 21 | 41 | 42 | 41 | 42 |
| 1856.25 | Data tone 22 | 43 | 44 | 43 | 44 |
| 1912.50 | Data tone 23 | 45 | 46 | 45 | 46 |
| 1968.75 | Data tone 24 | 47 | 48 | 47 | 48 |
| 2025.00 | Data tone 25 | 49 | 50 | 49 | 50 |
| 2081.25 | Data tone 26 | 51 | 52 | 51 | 52 |
| 2137.50 | Data tone 27 | 53 | 54 | 53 | 54 |
| 2193.75 | Data tone 28 | 55 | 56 | 55 | 56 |
| 2250.00 | Data tone 29 | 57 | 58 | 57 | 58 |
| 2306.25 | Data tone 30 | 59 | 60 | 59 | 60 |
| 2362.50 | Data tone 31 | 61 | 62 | 61 | 62 |
| 2418.75 | Data tone 32 | 63 | 64 | 63 | 64 |
| 2475.00 | Data tone 33 | 65 | 66 | 1 | 2 |
| 2531.25 | Data tone 34 | 67 | 68 | 3 | 4 |
| 2587.50 | Data tone 35 | 69 | 70 | 5 | 6 |
| 2643.75 | Data tone 36 | 71 | 72 | 7 | 8 |
| 2700.00 | Data tone 37 | 73 | 74 | 9 | 10 |
| 2756.25 | Data tone 38 | 75 | 76 | 11 | 12 |
| 2812.50 | Data tone 39 | 77 | 78 | 13 | 14 |

**TABLE B- V. Modulation characteristics of the 39-tone HF modem.**

| Logic sense of dibits | | |
|---|---|---|
| Later bit | Earlier bit | Phase change (degrees) |
| MARK (1) | SPACE (0) | +45 |
| SPACE (0) | SPACE (0) | +135 |
| SPACE (0) | MARK (1) | +225 |
| MARK (1) | MARK (1) | +315 |

**TABLE B- VI. In-band time/frequency diversity.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tone | 600 bps | Data | 300 bps | Data | 150 bps | Data | 75 bps | Data |

| number | | | word | | | word | | | word | | | word |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | i | 1 | 2 | i | 1 | 2 | i | 1 | 2 | i |
| 2 | 3 | 4 | | 3 | 4 | | 3 | 4 | | 3 | 4 | |
| 3 | 5 | 6 | | 5 | 6 | | 5 | 6 | | 1 | 2 | i-1 |
| 4 | 7 | 8 | | 7 | 8 | | 7 | 8 | | 3 | 4 | |
| 5 | 9 | 10 | | 9 | 10 | | 1 | 2 | i-2 | 1 | 2 | i-2 |
| 6 | 11 | 12 | | 11 | 12 | | 3 | 4 | | 3 | 4 | |
| 7 | 13 | 14 | | 13 | 14 | | 5 | 6 | | 1 | 2 | i-3 |
| 8 | 15 | 16 | | 15 | 16 | | 7 | 8 | | 3 | 4 | |
| 9 | 17 | 18 | | 1 | 2 | i-4 | 1 | 2 | i-4 | 1 | 2 | i-4 |
| 10 | 19 | 20 | | 3 | 4 | | 3 | 4 | | 3 | 4 | |
| 11 | 21 | 22 | | 5 | 6 | | 5 | 6 | | 1 | 2 | i-5 |
| 12 | 23 | 24 | | 7 | 8 | | 7 | 8 | | 3 | 4 | |
| 13 | 25 | 26 | | 9 | 10 | | 1 | 2 | i-6 | 1 | 2 | i-6 |
| 14 | 27 | 28 | | 11 | 12 | | 3 | 4 | | 3 | 4 | |
| 15 | 29 | 30 | | 13 | 14 | | 5 | 6 | | 1 | 2 | i-7 |
| 16 | 31 | 32 | | 15 | 16 | | 7 | 8 | | 3 | 4 | |
| 17 | 1 | 2 | i-8 | 1 | 2 | i-8 | 1 | 2 | i-8 | 1 | 2 | i-8 |
| 18 | 3 | 4 | | 3 | 4 | | 3 | 4 | | 3 | 4 | |
| 19 | 5 | 6 | | 5 | 6 | | 5 | 6 | | 1 | 2 | i-9 |
| 20 | 7 | 8 | | 7 | 8 | | 7 | 8 | | 3 | 4 | |
| 21 | 9 | 10 | | 9 | 10 | | 1 | 2 | i-10 | 1 | 2 | i-10 |
| 22 | 11 | 12 | | 11 | 12 | | 3 | 4 | | 3 | 4 | |
| 23 | 13 | 14 | | 13 | 14 | | 5 | 6 | | 1 | 2 | i-11 |
| 24 | 15 | 16 | | 15 | 16 | | 7 | 8 | | 3 | 4 | |
| 25 | 17 | 18 | | 1 | 2 | i-12 | 1 | 2 | i-12 | 1 | 2 | i-12 |
| 26 | 19 | 20 | | 3 | 4 | | 3 | 4 | | 3 | 4 | |
| 27 | 21 | 22 | | 5 | 6 | | 5 | 6 | | 1 | 2 | i-13 |
| 28 | 23 | 24 | | 7 | 8 | | 7 | 8 | | 3 | 4 | |
| 29 | 25 | 26 | | 9 | 10 | | 1 | 2 | i-14 | 1 | 2 | i-14 |
| 30 | 27 | 28 | | 11 | 12 | | 3 | 4 | | 3 | 4 | |
| 31 | 29 | 30 | | 13 | 14 | | 5 | 6 | | 1 | 2 | i-15 |
| 32 | 31 | 32 | | 15 | 16 | | 7 | 8 | | 3 | 4 | |
| 33 | 1 | 2 | i | 1 | 2 | i | 1 | 2 | i | 1 | 2 | i |
| 34 | 3 | 4 | | 3 | 4 | | 3 | 4 | | 3 | 4 | |
| 35 | 5 | 6 | | 5 | 6 | | 5 | 6 | | 1 | 2 | i-1 |
| 36 | 7 | 8 | | 7 | 8 | | 7 | 8 | | 3 | 4 | |
| 37 | 9 | 10 | | 9 | 10 | | 1 | 2 | i-2 | 1 | 2 | i-2 |
| 38 | 11 | 12 | | 11 | 12 | | 3 | 4 | | 3 | 4 | |
| 39 | 13 | 14 | | 13 | 14 | | 5 | 6 | | 1 | 2 | i-3 |

**TABLE B- VII. In-band frequency diversity.**

| Tone freq (Hz) | Function | 600 bps | | 300 bps | | 150 bps | | 75 bps | |
|---|---|---|---|---|---|---|---|---|---|
| 393.75 | Continuous Doppler | | | | | | | | |
| 675.00 | Data tone 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 731.25 | Data tone 2 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 |
| 787.50 | Data tone 3 | 5 | 6 | 5 | 6 | 5 | 6 | 1 | 2 |
| 843.75 | Data tone 4 | 7 | 8 | 7 | 8 | 7 | 8 | 3 | 4 |
| 900.00 | Data tone 5 | 9 | 10 | 9 | 10 | 1 | 2 | 1 | 2 |
| 956.25 | Data tone 6 | 11 | 12 | 11 | 12 | 3 | 4 | 3 | 4 |
| 1012.50 | Data tone 7 | 13 | 14 | 13 | 14 | 5 | 6 | 1 | 2 |
| 1068.75 | Data tone 8 | 15 | 16 | 15 | 16 | 7 | 8 | 3 | 4 |
| 1125.00 | Data tone 9 | 17 | 18 | 1 | 2 | 1 | 2 | 1 | 2 |
| 1181.25 | Data tone 10 | 19 | 20 | 3 | 4 | 3 | 4 | 3 | 4 |
| 1237.50 | Data tone 11 | 21 | 22 | 5 | 6 | 5 | 6 | 1 | 2 |
| 1293.75 | Data tone 12 | 23 | 24 | 7 | 8 | 7 | 8 | 3 | 4 |
| 1350.00 | Data tone 13 | 25 | 26 | 9 | 10 | 1 | 2 | 1 | 2 |
| 1406.25 | Data tone 14 | 27 | 28 | 11 | 12 | 3 | 4 | 3 | 4 |
| 1462.50 | Data tone 15 | 29 | 30 | 13 | 14 | 5 | 6 | 1 | 2 |
| 1518.75 | Data tone 16 | 31 | 32 | 15 | 16 | 7 | 8 | 3 | 4 |
| 1575.00 | Data tone 17 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 1631.25 | Data tone 18 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 |
| 1687.50 | Data tone 19 | 5 | 6 | 5 | 6 | 5 | 6 | 1 | 2 |
| 1743.75 | Data tone 20 | 7 | 8 | 7 | 8 | 7 | 8 | 3 | 4 |
| 1800.00 | Data tone 21 | 9 | 10 | 9 | 10 | 1 | 2 | 1 | 2 |
| 1856.25 | Data tone 22 | 11 | 12 | 11 | 12 | 3 | 4 | 3 | 4 |
| 1912.50 | Data tone 23 | 13 | 14 | 13 | 14 | 5 | 6 | 1 | 2 |
| 1968.75 | Data tone 24 | 15 | 16 | 15 | 16 | 7 | 8 | 3 | 4 |
| 2025.00 | Data tone 25 | 17 | 18 | 1 | 2 | 1 | 2 | 1 | 2 |
| 2081.25 | Data tone 26 | 19 | 20 | 3 | 4 | 3 | 4 | 3 | 4 |
| 2137.50 | Data tone 27 | 21 | 22 | 5 | 6 | 5 | 6 | 1 | 2 |
| 2193.75 | Data tone 28 | 23 | 24 | 7 | 8 | 7 | 8 | 3 | 4 |
| 2250.00 | Data tone 29 | 25 | 26 | 9 | 10 | 1 | 2 | 1 | 2 |
| 2306.25 | Data tone 30 | 27 | 28 | 11 | 12 | 3 | 4 | 3 | 4 |
| 2362.50 | Data tone 31 | 29 | 30 | 13 | 14 | 5 | 6 | 1 | 2 |
| 2418.75 | Data tone 32 | 31 | 32 | 15 | 16 | 7 | 8 | 3 | 4 |
| 2475.00 | Data tone 33 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 2531.25 | Data tone 34 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 |
| 2587.50 | Data tone 35 | 5 | 6 | 5 | 6 | 5 | 6 | 1 | 2 |
| 2643.75 | Data tone 36 | 7 | 8 | 7 | 8 | 7 | 8 | 3 | 4 |
| 2700.00 | Data tone 37 | 9 | 10 | 9 | 10 | 1 | 2 | 1 | 2 |
| 2756.25 | Data tone 38 | 11 | 12 | 11 | 12 | 3 | 4 | 3 | 4 |
| 2812.50 | Data tone 39 | 13 | 14 | 13 | 14 | 5 | 6 | 1 | 2 |

**TABLE B- VIII. Asynchronous character set.**

| | Character bit designation and location | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of bits | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 7 | St | Da | Da | Da | Da | Da | Sp | | | | | |
| 8 | St | Da | Da | Da | Da | Da | P+ | Sp | | | | |
| 8 | St | Da | Da | Da | Da | Da | P- | Sp | | | | |
| 8 | St | Da | Da | Da | Da | Da | Sp | Sp | | | | |
| 8 | St | Da | Da | Da | Da | Da | Da | Sp | | | | |
| 9 | St | Da | Da | Da | Da | Da | P+ | Sp | Sp | | | |
| 9 | St | Da | Da | Da | Da | Da | P- | Sp | Sp | | | |
| 9 | St | Da | Da | Da | Da | Da | Da | P+ | Sp | | | |
| 9 | St | Da | Da | Da | Da | Da | Da | P- | Sp | | | |
| 9 | St | Da | Da | Da | Da | Da | Da | Sp | Sp | | | |
| 9 | St | Da | Da | Da | DA | Da | Da | Da | Sp | | | |
| l0 | St | Da | Da | Da | Da | Da | Da | P+ | Sp | Sp | | |
| 10 | St | Da | Da | Da | Da | Da | Da | P- | Sp | Sp | | |
| 10 | St | Da | Da | Da | Da | Da | Da | Da | P+ | Sp | | |
| 10 | St | Da | Da | Da | Da | Da | Da | Da | P- | Sp | | |
| 10 | St | Da | Da | Da | Da | Da | Da | Da | Sp | Sp | | |
| 10 | St | Da | Da | Da | Da | Da | Da | Da | Da | Sp | | |
| 11 | St | Da | Da | Da | Da | Da | Da | Da | P+ | Sp | Sp | |
| 11 | St | Da | Da | Da | Da | Da | Da | Da | P- | Sp | Sp | |
| 11 | St | Da | Da | Da | Da | Da | Da | Da | Da | P+ | Sp | |
| 11 | St | Da | Da | Da | Da | Da | Da | Da | Da | P- | Sp | |
| 11 | St | Da | Da | Da | Da | Da | Da | Da | Da | Sp | Sp | |
| 12 | St | Da | Da | Da | Da | Da | Da | Da | Da | P+ | Sp | Sp |
| 12 | St | Da | Da | Da | Da | Da | Da | Da | Da | P- | Sp | Sp |

Bit labeling key: Da = Data St = Start Sp = Stop P+ = Positive parity P- = Negative parity

**TABLE B- IX. 75 bps and 150 bps asynchronous operational parameters.**

| Data rate (bps) | Char length (bits) | Intlv degree | Super blocks | Number of bits encoded | Number of source bits | fill bits | Seq Number length (bits) |
|---|---|---|---|---|---|---|---|
| 75 | 7 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 75 | 7 | 5 | 189 | 11340 | 11340 | 0 | 420 |
| 75 | 7 | 12 | 84 | 12096 | 12096 | 0 | 448 |
| 75 | 7 | 35 | 18 | 7560 | 7560 | 0 | 280 |
| 75 | 8 | 1 | 576 | 6912 | 6912 | 0 | 256 |
| 75 | 8 | 4 | 234 | 11232 | 11232 | 0 | 416 |
| 75 | 8 | 12 | 75 | 10800 | 10800 | 0 | 400 |
| 75 | 8 | 36 | 16 | 6912 | 6912 | 0 | 256 |
| 75 | 9 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 75 | 9 | 4 | 252 | 12096 | 12096 | 0 | 448 |
| 75 | 9 | 12 | 84 | 12096 | 12096 | 0 | 448 |
| 75 | 9 | 36 | 16 | 6912 | 6912 | 0 | 256 |
| 75 | 10 | 1 | 585 | 7020 | 7020 | 0 | 260 |
| 75 | 10 | 4 | 242 | 11616 | 11610 | 6 | 416 |
| 75 | 10 | 12 | 75 | 10800 | 10800 | 0 | 400 |
| 75 | 10 | 35 | 18 | 7560 | 7560 | 0 | 280 |
| 75 | 11 | 1 | 594 | 7128 | 7128 | 0 | 264 |
| 75 | 11 | 4 | 260 | 12480 | 12474 | 6 | 448 |
| 75 | 11 | 11 | 99 | 13068 | 13068 | 0 | 484 |
| 75 | 11 | 33 | 18 | 7128 | 7128 | 0 | 264 |
| 75 | 12 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 75 | 12 | 4 | 261 | 12528 | 12528 | 0 | 464 |
| 75 | 12 | 12 | 84 | 12096 | 12096 | 0 | 448 |
| 75 | 12 | 36 | 16 | 6912 | 6912 | 0 | 256 |
| 150 | 7 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 150 | 7 | 9 | 112 | 12096 | 12096 | 0 | 448 |
| 150 | 7 | 27 | 35 | 11340 | 11340 | 0 | 420 |
| 150 | 7 | 81 | 7 | 6804 | 6804 | 0 | 252 |
| 150 | 8 | 1 | 576 | 6912 | 6912 | 0 | 256 |
| 150 | 8 | 9 | 100 | 10800 | 10800 | 0 | 400 |

| Data rate (bps) | Char length (bits) | Intlv degree | Super blocks | Number of bits encoded | Number of source bits | fill bits | Seq Number length (bits) |
|---|---|---|---|---|---|---|---|
| 150 | 8 | 25 | 36 | 10800 | 10800 | 0 | 400 |
| 150 | 8 | 81 | 8 | 7776 | 7776 | 0 | 288 |
| 150 | 9 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 150 | 9 | 9 | 112 | 12096 | 12096 | 0 | 448 |
| 150 | 9 | 25 | 38 | 11400 | 11394 | 6 | 408 |
| 150 | 9 | 81 | 7 | 6804 | 6804 | 0 | 252 |
| 150 | 10 | 1 | 585 | 7020 | 7020 | 0 | 260 |
| 150 | 10 | 9 | 110 | 11880 | 11880 | 0 | 440 |
| 150 | 10 | 25 | 36 | 10800 | 10800 | 0 | 400 |
| 150 | 10 | 75 | 9 | 8100 | 8100 | 0 | 300 |
| 150 | 11 | 1 | 594 | 7128 | 7128 | 0 | 264 |
| 150 | 11 | 9 | 110 | 11880 | 11880 | 0 | 440 |
| 150 | 11 | 27 | 33 | 10692 | 10692 | 0 | 396 |
| 150 | 11 | 77 | 9 | 8316 | 8316 | 0 | 308 |
| 150 | 12 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 150 | 12 | 9 | 110 | 11880 | 11880 | 0 | 440 |
| 150 | 12 | 27 | 33 | 10692 | 10692 | 0 | 396 |
| 150 | 12 | 81 | 7 | 6804 | 6804 | 0 | 252 |

**TABLE B- X. 300 bps and 600 bps asynchronous operational parameters.**

| Data rate (bps) | Char length (bits) | Intlv degree | Super blocks | Number of bits encoded | Number of source bits | fill bits | Seq Number length (bits) |
|---|---|---|---|---|---|---|---|
| 300 | 7 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 300 | 7 | 15 | 63 | 11340 | 11340 | 0 | 420 |
| 300 | 7 | 49 | 18 | 10584 | 10584 | 0 | 392 |
| 300 | 7 | 145 | 5 | 8700 | 8694 | 6 | 308 |
| 300 | 8 | 1 | 576 | 6912 | 6912 | 0 | 256 |
| 300 | 8 | 17 | 54 | 11016 | 11016 | 0 | 408 |
| 300 | 8 | 47 | 18 | 10152 | 10152 | 0 | 376 |
| 300 | 8 | 153 | 4 | 7344 | 7344 | 0 | 272 |
| 300 | 9 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 300 | 9 | 17 | 54 | ll016 | 11016 | 0 | 408 |
| 300 | 9 | 47 | 18 | 10152 | 10152 | 0 | 376 |
| 300 | 9 | 153 | 4 | 7344 | 7344 | 0 | 272 |
| 300 | 10 | 1 | 585 | 7020 | 7020 | 0 | 260 |
| 300 | 10 | 17 | 49 | 9996 | 9990 | 6 | 356 |
| 300 | 10 | 45 | 22 | 11880 | 11880 | 0 | 440 |
| 300 | 10 | 153 | 5 | 9180 | 9180 | 0 | 340 |
| 300 | 11 | 1 | 594 | 7128 | 7128 | 0 | 264 |
| 300 | 11 | 19 | 43 | 9804 | 9801 | 3 | 356 |
| 300 | 11 | 45 | 22 | 11880 | 11880 | 0 | 440 |
| 300 | 11 | 161 | 4 | 7728 | 7722 | 6 | 272 |
| 300 | 12 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 300 | 12 | 17 | 54 | 11016 | 11016 | 0 | 408 |
| 300 | 12 | 49 | 18 | 10584 | 10584 | 0 | 392 |
| 300 | 12 | 153 | 4 | 7344 | 7344 | 0 | 272 |
| 600 | 7 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 600 | 7 | 35 | 27 | 11340 | 11340 | 0 | 420 |
| 600 | 7 | 105 | 9 | 11340 | 11340 | 0 | 420 |
| 600 | 7 | 315 | 2 | 7560 | 7560 | 0 | 280 |
| 600 | 8 | 1 | 576 | 6912 | 6912 | 0 | 256 |
| 600 | 8 | 33 | 30 | 11880 | 11880 | 0 | 440 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 600 | 8 | 99 | 10 | 11880 | 11880 | 0 | 440 |
| 600 | 8 | 297 | 2 | 7128 | 7128 | 0 | 264 |
| 600 | 9 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 600 | 9 | 33 | 30 | 11880 | 11880 | 0 | 440 |
| 600 | 9 | 99 | 10 | 11880 | 11880 | 0 | 440 |
| 600 | 9 | 297 | 2 | 7128 | 7128 | 0 | 264 |
| 600 | 10 | 1 | 585 | 7020 | 7020 | 0 | 260 |
| 600 | 10 | 33 | 30 | 11880 | 11880 | 0 | 440 |
| 600 | 10 | 99 | 10 | 11880 | 11880 | 0 | 440 |
| 600 | 10 | 315 | 2 | 7560 | 7560 | 0 | 280 |
| 600 | 11 | 1 | 594 | 7128 | 7128 | 0 | 264 |
| 600 | 11 | 33 | 30 | 11880 | 11880 | 0 | 440 |
| 600 | 11 | 99 | 10 | 11880 | 11880 | 0 | 440 |
| 600 | 11 | 297 | 2 | 7128 | 7128 | 0 | 264 |
| 600 | 12 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 600 | 12 | 33 | 30 | 11880 | 11880 | 0 | 440 |
| 600 | 12 | 99 | 10 | 11880 | 11880 | 0 | 440 |
| 600 | 12 | 297 | 2 | 7128 | 7128 | 0 | 264 |

**TABLE B- XI. 1200 bps and 2400 bps asynchronous operational parameters.**

| Data rate (bps) | Char length (bits) | Intlv degree | Super blocks | Number of bits encoded | Number of source bits | fill bits | Seq Number length (bits) |
|---|---|---|---|---|---|---|---|
| 1200 | 7 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 1200 | 7 | 63 | 15 | 11340 | 11340 | 0 | 420 |
| 1200 | 7 | 189 | 6 | 13608 | 13608 | 0 | 504 |
| 1200 | 7 | 567 | 1 | 6804 | 6804 | 0 | 252 |
| 1200 | 8 | 1 | 576 | 6912 | 6912 | 0 | 256 |
| 1200 | 8 | 63 | 14 | 10584 | 10584 | 0 | 392 |
| 1200 | 8 | 189 | 6 | 13608 | 13608 | 0 | 504 |
| 1200 | 8 | 576 | 1 | 6912 | 6912 | 0 | 256 |
| 1200 | 9 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 1200 | 9 | 63 | 15 | 11340 | 11340 | 0 | 420 |
| 1200 | 9 | 189 | 6 | 13608 | 13608 | 0 | 504 |
| 1200 | 9 | 567 | 1 | 6804 | 6804 | 0 | 252 |
| 1200 | 10 | 1 | 585 | 7020 | 7020 | 0 | 260 |
| 1200 | 10 | 63 | 15 | 11340 | 11340 | 0 | 420 |
| 1200 | 10 | 195 | 6 | 14040 | 14040 | 0 | 520 |
| 1200 | 10 | 585 | 1 | 7020 | 7020 | 0 | 260 |
| 1200 | 11 | 1 | 594 | 7128 | 7128 | 0 | 264 |
| 1200 | 11 | 65 | 16 | 12480 | 12474 | 6 | 448 |
| 1200 | 11 | 203 | 5 | 12180 | 12177 | 3 | 444 |
| 1200 | 11 | 619 | 1 | 7428 | 7425 | 3 | 268 |
| 1200 | 12 | 1 | 567 | 6804 | 6804 | 0 | 252 |
| 1200 | 12 | 63 | 15 | 11340 | 11340 | 0 | 420 |
| 1200 | 12 | 189 | 6 | 13608 | 13608 | 0 | 504 |
| 1200 | 12 | 567 | 1 | 6804 | 6804 | 0 | 252 |
| 2400 | 7 | 1 | 145 | 5800 | 5796 | 4 | 252 |
| 2400 | 7 | 36 | 7 | 10080 | 10080 | 0 | 448 |
| 2400 | 7 | 73 | 3 | 8760 | 8757 | 3 | 385 |
| 2400 | 7 | 282 | 1 | 11280 | 11277 | 3 | 497 |
| 2400 | 8 | 1 | 144 | 5760 | 5760 | 0 | 256 |
| 2400 | 8 | 36 | 7 | 10080 | 10080 | 0 | 448 |

| Data rate (bps) | Char length (bits) | Intlv degree | Super blocks | Number of bits encoded | Number of source bits | fill bits | Seq Number length (bits) |
|---|---|---|---|---|---|---|---|
| 2400 | 8 | 72 | 3 | 8640 | 8640 | 0 | 384 |
| 2400 | 8 | 288 | 1 | 11520 | 11520 | 0 | 512 |
| 2400 | 9 | 1 | 144 | 5760 | 5760 | 0 | 256 |
| 2400 | 9 | 36 | 7 | 10080 | 10080 | 0 | 448 |
| 2400 | 9 | 72 | 3 | 8640 | 8640 | 0 | 384 |
| 2400 | 9 | 288 | 1 | 11520 | 11520 | 0 | 512 |
| 2400 | 10 | 1 | 144 | 5760 | 5760 | 0 | 256 |
| 2400 | 10 | 36 | 7 | 10080 | 10080 | 0 | 448 |
| 2400 | 10 | 72 | 3 | 8640 | 8640 | 0 | 384 |
| 2400 | 10 | 288 | 1 | 11520 | 11520 | 0 | 512 |
| 2400 | 11 | 1 | 151 | 6040 | 6039 | 1 | 267 |
| 2400 | 11 | 33 | 9 | 11880 | 11880 | 0 | 528 |
| 2400 | 11 | 71 | 3 | 8520 | 8514 | 6 | 370 |
| 2400 | 11 | 297 | 1 | 11880 | 11880 | 0 | 528 |
| 2400 | 12 | 1 | 144 | 5760 | 5760 | 0 | 256 |
| 2400 | 12 | 36 | 7 | 10080 | 10080 | 0 | 448 |
| 2400 | 12 | 72 | 3 | 8640 | 8640 | 0 | 384 |
| 2400 | 12 | 288 | 1 | 11520 | 11520 | 0 | 512 |

**TABLE B- XII. Probability of bit error vs signal-to-noise ratio.**

| Signal-to-noise ratio (dB in 3-kHz bandwidth) | Probability of bit error | |
|---|---|---|
| | 2400 bps | 1200 bps |
| 5 | - | 6.4 E-2 |
| 11 | 3.5 E-2 | 4.4 E-3 |
| 16 | 1.0 E-2 | 3.4E-4 |
| 21 | 1.0 E-3 | 9.0 E-6 |
| 31 | 1.8 E-4 | 2.7 E-6 |
| | Probability of bit error | |
| | 300 bps | 75 bps |
| 1 | 1.8 E-2 | 4.4 E-4 |
| 3 | 6.4 E-3 | 5.0 E-5 |
| 5 | 1.0 E-3 | 1.0 E-6 |
| 7 | 5.0 E-5 | 1.0 E-6 |
| 9 | 1.5 E-6 | 1.0 E-6 |

NOTE: Two independent equal average power Rayleigh fading paths, with 2 Hz fading bandwidth and 2 ms multipath spread, using a simulator in accordance with Appendix E.

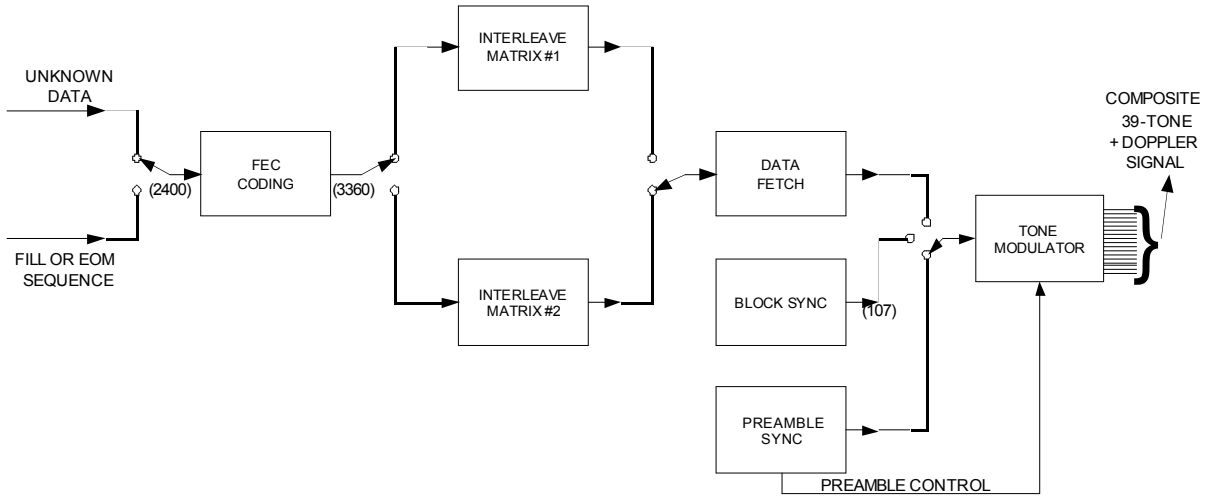


**FIGURE B- 2. Transmit direction functional diagram.**

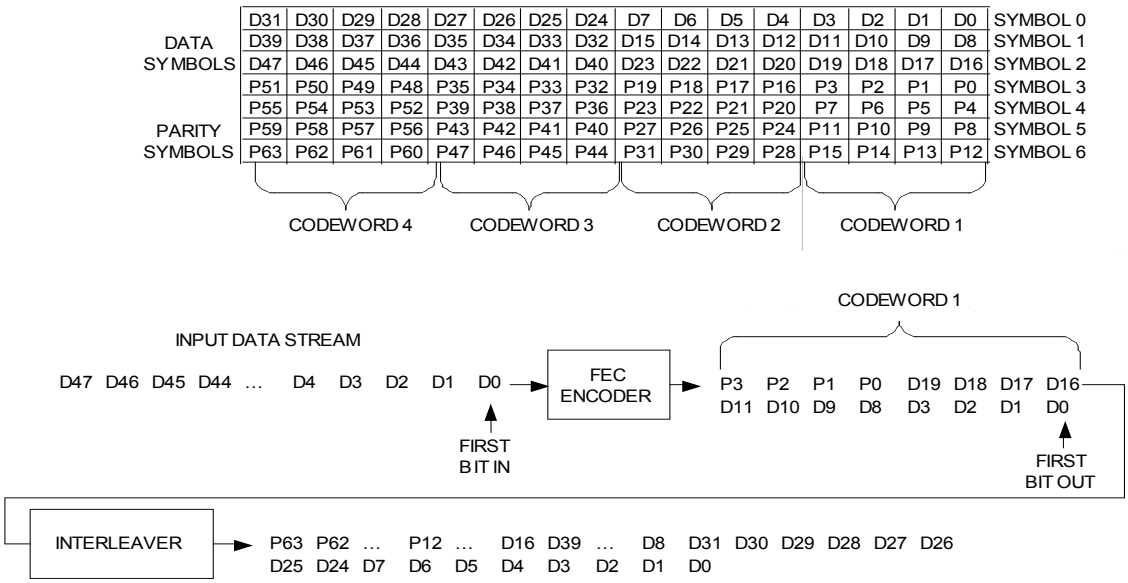


**FIGURE B- 3. Data flow through encoder and interleaver for an interleaver containing an even number of code words.**

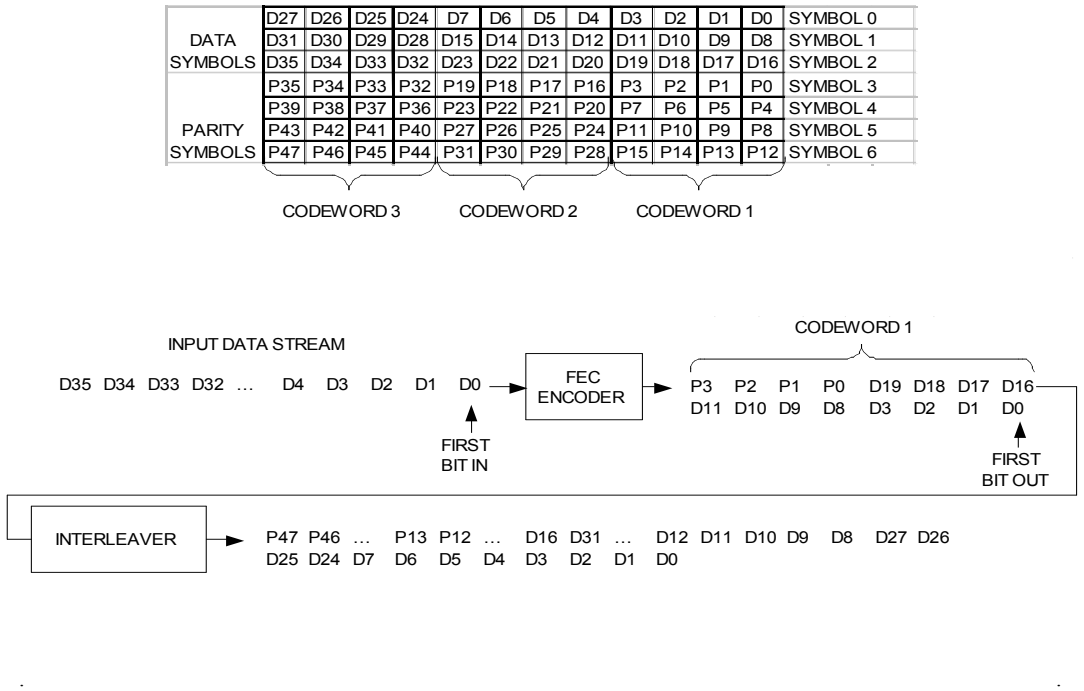


**FIGURE B- 4. Data flow through encoder and interleaver for an interleaver containing an odd number of code words.**

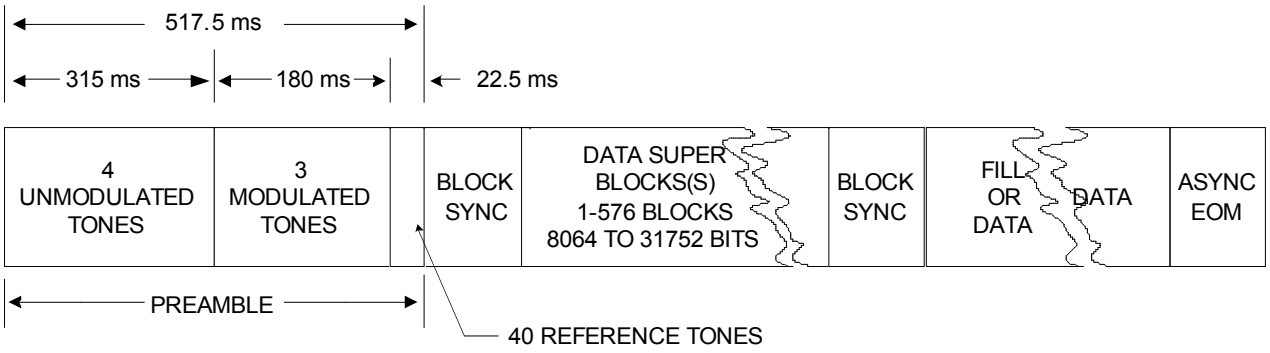


**FIGURE B- 5. Transmit sequence of events.**

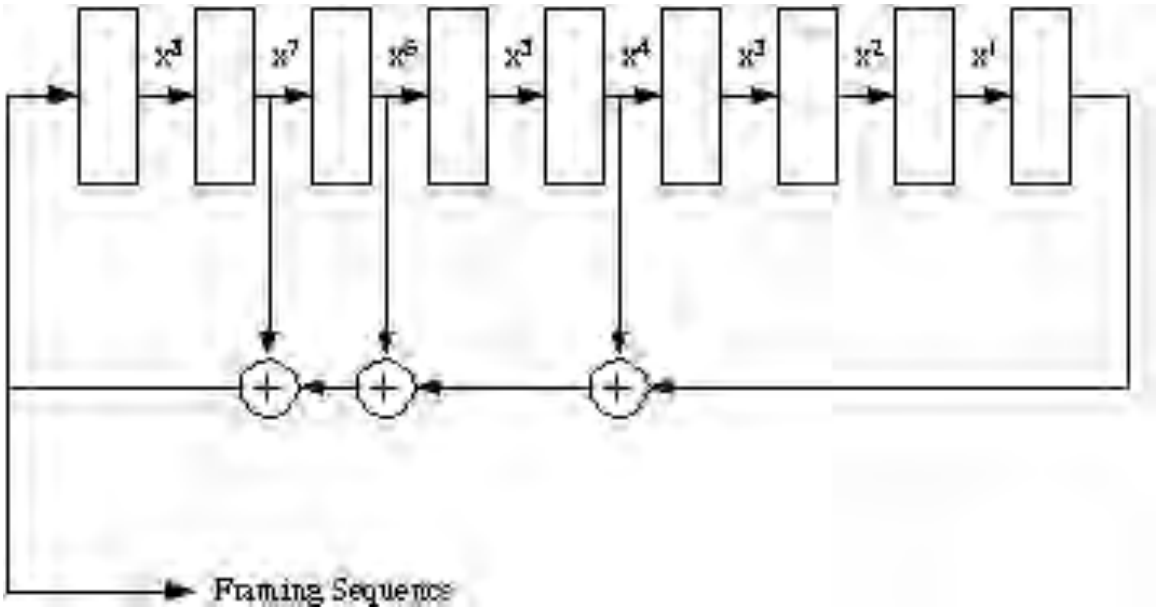


**FIGURE B- 6. Framing sequence feedback shift register generator**

# HF DATA MODEM WAVEFORMS FOR DATA RATES ABOVE 2400 BPS IN 3 KHZ BANDWIDTH

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**LIST OF TABLES**

**LIST OF FIGURES**

## C.1 SCOPE

### C.1.1 Scope.

This appendix describes HF data modem waveforms for data rates above 2400 bps in 3 kHz channels. These may be termed narrowband, medium data rate (MDR) waveforms.

### C.1.2 Applicability.

This appendix is a non-mandatory part of MIL-STD-188-110B; however, when using HF data modem waveforms for data rates above 2400 bps in 3 kHz channels, they shall be implemented in accordance with this appendix.

## C.2 APPLICABLE DOCUMENTS

This section is not applicable to this appendix.

## C.3 DEFINITIONS

See section 3.

## C.4 GENERAL REQUIREMENTS

This appendix presents a modem waveform and coding specification for data rates of 3200, 4800, 6400, 8000 and 9600 bps. Uncoded operation at 12800 bps is a DO. The single-tone waveforms specified in this appendix use modulation techniques of greater complexity and data blocks larger than those found in section 5.3.2 of this standard in order to achieve the efficiencies necessary to obtain the required data rates. A block interleaver is used to obtain 6 interleaving lengths ranging from 0.12 s to 8.64 s. A single coding option, a constraint length 7, rate 1/2 convolutional code, punctured to rate 3/4, is used for all data rates. The full-tail-biting approach is used to produce block codes from this convolutional code that are the same length as the interleaver. Since the minimum interleaver length spans a single data frame, there is no option of zero interleaving, since the time delays would not be reduced.

Both the data rate and interleaver settings are explicitly transmitted as a part of the waveform, both as part of the initial preamble and then periodically as both a reinserted preamble and in the periodic known symbol blocks. This “autobaud” feature is critical in developing an efficient (ARQ) protocol for high frequency (HF) channels. The receive modem is required to be able to deduce the data rate and interleaver setting both from the preamble or from the subsequent data portion of the waveform.

## C.5 DETAILED REQUIREMENTS

### C.5.1 Modulation.

The symbol rate for all symbols shall be 2400 symbols-per-second, which shall be accurate to a minimum of ±0.024 (10 ppm) symbols-per-second when the transmit data clock is generated by the modem and not provided by the data terminal equipment (DTE). Phase-shift keying (PSK) and quadrature amplitude modulation (QAM) modulation techniques shall be used. The sub-carrier (or pair of quadrature sub-carriers in the case of QAM) shall be centered at 1800 Hz accurate to a minimum of 0.018 Hz (10 ppm). The phase of the Quadrature sub-carrier relative to the In-phase carrier shall be 90 degrees. The correct relationship can be achieved by making the In-phase sub-carrier cos(1800 Hz) and the Quadrature sub-carrier -sin(1800 Hz).

The output of the modulator shall have an occupied bandwidth (see section 3) no greater than 3 kHz. This measurement can be performed at RF, IF or audio baseband.

#### C.5.1.1 Known symbols.

For all known symbols, the modulation used shall be PSK, with the symbol mapping shown in Table C-I and figure C-1. No scrambling shall be applied to the known symbols.

**TABLE C- I. 8PSK symbol mapping.**

| Symbol Number | Phase | In-Phase | Quadrature |
|---|---|---|---|
| 0 | 0 | 1.000000 | 0.000000 |
| 1 | $\pi/4$ | 0.707107 | 0.707107 |
| 2 | $\pi/2$ | 0.000000 | 1.000000 |
| 3 | $3\pi/4$ | -0.707107 | 0.707107 |
| 4 | $\pi$ | -1.000000 | 0.000000 |
| 5 | $5\pi/4$ | -0.707107 | -0.707107 |
| 6 | $3\pi/2$ | 0.0000000 | -1.000000 |
| 7 | $7\pi/4$ | 0.707107 | -0.707107 |

Note that the complex symbol values = $\exp[jn\pi/4]$ where n is the symbol number.

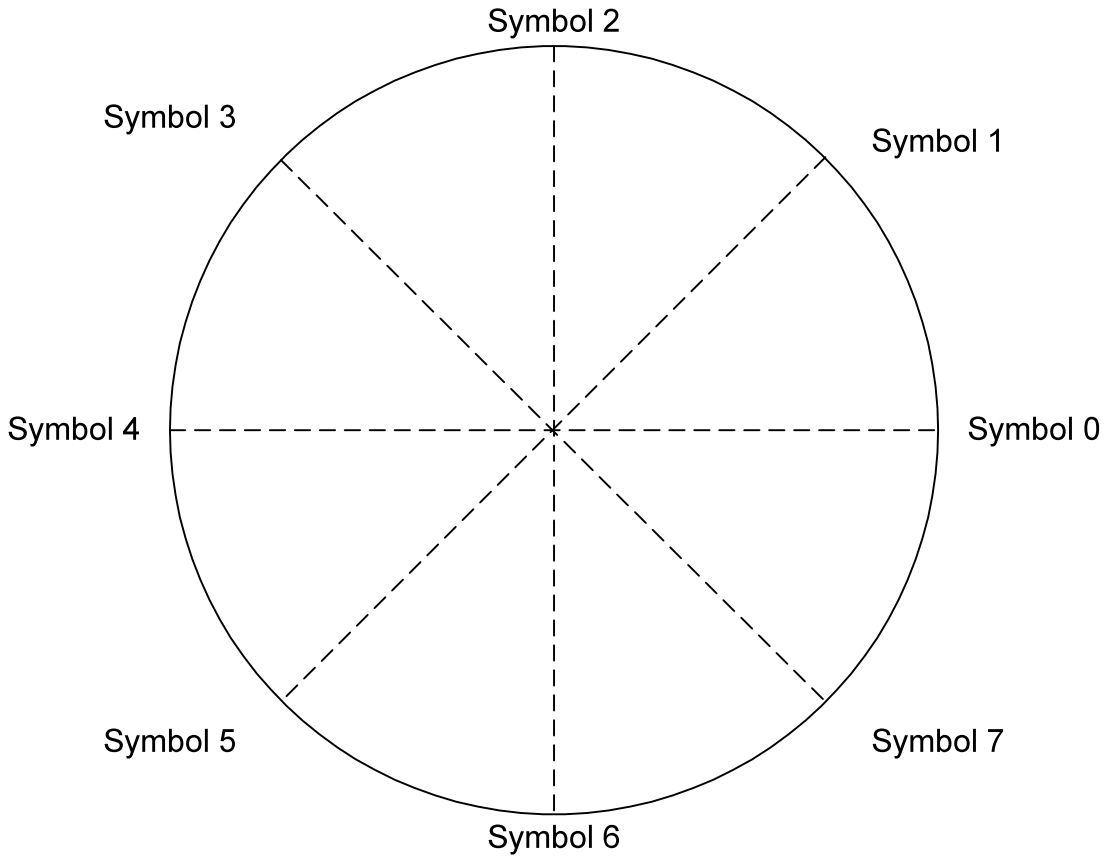


**FIGURE C- 1. 8PSK signal constellation and symbol mapping.**

C.5.1.2 Data symbols.
For data symbols, the modulation used shall depend upon the data rate. Table C-II specifies the modulation that shall be used with each data rate.

**TABLE C- II. Modulation used to obtain each data rate.**

| Data Rate (bps) | Modulation |
|---|---|
| 3200 | QPSK |
| 4800 | 8PSK |
| 6400 | 16QAM |
| 8000 | 32QAM |
| 9600 | 64QAM |
| 12800 | 64QAM |

The 3200 bps quadrature phase-shift keying (QPSK) constellation is scrambled to appear, on-air, as an 8PSK constellation. Both the 16QAM and 32QAM constellations use multiple PSK rings to maintain good peak-to-average ratios, and the 64QAM constellation is a variation of the standard square QAM constellation, which has been modified to improve the peak-to-average ratio.

C.5.1.2.1 PSK data symbols.
For the PSK constellations, a distinction is made between the data bits and the symbol number for the purposes of scrambling the QPSK modulation to appear as 8PSK, on-air. Scrambling is applied as a modulo 8 addition of a scrambling sequence to the 8PSK symbol number. Transcoding is an operation which links a symbol to be transmitted to a group of data bits.

C.5.1.2.1.1 QPSK symbol mapping.
For the 3200 bps user data rate, transcoding shall be achieved by linking one of the symbols specified in Table C-I to a set of two consecutive data bits (dibit) as shown in Table C-III. In this Table, the leftmost bit of the dibit shall be the older bit; i.e., fetched from the interleaver before the rightmost bit.

**TABLE C- III. Transcoding for 3200 bps.**

| Dibit | Symbol |
|---|---|
| 00 | 0 |
| 01 | 2 |
| 11 | 4 |
| 10 | 6 |

C.5.1.2.1.2 8PSK symbol mapping.
For the 4800 bps user data rate, transcoding shall be achieved by linking one symbol to a set of three consecutive data bits (tribit) as shown in Table C-IV. In this Table, the leftmost bit of the tribit shall be the oldest bit; i.e., fetched from the interleaver before the other two, and the rightmost bit is the most recent bit.

**TABLE C- IV. Transcoding for 4800 bps.**

| Tribit | Symbol |
|---|---|
| 000 | 1 |
| 001 | 0 |
| 010 | 2 |
| 011 | 3 |
| 100 | 6 |
| 101 | 7 |
| 110 | 5 |
| 111 | 4 |

C.5.1.2.2 QAM data symbols.
For the QAM constellations, no distinction is made between the number formed directly from the data bits and the symbol number. Each set of 4 bits (16QAM), 5 bits (32QAM) or 6 bits (64QAM) is mapped directly to a QAM symbol. For example, the four bit grouping 0111 would map to symbol 7 in the 16QAM constellation while the 6 bits 100011 would map to symbol 35 in the 64QAM constellation. Again, in each case the leftmost bit shall be the oldest bit, i.e. fetched from the interleaver before the other bits, and the rightmost bit is the most recent bit. The

mapping of bits to symbols for the QAM constellations has been selected to minimize the number of bit errors incurred when errors involve adjacent signaling points in the constellation.

C.5.1.2.2.1 The 16 QAM constellation.
The constellation points which shall be used for 16QAM are shown in figure C-2 and specified in terms of their In-phase and Quadrature components in Table C-V. As can be seen in the figure, the 16 QAM constellation is comprised of two PSK rings: 4 PSK inner and 12 PSK outer

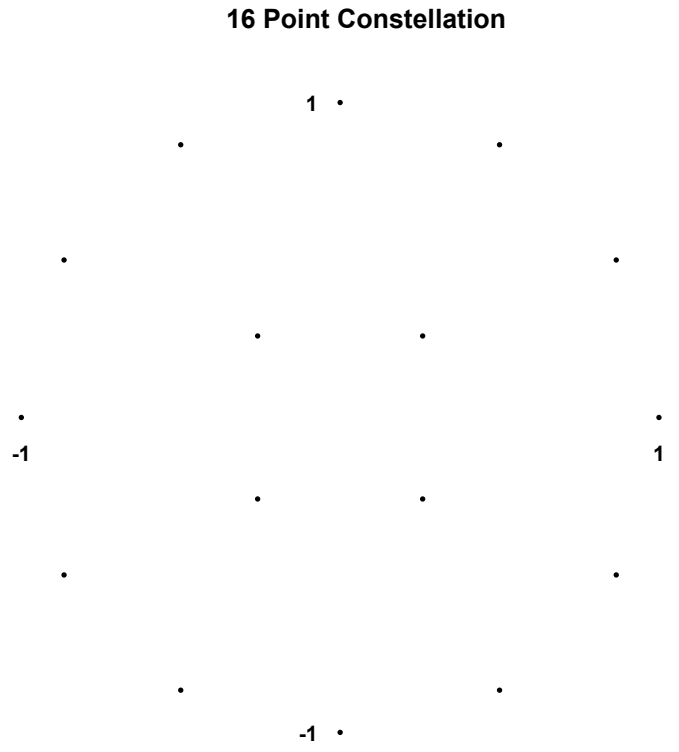


**FIGURE C- 2. 16QAM Signaling Constellation.**

**TABLE C- V. In-phase and Quadrature components of each 16QAM symbol.**

| Symbol Number | In-Phase | Quadrature |
|---|---|---|
| 0 | 0.866025 | 0.500000 |
| 1 | 0.500000 | 0.866025 |
| 2 | 1.000000 | 0.000000 |
| 3 | 0.258819 | 0.258819 |
| 4 | -0.500000 | 0.866025 |
| 5 | 0.000000 | 1.000000 |
| 6 | -0.866025 | 0.500000 |
| 7 | -0.258819 | 0.258819 |
| 8 | 0.500000 | -0.866025 |
| 9 | 0.000000 | -1.000000 |
| 10 | 0.866025 | -0.500000 |
| 11 | 0.258819 | -0.258819 |
| 12 | -0.866025 | -0.500000 |
| 13 | -0.500000 | -0.866025 |
| 14 | -1.000000 | 0.000000 |
| 15 | -0.258819 | -0.258819 |

C.5.1.2.2.2 The 32 QAM constellation.
The constellation points which shall be used for 32QAM are shown in figure C-3 and specified in terms of their In-phase and Quadrature components in Table C-VI. This constellation contains an outer ring of 16 symbols and an inner square of 16 symbols.

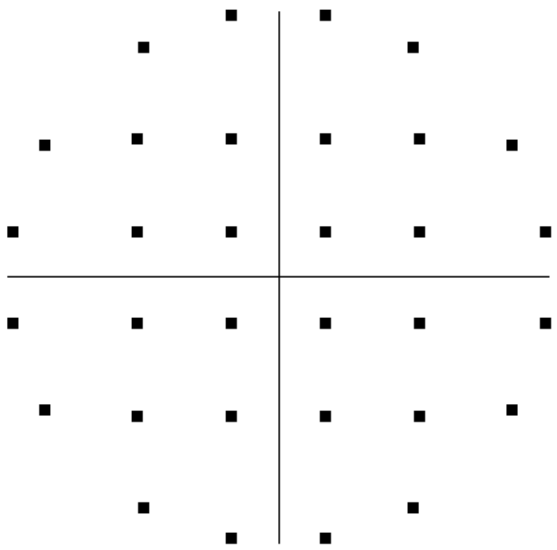

**FIGURE C- 3. 32QAM signaling constellation.**

**TABLE C- VI. In-phase and Quadrature components of each 32QAM symbol.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 0.866380 | 0.499386 | 16 | 0.866380 | -0.499386 |
| 1 | 0.984849 | 0.173415 | 17 | 0.984849 | -0.173415 |
| 2 | 0.499386 | 0.866380 | 18 | 0.499386 | -0.866380 |
| 3 | 0.173415 | 0.984849 | 19 | 0.173415 | -0.984849 |
| 4 | 0.520246 | 0.520246 | 20 | 0.520246 | -0.520246 |
| 5 | 0.520246 | 0.173415 | 21 | 0.520246 | -0.173415 |
| 6 | 0.173415 | 0.520246 | 22 | 0.173415 | -0.520246 |
| 7 | 0.173415 | 0.173415 | 23 | 0.173415 | -0.173415 |
| 8 | -0.866380 | 0.499386 | 24 | -0.866380 | -0.499386 |
| 9 | -0.984849 | 0.173415 | 25 | -0.984849 | -0.173415 |
| 10 | -0.499386 | 0.866380 | 26 | -0.499386 | -0.866380 |
| 11 | -0.173415 | 0.984849 | 27 | -0.173415 | -0.984849 |
| 12 | -0.520246 | 0.520246 | 28 | -0.520246 | -0.520246 |
| 13 | -0.520246 | 0.173415 | 29 | -0.520246 | -0.173415 |
| 14 | -0.173415 | 0.520246 | 30 | -0.173415 | -0.520246 |
| 15 | -0.173415 | 0.173415 | 31 | -0.173415 | -0.173415 |

C.5.1.2.2.3 The 64QAM constellation.
The constellation points which shall be used for the 64QAM modulation are shown in figure C-4 and specified in terms of their In-phase and Quadrature components in Table C-VII. This constellation is a variation on the standard 8 x 8 square constellation, which achieves better peak-to-average without sacrificing the very good pseudo-Gray code properties of the square constellation.

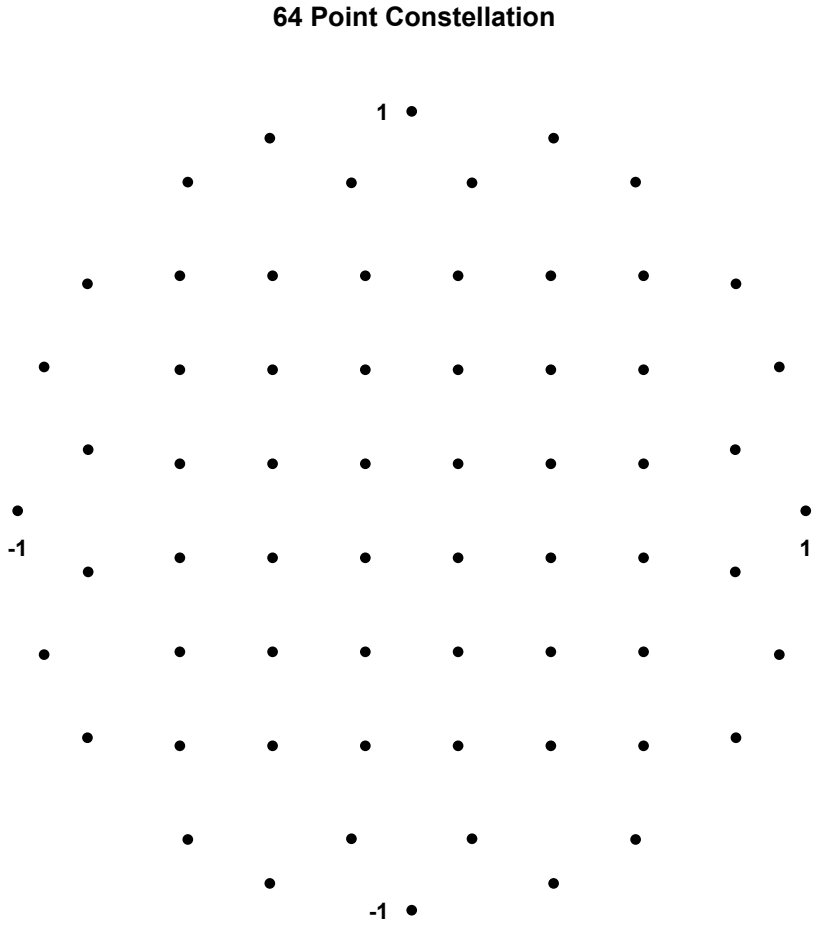


**FIGURE C- 4. 64QAM signaling constellation.**

**TABLE C- VII. In-phase and Quadrature components of each 64QAM symbol.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.000000 | 0.000000 | 32 | 0.000000 | 1.000000 |
| 1 | 0.822878 | 0.568218 | 33 | -0.822878 | 0.568218 |
| 2 | 0.821137 | 0.152996 | 34 | -0.821137 | 0.152996 |
| 3 | 0.932897 | 0.360142 | 35 | -0.932897 | 0.360142 |
| 4 | 0.000000 | -1.000000 | 36 | -1.000000 | 0.000000 |
| 5 | 0.822878 | -0.568218 | 37 | -0.822878 | -0.568218 |
| 6 | 0.821137 | -0.152996 | 38 | -0.821137 | -0.152996 |
| 7 | 0.932897 | -0.360142 | 39 | -0.932897 | -0.360142 |
| 8 | 0.568218 | 0.822878 | 40 | -0.568218 | 0.822878 |
| 9 | 0.588429 | 0.588429 | 41 | -0.588429 | 0.588429 |
| 10 | 0.588429 | 0.117686 | 42 | -0.588429 | 0.117686 |
| 11 | 0.588429 | 0.353057 | 43 | -0.588429 | 0.353057 |
| 12 | 0.568218 | -0.822878 | 44 | -0.568218 | -0.822878 |
| 13 | 0.588429 | -0.588429 | 45 | -0.588429 | -0.588429 |
| 14 | 0.588429 | -0.117686 | 46 | -0.588429 | -0.117686 |
| 15 | 0.588429 | -0.353057 | 47 | -0.588429 | -0.353057 |
| 16 | 0.152996 | 0.821137 | 48 | -0.152996 | 0.821137 |
| 17 | 0.117686 | 0.588429 | 49 | -0.117686 | 0.588429 |
| 18 | 0.117686 | 0.117686 | 50 | -0.117686 | 0.117686 |
| 19 | 0.117686 | 0.353057 | 51 | -0.117686 | 0.353057 |
| 20 | 0.152996 | -0.821137 | 52 | -0.152996 | -0.821137 |
| 21 | 0.117686 | -0.588429 | 53 | -0.117686 | -0.588429 |
| 22 | 0.117686 | -0.117686 | 54 | -0.117686 | -0.117686 |
| 23 | 0.117686 | -0.353057 | 55 | -0.117686 | -0.353057 |
| 24 | 0.360142 | 0.932897 | 56 | -0.360142 | 0.932897 |
| 25 | 0.353057 | 0.588429 | 57 | -0.353057 | 0.588429 |
| 26 | 0.353057 | 0.117686 | 58 | -0.353057 | 0.117686 |
| 27 | 0.353057 | 0.353057 | 59 | -0.353057 | 0.353057 |
| 28 | 0.360142 | -0.932897 | 60 | -0.360142 | -0.932897 |
| 29 | 0.353057 | -0.588429 | 61 | -0.353057 | -0.588429 |
| 30 | 0.353057 | -0.117686 | 62 | -0.353057 | -0.117686 |
| 31 | 0.353057 | -0.353057 | 63 | -0.353057 | -0.353057 |

C.5.1.3 Data scrambling.

Data symbols for the 8PSK symbol constellation (3200 bps, 4800 bps) shall be scrambled by modulo 8 addition with a scrambling sequence. The data symbols for the 16QAM, 32QAM, and 64QAM constellations shall be scrambled by using an exclusive or (XOR) operation. Sequentially, the data bits forming each symbol (4 for 16QAM, 5 for 32QAM, and 6 for 64QAM) shall be XOR'd with an equal number of bits from the scrambling sequence. In all cases, the scrambling sequence generator polynomial shall be $x^9+x^4+1$ and the generator shall be

initialized to 1 at the start of each data frame. A block diagram of the scrambling sequence generator is shown in figure C-5.

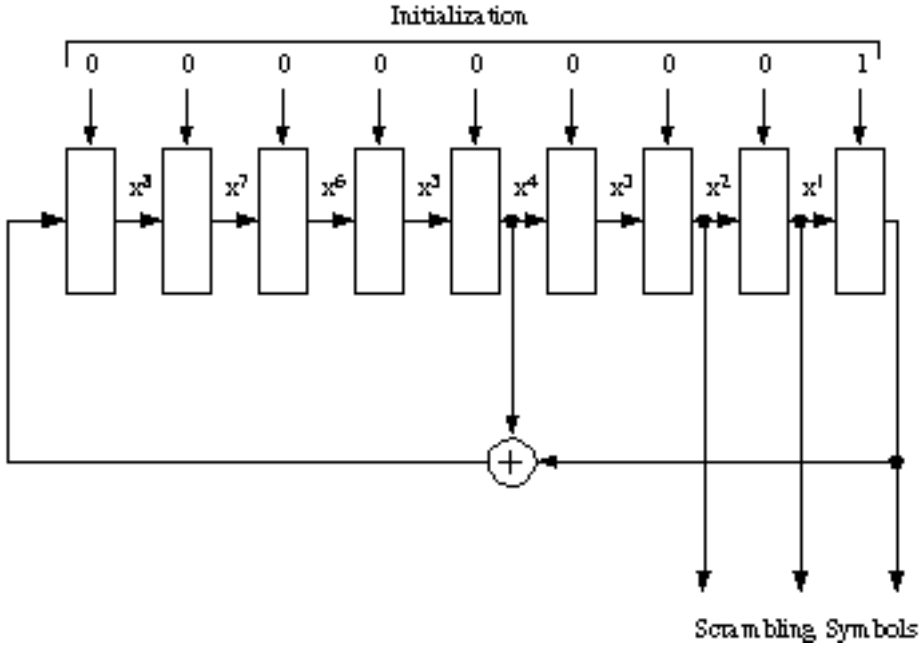


**FIGURE C- 5. Scrambling sequence generator illustrating scrambling generator for 8PSK symbols.**

For 8PSK symbols (3200 bps and 4800 bps), the scrambling shall be carried out taking the modulo 8 sum of the numerical value of the binary triplet consisting of the last (rightmost) three bits in the shift register, and the symbol number (transcoded value). For example, if the last three bits in the scrambling sequence shift register were 010 which has a numerical value equal 2, and the symbol number before scrambling was 6, symbol 0 would be transmitted since: (6+2) Modulo 8 = 0. For 16QAM symbols, scrambling shall be carried out by XORing the 4 bit number consisting of the last (rightmost) four bits in the shift register with the symbol number. For example, if the last 4 bits in the scrambling sequence shift register were 0101 and the 16QAM symbol number before scrambling was 3 (i.e. 0011), symbol 6 (0110) would be transmitted. For 32QAM symbols, scrambling shall be carried out by XORing the 5 bit number formed by the last (rightmost) five bits in the shift register with the symbol number. For 64QAM symbols, scrambling shall be carried out by XORing the 6 bit number formed by the last (rightmost) six bits in the shift register with the symbol number.

After each data symbol is scrambled, the generator shall be iterated (shifted) the required number of times to produce all new bits for use in scrambling the next symbol (i.e., 3 iterations for 8PSK, 4 iterations for 16QAM, 5 iterations for 32QAM and 6 iterations for 64QAM). Since the generator is iterated after the bits are use, the first data symbol of every data frame shall, therefore, be scrambled by the appropriate number of bits from the initialization value of 00000001.

The length of the scrambling sequence is 511 bits. For a 256 symbol data block with 6 bits per symbol, this means that the scrambling sequence will be repeated just slightly more than 3 times, although in terms of symbols, there will be no repetition.

C.5.1.4 Modulation filter.

The role of the modulation filter is to spectrally constrain the transmit waveform to within the specified bandwidth. A square root of raised cosine filter is recommended with a roll off factor (excess bandwidth) of 35%. Utilizing this filter as both the modem modulation filter and demodulation filter will maximize the signal to noise ratio and minimize inter-symbol interference. The combined modulation and demodulation filters will have the following frequency response:

$H(f) = 1 \quad \text{for } f <= f_n - pf_n$

$H(f) = 0.5( 1 - \sin(f-f_n * PI / 2pf_n) \quad \text{for } f_n-pf_n <= f <= f_n+pf_n$

$H(f) = 0 \quad \text{elsewhere}$

Where:

$f_n$ is the Nyquist frequency ( $f_n = 1 / (2T) = 1200$ Hz)

p is the roll off factor or excess bandwidth.

The individual modulation and demodulation filters are realized by taking the square root of the above frequency response.

C.5.2 Frame structure.

The frame structure that shall be used for the waveforms specified in this appendix is shown in figure C-6. An initial 287 symbol preamble is followed by 72 frames of alternating data and known symbols. Each data frame shall consist of a data block consisting of 256 data symbols, followed by a mini-probe consisting of 31 symbols of known data. After 72 data frames, a 72 symbol subset of the initial preamble is reinserted to facilitate late acquisition, Doppler shift removal, and sync adjustment. It should be noted that the total length of known data in this segment is actually 103 symbols: the 72 reinserted preamble symbols plus the preceding 31 symbol mini-probe segment which follows the last 256 symbol data block.

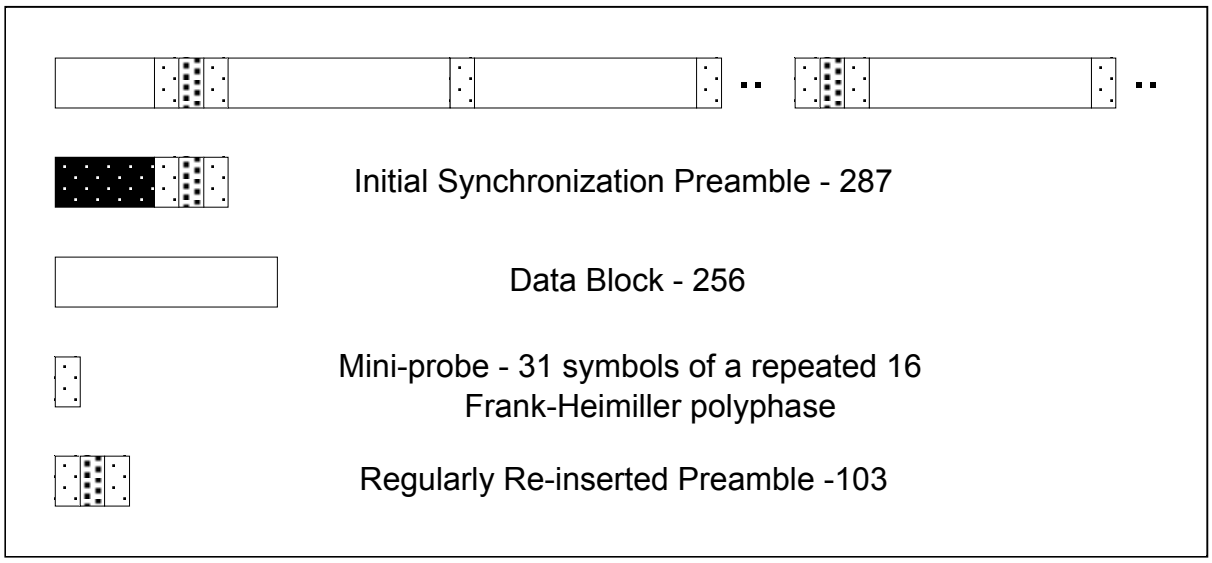


**FIGURE C- 6. Frame structure for all waveforms.**

C.5.2.1 Synchronization and reinserted preambles.
The synchronization preamble is used for rapid initial synchronization. The reinserted preamble is used to facilitate acquisition of an ongoing transmission (acquisition on data).

C.5.2.1.1 Synchronization preamble.
The synchronization preamble shall consist of two parts. The first part shall consist of at least N blocks of 184 8-PSK symbols to be used exclusively for radio and modem AGC. The value of N shall be configurable to range from values of 0 to 7 (for N=0 this first section is not sent at all). These 184 symbols shall be formed by taking the complex conjugate of the first 184 symbols of the sequence specified below for the second section.
The second section shall consist of 287 symbols. The first 184 symbols are intended exclusively for synchronization and Doppler offset removal purposes while the final 103 symbols, which are common with the reinserted preamble, also carry information regarding the data rate and interleaver settings.

Expressed as a sequence of 8PSK symbols, using the symbol numbers given in Table C-I the synchronization preamble shall be as shown in Table C-VIII:

**TABLE C- VIII. Synchronization preamble.**

1, 5, 1, 3, 6, 1, 3, 1, 1, 6, 3, 7, 7, 3, 5, 4, 3, 6, 6, 4, 5, 4, 0,
2, 2, 2, 6, 0, 7, 5, 7, 4, 0, 7, 5, 7, 1, 6, 1, 0, 5, 2, 2, 6, 2, 3,
6, 0, 0, 5, 1, 4, 2, 2, 2, 3, 4, 0, 6, 2, 7, 4, 3, 3, 7, 2, 0, 2, 6,
4, 4, 1, 7, 6, 2, 0, 6, 2, 3, 6, 7, 4, 3, 6, 1, 3, 7, 4, 6, 5, 7, 2,
0, 1, 1, 1, 4, 4, 0, 0, 5, 7, 7, 4, 7, 3, 5, 4, 1, 6, 5, 6, 6, 4, 6,
3, 4, 3, 0, 7, 1, 3, 4, 7, 0, 1, 4, 3, 3, 3, 5, 1, 1, 1, 4, 6, 1, 0,
6, 0, 1, 3, 1, 4, 1, 7, 7, 6, 3, 0, 0, 7, 2, 7, 2, 0, 2, 6, 1, 1, 1,
2, 7, 7, 5, 3, 3, 6, 0, 5, 3, 3, 1, 0, 7, 1, 1, 0, 3, 0, 4, 0, 7, 3,

0, 0, 0, 0, 0, 2, 4, 6, 0, 4, 0, 4, 0, 6, 4, 2, 0, 0, 0, 0, 0, 2, 4, 6, 0, 4, 0, 4, 0, 6, 4,
2,

( $D_0$, $D_0$, $D_0$, $D_0$, $D_0$, $D_0$, $D_0$, $D_0$, $D_0$, $D_0$, $D_0$, $D_0$, $D_0$ + 0, 4, 0, 4, 0, 0, 4, 4, 0, 0, 0, 0, 0) Modulo 8
( $D_1$, $D_1$, $D_1$, $D_1$, $D_1$, $D_1$, $D_1$, $D_1$, $D_1$, $D_1$, $D_1$, $D_1$, $D_1$ + 0, 4, 0, 4, 0, 0, 4, 4, 0, 0, 0, 0, 0) Modulo 8
( $D_2$, $D_2$, $D_2$, $D_2$, $D_2$, $D_2$, $D_2$, $D_2$, $D_2$, $D_2$, $D_2$, $D_2$, $D_2$ + 0, 4, 0, 4, 0, 0, 4, 4, 0, 0, 0, 0, 0) Modulo 8

6,
4, 4, 4, 4, 4, 6, 0, 2, 4, 0, 4, 0, 4, 2, 0, 6, 4, 4, 4, 4, 4, 6, 0, 2, 4, 0, 4, 0, 4, 2, 0

where the data symbols $D_0$, $D_1$, and $D_2$ take one of 30 sets of values chosen from Table C-IX to indicate the data rate and interleaver settings. The Modulo operations are meant to signify that each of the D values are used to shift the phase of a length 13 bit Barker code (0101001100000) by performing modulo 8 addition of the D value with each of the Barker code 13 phase values (0 or 4). This operation can encode 6 bits of information using QPSK modulation of the 13 bit (chip) Barker codes. Since the three Barker code sequences only occupy 39 symbols, the 31 symbol mini-probes are lengthened to 32 symbols each to provide the additional 2 symbols required to pad the three 13 symbol Barker codes up to a total of 41 symbols.

**TABLE C- IX. D0, D1, D2 8 PSK symbol values as a function of data rate and interleaver length.**

| | Interleaver Length in Frames (256 Symbol Data Blocks) | | | | | |
|---|---|---|---|---|---|---|
| Data Rate (bps) | 1 | 3 | 9 | 18 | 36 | 72 |
| 3200 | 0,0,4 | 0,2,6 | 0,2,4 | 2,0,6 | 2,0,4 | 2,2,6 |
| 4800 | 0,6,2 | 0,4,0 | 0,4,2 | 2,6,0 | 2,6,2 | 2,4,0 |
| 6400 | 0,6,4 | 0,4,6 | 0,4,4 | 2,6,6 | 2,6,4 | 2,4,6 |
| 8000 | 6,0,2 | 6,2,0 | 6,2,2 | 4,0,0 | 4,0,2 | 4,2,0 |
| 9600 | 6,0,4 | 6,2,6 | 6,2,4 | 4,0,6 | 4,0,4 | 4,2,6 |
| 12800 | 6,6,2* | reserved | reserved | reserved | reserved | reserved |

* For 12800 bps 1 frame interleaver shall be interpreted as no interleaving

The mapping chosen to create Table C-IX uses 3 bits each to specify the data rate and interleaver length. The 3 data rate bits are the 3 most significant bits (MSB) of 3 dibit symbols and the interleaver length bits are the least significant bits (LSB). The phase of the Barker code is determined from the 3 resulting dibit words using TABLE C- III, the dibit transcoding Table. The 3 bit data rate and interleaver length mappings are shown in Table C-X. Note that the transcoding has the effect of placing the 3 interleaver length bits in quadrature with the 3 data rate bits.

**TABLE C- X. Bit patterns for specifying data rate and interleaver length.**

| Data Rate | 3 Bit Mapping |
|---|---|
| reserved | 000 |
| 3200 | 001 |
| 4800 | 010 |
| 6400 | 011 |
| 8000 | 100 |
| 9600 | 101 |
| 12800 | 110 |
| reserved | 111 |

| Interleaver Length | 3 Bit Mapping | Name |
|---|---|---|
| illegal: see C.5.2.1.2 | 000 | |
| 1 Frame | 001 | Ultra Short (US) |
| 3 Frames | 010 | Very Short (VS) |
| 9 Frames | 011 | Short (S) |
| 18 Frames | 100 | Medium (M) |
| 36 Frames | 101 | Long (L) |
| 72 Frames | 110 | Very Long (VL) |
| illegal: see C.5.2.1.2 | 111 | |

Because the Barker code is unbalanced in terms of the number of 0s and 1s, the 000 or 111 patterns exhibit a net imbalance in each quadrature component of the 39 symbols that is 12 to 27. These two patterns are reserved for future standardization of higher data rate modes that employ constellations more dense than those specified in C.5.1. The other 3-bit patterns are more balanced (17 to 22) and are used for the more robust constellations.

C.5.2.1.2 Reinserted preamble.
The reinserted preamble shall be identical to the final 72 symbols of the synchronization preamble. In fact, the final 103 symbols are common between the synchronization preamble and

the contiguous block consisting of the reinserted preamble and the mini-probe which immediately precedes it. The 103 symbols of known data (including the 31 mini-probe symbols of the preceding data frame) are thus:

**TABLE C- XI. Reinserted preamble.**

0, 0, 0, 0, 0, 2, 4, 6, 0, 4, 0, 4, 0, 6, 4, 2, 0, 0, 0, 0, 0, 2, 4, 6, 0, 4, 0, 4, 0, 6, 4,
2,

( $D_0, D_0, D_0, D_0, D_0, D_0, D_0, D_0, D_0, D_0, D_0, D_0$ + 0, 4, 0, 4, 0, 0, 4, 4, 0, 0, 0, 0, 0) Modulo 8
( $D_1, D_1, D_1, D_1, D_1, D_1, D_1, D_1, D_1, D_1, D_1, D_1$ + 0, 4, 0, 4, 0, 0, 4, 4, 0, 0, 0, 0, 0) Modulo 8
( $D_2, D_2, D_2, D_2, D_2, D_2, D_2, D_2, D_2, D_2, D_2, D_2$ + 0, 4, 0, 4, 0, 0, 4, 4, 0, 0, 0, 0, 0) Modulo 8

6,
4, 4, 4, 4, 4, 6, 0, 2, 4, 0, 4, 0, 4, 2, 0, 6, 4, 4, 4, 4, 4, 6, 0, 2, 4, 0, 4, 0, 4, 2, 0;

where the data symbols $D_0$, $D_1$, and $D_2$ again take one of 30 sets of values chosen from Table C-IX to indicate the data rate and interleaver settings as described in the Synchronization Preamble section above. The first 31 of these symbols are the immediately preceding mini-probe, which follows the last of the 72 data blocks.

Note that the 3 Bit Mappings for Interleaver Length of 000 or 111 may result in an $S_0$ to $S_8$ pattern that could be confused with the fixed (- - - - - - - +) mini probe pattern. For this reason, these mappings are referred to as “illegal” in Table C-X.

C.5.2.2 Mini-probes.
Mini-probes 31 symbols in length shall be inserted following every 256 symbol data block and at the end of each preamble (where they are considered to be part of the preamble). Using the 8PSK symbol mapping, each mini-probe shall be based on the repeated Frank-Heimiller sequence. The sequence that shall be used, specified in terms of the 8PSK symbol numbers, is given by:

0, 0, 0, 0, 0, 2, 4, 6, 0, 4, 0, 4, 0, 6, 4, 2, 0, 0, 0, 0, 0, 2, 4, 6, 0, 4, 0, 4, 0, 6, 4.

This mini-probe will be designated **‘+’**.

The phase inverted version of this is:

4, 4, 4, 4, 4, 6, 0, 2, 4, 0, 4, 0, 4, 2, 0, 6, 4, 4, 4, 4, 4, 6, 0, 2, 4, 0, 4, 0, 4, 2, 0

and mini-probes using this sequence will be designated ‘-’, as the phase of each symbol has been rotated 180 degrees from the **‘+’**.

There are a total of 73 mini-probes for each set of 72 data blocks. For convenience, each mini-probe will be sequentially numbered, with mini-probe 0 being defined as the last 31 symbols of

the preceding (reinserted) preamble, mini-probe number 1 following the first data block after a (reinserted) preamble. Mini-probe 72 follows the 72nd data block, and is also the first 31 symbols of the next 103 symbol reinserted preamble. Mini-probes 0 and 72 have been defined as part of the reinsertion preamble to have the signs - and + respectively. The data rate and interleaver length information encoded into the synchronization and reinserted preambles shall also be encoded into mini-probes 1 through 72. These 72 mini-probes are grouped into four sets of 18 consecutive mini-probes (1 to 18, 19 to 36, 37 to 54, and 55 to 72). Note that the 256 symbol data block that immediately follows the $18^{th}$ mini-probe, in each of the first three sets, is also the $1^{st}$ data block of an interleaver block with frame lengths of 1, 3, 9, and 18. The length 36 interleaver block begins after the second set, and a reinserted preamble begins after the fourth set. This structure permits data to begin to be demodulated as soon as the interleaver boundary becomes known.

Each 18 mini-probe sequence shall consists of seven – signs, a + sign, followed by six sign values that are dependent on the data rate and interleaver length, three sign values that specify which of the four sets of 18 mini-probes it is, and then finally a + sign. For the fourth set, this final + sign (mini-probe 72) is also the initial mini-probe of the next reinserted preamble (which uses the + phase).

Pictorially, this length 18 sequence is: $- - - - - - - + S_0 S_1 S_2 S_3 S_4 S_5 S_6 S_7 S_8 +$, where the first six $S_i$ sign values are defined in Table C-XII. Note that these 6 bit patterns ( + is a 0 ) correspond to the concatenation of the 3 bit mappings from Table C-X for the data rate ($S_0$ $S_1$ $S_2$) and the interleaver length ($S_3$ $S_4$ $S_5$). The final three $S_i$ sign values which specify the mini-probe set (count) are defined in Table C-XIII.

**TABLE C- XII. S0, S1, S2, S3, S4, S5 (sign) values as a function of data rate and interleaver setting.**

| Data Rate (bps) | Interleaver Length in Frames (256 Symbol Data Blocks) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 3 | 9 | 18 | 36 | 72 |
| 3200 | ++-++- | ++-+-+ | ++-+-- | ++--++ | ++--+- | ++---+ |
| 4800 | +-+++- | +-++-+ | +-++-- | +-+-++ | +-+-+- | +-+--+ |
| 6400 | +--++- | +--+-+ | +--+-- | +---++ | +---+- | +----+ |
| 8000 | -++++- | -+++-+ | -+++-- | -++-++ | -++-+- | -++--+ |
| 9600 | -+-++- | -+-+-+ | -+-+-- | -+--++ | -+--+- | -+---+ |
| 12800 | --+++- | N/A | N/A | N/A | N/A | N/A |

**TABLE C- XIII. S6, S7, S8 (sign) values as a function of mini-probe set.**

| Mini-probe set | | | |
|---|---|---|---|
| 1 to 18 | 19 to 36 | 37 to 54 | 55 to 72 |
| ++- | +-+ | +-- | -++ |

The 1st eight mini-probes in each set (- - - - - - - - +) uniquely locate the starting point for the following nine $S_i$ values. This is possible since the $S_i$ sequences used contain at most runs of four + or - phases. This makes it impossible for a sequence of 7 mini-probes with the same phase followed by one with a phase reversal to occur anywhere else except at the beginning of one of the 18 mini-probe sequences. Once this fixed 8 mini-probe pattern is located, the 0 or 180 degree phase ambiguity is also resolved so that the following 9 mini-probes can be properly matched to the data rate, interleaver length, and mini-probe set count. The entire mini-probe sequence shall therefore be as follows:

[rp] - - - - - - - + $S_0 S_1 S_2 S_3 S_4 S_5 S_6 S_7 S_8$ + - - - - - - - + $S_0 S_1 S_2 S_3 S_4 S_5 S_6 S_7 S_8$ +
- - - - - - - + $S_0 S_1 S_2 S_3 S_4 S_5 S_6 S_7 S_8$ + - - - - - - - + $S_0 S_1 S_2 S_3 S_4 S_5 S_6 S_7 S_8$ [rp]

where the [rp] represents the 103 reinserted preamble symbols (includes mini-probes 72 and 0).

C.5.3 Coding and interleaving.
The interleaver used shall be a block interleaver. Each block of input data shall also be encoded using a block encoding technique with a code block size equal to the size of the block interleaver. Thus, the input data bits will be sent as successive blocks of bits that span the duration of the interleaver length selected. Table C-XIV shows the number of input data bits per block as function of both data rate and interleaver length. Note that an "input data block" should not be confused with the 256 symbol data block that is part of a data frame in the waveform format. The bits from an input data block will be mapped through the coding and interleaving to the number of data frames, and thus 256 symbol data blocks, that define the interleaver length.

**TABLE C- XIV. Input data block size in bits as a function of data rate and interleaver length**

| Data Rate (bps) | Interleaver Length in Frames | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 3 | 9 | 18 | 36 | 72 |
| | Number of Input Data Bits per Block | | | | | |
| 3200 | 384 | 1,152 | 3,456 | 6,912 | 13,824 | 27,648 |
| 4800 | 576 | 1,728 | 5,184 | 10,368 | 20,736 | 41,472 |
| 6400 | 768 | 2,304 | 6,912 | 13,824 | 27,648 | 55,296 |
| 8000 | 960 | 2,880 | 8,640 | 17,280 | 34,560 | 69,120 |
| 9600 | 1152 | 3,456 | 10,368 | 20,736 | 41,472 | 82,944 |

C.5.3.1 Block boundary alignment.
Each code block shall be interleaved within a single interleaver block of the same size. The boundaries of these blocks shall be aligned such that the beginning of the first data frame following each reinserted preamble shall coincide with an interleaver boundary. Thus for an interleaver length of 3 frames, the first three data frames following a reinserted preamble will

contain all of the encoded bits for a single input data block. The first data symbol from the first data frame in each interleaver set shall have as its MSB the first bit fetched from the interleaver. This is no different from what would normally be expected, but is a requirement.

C.5.3.2 Block encoding.
The full-tail-biting and puncturing techniques shall be used with a rate 1/2 convolutional code to produce a rate 3/4 block code that is the same length as the interleaver.

C.5.3.2.1 Rate 1/2 convolutional code.
A constraint length 7, rate 1/2 convolutional code shall be used prior to puncturing. This shall be the same code as is used in the single-tone waveform described in section 5.3.2 of this standard. figure C-7 is a pictorial representation of the encoder.

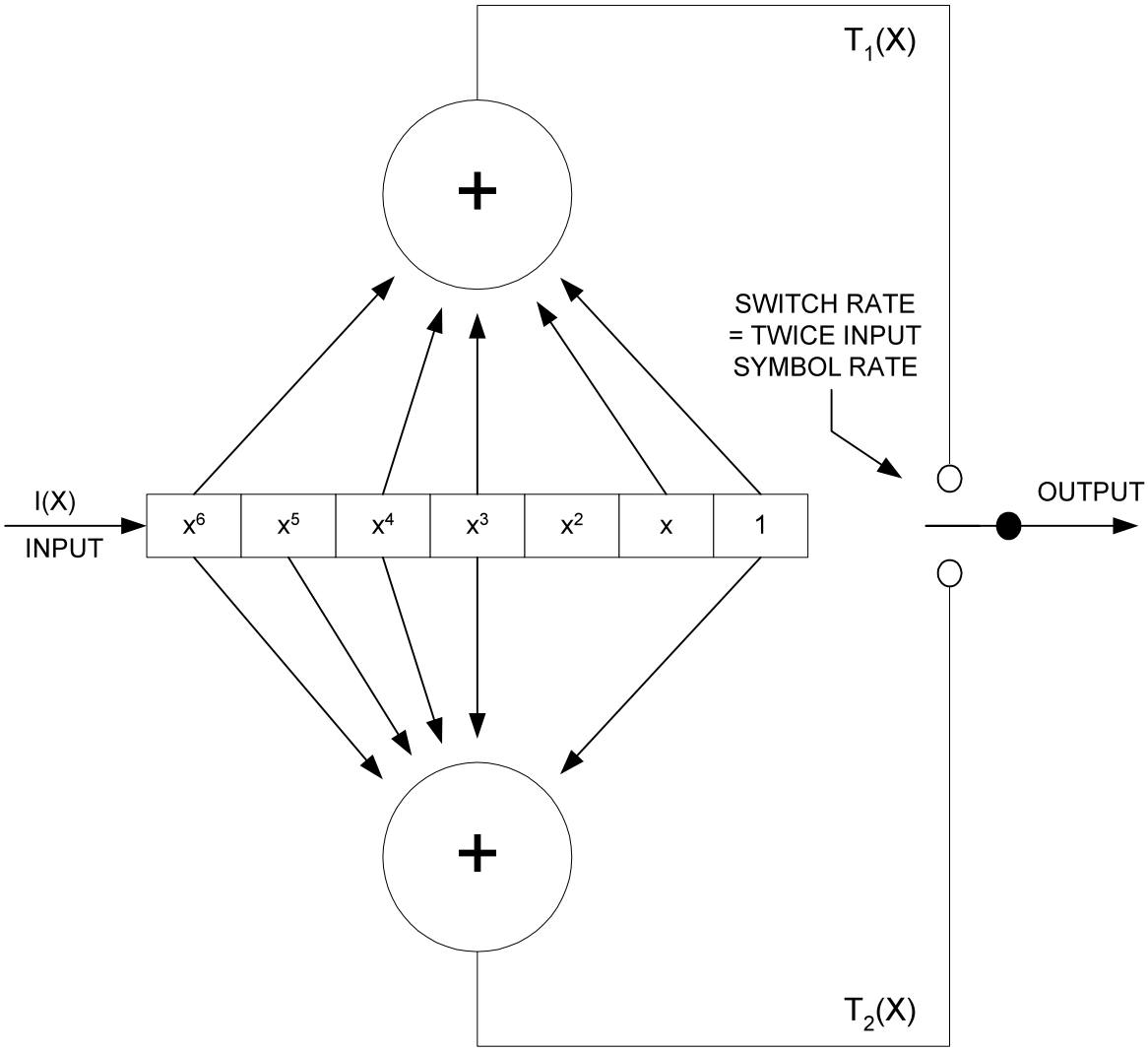


**FIGURE C- 7. Constraint length 7, rate 1/2 convolutional encoder.**

The two summing nodes in the figure represent modulo 2 addition. For each bit input to the encoder, two bits are taken from the encoder, with the upper output bit, $T_1(x)$, taken first.

C.5.3.2.2 Full-tail-biting encoding.
To begin encoding each block of input data, the encoder shall be preloaded by shifting in the first six input data bits without taking any output bits. These six input bits shall be temporarily saved so that they can be used to "flush" the encoder. The first two coded output bits shall be taken after the seventh bit has been shifted in, and shall be defined to be the first two bits of the resulting block code. After the last input data bit has been encoded, the first six "saved" data bits

shall be encoded. Note that the encoder shift register should not be changed before encoding these saved bits; i.e., it should be filled with the last seven input data bits. The six "saved" data bits are encoded by shifting them into the encoder one at a time, beginning with the earliest of the six. The encoding thus continues by taking the two resulting coded output bits as each of the saved six bits is shifted in. These encoded bits shall be the final bits of the resulting (unpunctured) block code. Prior to puncturing, the resulting block code will have exactly twice as many bits as the input information bits. Puncturing of the rate 1/2 code to the required rate 3/4 shall be done prior to sending bits to the interleaver.

C.5.3.2.3 Puncturing to rate 3/4.
In order to obtain a rate 3/4 code from the rate 1/2 code used, the output of the encoder must be punctured by not transmitting 1 bit out of every 3. Puncturing shall be performed by using a puncturing mask of 1 1 1 0 0 1, applied to the bits output from the encoder. In this notation a 1 indicates that the bit is retained and a 0 indicates that the bit is not transmitted. For an encoder generated sequence of

$T_1(k), T_2(k), T_1(k+1), T_2(k+1), T_1(k+2), T_2(k+2) \ldots$

the transmitted sequence shall be

$T_1(k), T_2(k), T_1(k+1), T_2(k+2) \ldots$

Defining $T_1(0), T_2(0)$ to be the first two bits of the block code generated as defined in paragraph C.5.3.2, then the value of k in the above sequences shall be an integral multiple of 3. The block code shall be punctured in this manner before being input to the interleaver.

C.5.3.3 Block interleaver structure.
The block interleaver used is designed to separate neighboring bits in the punctured block code as far as possible over the span of the interleaver with the largest separations resulting for the bits that were originally closest to each other. Because of the 30 different combinations of data rates and interleaver lengths, a more flexible interleaver structure than used for the single-tone waveform described in section 5.3.2 of this standard is needed. The structure to be used is actually simpler than that used previously.

C.5.3.3.1 Interleaver size in bits.
The interleaver shall consist of a single dimension array, numbered from 0 to its size in bits –1. The array size shall depend on both the data rate and interleaver length selected as shown in Table C-XV.

**TABLE C- XV. Interleaver size in bits as a function of data rate and interleaver length.**

| Data Rate (bps) | Interleaver Length in Frames | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 3 | 9 | 18 | 36 | 72 |
| | Interleaver Size in Bits | | | | | |
| 3200 | 512 | 1536 | 4608 | 9216 | 18,432 | 36,864 |
| 4800 | 768 | 2304 | 6912 | 13,824 | 27,648 | 55,296 |
| 6400 | 1024 | 3072 | 9216 | 18,432 | 36,864 | 73,728 |
| 8000 | 1280 | 3840 | 11,520 | 23,040 | 46,080 | 92,160 |
| 9600 | 1536 | 4608 | 13,824 | 27,648 | 55,296 | 110,592 |

C.5.3.3.2 Interleaver load.
The punctured block code bits shall be loaded into the interleaver array beginning with location 0. The location for loading each successive bit shall be obtained from the previous location by incrementing by the "Interleaver Increment Value" specified in Table C-XVI, modulo the "Interleaver Size in Bits."

Defining the first punctured block code bit to be B(0), then the load location for B(n) is given by:

Load Location = ( n * Interleaver Increment Value) Modulo (Interleaver Size in Bits)

Thus for 3200 bps, with a one frame interleaver (512 bit size with an increment of 97), the first 8 interleaver load locations are: 0, 97, 194, 291, 388, 485, 70, and 167.

**TABLE C- XVI. Interleaver increment value as a function of data rate and interleaver length.**

| Data Rate (bps) | Interleaver Length in Frames | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 3 | 9 | 18 | 36 | 72 |
| | Interleaver Increment Value | | | | | |
| 3200 | 97 | 229 | 805 | 1393 | 3281 | 6,985 |
| 4800 | 145 | 361 | 1045 | 2089 | 5137 | 10,273 |
| 6400 | 189 | 481 | 1393 | 3281 | 6985 | 11,141 |
| 8000 | 201 | 601 | 1741 | 3481 | 8561 | 14,441 |
| 9600 | 229 | 805 | 2089 | 5137 | 10,273 | 17,329 |

These increment values have been chosen to ensure that the combined cycles of puncturing and assignment of bit positions in each symbol for the specific constellation being used is the same as

if there had been no interleaving. This is important, because each symbol of a constellation contains "strong" and "weak" bit positions, except for the lowest data rate. Bit position refers to the location of the bit, ranging from MSB to LSB, in the symbol mapping. A strong bit position is one that has a large average distance between all the constellation points where the bit is a 0 and the closest point where it is a 1. Typically, the MSB is a strong bit and the LSB a weak bit. An interleaving strategy that did not evenly distribute these bits in the way they occur without interleaving could degrade performance.

C.5.3.3.3 Interleaver fetch.
The fetching sequence for all data rates and interleaver lengths shall start with location 0 of the interleaver array and increment the fetch location by 1. This is a simple linear fetch from beginning to end of the interleaver array.

C.5.4 Operational features and message protocols.
The format of this narowband MDR waveform has been designed to permit it to work well with most of the protocols used and planned for use with HF. The reinserted preamble facilitates acquisition (or re-acquisition) of an ongoing broadcast transmission. The short length of the synchronization preamble, wide range of interleaving lengths, and the use of full-tail-biting coding is intended to provide efficient operation with ARQ protocols. To further enhance the operation with these protocols, the following operational features shall be included in the HF modem.

C.5.4.1 User interfaces.

C.5.4.1.1 Conventional asynchronous interface.
In addition to the standard synchronous serial interface (see 4.2.3), the modem shall also be capable of interfacing with an asynchronous DTE. In this case the DTE provides (accepts) asynchronous Words consisting of a Start Bit, an N bit Character, and some minimum number of Stop Bits. Additional Stop Bits are provided (accepted) by the DTE between Words as necessary to accommodate gaps between their occurrence. Interoperability shall be provided for those cases where the value of N, the number of Bits in the Character, is 5,6,7, or 8 (including any parity bits), and the minimum number of Stop Bits is 1 or 2. Hence interoperability is defined for those cases where the number of Bits in the Word is N+2 and N+3. In these cases the entire N+2 or N+3 bits of the Word shall be conveyed contiguously in the modulated signal. Additional Stop Bits shall be conveyed as necessary to accommodate gaps in data from the DTE; there shall be no modem-defined null character incorporated into the modulated signal.

C.5.4.1.2 High speed asynchronous user interface with flow control.
Certain high speed user interfaces provide data to (and accept data from) the modem in units of 8 bit bytes. Furthermore, the Input Data Blocks shown in Table C-XIV are all multiples of 8 bit bytes. An optional mode shall be provided to accommodate the special case of an 8 bit character (which includes any parity check bits) and a 1.0 unit interval Stop Bit. In this optional mode, the 8 bit Character shall be aligned with the 256 symbol modem frame boundary, and no Start or Stop Bits shall be transmitted. In this mode of operation it is assumed that the DTE data rate is greater than that which can be accommodated by the modem. Consequently flow control shall be

used to temporarily stop data flow from the DTE to the modem when the modem's input buffer becomes full. Conversely, when the modem's input buffer becomes empty, the modem shall assume that the DTE has finished its message, and the modem shall initiate its normal message-termination procedure. This method of operation obviates the need for the transmission of Null characters for the purpose of "rate padding." Consequently, no Null characters shall be transmitted for this purpose.

C.5.4.1.3 Ethernet interface.
The modem shall provide an Ethernet interface (see Appendix A) for byte oriented user data transfers (see C.5.4.1.2), and these bytes shall be aligned with the Input Data Block boundaries.

C.5.4.2 Onset of transmission.
The modem shall begin a transmission no later than 100 ms after it has received an entire input data block (enough bits to fill a coded and interleaved block), or upon receipt of the last input data bit, whichever occurs first. The latter would only occur when the message is shorter than one interleaver block. A transmission shall be defined as beginning with the keying of the radio, followed by the output of the preamble waveform after the configured pre-key delay, if any.

The delay between when the modem receives the first input data bit and the onset of transmission will be highly dependent on the means for delivery of the input data bits to the modem. A synchronous serial interface at the user data rate will have the greatest delay. For this reason it is recommended that a high speed asynchronous interface (serial or Ethernet port) with flow-control be used if this delay is of concern for the deployed application.

C.5.4.3 End of message.
The use of an end-of-message (EOM) in the transmit waveform shall be a configurable option. When the use of an EOM has been selected, a 32-bit EOM pattern shall be appended after the last input data bit of the message. The EOM, expressed in hexadecimal notation is 4B65A5B2, where the left most bit is sent first. If the last bit of the EOM does not fill out an input data block, the remaining bits in the input data block shall be set to zero before encoding and interleaving the block.

If the use of an EOM has been inhibited, and the last input data bit does not fill out an input data block, the remaining bits in the input data block shall be set to zero before encoding and interleaving the block. It is anticipated that the use of an EOM will only be inhibited when an ARQ data protocol uses ARQ blocks which completely fill (or nearly so) the selected input data block size (interleaver block). Without this feature, the use of an EOM would require the transmission of an additional interleaver block under these circumstances.

C.5.4.4 Termination of a transmission.
Upon receipt of a radio silence (or equivalent) command, the modem shall immediately un-key the radio and terminate its transmit waveform.

In normal operation, the modem shall terminate a transmission only after the transmission of the final data frame, including a mini-probe, associated with the final interleaver block. Note that a data frame consists of a 256 symbol data block followed by a mini-probe. Note that any signal

processing and/or filter delays in the modem and the HF transmitter must be accounted for (as part of the key line control timing) to ensure that the entire final mini-probe is transmitted before the transmitter power is turned off.

C.5.4.5 Termination of receive data processing.
There are a number of events which shall cause the HF modem to cease processing the received signal to recover data, and return to the acquisition mode. These are necessary because a modem is not able to acquire a new transmission while it is attempting to demodulate and decode data.

C.5.4.5.1 Detection of EOM.
The HF modem shall always scan all of the decoded bits for the 32-bit EOM pattern defined in paragraph C.5.4.3. Upon detection of the EOM the modem shall return to the acquisition mode. The modem shall continue to deliver decoded bits to the user (DTE) until the final bit immediately preceding the EOM has been delivered.

C.5.4.5.2 Command to return to acquisition.
Upon receipt of a command to terminate reception, the HF modem shall return to the acquisition mode and terminate the delivery of decoded bits to the user (DTE).

C.5.4.5.3 Receipt of a specified number of data blocks.
The maximum message duration measured in number of Input Data Blocks (interleaver blocks) shall be a configurable parameter. One value of this parameter shall specify that an unlimited number may be received. Once the modem has decoded and delivered to the user (DTE), the number of bits corresponding to the configured maximum message duration, the HF modem shall return to the acquisition mode and terminate the delivery of decoded bits to the user (DTE). Note that for a given interleaver length, this parameter also specifies the maximum message duration in time, independent of the bit rate. Note that this parameter is the maximum duration and that the transmit end always has the option of using an EOM for shorter transmissions.
Operation with a specified number of input data blocks may be used by an ARQ protocol where the size of the ARQ packet is fixed, or occasionally changed to accommodate changing propagation conditions. In this case we anticipate that this parameter (maximum message duration) will be sent to the receiving end of the link as part of the ARQ protocol. It would then be sent to the receiving modem through the remote control interface (see C.5.4.6 below), since it is not embedded in the waveform itself as the data rate and interleaver length parameters are.

C.5.4.5.4 Initiation of a transmission.
If, and only if, the HF Modem is configured to operate in half-duplex mode with transmit override, the initiation of a transmission by the user (DTE) shall cause the HF modem to terminate the receive processing and the delivery of decoded bits to the user (DTE).

C.5.4.6 Remote control.
The remote control interface (see section 5.3.1.5) shall provide the capability to specify the following parameters and commands:

a. MDR waveform parameters:
   1) The 5 data rates for the MDR waveform
   2) The 6 interleaver lengths for the MDR waveform

b. A command to select the usage of the optional EOM in the transmit waveform. Note that the receiving modem must always scan for the EOM regardless of this setting.

c. A command to specify the maximum message duration measured in number of Input Data Blocks (interleaver blocks). The value of 0 (zero) for this parameter shall specify that an unlimited number may be received.

d. A command to cause the modem to terminate receive data processing and return to acquisition mode.

## C.6 PERFORMANCE

### C.6.1 BER performance.

The measured performance of the narrowband MDR waveform, using fixed-frequency operation and employing the maximum interleaving period (the 72-frame "Very Long" interleaver), shall achieve coded BER of no more than 1.0E-5 under each of the conditions listed in Table C-XVII.

**TABLE C- XVII. MDR waveform performance requirements.**

| User data rate (bps) | Average SNR (dB) for BER ≤ 1.0E-5 | |
|---|---|---|
| | AWGN Channel | ITU-R Poor Channel |
| 12800 | 27 | - |
| 9600 | 21 | 31 |
| 8000 | 19 | 27 |
| 6400 | 16 | 23 |
| 4800 | 13 | 19 |
| 3200 | 9 | 14 |

Performance shall be tested using a baseband HF simulator patterned after the Watterson Model in accordance with Appendix E.

- The AWGN channel shall consist of a single, non-fading path. Each condition shall be measured for at least 60 minutes.
- The ITU-R Poor channel shall consist of two independent but equal average power Rayleigh fading paths, with a fixed 2 ms delay between paths, and with a fading (two sigma) bandwidth (BW) of 1 Hz. Each condition shall be measured for at least 5 hours.
- Both signal and noise power shall be measured in a 3 kHz bandwidth. Note that the average power of QAM symbols is different from that of the 8PSK mini-probes and reinserted preambles; the measured signal power shall be the long-term average of user data, mini-probe, and reinserted preamble symbols.

When testing a modem embedded with a radio, so that only radio frequency (RF) signals are available for testing, the RF signals must be downconverted to baseband for processing by the channel simulator, and the result upconverted to RF for the receiver. In this case, the built-in radio filters will affect the performance of the modems. Therefore, when testing embedded modems, the SNR values specified in Table C-XVII shall be increased by 2 dB (3 dB at 9600 bps and above).

When the sending and receiving modems used in this test are not identical make and model, an extra dB of SNR shall be allowed due to potential degradation in mismatched filters.

### C.6.2 Acquisition performance.

Not yet standardized.

C.6.3 Doppler shift test.
The modem shall acquire and maintain synchronization for at least 5 minutes with a test signal having the following characteristics: 9600 bps/Very Long interleaver, 75 Hz frequency offset, 2 ms delay spread, a fading BW of 1 Hz, and an average SNR of 30 dB. The test shall be repeated with a –75 Hz frequency offset. No BER test is required.

C.6.4 Doppler sweep performance.
The AWGN BER test at 9600 bps from Table C-XVII shall be repeated with a test signal having a frequency offset that continuously varies at a rate of 3.5 Hz/s between the limits of -75 and +75 Hz, such that a plot of frequency offset vs. time describes a periodic "triangle" waveform having a period of (300/3.5) seconds. Over a test duration of 1 hour, the modem shall achieve a BER of 1.0E-5 or less at an SNR of 24 dB.

## C.7 ASSOCIATED COMMUNICATIONS EQUIPMENT

The QAM constellations specified in this appendix are more sensitive to equipment variations than the PSK constellations specified in section 5.3.2 of this standard. Because of this sensitivity, radio filters will have a significant impact on the performance of modems implementing the waveforms in this appendix. In addition, because of the level sensitive nature of the QAM constellations, turn-on transients, AGC, and ALC can cause significant performance degradation.

It is recommended that modems implementing the waveforms in this appendix should include a variable pre-key feature, by which the user can specify a delay between the time when the transmitter is keyed and the modem signal begins. This allows for turn-on transient settling, which is particularly important for legacy radio equipment.

It is recommended that a slow AGC setting (e.g., the "nondata" mode in MIL-STD-188-141) be used when receiving the waveforms in this appendix.

# HF DATA MODEM WAVEFORMS FOR SINGLE CONTIGUOUS BANDWIDTHS UP TO 48 KHZ

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**LIST OF TABLES (continued)**

# D.1 SCOPE

## D.1.1 Scope.

This appendix describes the HF data modem waveforms for use with single contiguous bandwidths from 3 KHz to 48 KHz.

## D.1.2 Applicability.

This appendix is a non-mandatory part of MIL-STD-188-110C; however, when data is to be communicated in single contiguous HF radio bandwidths greater than 3 kHz, up to 48 kHz, the waveforms employed shall be in accordance with this appendix.

# D.2 APPLICABLE DOCUMENTS

This section is not applicable to this appendix.

# D.3 DEFINITIONS

## D.3.1 Abbreviations and acronyms.

Abbreviations and acronyms used in this appendix are defined below. Also see section 3 of this document.

| | |
|---|---|
| WBHF | Wide Band High Frequency (radio) |

## D.4 GENERAL REQUIREMENTS

This appendix presents a family of wideband high-frequency radio (WBHF) modem waveforms and coding specifications for bandwidths of 3, 6, 9, 12, 15, 18, 21, 24, 30, 36, 42, and 48 kHz. Data rates of 75 through 240,000 bps are supported. The single-tone waveforms specified in this appendix use modulation techniques similar to those found in Appendix C of this standard in order to achieve the required data rates. A block interleaver is used to obtain 4 interleaving lengths ranging from approximately 0.12 s to 10.24 s. Various code rates are implemented based on a constraint length 7 or a constraint length 9 convolutional code. Various puncturing and repeat coding schemes are utilized to achieve a family of code rates from 1/16 up to 9/10. The full-tail-biting approach is used to produce block codes from this convolutional code that are the same length as the interleaver. Since the minimum interleaver length spans approximately 120ms, there is no option of zero interleaving, since the time delays would not be reduced.

The waveform data rate, encoder constraint length and interleaver settings are explicitly transmitted as a part of the initial preamble of the waveform. This "autobaud" feature is critical in developing an efficient (ARQ) protocol for high frequency (HF) channels. The receive modem is required to be able to determine the data rate, encoder constraint length and interleaver setting during the reception of the preamble.

For broadcast applications, the receive modem is required to know the bandwidth, data rate, encoder constraint length and interleaver setting in order to acquire the waveform without the initial preamble.

### D.4.1 WBHF Block 1 Requirements

A subset of the requirements of this appendix when implemented only for 3 kHz is termed the WBHF Block 1 capability. A Block 1 WBHF modem shall implement all of the following:

- Waveforms 0 through 13 for bandwidth of 3 kHz (see Table D-II).
- Constraint length 7 convolutional coding

and shall meet the Performance Requirements in D.6 for those waveforms.

### D.4.2 WBHF Block 2 Requirements

The same subset of the requirements, but offered at 3, 6, 9, and 12 kHz, is termed the WBHF Block 2 capability. A Block 2 WBHF modem shall implement all of the following:

- Waveforms 0 through 12 for bandwidth of 3, 6, 9, and 12 kHz, and waveform 13 for 3 kHz only (see Table D-II).
- Constraint length 7 convolutional coding

and shall meet the Performance Requirements in D.6 for those waveforms.

### D.4.3 WBHF Block 3 Requirements

A Block 3 WBHF modem shall implement all of the Detailed Requirements in D.5 for bandwidths up to 24 kHz and all of the corresponding Performance Requirements in D.6 in this appendix.

D.4.4 WBHF Block 4 Requirements

A Block 4 WBHF modem shall implement all of the Detailed Requirements in D.5 and all of the Performance Requirements in D.6 in this appendix.

## D.5 DETAILED REQUIREMENTS

### D.5.1 Modulation.

The symbol rate for all symbols is dependent on the bandwidth (BW). The symbol rate shall be accurate to within 10ppm. For example, at 2400 symbols per second, the symbol rate shall be accurate to a minimum of ±0.024 symbols per second when the transmit data clock is generated by the modem and not provided by the data terminal equipment (DTE). Phase-shift keying (PSK) and quadrature amplitude modulation (QAM) modulation techniques shall be used. The sub-carrier (or pair of quadrature sub-carriers in the case of QAM) shall be centered at (300+(BW/2)) Hz accurate to a minimum of 10 ppm. The phase of the quadrature sub-carrier relative to the In-phase carrier shall be 90 degrees. The correct relationship can be achieved by making the In-phase sub-carrier cos(Sub-Carrier) and the quadrature sub-carrier -sin(Sub-Carrier). Table D-I specifies the symbol rates and sub-carrier frequencies for all Bandwidths.

**TABLE D-I. Symbol Rates and Sub Carrier**

| Bandwidth (kHz) | Symbol Rate (Sym/sec) | Sub-Carrier (Hz) |
|---|---|---|
| 3 | 2400 | 1800 |
| 6 | 4800 | 3300 |
| 9 | 7200 | 4800 |
| 12 | 9600 | 6300 |
| 15 | 12000 | 7800 |
| 18 | 14400 | 9300 |
| 21 | 16800 | 10800 |
| 24 | 19200 | 12300 |
| 30 | 24,000 | 15,300 |
| 36 | 28,800 | 18,300 |
| 42 | 33,600 | 21,300 |
| 48 | 38,400 | 24,300 |

The output of the modulator shall have an occupied bandwidth (see section 3) no greater than the bandwidth of the waveform in Table D-I. This measurement can be performed at RF, IF or audio baseband.

#### D.5.1.1 Known symbols.

For all known symbols, the modulation used shall be PSK. No scrambling shall be applied to the known symbols.

#### D.5.1.2 Data symbols.

For data symbols, the modulation used shall depend upon the data rate. Table D-II specifies the modulation that shall be used with each data rate.

**TABLE D-II. Modulation used to obtain each data rate.**

| Waveform Number | **0 Walsh** | **1 BPSK** | **2 BPSK** | **3 BPSK** | **4 BPSK** | **5 BPSK** | **6 QPSK** | **7 8PSK** | **8 16QAM** | **9 32QAM** | **10 64QAM** | **11 64QAM** | **12 256QAM** | **13 QPSK** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Bandwidth** (kHz) | | | | | | | | | | | | | | |
| 3 | 75 | 150 | 300 | 600 | 1200 | 1600 | 3200 | 4800 | 6400 | 8000 | 9600 | 12000 | 16000 | 2400 |
| 6 | 150 | 300 | 600 | 1200 | 2400 | 3200 | 6400 | 9600 | 12800 | 16000 | 19200 | 24000 | 32000 | |
| 9 | 300 | 600 | 1200 | 2400 | - | 4800 | 9600 | 14400 | 19200 | 24000 | 28800 | 36000 | 48000 | |
| 12 | 300 | 600 | 1200 | 2400 | 4800 | 6400 | 12800 | 19200 | 25600 | 32000 | 38400 | 48000 | 64000 | |
| 15 | 300 | 600 | 1200 | 2400 | 4800 | 8000 | 16000 | 24000 | 32000 | 40000 | 48000 | 57600 | 76800 | |
| 18 | 600 | 1200 | 2400 | 4800 | - | 9600 | 19200 | 28800 | 38400 | 48000 | 57600 | 72000 | 90000 | |
| 21 | 300 | 600 | 1200 | 2400 | 4800 | 9600 | 19200 | 28800 | 38400 | 48000 | 57600 | 76800 | 115200 | |
| 24 | 600 | 1200 | 2400 | 4800 | 9600 | 12800 | 25600 | 38400 | 51200 | 64000 | 76800 | 96000 | 120000 | |
| 30 | 600 | 1200 | 2400 | 4800 | 9600 | 16000 | 32000 | 48000 | 64000 | 80000 | 96000 | 120000 | 160000 | |
| 36 | 1200 | 2400 | 4800 | 9600 | 12800 | 19200 | 38400 | 57600 | 76800 | 96000 | 115200 | 144000 | 192000 | |
| 42 | 1200 | 2400 | 4800 | 9600 | 14400 | 19200 | 38400 | 57600 | 76800 | 96000 | 115200 | 160000 | 192000 | |
| 48 | 1200 | 2400 | 4800 | 9600 | 16000 | 24000 | 48000 | 72000 | 96000 | 120000 | 144000 | 192000 | 240000 | |

The waveforms utilizing binary phase-shift keying BPSK, quadrature phase-shift keying (QPSK), and eight-ary phase-shift keying (8PSK) constellations are scrambled to appear, on-air, as an 8PSK constellation. The scrambling serves a secondary purpose of randomizing the on air waveform in the presence of a fixed user data stream. The 16QAM and 32QAM constellations use multiple PSK rings to maintain good peak-to-average ratios, and the 64QAM constellation is a variation of the standard square QAM constellation, which has been modified to improve the peak-to-average ratio. The 256 QAM constellation is better than the standard 16 x 16 square constellation and achieves superior peak-to-average without sacrificing the very good pseudo-Gray code properties of the square constellation. An interesting feature of the constellation is the slight displacement of the 2 center-top and center-bottom constellation points to protect constellation points with larger Hamming distances by increasing the signal-space distance.

D.5.1.2.1 PSK data symbols.

For the PSK constellations, a distinction is made between the data bits and the symbol number for the purposes of scrambling the BPSK and QPSK modulations to appear as 8PSK, on-air. Scrambling is applied as a modulo 8 addition of a scrambling sequence to the 8PSK symbol number. Transcoding is an operation that links a symbol to be transmitted to a group of data bits.

D.5.1.2.1.1 BPSK symbol mapping.

For the waveforms utilizing binary phase-shift keying BPSK, transcoding shall be achieved by linking one of the symbols specified in Table D-VI to a single data bits (bit) as shown in Table D-III.

**TABLE D-III. Transcoding for BPSK.**

| bit | Symbol |
|---|---|
| 0 | 0 |
| 1 | 4 |

D.5.1.2.1.2 QPSK symbol mapping.

For the waveforms utilizing quadrature phase-shift keying QPSK, transcoding shall be achieved by linking one of the symbols specified in Table D-VI to a set of two consecutive data bits (dibit) as shown in Table D-IV. In this Table, the leftmost bit of the dibit shall be the older bit; i.e., fetched from the interleaver before the rightmost bit.

**TABLE D-IV. Transcoding for QPSK.**

| Dibit | Symbol |
|---|---|
| 00 | 0 |
| 01 | 2 |
| 11 | 4 |
| 10 | 6 |

D.5.1.2.1.3 8PSK symbol mapping.
For the waveforms utilizing quadrature 8-ary phase-shift keying 8PSK, transcoding shall be achieved by linking one symbol to a set of three consecutive data bits (tribit) as shown in Table D-V. In this Table, the leftmost bit of the tribit shall be the oldest bit; i.e., fetched from the interleaver before the other two, and the rightmost bit is the most recent bit.

**TABLE D-V. Transcoding for 8PSK.**

| Tribit | Symbol |
|---|---|
| 000 | 1 |
| 001 | 0 |
| 010 | 2 |
| 011 | 3 |
| 100 | 6 |
| 101 | 7 |
| 110 | 5 |
| 111 | 4 |

D.5.1.2.1.4 The 8PSK constellation.
The constellation points which shall be used for 8PSK are shown in figure D-1 and specified in terms of their In-phase and Quadrature components in Table D-VI.

**TABLE D-VI. 8PSK symbol mapping.**

| Symbol Number | Phase | In-Phase | Quadrature |
|---|---|---|---|
| 0 | 0 | 1.000000 | 0.000000 |
| 1 | $\pi/4$ | 0.707107 | 0.707107 |
| 2 | $\pi/2$ | 0.000000 | 1.000000 |
| 3 | $3\pi/4$ | -0.707107 | 0.707107 |
| 4 | $\pi$ | -1.000000 | 0.000000 |
| 5 | $5\pi/4$ | -0.707107 | -0.707107 |
| 6 | $3\pi/2$ | 0.0000000 | -1.000000 |
| 7 | $7\pi/4$ | 0.707107 | -0.707107 |

Note that the complex symbol values = exp[jnπ/4] where n is the symbol number.

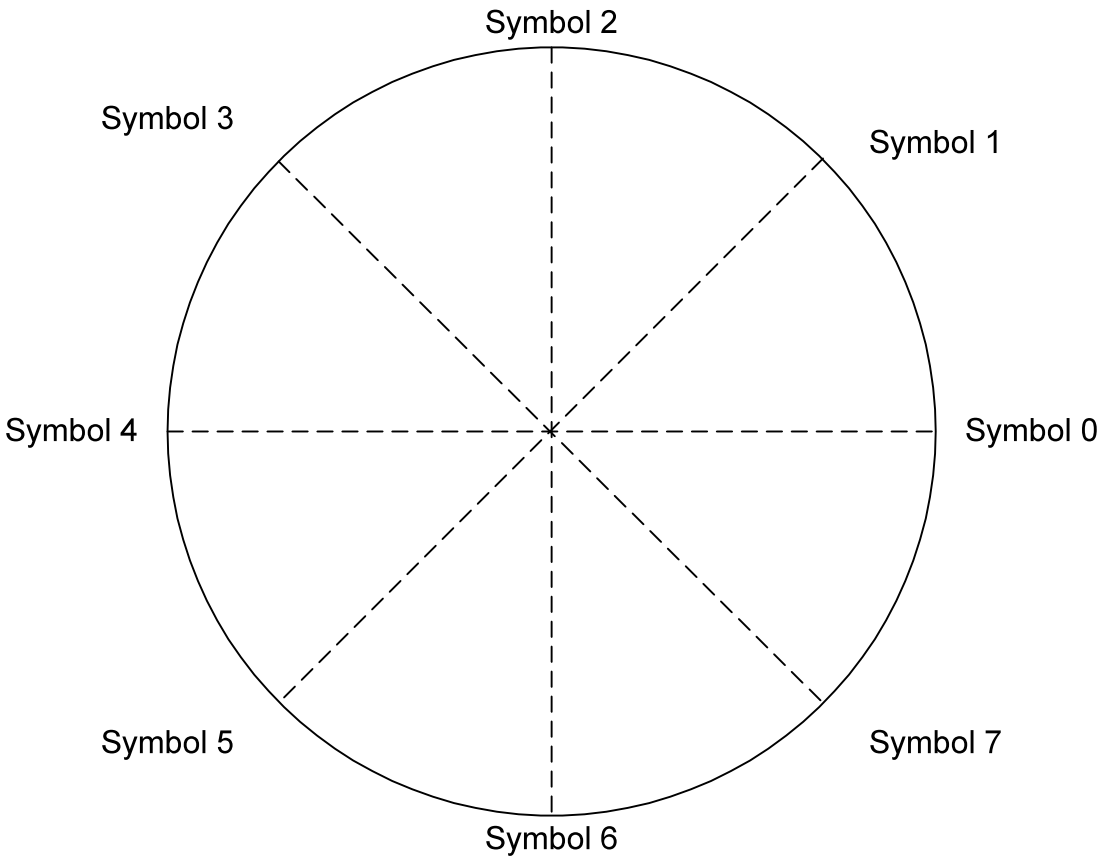


**FIGURE D-1. 8PSK signal constellation and symbol mapping.**

D.5.1.2.2 QAM data symbols.

For the QAM constellations, no distinction is made between the number formed directly from the data bits and the symbol number. Each set of 4 bits (16QAM), 5 bits (32QAM), 6 bits (64QAM), or 8 bits (256QAM) is mapped directly to a QAM symbol. For example, the four bit grouping 0111 would map to symbol 7 in the 16QAM constellation while the 6 bits 100011 would map to symbol 35 in the 64QAM constellation. Again, in each case the leftmost bit shall be the oldest bit, i.e. fetched from the interleaver before the other bits, and the rightmost bit is the most recent bit. The mapping of bits to symbols for the QAM constellations has been selected to minimize the number of bit errors incurred when errors involve adjacent signaling points in the constellation.

D.5.1.2.2.1 The 16 QAM constellation.

The constellation points which shall be used for 16QAM are shown in figure D-2 and specified in terms of their In-phase and Quadrature components in Table D-VII. As can be seen in the figure, the 16 QAM constellation is comprised of two PSK rings: a 4 PSK inner ring and a 12 PSK outer ring.

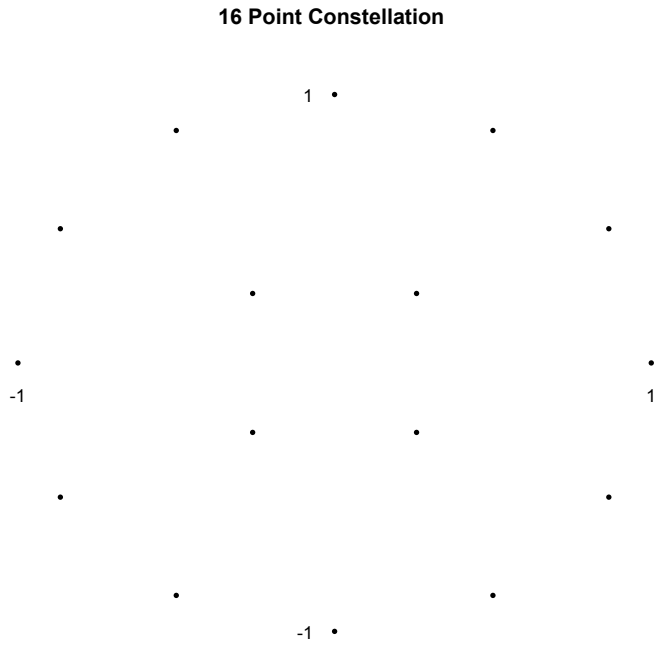


**FIGURE D-2. 16QAM Signaling Constellation.**

**TABLE D-VII. In-phase and Quadrature components of each 16QAM symbol.**

| Symbol Number | In-Phase | Quadrature |
|---|---|---|
| 0 | 0.866025 | 0.500000 |
| 1 | 0.500000 | 0.866025 |
| 2 | 1.000000 | 0.000000 |
| 3 | 0.258819 | 0.258819 |
| 4 | -0.500000 | 0.866025 |
| 5 | 0.000000 | 1.000000 |
| 6 | -0.866025 | 0.500000 |
| 7 | -0.258819 | 0.258819 |
| 8 | 0.500000 | -0.866025 |
| 9 | 0.000000 | -1.000000 |
| 10 | 0.866025 | -0.500000 |
| 11 | 0.258819 | -0.258819 |
| 12 | -0.866025 | -0.500000 |
| 13 | -0.500000 | -0.866025 |
| 14 | -1.000000 | 0.000000 |
| 15 | -0.258819 | -0.258819 |

D.5.1.2.2.2 The 32 QAM constellation.

The constellation points which shall be used for 32QAM are shown in figure D-3 and specified in terms of their In-phase and Quadrature components in Table D-VIII. This constellation contains an outer ring of 16 symbols and an inner square of 16 symbols.

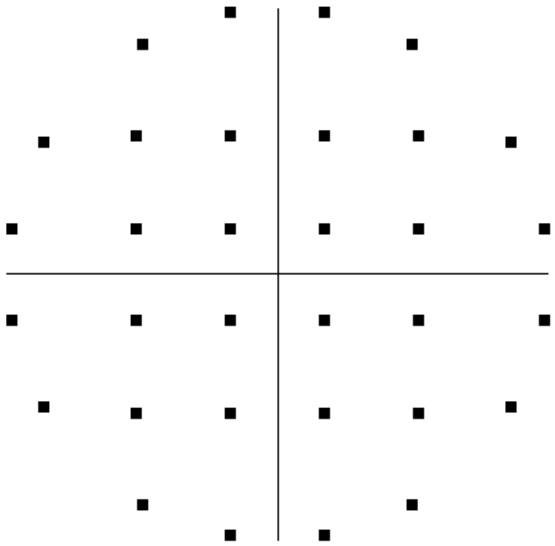

**FIGURE D-3. 32QAM signaling constellation.**

**TABLE D-VIII. In-phase and Quadrature components of each 32QAM symbol.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 0.866380 | 0.499386 | 16 | 0.866380 | -0.499386 |
| 1 | 0.984849 | 0.173415 | 17 | 0.984849 | -0.173415 |
| 2 | 0.499386 | 0.866380 | 18 | 0.499386 | -0.866380 |
| 3 | 0.173415 | 0.984849 | 19 | 0.173415 | -0.984849 |
| 4 | 0.520246 | 0.520246 | 20 | 0.520246 | -0.520246 |
| 5 | 0.520246 | 0.173415 | 21 | 0.520246 | -0.173415 |
| 6 | 0.173415 | 0.520246 | 22 | 0.173415 | -0.520246 |
| 7 | 0.173415 | 0.173415 | 23 | 0.173415 | -0.173415 |
| 8 | -0.866380 | 0.499386 | 24 | -0.866380 | -0.499386 |
| 9 | -0.984849 | 0.173415 | 25 | -0.984849 | -0.173415 |
| 10 | -0.499386 | 0.866380 | 26 | -0.499386 | -0.866380 |
| 11 | -0.173415 | 0.984849 | 27 | -0.173415 | -0.984849 |
| 12 | -0.520246 | 0.520246 | 28 | -0.520246 | -0.520246 |
| 13 | -0.520246 | 0.173415 | 29 | -0.520246 | -0.173415 |
| 14 | -0.173415 | 0.520246 | 30 | -0.173415 | -0.520246 |
| 15 | -0.173415 | 0.173415 | 31 | -0.173415 | -0.173415 |

D.5.1.2.2.3 The 64QAM constellation.

The constellation points which shall be used for the 64QAM modulation are shown in figure D-4 and specified in terms of their In-phase and Quadrature components in Table D-IX. This constellation is a variation on the standard 8 x 8 square constellation, which achieves better peak-to-average without sacrificing the very good pseudo-Gray code properties of the square constellation.

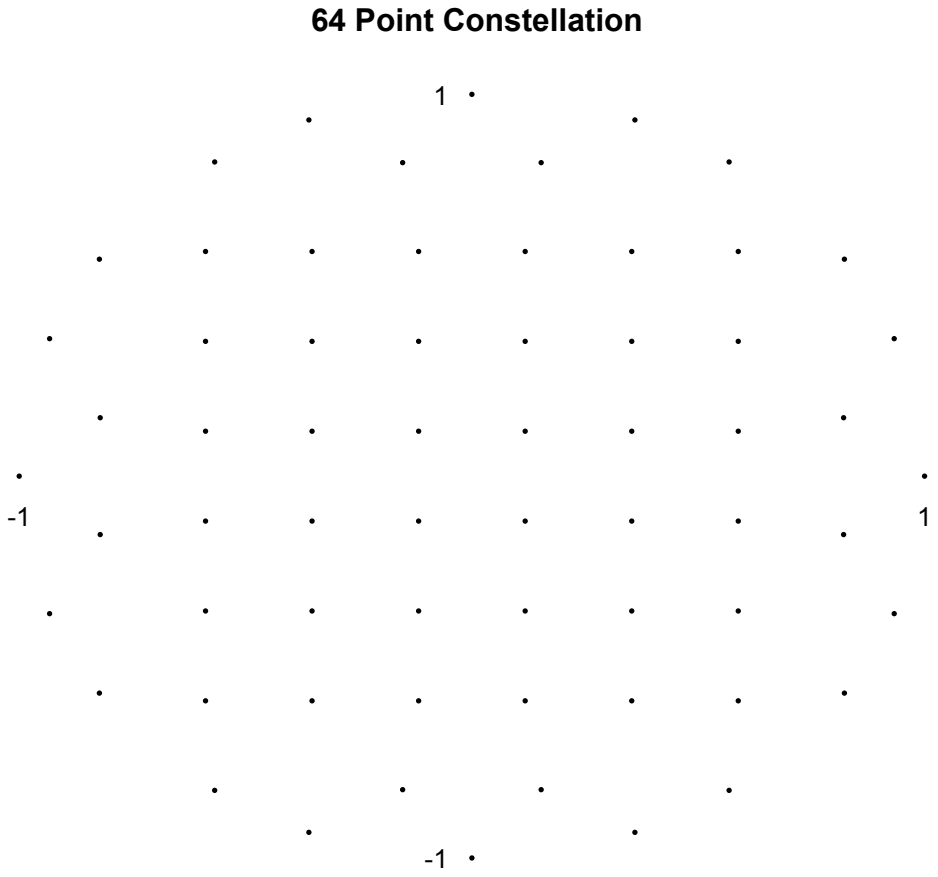


**FIGURE D-4. 64QAM signaling constellation.**

**TABLE D-IX. In-phase and Quadrature components of each 64QAM symbol.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.000000 | 0.000000 | 32 | 0.000000 | 1.000000 |
| 1 | 0.822878 | 0.568218 | 33 | -0.822878 | 0.568218 |
| 2 | 0.821137 | 0.152996 | 34 | -0.821137 | 0.152996 |
| 3 | 0.932897 | 0.360142 | 35 | -0.932897 | 0.360142 |
| 4 | 0.000000 | -1.000000 | 36 | -1.000000 | 0.000000 |
| 5 | 0.822878 | -0.568218 | 37 | -0.822878 | -0.568218 |
| 6 | 0.821137 | -0.152996 | 38 | -0.821137 | -0.152996 |
| 7 | 0.932897 | -0.360142 | 39 | -0.932897 | -0.360142 |
| 8 | 0.568218 | 0.822878 | 40 | -0.568218 | 0.822878 |
| 9 | 0.588429 | 0.588429 | 41 | -0.588429 | 0.588429 |
| 10 | 0.588429 | 0.117686 | 42 | -0.588429 | 0.117686 |
| 11 | 0.588429 | 0.353057 | 43 | -0.588429 | 0.353057 |
| 12 | 0.568218 | -0.822878 | 44 | -0.568218 | -0.822878 |
| 13 | 0.588429 | -0.588429 | 45 | -0.588429 | -0.588429 |
| 14 | 0.588429 | -0.117686 | 46 | -0.588429 | -0.117686 |
| 15 | 0.588429 | -0.353057 | 47 | -0.588429 | -0.353057 |
| 16 | 0.152996 | 0.821137 | 48 | -0.152996 | 0.821137 |
| 17 | 0.117686 | 0.588429 | 49 | -0.117686 | 0.588429 |
| 18 | 0.117686 | 0.117686 | 50 | -0.117686 | 0.117686 |
| 19 | 0.117686 | 0.353057 | 51 | -0.117686 | 0.353057 |
| 20 | 0.152996 | -0.821137 | 52 | -0.152996 | -0.821137 |
| 21 | 0.117686 | -0.588429 | 53 | -0.117686 | -0.588429 |
| 22 | 0.117686 | -0.117686 | 54 | -0.117686 | -0.117686 |
| 23 | 0.117686 | -0.353057 | 55 | -0.117686 | -0.353057 |
| 24 | 0.360142 | 0.932897 | 56 | -0.360142 | 0.932897 |
| 25 | 0.353057 | 0.588429 | 57 | -0.353057 | 0.588429 |
| 26 | 0.353057 | 0.117686 | 58 | -0.353057 | 0.117686 |
| 27 | 0.353057 | 0.353057 | 59 | -0.353057 | 0.353057 |
| 28 | 0.360142 | -0.932897 | 60 | -0.360142 | -0.932897 |
| 29 | 0.353057 | -0.588429 | 61 | -0.353057 | -0.588429 |
| 30 | 0.353057 | -0.117686 | 62 | -0.353057 | -0.117686 |
| 31 | 0.353057 | -0.353057 | 63 | -0.353057 | -0.353057 |

D.5.1.2.2.4 The 256QAM constellation.

The constellation points that shall be used for the 256QAM modulation are shown in Figure D-5 and specified in terms of their In-phase and Quadrature components in Table D-X. This constellation is better than the standard 16 x 16 square constellation and achieves superior peak-to-average without sacrificing the very good pseudo-Gray code properties of the square constellation. An interesting feature of the constellation is the slight displacement of the 2 center-top and center-bottom constellation points to protect constellation points with larger Hamming distances by increasing the signal-space distance.

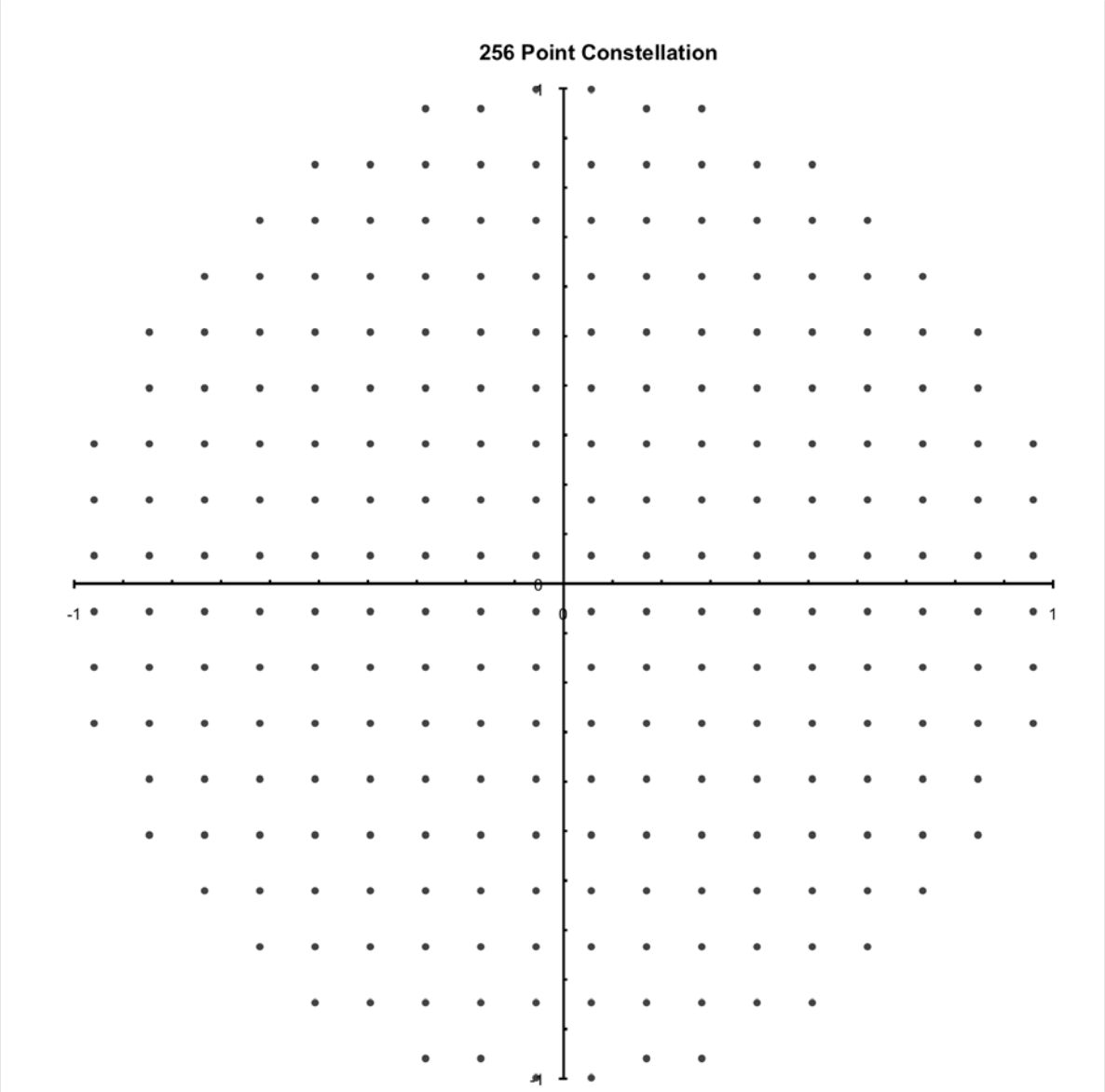


**FIGURE D-5. 256QAM signaling constellation.**

**TABLE D-X. In-phase and Quadrature components of each 256QAM symbol.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 0.959366 | 0.056433 | 32 | 0.507899 | 0.846499 |
| 1 | 0.959366 | 0.169300 | 33 | 0.507899 | 0.733632 |
| 2 | 0.846499 | 0.507899 | 34 | 0.507899 | 0.507899 |
| 3 | 0.959366 | 0.282166 | 35 | 0.507899 | 0.620766 |
| 4 | 0.846499 | 0.056433 | 36 | 0.507899 | 0.056433 |
| 5 | 0.846499 | 0.169300 | 37 | 0.507899 | 0.169300 |
| 6 | 0.846499 | 0.395033 | 38 | 0.507899 | 0.395033 |
| 7 | 0.846499 | 0.282166 | 39 | 0.507899 | 0.282166 |
| 8 | 0.959366 | -0.056433 | 40 | 0.507899 | -0.846499 |
| 9 | 0.959366 | -0.169300 | 41 | 0.507899 | -0.733632 |
| 10 | 0.846499 | -0.507899 | 42 | 0.507899 | -0.507899 |
| 11 | 0.959366 | -0.282166 | 43 | 0.507899 | -0.620766 |
| 12 | 0.846499 | -0.056433 | 44 | 0.507899 | -0.056433 |
| 13 | 0.846499 | -0.169300 | 45 | 0.507899 | -0.169300 |
| 14 | 0.846499 | -0.395033 | 46 | 0.507899 | -0.395033 |
| 15 | 0.846499 | -0.282166 | 47 | 0.507899 | -0.282166 |
| 16 | 0.169300 | 0.959366 | 48 | 0.282166 | 0.959366 |
| 17 | 0.056433 | 0.998304 | 49 | 0.620766 | 0.733632 |
| 18 | 0.733632 | 0.507899 | 50 | 0.620766 | 0.507899 |
| 19 | 0.733632 | 0.620766 | 51 | 0.620766 | 0.620766 |
| 20 | 0.733632 | 0.056433 | 52 | 0.620766 | 0.056433 |
| 21 | 0.733632 | 0.169300 | 53 | 0.620766 | 0.169300 |
| 22 | 0.733632 | 0.395033 | 54 | 0.620766 | 0.395033 |
| 23 | 0.733632 | 0.282166 | 55 | 0.620766 | 0.282166 |
| 24 | 0.169300 | -0.959366 | 56 | 0.282166 | -0.959366 |
| 25 | 0.056433 | -0.998304 | 57 | 0.620766 | -0.733632 |
| 26 | 0.733632 | -0.507899 | 58 | 0.620766 | -0.507899 |
| 27 | 0.733632 | -0.620766 | 59 | 0.620766 | -0.620766 |
| 28 | 0.733632 | -0.056433 | 60 | 0.620766 | -0.056433 |
| 29 | 0.733632 | -0.169300 | 61 | 0.620766 | -0.169300 |
| 30 | 0.733632 | -0.395033 | 62 | 0.620766 | -0.395033 |
| 31 | 0.733632 | -0.282166 | 63 | 0.620766 | -0.282166 |

**TABLE D-X continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 64 | 0.056433 | 0.846499 | 96 | 0.395033 | 0.846499 |
| 65 | 0.056433 | 0.733632 | 97 | 0.395033 | 0.733632 |
| 66 | 0.056433 | 0.507899 | 98 | 0.395033 | 0.507899 |
| 67 | 0.056433 | 0.620766 | 99 | 0.395033 | 0.620766 |
| 68 | 0.056433 | 0.056433 | 100 | 0.395033 | 0.056433 |
| 69 | 0.056433 | 0.169300 | 101 | 0.395033 | 0.169300 |
| 70 | 0.056433 | 0.395033 | 102 | 0.395033 | 0.395033 |
| 71 | 0.056433 | 0.282166 | 103 | 0.395033 | 0.282166 |
| 72 | 0.056433 | -0.846499 | 104 | 0.395033 | -0.846499 |
| 73 | 0.056433 | -0.733632 | 105 | 0.395033 | -0.733632 |
| 74 | 0.056433 | -0.507899 | 106 | 0.395033 | -0.507899 |
| 75 | 0.056433 | -0.620766 | 107 | 0.395033 | -0.620766 |
| 76 | 0.056433 | -0.056433 | 108 | 0.395033 | -0.056433 |
| 77 | 0.056433 | -0.169300 | 109 | 0.395033 | -0.169300 |
| 78 | 0.056433 | -0.395033 | 110 | 0.395033 | -0.395033 |
| 79 | 0.056433 | -0.282166 | 111 | 0.395033 | -0.282166 |
| 80 | 0.169300 | 0.846499 | 112 | 0.282166 | 0.846499 |
| 81 | 0.169300 | 0.733632 | 113 | 0.282166 | 0.733632 |
| 82 | 0.169300 | 0.507899 | 114 | 0.282166 | 0.507899 |
| 83 | 0.169300 | 0.620766 | 115 | 0.282166 | 0.620766 |
| 84 | 0.169300 | 0.056433 | 116 | 0.282166 | 0.056433 |
| 85 | 0.169300 | 0.169300 | 117 | 0.282166 | 0.169300 |
| 86 | 0.169300 | 0.395033 | 118 | 0.282166 | 0.395033 |
| 87 | 0.169300 | 0.282166 | 119 | 0.282166 | 0.282166 |
| 88 | 0.169300 | -0.846499 | 120 | 0.282166 | -0.846499 |
| 89 | 0.169300 | -0.733632 | 121 | 0.282166 | -0.733632 |
| 90 | 0.169300 | -0.507899 | 122 | 0.282166 | -0.507899 |
| 91 | 0.169300 | -0.620766 | 123 | 0.282166 | -0.620766 |
| 92 | 0.169300 | -0.056433 | 124 | 0.282166 | -0.056433 |
| 93 | 0.169300 | -0.169300 | 125 | 0.282166 | -0.169300 |
| 94 | 0.169300 | -0.395033 | 126 | 0.282166 | -0.395033 |
| 95 | 0.169300 | -0.282166 | 127 | 0.282166 | -0.282166 |

**TABLE D-X continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 128 | -0.959366 | 0.056433 | 160 | -0.507899 | 0.846499 |
| 129 | -0.959366 | 0.169300 | 161 | -0.507899 | 0.733632 |
| 130 | -0.846499 | 0.507899 | 162 | -0.507899 | 0.507899 |
| 131 | -0.959366 | 0.282166 | 163 | -0.507899 | 0.620766 |
| 132 | -0.846499 | 0.056433 | 164 | -0.507899 | 0.056433 |
| 133 | -0.846499 | 0.169300 | 165 | -0.507899 | 0.169300 |
| 134 | -0.846499 | 0.395033 | 166 | -0.507899 | 0.395033 |
| 135 | -0.846499 | 0.282166 | 167 | -0.507899 | 0.282166 |
| 136 | -0.959366 | -0.056433 | 168 | -0.507899 | -0.846499 |
| 137 | -0.959366 | -0.169300 | 169 | -0.507899 | -0.733632 |
| 138 | -0.846499 | -0.507899 | 170 | -0.507899 | -0.507899 |
| 139 | -0.959366 | -0.282166 | 171 | -0.507899 | -0.620766 |
| 140 | -0.846499 | -0.056433 | 172 | -0.507899 | -0.056433 |
| 141 | -0.846499 | -0.169300 | 173 | -0.507899 | -0.169300 |
| 142 | -0.846499 | -0.395033 | 174 | -0.507899 | -0.395033 |
| 143 | -0.846499 | -0.282166 | 175 | -0.507899 | -0.282166 |
| 144 | -0.169300 | 0.959366 | 176 | -0.282166 | 0.959366 |
| 145 | -0.056433 | 0.998304 | 177 | -0.620766 | 0.733632 |
| 146 | -0.733632 | 0.507899 | 178 | -0.620766 | 0.507899 |
| 147 | -0.733632 | 0.620766 | 179 | -0.620766 | 0.620766 |
| 148 | -0.733632 | 0.056433 | 180 | -0.620766 | 0.056433 |
| 149 | -0.733632 | 0.169300 | 181 | -0.620766 | 0.169300 |
| 150 | -0.733632 | 0.395033 | 182 | -0.620766 | 0.395033 |
| 151 | -0.733632 | 0.282166 | 183 | -0.620766 | 0.282166 |
| 152 | -0.169300 | -0.959366 | 184 | -0.282166 | -0.959366 |
| 153 | -0.056433 | -0.998304 | 185 | -0.620766 | -0.733632 |
| 154 | -0.733632 | -0.507899 | 186 | -0.620766 | -0.507899 |
| 155 | -0.733632 | -0.620766 | 187 | -0.620766 | -0.620766 |
| 156 | -0.733632 | -0.056433 | 188 | -0.620766 | -0.056433 |
| 157 | -0.733632 | -0.169300 | 189 | -0.620766 | -0.169300 |
| 158 | -0.733632 | -0.395033 | 190 | -0.620766 | -0.395033 |
| 159 | -0.733632 | -0.282166 | 191 | -0.620766 | -0.282166 |

**TABLE D-X continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 192 | -0.056433 | 0.846499 | 224 | -0.395033 | 0.846499 |
| 193 | -0.056433 | 0.733632 | 225 | -0.395033 | 0.733632 |
| 194 | -0.056433 | 0.507899 | 226 | -0.395033 | 0.507899 |
| 195 | -0.056433 | 0.620766 | 227 | -0.395033 | 0.620766 |
| 196 | -0.056433 | 0.056433 | 228 | -0.395033 | 0.056433 |
| 197 | -0.056433 | 0.169300 | 229 | -0.395033 | 0.169300 |
| 198 | -0.056433 | 0.395033 | 230 | -0.395033 | 0.395033 |
| 199 | -0.056433 | 0.282166 | 231 | -0.395033 | 0.282166 |
| 200 | -0.056433 | -0.846499 | 232 | -0.395033 | -0.846499 |
| 201 | -0.056433 | -0.733632 | 233 | -0.395033 | -0.733632 |
| 202 | -0.056433 | -0.507899 | 234 | -0.395033 | -0.507899 |
| 203 | -0.056433 | -0.620766 | 235 | -0.395033 | -0.620766 |
| 204 | -0.056433 | -0.056433 | 236 | -0.395033 | -0.056433 |
| 205 | -0.056433 | -0.169300 | 237 | -0.395033 | -0.169300 |
| 206 | -0.056433 | -0.395033 | 238 | -0.395033 | -0.395033 |
| 207 | -0.056433 | -0.282166 | 239 | -0.395033 | -0.282166 |
| 208 | -0.169300 | 0.846499 | 240 | -0.282166 | 0.846499 |
| 209 | -0.169300 | 0.733632 | 241 | -0.282166 | 0.733632 |
| 210 | -0.169300 | 0.507899 | 242 | -0.282166 | 0.507899 |
| 211 | -0.169300 | 0.620766 | 243 | -0.282166 | 0.620766 |
| 212 | -0.169300 | 0.056433 | 244 | -0.282166 | 0.056433 |
| 213 | -0.169300 | 0.169300 | 245 | -0.282166 | 0.169300 |
| 214 | -0.169300 | 0.395033 | 246 | -0.282166 | 0.395033 |
| 215 | -0.169300 | 0.282166 | 247 | -0.282166 | 0.282166 |
| 216 | -0.169300 | -0.846499 | 248 | -0.282166 | -0.846499 |
| 217 | -0.169300 | -0.733632 | 249 | -0.282166 | -0.733632 |
| 218 | -0.169300 | -0.507899 | 250 | -0.282166 | -0.507899 |
| 219 | -0.169300 | -0.620766 | 251 | -0.282166 | -0.620766 |
| 220 | -0.169300 | -0.056433 | 252 | -0.282166 | -0.056433 |
| 221 | -0.169300 | -0.169300 | 253 | -0.282166 | -0.169300 |
| 222 | -0.169300 | -0.395033 | 254 | -0.282166 | -0.395033 |
| 223 | -0.169300 | -0.282166 | 255 | -0.282166 | -0.282166 |

D.5.1.2.3 Walsh Orthogonal Modulation.
Waveform ID 0 utilizes a different modulation technique, Walsh Orthogonal Modulation. Slightly different methods are used for bandwidths from 3 to 24 kHz and bandwidths from 30 to 48 kHz, as specified in the following paragraphs.

D.5.1.2.3.1 Walsh Orthogonal Modulation for bandwidths from 3 to 24 kHz.
In bandwidths from 3 to 24 kHz, for each pair of coded and interleaved data bits, the method produces a 32 symbol repeated Walsh sequence. The Walsh Orthogonal Modulation is accomplished by taking each pair of bits, or di-bit, and selecting a corresponding Walsh Sequence.

| Di-bit | Walsh Sequence |
|---|---|
| 00 | 0000 |
| 01 | 0404 |
| 10 | 0044 |
| 11 | 0440 |

The selected four element Walsh sequence is repeated 8 times to yield a 32 element Walsh sequence.

For example, if the di-bit is 01, the sequence 0404 is repeated to generate

0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4

The last di-bit in any interleaver block shall be identified by use of an alternate set of Walsh sequences, which are repeated 4 times to achieve 32 symbols:

| Di-bit | Alternate Walsh Sequence |
|---|---|
| 00 | 00004444 |
| 01 | 04044040 |
| 10 | 00444400 |
| 11 | 04404004 |

The 32-symbol channel symbol shall be produced by an element by element modulo 8 addition of the repeated Walsh Sequence and the scrambling sequence (see D.5.1.4).

D.5.1.2.3.2 Walsh Orthogonal Modulation for bandwidths from 30 to 48 kHz.
In bandwidths from 30 to 48 kHz, for each four coded and interleaved data bits, the method produces a 64-symbol repeated Walsh sequence. The Walsh Orthogonal Modulation is accomplished by taking each set of four bits, or quad-bit, and selecting a corresponding Walsh Sequence.

| Quad-bit | Walsh Sequence |
|---|---|
| 0000 | 0000000000000000 |
| 0001 | 0404040404040404 |
| 0010 | 0044004400440044 |
| 0011 | 0440044004400440 |
| 0100 | 0000444400004444 |
| 0101 | 0404404004044040 |
| 0110 | 0044440000444400 |
| 0111 | 0440400404404004 |
| 1000 | 0000000044444444 |
| 1001 | 0404040440404040 |
| 1010 | 0044004444004400 |
| 1011 | 0440044040044004 |
| 1100 | 0000444444440000 |
| 1101 | 0404404040400404 |
| 1110 | 0044440044000044 |
| 1111 | 0440400440040440 |

The selected 16-element Walsh sequence is repeated 4 times to yield a 64-element Walsh sequence. For example, if the quad-bit is 0001, the sequence 0404040404040404 is repeated to generate

0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4

The last quad-bit in any interleaver block shall be identified by use of an alternate set of 32-symbol Walsh sequences. The selected sequence is repeated to yield a 64-element sequence:

| Quad-bit | Alternate Walsh Sequence |
|---|---|
| 0000 | 0000000000000000 4444444444444444 |
| 0001 | 0404040404040404 4040404040404040 |
| 0010 | 0044004400440044 4400440044004400 |
| 0011 | 0440044004400440 4004400440044004 |
| 0100 | 0000444400004444 4444000044440000 |
| 0101 | 0404404004044040 4040040440400404 |
| 0110 | 0044440000444400 4400004444000044 |
| 0111 | 0440400404404004 4004044040040440 |
| 1000 | 0000000044444444 4444444400000000 |
| 1001 | 0404040440404040 4040404004040404 |
| 1010 | 0044004444004400 4400440000440044 |
| 1011 | 0440044040044004 4004400404400440 |
| 1100 | 0000444444440000 4444000000004444 |
| 1101 | 0404404040400404 4040040404044040 |
| 1110 | 0044440044000044 4400004400444400 |
| 1111 | 0440400440040440 4004044004404004 |

The 64-symbol channel symbol shall be produced by an element by element modulo 8 addition of the repeated Walsh Sequence and the scrambling sequence (see D.5.1.4).

D.5.1.3 Data scrambling.

Data symbols for Waveforms 1 through 7 and 13 (using BPSK, QPSK, or 8PSK modulation) shall be scrambled by modulo 8 addition with a scrambling sequence.

The data symbols for Waveforms 8 through 12(16QAM, 32QAM, 64QAM and 256QAM modulation) shall be scrambled by using an exclusive or (XOR) operation. Sequentially, the data bits forming each symbol (4 for 16QAM, 5 for 32QAM, 6 for 64QAM and 8 for 256 QAM) shall be XOR'd with an equal number of bits from the scrambling sequence.

For Waveforms 1 through 13, the scrambling sequence generator polynomial shall be $x^9+x^4+1$ and the generator shall be initialized to 1 at the start of each data frame. A block diagram of the scrambling sequence generator is shown in Figure D-6. In this illustration, three output bits are shown; this is the case for all PSK waveforms. For $2^N$ QAM waveforms, the rightmost N bits are used.

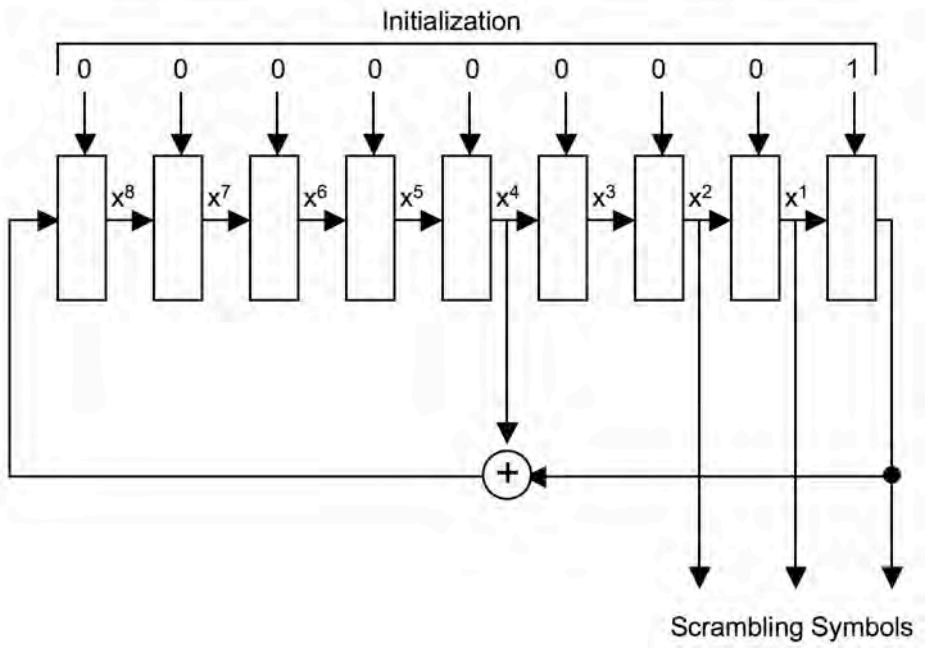


**FIGURE D-6. Scrambling sequence generator illustrating scrambling generator for PSK symbols.**

For PSK symbols (BPSK, QPSK, and 8PSK), the scrambling shall be carried out taking the modulo 8 sum of the numerical value of the binary triplet consisting of the last (rightmost) three bits in the shift register, and the symbol number (transcoded value). For example, if the last three bits in the scrambling sequence shift register were 010 which has a numerical value equal 2, and the symbol number before scrambling was 6, symbol 0 would be transmitted since (6+2) Modulo 8 = 0.

For 16QAM symbols, scrambling shall be carried out by XORing the 4 bit number consisting of the last (rightmost) four bits in the shift register with the symbol number. For example, if the last 4 bits in the scrambling sequence shift register were 0101 and the 16QAM symbol number

before scrambling was 3 (i.e. 0011), symbol 6 (0110) would be transmitted. For 32QAM symbols, scrambling shall be carried out by XORing the 5 bit number formed by the last (rightmost) five bits in the shift register with the symbol number. For 64QAM symbols, scrambling shall be carried out by XORing the 6 bit number formed by the last (rightmost) six bits in the shift register with the symbol number. For 256QAM symbols, scrambling shall be carried out by XORing the 8 bit number formed by the last (rightmost) eight bits in the shift register with the symbol number.

After each data symbol is scrambled, the generator shall be iterated (shifted) the required number of times to produce all new bits for use in scrambling the next symbol (i.e., 3 iterations for 8PSK, 4 iterations for 16QAM, 5 iterations for 32QAM and 6 iterations for 64QAM, and 8 iterations for 256QAM). Since the generator is iterated after the bits are used, the first data symbol of every data frame shall, therefore, be scrambled by the appropriate number of bits from the initialization value of 00000001.

The length of the scrambling sequence is 511 bits. For a 256 symbol data block with 6 bits per symbol, this means that the scrambling sequence will be repeated just slightly more than 3 times, although in terms of symbols, there will be no repetition.

D.5.1.4 Waveform ID 0 Walsh Orthogonal Modulation Data scrambling.
For the case of Waveform ID 0, an 8-PSK data scrambling sequence is utilized. This sequence is generated in a fashion similar to that described above but is based on a longer shift register of 159 bits with a single tap after bit 31. This is an implementation of a Trinomial (159, 31). The shift register is initialized to the following state:

```
int bitshift[159] =
{0, 0, 0, 1, 0, 0, 1, 1, 0, 1, 1, 0, 0, 1, 0, 1,
 1, 1, 1, 1, 0, 1, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0,
 1, 0, 1, 1, 0, 0, 1, 1, 0, 0, 1, 0, 1, 1, 1, 0,
 1, 1, 1, 0, 0, 0, 1, 1, 0, 0, 0, 1, 0, 0, 0, 0,
 1, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 1, 1, 0, 1,
 0, 1, 1, 1, 1, 0, 1, 0, 1, 0, 0, 0, 1, 1, 1, 1,
 1, 1, 0, 0, 1, 1, 0, 1, 0, 1, 1, 1, 1, 1, 0, 1,
 1, 1, 1, 0, 0, 0, 1, 1, 0, 0, 0, 1, 1, 0, 1, 0,
 1, 1, 1, 0, 0, 1, 1, 1, 0, 0, 0, 1, 1, 0, 0, 0,
 1, 0, 0, 1, 0, 0, 0, 1, 1, 0, 1, 0, 0, 1, 1};
```

For Waveform ID 0 this implementation is used to generate 256*8 or 2048 values. The shift register is iterated 16 times between the generation of each 8-PSK symbol.

```
int tri( void)
{
   int bitout, bittap, bitin;
   int i,j;

   for(j=0;j<16;j++)
   {
      bitout = bitshift[158];
      bittap = bitshift[31];
      for(i=158;i>=1;i--) bitshift[i]=bitshift[i-1];
      bitin = bitout^bittap;
      bitshift[0]=bitin;
   }
   return (bitshift[2]<<2)+(bitshift[1]<<1)+bitshift[0];
}
```

Each channel symbol of the WID 0 waveforms is scrambled using 32 chips or symbols of the scramble sequence, generated as defined above.

For example, the first 32 symbols of the scramble sequence are

5, 6, 2, 1, 7, 3, 1, 1, 6, 0, 5, 4, 0, 7, 7, 0, 5, 3, 1, 3, 3, 2, 2, 5, 5, 4, 7, 3, 5, 4, 3, 0,

For this example, assume the coded and interleaved data di-bit to be sent is 01; then the corresponding Walsh sequence 0 4 0 4 is repeated and combined with this scrambling sequence as shown below:

0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4, 0, 4
5, 6, 2, 1, 7, 3, 1, 1, 6, 0, 5, 4, 0, 7, 7, 0, 5, 3, 1, 3, 3, 2, 2, 5, 5, 4, 7, 3, 5, 4, 3, 0,
==========
5, 2, 2, 5, 7, 7, 1, 5, 6, 4, 5, 0, 0, 3, 7, 4, 5, 7, 1, 7, 3, 6, 2, 1, 5, 0, 7, 7, 5, 0, 3, 4

For the Walsh Orthogonal Modes the sequences are continuously wrapped around the 2048 symbol boundary. The sequence is reset to the initialization value at the interleaver boundary.

D.5.1.5 Modulation filter.

The role of the modulation filter is to spectrally constrain the transmit waveform to within the specified bandwidth. A square root of raised cosine filter is recommended with a roll off factor (excess bandwidth) of 35%. Utilizing this filter as both the modem modulation filter and demodulation filter will maximize the signal to noise ratio and minimize inter-symbol interference. The combined modulation and demodulation filters will have the following frequency response (symmetric around 0 Hz):

$H(f) = 1$ for $|f| <= f_n - pf_n$

$H(f) = 0.5( 1 - \sin(f-f_n * PI / 2pf_n)$ for $f_n - pf_n < |f| <= f_n + pf_n$

$H(f) = 0$ elsewhere

Where:

$f_n$ is the Nyquist frequency ( $f_n$ = 1 / (2T) = (1 / 2) * SYMBOL RATE = 1200 Hz for 3kHz BW, 9600Hz for 24kHz BW)

p is the roll off factor or excess bandwidth.

The individual modulation and demodulation filters are realized by taking the square root of the above frequency response.

D.5.2 Frame structure.

The frame structure that shall be used for the waveforms specified in this appendix is shown in Figure D-7. An initial synchronization preamble is followed by frames of alternating data (Unknown) and probe (Known) symbols. Each data frame shall consist of a data block consisting of U data symbols, followed by a mini-probe consisting of K known symbols.

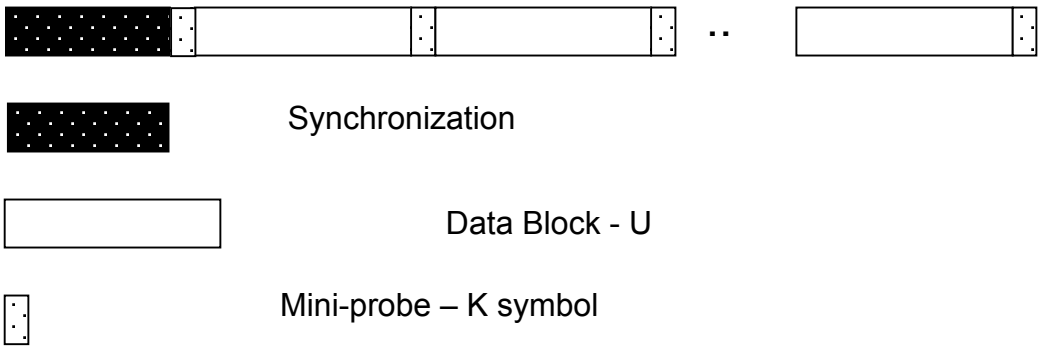


**FIGURE D-7. Frame structure for waveforms 1-13.**

Tables D-XI and D-XII provide the Unknown and Known frame structure for waveforms 1 through 12.

Waveform 0 uses a different structure after the Synchronization Preamble, in which data "frames" are 32-symbol Walsh sequences (channel symbols), each corresponding to a single unknown (data) bit (a di-bit after coding). Mini-probes are not sent in waveform 0, so Walsh-coded data symbols are sent continuously after the initial Synchronization Preamble.

## TABLE D- XI. Number of Unknown (Data) Symbols in Frame

| Waveform Number | 0 Walsh | 1 BPSK | 2 BPSK | 3 BPSK | 4 BPSK | 5 BPSK | 6 QPSK | 7 8PSK | 8 16QAM | 9 32QAM | 10 64QAM | 11 64QAM | 12 256QAM | 13 QPSK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Bandwidth** (kHz) | | | | | | | | | | | | | | |
| 3 | N/A | 48 | 48 | 96 | 96 | 256 | 256 | 256 | 256 | 256 | 256 | 360 | 360 | 256 |
| 6 | N/A | 96 | 96 | 204 | 204 | 544 | 544 | 544 | 544 | 544 | 544 | 540 | 540 | |
| 9 | N/A | 288 | 288 | 288 | - | 768 | 768 | 768 | 768 | 768 | 768 | 1080 | 1080 | |
| 12 | N/A | 192 | 192 | 384 | 384 | 1024 | 1024 | 1024 | 1024 | 1024 | 1024 | 1080 | 1080 | |
| 15 | N/A | 288 | 288 | 288 | 288 | 1280 | 1280 | 1280 | 1280 | 1280 | 1280 | 1152 | 1152 | |
| 18 | N/A | 448 | 448 | 448 | - | 1536 | 1536 | 1536 | 1536 | 1536 | 1536 | 1920 | 1920 | |
| 21 | N/A | 320 | 320 | 320 | 320 | 1344 | 1344 | 1344 | 1344 | 1344 | 1344 | 2560 | 2560 | |
| 24 | N/A | 272 | 272 | 816 | 816 | 2176 | 2176 | 2176 | 2176 | 2176 | 2176 | 1920 | 1920 | |
| 30 | N/A | 576 | 576 | 576 | 576 | 2560 | 2560 | 2560 | 2560 | 2560 | 2560 | 2700 | 2700 | |
| 36 | N/A | 1152 | 1152 | 1152 | 3072 | 3072 | 3072 | 3072 | 3072 | 3072 | 3072 | 3240 | 3240 | |
| 42 | N/A | 768 | 768 | 768 | 3456 | 3456 | 3456 | 3456 | 3456 | 3456 | 3456 | 3840 | 3840 | |
| 48 | N/A | 512 | 512 | 512 | 2560 | 2560 | 2560 | 2560 | 2560 | 2560 | 2560 | 2880 | 2880 | |

## TABLE D- XII. Number of Known Symbols (Mini-Probe) in Frame

| Waveform Number | 0 Walsh | 1 BPSK | 2 BPSK | 3 BPSK | 4 BPSK | 5 BPSK | 6 QPSK | 7 8PSK | 8 16QAM | 9 32QAM | 10 64QAM | 11 64QAM | 12 256QAM | 13 QPSK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Bandwidth** (kHz) | | | | | | | | | | | | | | |
| 3 | N/A | 48 | 48 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 24 | 24 | 32 |
| 6 | N/A | 96 | 96 | 68 | 68 | 68 | 68 | 68 | 68 | 68 | 68 | 36 | 36 | |
| 9 | N/A | 144 | 144 | 144 | - | 96 | 96 | 96 | 96 | 96 | 96 | 72 | 72 | |
| 12 | N/A | 192 | 192 | 128 | 128 | 128 | 128 | 128 | 128 | 128 | 128 | 72 | 72 | |
| 15 | N/A | 192 | 192 | 192 | 192 | 160 | 160 | 160 | 160 | 160 | 160 | 128 | 128 | |
| 18 | N/A | 224 | 224 | 224 | - | 192 | 192 | 192 | 192 | 192 | 192 | 128 | 128 | |
| 21 | N/A | 240 | 240 | 240 | 240 | 224 | 224 | 224 | 224 | 224 | 224 | 128 | 128 | |
| 24 | N/A | 272 | 272 | 272 | 272 | 272 | 272 | 272 | 272 | 272 | 272 | 128 | 128 | |
| 30 | N/A | 384 | 384 | 384 | 384 | 320 | 320 | 320 | 320 | 320 | 320 | 180 | 180 | |
| 36 | N/A | 576 | 576 | 576 | 384 | 384 | 384 | 384 | 384 | 384 | 384 | 216 | 216 | |
| 42 | N/A | 576 | 576 | 576 | 576 | 576 | 576 | 576 | 576 | 576 | 576 | 192 | 192 | |
| 48 | N/A | 512 | 512 | 512 | 512 | 512 | 512 | 512 | 512 | 512 | 512 | 192 | 192 | |

D.5.2.1 Synchronization preamble.

The synchronization preamble is used for rapid initial synchronization and provides time and frequency alignment. The synchronization preamble shall consist of two main sections, a transmitter level control (TLC) settling time section, and a synchronization section containing a repeated preamble super-frame. The preamble super-frame consists of three distinct subsections, one with a fixed (known) modulation, one to convey a downcount, and one to convey waveform identification. The superframe shall be repeated M times. The Synchronization section shall be immediately followed by the modulated data (Figure D-8).

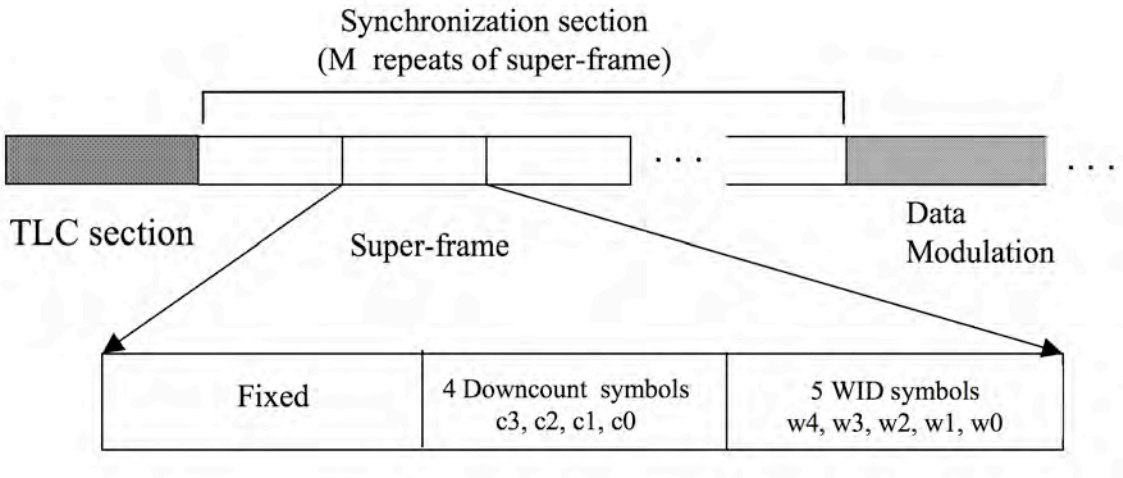


**FIGURE D-8. Synchronization preamble structure.**

D.5.2.1.1 4-ary Orthogonal Walsh Modulation in the preamble.

4-ary orthogonal Walsh modulation shall be used in the synchronization section of the preamble. The length of each channel symbol, in chips or symbols, is dependent on the bandwidth of the modem waveform selected and shall be as given by Table D-XIII.

**TABLE D-XIII. Length of Preamble Channel Symbols**

| Bandwidth (kHz) | Walsh Sequence Length in Preamble |
|---|---|
| 3 | 32 |
| 6 | 64 |
| 9 | 96 |
| 12 | 128 |
| 15 | 160 |
| 18 | 192 |
| 21 | 224 |
| 24 | 256 |

The 4-ary orthogonal Walsh modulation shall use the Walsh sequences in Table D-XIV. The di-bit representing the 2 bits of information to convey is mapped into a 4 element Walsh sequence of 0 and 4 as defined in Table D-XIV. This 4-element sequence shall be repeated to satisfy the Walsh sequence length requirement in Table D-XIII for the bandwidth in use.

**TABLE D-XIV. Walsh Sequences for Synchronization Section of the Preamble**

| Di-bit | Walsh Sequence |
|---|---|
| 00 | 0000 |
| 01 | 0404 |
| 10 | 0044 |
| 11 | 0440 |

Scrambling shall be performed by aligning the expanded Walsh sequence with the Fixed, Count, or the Waveform ID synchronization preambles defined in Tables D-XVIII, D-XIX, D-XX, respectively, and performing a modulo 8 addition between the specified 8-PSK symbol from the table and the corresponding Walsh element.

D.5.2.1.2 TLC Section.
The first section of the preamble, denoted TLC, is provided exclusively for radio and modem TGC and AGC. It shall consist of N blocks of 8-PSK. The length of each block in PSK symbols, based on the bandwidth used in the transmission to follow, shall be as shown in Table D-XIII. The value of N shall be configurable to range from 0 to 255 (for N=0 this first section is not transmitted). These symbols shall be formed by taking the complex conjugate of the symbols of the sequence specified below for the Fixed section in Table D-XVIII.

D.5.2.1.3 Synchronization Section.
The Fixed subsection of the super-frame shall consist of either 1 or 9 orthogonal Walsh modulated channel symbols. The length of each channel symbol, dependent on bandwidth, is given in Table D-XIII. For the case of the single Walsh symbol the di-bit shall be 3 (binary 11) , and the super frame shall be transmitted only once (M=1). For the case of 9 Walsh symbols the di-bits shall be {0, 0, 2, 1, 2, 1, 0, 2, 3}, 3 being the last di-bit transmitted. The Fixed subsection is intended exclusively for synchronization and Doppler offset removal purposes.

The next subsection shall consists of four, orthogonal Walsh modulated di-bits, labeled as c3, c2, c1 and c0, each conveying two bits of information. This subsection represents a 5 bit downcount plus 3 parity bits. This count shall be initialized to a value of (M-1) and shall be decremented with each of the M preamble repetitions until it reaches zero in the final super-frame before data begins.

The final subsection of the preamble super-frame shall consist of five, orthogonal Walsh modulated channel symbols, each conveying two bits of information. These di-bits are labeled as w4, w3, w2, w1, and w0. These 10 bits represent a Waveform ID consisting of waveform number, interleaver option, convolutional code length and parity check.

D.5.2.1.3.1 Mapping of the downcount di-bits c3, c2, c1, and c0.
The 5 bit super-frame down count is initialized to M-1 where M is the number of repeats of the super-frame and can be viewed as a binary number b4b3b2b1b0 where b4 is the MSB and b0 is the LSB. Bits b7, b6, and b5 shall contain a parity check computed over b4b3b2b1b0 as follows, where the ^ symbol indicates exclusive-or:

b7 = b1 ^ b2 ^ b3

b6 = b2 ^ b3 ^ b4

b5 = b0 ^ b1 ^ b2

C3 shall contain the two MSBs b7 and b6, b7 being the MSB. C2 shall contain the next two bits of the count b5 and b4, b5 being the MSB. C1 shall contain the next two bits of the count b3 and b2, b3 being the MSB. C0 shall contain the last two bits of the count b1 and b0, b1 being the MSB.

D.5.2.1.3.2 Mapping of the Waveform ID di-bits w4, w3, w2, w1, and w0.
The 10 bit waveform ID field consists of 5 di-bits w4, w3, w2, w1, and w0. The 10 bits are labeled d9 down to d0. W4 contains d9 and d8, where d9 is the MSB, w3 contains d7 and d6, and so on down to w0 which contains d1 and d0.

The 3 LSBs, d2, d1, and d0, shall contain a 3 bit checksum calculated over d9d8d7d6d5d4d3 as follows, where the ^ symbol indicates exclusive-or:

d2 = d9 ^ d8 ^ d7

d1 = d7 ^ d6 ^ d5

d0 = d5 ^ d4 ^ d3

The four bit waveform number, defined in Table D-II for all possible waveform options for a given bandwidth, shall be mapped into the w4 and w3 di-bits as defined in Table D-XV. The reserved encodings shall not be sent.

**TABLE D-XV. Waveform number mapping.**

| Waveform Number | w4 d9 d8 | w3 d7 d6 |
|---|---|---|
| 0 | 0 0 | 0 0 |
| 1 | 0 0 | 0 1 |
| 2 | 0 0 | 1 0 |
| 3 | 0 0 | 1 1 |
| 4 | 0 1 | 0 0 |
| 5 | 0 1 | 0 1 |
| 6 | 0 1 | 1 0 |
| 7 | 0 1 | 1 1 |
| 8 | 1 0 | 0 0 |
| 9 | 1 0 | 0 1 |
| 10 | 1 0 | 1 0 |
| 11 | 1 0 | 1 1 |
| 12 | 1 1 | 0 0 |
| 13 | 1 1 | 0 1 |
| (reserved) | 1 1 | 1 0 |
| (reserved) | 1 1 | 1 1 |

The Interleaver selection shall be mapped to w2 as defined in Table D-XVI.

**TABLE D-XVI. Interleaver selection mapping.**

| Interleaver | w2 d5 d4 |
|---|---|
| Ultra Short | 0 0 |
| Short | 0 1 |
| Medium | 1 0 |
| Long | 1 1 |

The convolutional code constraint length shall be mapped into w1 as defined in Table D-XVII. The lsb of w1 shall be 0.

**TABLE D-XVII. Constraint length and voice mode mapping.**

| Constraint Length | MSB of w1 d3 |
|---|---|
| 7 | 0 |
| 9 | 1 |

D.5.2.1.4 Preamble scrambling sequences.
Expressed as a sequence of 8PSK symbols, using the symbol numbers given in Table D-VI the sections of the preamble shall be scrambled as described in D.5.2.1.1 using the respective sequences shown in Table D-XVIII through D-XX:

**TABLE D-XVIII. TLC / Fixed Synchronization preamble**

```
int fixedPN[256] =
{2,4,0,0,6,2,1,4,6,1,0,5,7,3,4,1,2,6,1,7,0,7,3,2,2,2,3,2,4,6,3,6,
 6,3,7,5,4,7,5,6,7,4,0,2,6,1,5,3,0,4,2,4,6,4,5,2,5,4,5,3,1,5,4,5,
 6,5,1,0,7,1,0,1,0,5,3,5,2,2,4,5,4,0,6,4,1,4,0,3,3,0,0,3,3,7,3,4,
 2,7,4,4,4,0,3,4,7,6,4,2,6,2,0,3,5,3,2,2,4,5,2,0,0,3,5,0,3,2,6,6,
 1,4,2,3,6,1,3,0,3,3,2,4,2,2,6,5,5,3,6,7,6,5,6,6,5,2,5,4,2,3,3,3,
 5,7,5,5,3,7,0,4,7,0,4,1,6,2,3,5,5,6,2,6,4,6,3,4,0,7,0,0,5,2,1,5,
 4,3,4,5,7,0,5,3,7,6,6,6,4,5,6,0,2,0,4,2,3,4,4,0,7,6,6,2,0,0,3,3,
 0,5,2,4,2,2,4,5,4,6,6,6,3,2,1,0,3,2,6,0,6,2,4,0,6,4,1,3,3,5,3,6};
```

**TABLE D-XIX. Count Synchronization preamble.**

```
int cntPN[256] =
{5,5,2,2,0,2,5,6,7,1,3,5,1,5,6,5,3,7,0,4,0,3,3,2,1,3,0,3,1,6,2,6,
 0,6,4,1,2,5,6,3,5,3,7,4,2,6,7,3,0,2,0,1,7,5,0,6,1,5,0,3,2,2,5,2,
 5,2,3,4,2,7,6,1,1,5,2,1,5,4,0,3,5,5,0,3,1,4,0,5,0,3,0,6,0,0,3,1,
 6,1,4,4,7,7,0,5,7,0,1,5,1,0,1,3,1,5,0,7,1,2,2,2,7,1,2,5,0,3,3,2,
 2,0,4,5,1,3,1,3,5,3,1,7,5,2,7,1,3,1,5,6,2,4,6,0,6,1,0,0,3,6,2,7,
 3,2,4,7,6,4,1,3,6,6,0,3,0,0,7,5,4,5,1,2,1,5,0,3,1,0,4,6,6,1,0,5,
 2,6,3,2,7,4,2,4,0,1,7,0,7,0,5,1,4,5,7,2,0,4,4,3,5,2,7,7,4,5,1,4,
 4,6,3,3,0,5,1,5,5,4,3,2,0,3,0,4,7,4,5,1,5,5,7,7,6,2,4,3,5,2,2,4};
```

**TABLE D-XX. Waveform Number Synchronization preamble.**

```
int widPN[256] =
{2,3,0,3,7,3,3,0,1,4,4,6,5,5,4,5,6,2,0,5,6,6,5,3,5,5,2,2,1,2,3,6,
 1,1,4,3,1,0,5,1,0,3,3,0,3,0,4,4,6,2,5,6,1,7,2,6,2,0,0,4,7,2,3,5,
 2,7,1,6,5,0,4,1,6,2,1,5,4,3,5,0,3,4,1,3,2,1,6,1,5,7,0,4,7,6,6,0,
 4,7,6,6,6,6,2,3,5,0,7,0,3,1,5,1,2,0,5,3,2,4,5,6,6,7,7,3,5,1,6,0,
 1,4,4,5,6,0,6,7,2,4,4,0,3,7,2,0,0,1,4,0,7,1,7,4,5,4,5,5,5,3,3,2,
 0,5,1,3,1,5,3,4,1,5,4,1,4,4,2,2,4,3,0,7,4,1,5,7,1,4,7,2,5,5,6,6,
 1,6,5,6,3,0,2,5,7,7,4,4,3,4,4,6,0,7,2,2,0,0,2,1,0,0,3,6,6,4,0,2,
 4,3,4,5,2,6,3,7,7,5,7,3,0,7,0,0,7,2,6,2,2,6,1,4,3,7,6,5,0,6,5,4};
```

D.5.2.2 Mini-probes.

Mini-probes shall be inserted, following every data block and at the end of each preamble, for non-Walsh based modulations (i.e., all except Waveform ID 0). To support the wide range of bit rate and bandwidth options of this standard, 14 different mini-probe sequences are utilized. Each of the mini-probes consists of the base sequence cyclically extended to the required length.

The mini-probes are also utilized to identify the long interleaver block boundary. This is accomplished by transmitting a cyclically rotated version of the mini-probe following the second to last data block of the long interleaver frame. The position of this cyclically shifted mini-probe remains constant regardless of which interleaver has actually been selected. As all interleavers line up on the long interleaver block boundary, this feature can be used to synchronize to a broadcast transmission and provide a late entry feature when the Waveform ID fields are known in advance by the receiver. The cyclically rotated version of the mini-probe is obtained by first cyclically extending the base sequence, and then shifting by a predetermined number of symbols.

Table D-XXI defines the mini-probe lengths and the base sequence used to generate the full mini-probe and also the cyclic shift utilized to signal the interleaver block boundary.

**TABLE D-XXI. Mini-probe lengths and base sequences.**

| Mini-Probe Length | Base Sequence | Cyclic Shift for Interleaver Boundary |
|---|---|---|
| 24 | 13 | 6 |
| 32 | 16 | 8 |
| 36 | 19 | 9 |
| 48 | 25 | 12 |
| 64 | 36 | 18 |
| 68 | 36 | 18 |
| 72 | 36 | 18 |
| 96 | 49 | 24 |
| 128 | 64 | 32 |
| 144 | 81 | 40 |
| 160 | 81 | 40 |
| 180 | 100 | 50 |
| 192 | 100 | 50 |
| 216 | 121 | 60 |
| 224 | 121 | 60 |
| 240 | 121 | 60 |
| 272 | 144 | 72 |
| 320 | 169 | 85 |
| 384 | 196 | 98 |
| 512 | 256 | 128 |
| 576 | 289 | 145 |

In the case of the cyclic shift applied to the mini-probe for use in marking the long interleaver block boundary, the first element of the sequence transmitted is the one corresponding to the specified cyclic shift.

The method of forming the mini-probe from the specified base sequence will be illustrated using the 24 symbol mini-probe and the cyclically shifted version of the 24 symbol mini-probe formed from the 13 symbol base sequence. The base sequence of length 13 is listed in Table D-XXII(a). This sequence is cyclically extended by repeating the first 11 symbols of the sequence as shown in Table D-XXII (b) to obtain the required mini-probe of length 24.

**TABLE D-XXII (a). In-phase and Quadrature components of base sequence of length 13 used to form 24 symbol mini-probe.**

| Symbol Number | In-Phase | Quadrature |
|---|---|---|
| 0 | 1.00000 | 0.0 |
| 1 | 1.00000 | 0.0 |
| 2 | 1.00000 | 0.0 |
| 3 | 1.00000 | 0.0 |
| 4 | 1.00000 | 0.0 |
| 5 | -1.00000 | 0.0 |
| 6 | -1.00000 | 0.0 |
| 7 | 1.00000 | 0.0 |
| 8 | 1.00000 | 0.0 |
| 9 | -1.00000 | 0.0 |
| 10 | 1.00000 | 0.0 |
| 11 | -1.00000 | 0.0 |
| 12 | 1.00000 | 0.0 |

**TABLE D-XXII (b). In-phase and Quadrature components of Length 24 mini-probe**

| Symbol Number | In-Phase | Quadrature |
|---|---|---|
| 0 | 1.00000 | 0.0 |
| 1 | 1.00000 | 0.0 |
| 2 | 1.00000 | 0.0 |
| 3 | 1.00000 | 0.0 |
| 4 | 1.00000 | 0.0 |
| 5 | -1.00000 | 0.0 |
| 6 | -1.00000 | 0.0 |
| 7 | 1.00000 | 0.0 |
| 8 | 1.00000 | 0.0 |
| 9 | -1.00000 | 0.0 |
| 10 | 1.00000 | 0.0 |
| 11 | -1.00000 | 0.0 |
| 12 | 1.00000 | 0.0 |
| 13 | 1.00000 | 0.0 |
| 14 | 1.00000 | 0.0 |
| 15 | 1.00000 | 0.0 |
| 16 | 1.00000 | 0.0 |
| 17 | 1.00000 | 0.0 |
| 18 | -1.00000 | 0.0 |
| 19 | -1.00000 | 0.0 |
| 20 | 1.00000 | 0.0 |
| 21 | 1.00000 | 0.0 |
| 22 | -1.00000 | 0.0 |
| 23 | 1.00000 | 0.0 |

Table D-XXII(c) provides an example of the cyclic shift of the 24 symbol mini-probe. As specified in Table D-XXI, the shifted mini-probe sequence begins 6 symbols into the original 13 symbol base sequence. Thus, the shifted mini-probe contains the last 7 symbols of the length 13 base sequence, followed by a complete length 13 base sequence, followed by the first 4 symbols of the length 13 base sequence to complete the 24 symbol mini-probe.

**TABLE D-XXII(c). In-phase and Quadrature components of Length 24 mini-probe cyclically shifted by 6 symbols**

| Symbol Number | In-Phase | Quadrature |
|---|---|---|
| 0 | -1.00000 | 0.0 |
| 1 | 1.00000 | 0.0 |
| 2 | 1.00000 | 0.0 |
| 3 | -1.00000 | 0.0 |
| 4 | 1.00000 | 0.0 |
| 5 | -1.00000 | 0.0 |
| 6 | 1.00000 | 0.0 |
| 7 | 1.00000 | 0.0 |
| 8 | 1.00000 | 0.0 |
| 9 | 1.00000 | 0.0 |
| 10 | 1.00000 | 0.0 |
| 11 | 1.00000 | 0.0 |
| 12 | -1.00000 | 0.0 |
| 13 | -1.00000 | 0.0 |
| 14 | 1.00000 | 0.0 |
| 15 | 1.00000 | 0.0 |
| 16 | -1.00000 | 0.0 |
| 17 | 1.00000 | 0.0 |
| 18 | -1.00000 | 0.0 |
| 19 | 1.00000 | 0.0 |
| 20 | 1.00000 | 0.0 |
| 21 | 1.00000 | 0.0 |
| 22 | 1.00000 | 0.0 |
| 23 | 1.00000 | 0.0 |

The tables which follow provide the In-phase and Quadrature components of each of the base sequences used to form the mini-probes identified in Table D-XXI. The method of construction of each of the mini-probe sequences and the cyclic shifted variant of the mini-probe sequence follows the methodology just illustrated for the length 13 base sequence.

**TABLE D-XXIII. In-phase and Quadrature components of 16 symbol Base Sequence used to form the 32 symbol mini-probe.**

| Symbol Number | In-Phase | Quadrature |
|---|---|---|
| 0 | 1.000000 | 0.000000 |
| 1 | 1.000000 | 0.000000 |
| 2 | 1.000000 | 0.000000 |
| 3 | 1.000000 | 0.000000 |
| 4 | 1.000000 | 0.000000 |
| 5 | 0.000000 | -1.000000 |
| 6 | -1.000000 | 0.000000 |
| 7 | 0.000000 | 1.000000 |
| 8 | 1.000000 | 0.000000 |
| 9 | -1.000000 | 0.000000 |
| 10 | 1.000000 | 0.000000 |
| 11 | -1.000000 | 0.000000 |
| 12 | 1.000000 | 0.000000 |
| 13 | 0.000000 | 1.000000 |
| 14 | -1.000000 | 0.000000 |
| 15 | 0.000000 | -1.000000 |

**TABLE D-XXIV. In-phase and Quadrature components of 19 symbol Base Sequence used to form the 36 symbol mini-probe**

| Symbol Number | In-Phase | Quadrature |
|---|---|---|
| 0 | 1.000000 | 0.000000 |
| 1 | -1.000000 | 0.000000 |
| 2 | 1.000000 | 0.000000 |
| 3 | 1.000000 | 0.000000 |
| 4 | -1.000000 | 0.000000 |
| 5 | -1.000000 | 0.000000 |
| 6 | -1.000000 | 0.000000 |
| 7 | -1.000000 | 0.000000 |
| 8 | 1.000000 | 0.000000 |
| 9 | -1.000000 | 0.000000 |
| 10 | 1.000000 | 0.000000 |
| 11 | -1.000000 | 0.000000 |
| 12 | 1.000000 | 0.000000 |
| 13 | 1.000000 | 0.000000 |
| 14 | 1.000000 | 0.000000 |
| 15 | 1.000000 | 0.000000 |
| 16 | -1.000000 | 0.000000 |
| 17 | -1.000000 | 0.000000 |
| 18 | 1.000000 | 0.000000 |

**TABLE D-XXV. In-phase and Quadrature components of 25 symbol Base Sequence used to form the 48 symbol mini-probe.**

| Symbol Number | In-Phase | Quadrature |
|---|---|---|
| 0 | 1.000000 | 0.000000 |
| 1 | 1.000000 | 0.000000 |
| 2 | 1.000000 | 0.000000 |
| 3 | 1.000000 | 0.000000 |
| 4 | 1.000000 | 0.000000 |
| 5 | 1.000000 | 0.000000 |
| 6 | 0.309017 | -0.951057 |
| 7 | -0.809017 | -0.587785 |
| 8 | -0.809017 | 0.587785 |
| 9 | 0.309017 | 0.951056 |
| 10 | 1.000000 | 0.000000 |
| 11 | -0.809017 | -0.587785 |
| 12 | 0.309017 | 0.951056 |
| 13 | 0.309017 | -0.951057 |
| 14 | -0.809017 | 0.587785 |
| 15 | 1.000000 | 0.000000 |
| 16 | -0.809017 | 0.587785 |
| 17 | 0.309017 | -0.951057 |
| 18 | 0.309017 | 0.951057 |
| 19 | -0.809017 | -0.587785 |
| 20 | 1.000000 | 0.000000 |
| 21 | 0.309017 | 0.951056 |
| 22 | -0.809017 | 0.587785 |
| 23 | -0.809017 | -0.587785 |
| 24 | 0.309016 | -0.951057 |

**TABLE D-XXVI. In-phase and Quadrature components of 36 symbol Base Sequence used to form the 64 and 72 symbol mini-probes.**

| Symbol Number | In-Phase | Quadrature |
|---|---|---|
| 0 | 1.000000 | 0.000000 |
| 1 | 1.000000 | 0.000000 |
| 2 | 1.000000 | 0.000000 |
| 3 | 1.000000 | 0.000000 |
| 4 | 1.000000 | 0.000000 |
| 5 | 1.000000 | 0.000000 |
| 6 | 1.000000 | 0.000000 |
| 7 | 0.500000 | -0.866025 |
| 8 | -0.500000 | -0.866025 |
| 9 | -1.000000 | 0.000000 |
| 10 | -0.500000 | 0.866025 |
| 11 | 0.500000 | 0.866025 |
| 12 | 1.000000 | 0.000000 |
| 13 | -0.500000 | -0.866025 |
| 14 | -0.500000 | 0.866025 |
| 15 | 1.000000 | 0.000000 |
| 16 | -0.500000 | -0.866025 |
| 17 | -0.500000 | 0.866025 |
| 18 | 1.000000 | 0.000000 |
| 19 | -1.000000 | 0.000000 |
| 20 | 1.000000 | 0.000000 |
| 21 | -1.000000 | 0.000000 |
| 22 | 1.000000 | 0.000000 |
| 23 | -1.000000 | 0.000000 |
| 24 | 1.000000 | 0.000000 |
| 25 | -0.500000 | 0.866025 |
| 26 | -0.500000 | -0.866025 |
| 27 | 1.000000 | 0.000000 |
| 28 | -0.500000 | 0.866026 |
| 29 | -0.500000 | -0.866026 |
| 30 | 1.000000 | 0.000000 |
| 31 | 0.500000 | 0.866025 |
| 32 | -0.500000 | 0.866025 |
| 33 | -1.000000 | 0.000000 |
| 34 | -0.500000 | -0.866026 |
| 35 | 0.500000 | -0.866026 |

**TABLE D-XXVII. In-phase and Quadrature components of length 49 Base Sequence used to form the 96 symbol mini-probe.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.000000 | 0.000000 | 25 | -0.222521 | 0.974928 |
| 1 | 1.000000 | 0.000000 | 26 | 0.623490 | -0.781831 |
| 2 | 1.000000 | 0.000000 | 27 | -0.900968 | 0.433885 |
| 3 | 1.000000 | 0.000000 | 28 | 1.000000 | 0.000000 |
| 4 | 1.000000 | 0.000000 | 29 | -0.900969 | 0.433884 |
| 5 | 1.000000 | 0.000000 | 30 | 0.623490 | -0.781832 |
| 6 | 1.000000 | 0.000000 | 31 | -0.222521 | 0.974928 |
| 7 | 1.000000 | 0.000000 | 32 | -0.222521 | -0.974928 |
| 8 | 0.623490 | -0.781832 | 33 | 0.623490 | 0.781832 |
| 9 | -0.222521 | -0.974928 | 34 | -0.900969 | -0.433884 |
| 10 | -0.900969 | -0.433884 | 35 | 1.000000 | 0.000000 |
| 11 | -0.900969 | 0.433884 | 36 | -0.222521 | 0.974928 |
| 12 | -0.222521 | 0.974928 | 37 | -0.900969 | -0.433884 |
| 13 | 0.623490 | 0.781832 | 38 | 0.623490 | -0.781831 |
| 14 | 1.000000 | 0.000000 | 39 | 0.623490 | 0.781832 |
| 15 | -0.222521 | -0.974928 | 40 | -0.900969 | 0.433883 |
| 16 | -0.900969 | 0.433884 | 41 | -0.222520 | -0.974928 |
| 17 | 0.623490 | 0.781832 | 42 | 1.000000 | 0.000000 |
| 18 | 0.623490 | -0.781832 | 43 | 0.623490 | 0.781832 |
| 19 | -0.900969 | -0.433884 | 44 | -0.222521 | 0.974928 |
| 20 | -0.222521 | 0.974928 | 45 | -0.900968 | 0.433885 |
| 21 | 1.000000 | 0.000000 | 46 | -0.900969 | -0.433884 |
| 22 | -0.900969 | -0.433884 | 47 | -0.222520 | -0.974928 |
| 23 | 0.623490 | 0.781832 | 48 | 0.623488 | -0.781833 |
| 24 | -0.222521 | -0.974928 | | | |

**TABLE D-XXVIII. In-phase and Quadrature components of length 64 Base Sequence used to form the 128 symbol mini-probe.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.000000 | 0.000000 | 32 | 1.000000 | 0.000000 |
| 1 | 1.000000 | 0.000000 | 33 | -1.000000 | 0.000000 |
| 2 | 1.000000 | 0.000000 | 34 | 1.000000 | 0.000000 |
| 3 | 1.000000 | 0.000000 | 35 | -1.000000 | 0.000000 |
| 4 | 1.000000 | 0.000000 | 36 | 1.000000 | 0.000000 |
| 5 | 1.000000 | 0.000000 | 37 | -1.000000 | 0.000000 |
| 6 | 1.000000 | 0.000000 | 38 | 1.000000 | 0.000000 |
| 7 | 1.000000 | 0.000000 | 39 | -1.000000 | -0.000000 |
| 8 | 1.000000 | 0.000000 | 40 | 1.000000 | 0.000000 |
| 9 | 0.707107 | -0.707107 | 41 | -0.707107 | 0.707107 |
| 10 | 0.000000 | -1.000000 | 42 | 0.000000 | -1.000000 |
| 11 | -0.707107 | -0.707107 | 43 | 0.707107 | 0.707107 |
| 12 | -1.000000 | 0.000000 | 44 | -1.000000 | 0.000000 |
| 13 | -0.707107 | 0.707107 | 45 | 0.707107 | -0.707107 |
| 14 | 0.000000 | 1.000000 | 46 | 0.000000 | 1.000000 |
| 15 | 0.707107 | 0.707107 | 47 | -0.707107 | -0.707107 |
| 16 | 1.000000 | 0.000000 | 48 | 1.000000 | 0.000000 |
| 17 | 0.000000 | -1.000000 | 49 | 0.000000 | 1.000000 |
| 18 | -1.000000 | 0.000000 | 50 | -1.000000 | 0.000000 |
| 19 | 0.000000 | 1.000000 | 51 | 0.000000 | -1.000000 |
| 20 | 1.000000 | 0.000000 | 52 | 1.000000 | 0.000000 |
| 21 | 0.000000 | -1.000000 | 53 | 0.000000 | 1.000000 |
| 22 | -1.000000 | 0.000000 | 54 | -1.000000 | 0.000000 |
| 23 | 0.000000 | 1.000000 | 55 | 0.000000 | -1.000000 |
| 24 | 1.000000 | 0.000000 | 56 | 1.000000 | 0.000000 |
| 25 | -0.707107 | -0.707107 | 57 | 0.707107 | 0.707107 |
| 26 | 0.000000 | 1.000000 | 58 | 0.000000 | 1.000000 |
| 27 | 0.707107 | -0.707107 | 59 | -0.707107 | 0.707106 |
| 28 | -1.000000 | 0.000000 | 60 | -1.000000 | -0.000001 |
| 29 | 0.707107 | 0.707107 | 61 | -0.707107 | -0.707107 |
| 30 | 0.000000 | -1.000000 | 62 | 0.000000 | -1.000000 |
| 31 | -0.707107 | 0.707106 | 63 | 0.707108 | -0.707106 |

**TABLE D-XXIX. In-phase and Quadrature components of 81 symbol Base Sequence used to form the 144 and 160 symbol mini-probes.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.000000 | 0.000000 | 32 | -0.500000 | 0.866025 |
| 1 | 1.000000 | 0.000000 | 33 | 1.000000 | 0.000000 |
| 2 | 1.000000 | 0.000000 | 34 | -0.500000 | -0.866025 |
| 3 | 1.000000 | 0.000000 | 35 | -0.500000 | 0.866026 |
| 4 | 1.000000 | 0.000000 | 36 | 1.000000 | 0.000000 |
| 5 | 1.000000 | 0.000000 | 37 | -0.939693 | -0.342020 |
| 6 | 1.000000 | 0.000000 | 38 | 0.766044 | 0.642788 |
| 7 | 1.000000 | 0.000000 | 39 | -0.500000 | -0.866025 |
| 8 | 1.000000 | 0.000000 | 40 | 0.173648 | 0.984808 |
| 9 | 1.000000 | 0.000000 | 41 | 0.173648 | -0.984808 |
| 10 | 0.766044 | -0.642788 | 42 | -0.500000 | 0.866026 |
| 11 | 0.173648 | -0.984808 | 43 | 0.766044 | -0.642788 |
| 12 | -0.500000 | -0.866025 | 44 | -0.939693 | 0.342020 |
| 13 | -0.939693 | -0.342020 | 45 | 1.000000 | 0.000000 |
| 14 | -0.939693 | 0.342020 | 46 | -0.939693 | 0.342020 |
| 15 | -0.500000 | 0.866025 | 47 | 0.766044 | -0.642788 |
| 16 | 0.173648 | 0.984808 | 48 | -0.500000 | 0.866025 |
| 17 | 0.766044 | 0.642788 | 49 | 0.173648 | -0.984808 |
| 18 | 1.000000 | 0.000000 | 50 | 0.173649 | 0.984808 |
| 19 | 0.173648 | -0.984808 | 51 | -0.500000 | -0.866026 |
| 20 | -0.939693 | -0.342020 | 52 | 0.766045 | 0.642787 |
| 21 | -0.500000 | 0.866025 | 53 | -0.939693 | -0.342020 |
| 22 | 0.766044 | 0.642788 | 54 | 1.000000 | 0.000000 |
| 23 | 0.766044 | -0.642788 | 55 | -0.500000 | 0.866025 |
| 24 | -0.500000 | -0.866025 | 56 | -0.500000 | -0.866025 |
| 25 | -0.939693 | 0.342020 | 57 | 1.000000 | 0.000000 |
| 26 | 0.173648 | 0.984808 | 58 | -0.500000 | 0.866026 |
| 27 | 1.000000 | 0.000000 | 59 | -0.500000 | -0.866026 |
| 28 | -0.500000 | -0.866025 | 60 | 1.000000 | -0.000000 |
| 29 | -0.500000 | 0.866025 | 61 | -0.500000 | 0.866025 |
| 30 | 1.000000 | 0.000000 | 62 | -0.500000 | -0.866025 |
| 31 | -0.500000 | -0.866025 | 63 | 1.000000 | 0.000000 |

**TABLE D-XXIX. In-phase and Quadrature components of 81 symbol Base Sequence used to form the 144 and 160 symbol mini-probes-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 64 | 0.173648 | 0.984808 | 73 | 0.766044 | 0.642788 |
| 65 | -0.939693 | 0.342020 | 74 | 0.173648 | 0.984808 |
| 66 | -0.500000 | -0.866025 | 75 | -0.500000 | 0.866026 |
| 67 | 0.766044 | -0.642788 | 76 | -0.939693 | 0.342020 |
| 68 | 0.766045 | 0.642787 | 77 | -0.939693 | -0.342020 |
| 69 | -0.500000 | 0.866025 | 78 | -0.500001 | -0.866025 |
| 70 | -0.939693 | -0.342019 | 79 | 0.173648 | -0.984808 |
| 71 | 0.173648 | -0.984808 | 80 | 0.766045 | -0.642787 |
| 72 | 1.000000 | 0.000000 | | | |

**TABLE D-XXX. In-phase and Quadrature components of 100 symbol Base Sequence used to form the 180 and 192 symbol mini-probes.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.000000 | 0.000000 | 32 | -0.809017 | 0.587785 |
| 1 | 1.000000 | 0.000000 | 33 | 0.809017 | 0.587785 |
| 2 | 1.000000 | 0.000000 | 34 | 0.309017 | -0.951057 |
| 3 | 1.000000 | 0.000000 | 35 | -1.000000 | 0.000000 |
| 4 | 1.000000 | 0.000000 | 36 | 0.309017 | 0.951057 |
| 5 | 1.000000 | 0.000000 | 37 | 0.809017 | -0.587785 |
| 6 | 1.000000 | 0.000000 | 38 | -0.809017 | -0.587785 |
| 7 | 1.000000 | 0.000000 | 39 | -0.309018 | 0.951056 |
| 8 | 1.000000 | 0.000000 | 40 | 1.000000 | 0.000000 |
| 9 | 1.000000 | 0.000000 | 41 | -0.809017 | -0.587785 |
| 10 | 1.000000 | 0.000000 | 42 | 0.309017 | 0.951056 |
| 11 | 0.809017 | -0.587785 | 43 | 0.309017 | -0.951057 |
| 12 | 0.309017 | -0.951057 | 44 | -0.809017 | 0.587785 |
| 13 | -0.309017 | -0.951056 | 45 | 1.000000 | 0.000000 |
| 14 | -0.809017 | -0.587785 | 46 | -0.809017 | -0.587785 |
| 15 | -1.000000 | 0.000000 | 47 | 0.309017 | 0.951057 |
| 16 | -0.809017 | 0.587785 | 48 | 0.309016 | -0.951057 |
| 17 | -0.309017 | 0.951056 | 49 | -0.809017 | 0.587785 |
| 18 | 0.309017 | 0.951056 | 50 | 1.000000 | 0.000000 |
| 19 | 0.809017 | 0.587785 | 51 | -1.000000 | 0.000000 |
| 20 | 1.000000 | 0.000000 | 52 | 1.000000 | 0.000000 |
| 21 | 0.309017 | -0.951057 | 53 | -1.000000 | 0.000000 |
| 22 | -0.809017 | -0.587785 | 54 | 1.000000 | 0.000000 |
| 23 | -0.809017 | 0.587785 | 55 | -1.000000 | 0.000000 |
| 24 | 0.309017 | 0.951056 | 56 | 1.000000 | 0.000000 |
| 25 | 1.000000 | 0.000000 | 57 | -1.000000 | -0.000000 |
| 26 | 0.309017 | -0.951057 | 58 | 1.000000 | -0.000000 |
| 27 | -0.809017 | -0.587785 | 59 | -1.000000 | 0.000000 |
| 28 | -0.809017 | 0.587785 | 60 | 1.000000 | 0.000000 |
| 29 | 0.309017 | 0.951057 | 61 | -0.809017 | 0.587785 |
| 30 | 1.000000 | 0.000000 | 62 | 0.309017 | -0.951057 |
| 31 | -0.309017 | -0.951056 | 63 | 0.309017 | 0.951057 |

**TABLE D-XXX. In-phase and Quadrature components of 100 symbol Base Sequence used to form the 180 and 192 symbol mini-probes. - Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 64 | -0.809017 | -0.587785 | 82 | -0.809017 | 0.587785 |
| 65 | 1.000000 | 0.000000 | 83 | -0.809017 | -0.587785 |
| 66 | -0.809017 | 0.587785 | 84 | 0.309016 | -0.951057 |
| 67 | 0.309018 | -0.951056 | 85 | 1.000000 | -0.000000 |
| 68 | 0.309018 | 0.951056 | 86 | 0.309018 | 0.951056 |
| 69 | -0.809016 | -0.587786 | 87 | -0.809018 | 0.587785 |
| 70 | 1.000000 | 0.000000 | 88 | -0.809018 | -0.587784 |
| 71 | -0.309017 | 0.951056 | 89 | 0.309018 | -0.951056 |
| 72 | -0.809017 | -0.587785 | 90 | 1.000000 | 0.000000 |
| 73 | 0.809017 | -0.587785 | 91 | 0.809017 | 0.587785 |
| 74 | 0.309017 | 0.951057 | 92 | 0.309017 | 0.951057 |
| 75 | -1.000000 | -0.000000 | 93 | -0.309018 | 0.951056 |
| 76 | 0.309018 | -0.951056 | 94 | -0.809017 | 0.587785 |
| 77 | 0.809017 | 0.587786 | 95 | -1.000000 | 0.000000 |
| 78 | -0.809018 | 0.587785 | 96 | -0.809016 | -0.587786 |
| 79 | -0.309018 | -0.951056 | 97 | -0.309018 | -0.951056 |
| 80 | 1.000000 | 0.000000 | 98 | 0.309018 | -0.951056 |
| 81 | 0.309017 | 0.951056 | 99 | 0.809016 | -0.587787 |

**TABLE D-XXXI. In-phase and Quadrature components of 121 symbol Base Sequence used to form the 216, 224 and 240 symbol mini-probes.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.000000 | 0.000000 | 32 | 0.415415 | 0.909632 |
| 1 | 1.000000 | 0.000000 | 33 | 1.000000 | 0.000000 |
| 2 | 1.000000 | 0.000000 | 34 | -0.142315 | -0.989821 |
| 3 | 1.000000 | 0.000000 | 35 | -0.959493 | 0.281733 |
| 4 | 1.000000 | 0.000000 | 36 | 0.415415 | 0.909632 |
| 5 | 1.000000 | 0.000000 | 37 | 0.841254 | -0.540641 |
| 6 | 1.000000 | 0.000000 | 38 | -0.654861 | -0.755750 |
| 7 | 1.000000 | 0.000000 | 39 | -0.654861 | 0.755750 |
| 8 | 1.000000 | 0.000000 | 40 | 0.841253 | 0.540641 |
| 9 | 1.000000 | 0.000000 | 41 | 0.415415 | -0.909632 |
| 10 | 1.000000 | 0.000000 | 42 | -0.959493 | -0.281732 |
| 11 | 1.000000 | 0.000000 | 43 | -0.142315 | 0.989821 |
| 12 | 0.841254 | -0.540641 | 44 | 1.000000 | 0.000000 |
| 13 | 0.415415 | -0.909632 | 45 | -0.654861 | -0.755750 |
| 14 | -0.142315 | -0.989821 | 46 | -0.142315 | 0.989821 |
| 15 | -0.654861 | -0.755750 | 47 | 0.841254 | -0.540641 |
| 16 | -0.959493 | -0.281733 | 48 | -0.959493 | -0.281733 |
| 17 | -0.959493 | 0.281733 | 49 | 0.415415 | 0.909632 |
| 18 | -0.654861 | 0.755750 | 50 | 0.415415 | -0.909632 |
| 19 | -0.142315 | 0.989821 | 51 | -0.959493 | 0.281733 |
| 20 | 0.415415 | 0.909632 | 52 | 0.841253 | 0.540641 |
| 21 | 0.841253 | 0.540641 | 53 | -0.142315 | -0.989821 |
| 22 | 1.000000 | 0.000000 | 54 | -0.654861 | 0.755749 |
| 23 | 0.415415 | -0.909632 | 55 | 1.000000 | 0.000000 |
| 24 | -0.654861 | -0.755750 | 56 | -0.959493 | -0.281733 |
| 25 | -0.959493 | 0.281733 | 57 | 0.841253 | 0.540641 |
| 26 | -0.142315 | 0.989821 | 58 | -0.654861 | -0.755750 |
| 27 | 0.841253 | 0.540641 | 59 | 0.415415 | 0.909632 |
| 28 | 0.841254 | -0.540641 | 60 | -0.142315 | -0.989821 |
| 29 | -0.142315 | -0.989821 | 61 | -0.142315 | 0.989821 |
| 30 | -0.959493 | -0.281733 | 62 | 0.415415 | -0.909632 |
| 31 | -0.654861 | 0.755750 | 63 | -0.654861 | 0.755749 |

**TABLE D-XXXI. In-phase and Quadrature components of 121 symbol Base Sequence used to form the 224 and 240 symbol mini-probes.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 64 | 0.841254 | -0.540640 | 93 | -0.654861 | 0.755749 |
| 65 | -0.959493 | 0.281732 | 94 | -0.654861 | -0.755750 |
| 66 | 1.000000 | 0.000000 | 95 | 0.841253 | -0.540641 |
| 67 | -0.959493 | 0.281733 | 96 | 0.415414 | 0.909633 |
| 68 | 0.841254 | -0.540641 | 97 | -0.959493 | 0.281733 |
| 69 | -0.654861 | 0.755750 | 98 | -0.142314 | -0.989822 |
| 70 | 0.415415 | -0.909632 | 99 | 1.000000 | 0.000000 |
| 71 | -0.142315 | 0.989821 | 100 | 0.415415 | 0.909632 |
| 72 | -0.142315 | -0.989821 | 101 | -0.654861 | 0.755750 |
| 73 | 0.415414 | 0.909632 | 102 | -0.959493 | -0.281732 |
| 74 | -0.654861 | -0.755750 | 103 | -0.142315 | -0.989821 |
| 75 | 0.841254 | 0.540640 | 104 | 0.841254 | -0.540640 |
| 76 | -0.959493 | -0.281733 | 105 | 0.841254 | 0.540640 |
| 77 | 1.000000 | 0.000000 | 106 | -0.142315 | 0.989821 |
| 78 | -0.654861 | 0.755750 | 107 | -0.959493 | 0.281733 |
| 79 | -0.142315 | -0.989821 | 108 | -0.654862 | -0.755748 |
| 80 | 0.841253 | 0.540641 | 109 | 0.415416 | -0.909632 |
| 81 | -0.959493 | 0.281733 | 110 | 1.000000 | 0.000000 |
| 82 | 0.415415 | -0.909632 | 111 | 0.841253 | 0.540641 |
| 83 | 0.415414 | 0.909632 | 112 | 0.415415 | 0.909632 |
| 84 | -0.959493 | -0.281732 | 113 | -0.142315 | 0.989821 |
| 85 | 0.841253 | -0.540641 | 114 | -0.654861 | 0.755749 |
| 86 | -0.142315 | 0.989821 | 115 | -0.959493 | 0.281732 |
| 87 | -0.654860 | -0.755750 | 116 | -0.959493 | -0.281733 |
| 88 | 1.000000 | 0.000000 | 117 | -0.654860 | -0.755750 |
| 89 | -0.142315 | 0.989821 | 118 | -0.142314 | -0.989822 |
| 90 | -0.959493 | -0.281733 | 119 | 0.415416 | -0.909632 |
| 91 | 0.415415 | -0.909632 | 120 | 0.841254 | -0.540640 |
| 92 | 0.841253 | 0.540641 | | | |

**TABLE D-XXXII. In-phase and Quadrature components of 144 symbol Base Sequence used to form the 272 symbol mini-probe.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.000000 | 0.000000 | 32 | -0.500000 | -0.866025 |
| 1 | 1.000000 | 0.000000 | 33 | -1.000000 | 0.000000 |
| 2 | 1.000000 | 0.000000 | 34 | -0.500000 | 0.866025 |
| 3 | 1.000000 | 0.000000 | 35 | 0.500000 | 0.866026 |
| 4 | 1.000000 | 0.000000 | 36 | 1.000000 | 0.000000 |
| 5 | 1.000000 | 0.000000 | 37 | 0.000000 | -1.000000 |
| 6 | 1.000000 | 0.000000 | 38 | -1.000000 | 0.000000 |
| 7 | 1.000000 | 0.000000 | 39 | 0.000000 | 1.000000 |
| 8 | 1.000000 | 0.000000 | 40 | 1.000000 | 0.000000 |
| 9 | 1.000000 | 0.000000 | 41 | 0.000000 | -1.000000 |
| 10 | 1.000000 | 0.000000 | 42 | -1.000000 | 0.000000 |
| 11 | 1.000000 | 0.000000 | 43 | 0.000000 | 1.000000 |
| 12 | 1.000000 | 0.000000 | 44 | 1.000000 | 0.000000 |
| 13 | 0.866025 | -0.500000 | 45 | 0.000000 | -1.000000 |
| 14 | 0.500000 | -0.866025 | 46 | -1.000000 | 0.000000 |
| 15 | 0.000000 | -1.000000 | 47 | -0.000001 | 1.000000 |
| 16 | -0.500000 | -0.866025 | 48 | 1.000000 | 0.000000 |
| 17 | -0.866025 | -0.500000 | 49 | -0.500000 | -0.866025 |
| 18 | -1.000000 | 0.000000 | 50 | -0.500000 | 0.866025 |
| 19 | -0.866025 | 0.500000 | 51 | 1.000000 | 0.000000 |
| 20 | -0.500000 | 0.866025 | 52 | -0.500000 | -0.866025 |
| 21 | 0.000000 | 1.000000 | 53 | -0.500000 | 0.866025 |
| 22 | 0.500000 | 0.866025 | 54 | 1.000000 | 0.000000 |
| 23 | 0.866025 | 0.500000 | 55 | -0.500000 | -0.866025 |
| 24 | 1.000000 | 0.000000 | 56 | -0.500000 | 0.866026 |
| 25 | 0.500000 | -0.866025 | 57 | 1.000000 | 0.000000 |
| 26 | -0.500000 | -0.866025 | 58 | -0.500000 | -0.866026 |
| 27 | -1.000000 | 0.000000 | 59 | -0.500001 | 0.866025 |
| 28 | -0.500000 | 0.866025 | 60 | 1.000000 | 0.000000 |
| 29 | 0.500000 | 0.866025 | 61 | -0.866025 | -0.500000 |
| 30 | 1.000000 | 0.000000 | 62 | 0.500000 | 0.866025 |
| 31 | 0.500000 | -0.866025 | 63 | 0.000000 | -1.000000 |

**TABLE D-XXXII. In-phase and Quadrature components of 144 symbol Base Sequence used to form the 272 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 64 | -0.500000 | 0.866025 | 96 | 1.000000 | 0.000000 |
| 65 | 0.866025 | -0.500000 | 97 | -0.500000 | 0.866025 |
| 66 | -1.000000 | 0.000000 | 98 | -0.500000 | -0.866025 |
| 67 | 0.866025 | 0.500001 | 99 | 1.000000 | 0.000000 |
| 68 | -0.500000 | -0.866026 | 100 | -0.500000 | 0.866026 |
| 69 | 0.000000 | 1.000000 | 101 | -0.500000 | -0.866026 |
| 70 | 0.500000 | -0.866026 | 102 | 1.000000 | -0.000001 |
| 71 | -0.866025 | 0.500001 | 103 | -0.500000 | 0.866025 |
| 72 | 1.000000 | 0.000000 | 104 | -0.500001 | -0.866025 |
| 73 | -1.000000 | 0.000000 | 105 | 1.000000 | 0.000000 |
| 74 | 1.000000 | 0.000000 | 106 | -0.500001 | 0.866025 |
| 75 | -1.000000 | 0.000000 | 107 | -0.499999 | -0.866026 |
| 76 | 1.000000 | 0.000000 | 108 | 1.000000 | 0.000000 |
| 77 | -1.000000 | 0.000000 | 109 | 0.000000 | 1.000000 |
| 78 | 1.000000 | 0.000000 | 110 | -1.000000 | 0.000000 |
| 79 | -1.000000 | -0.000001 | 111 | 0.000000 | -1.000000 |
| 80 | 1.000000 | -0.000001 | 112 | 1.000000 | 0.000000 |
| 81 | -1.000000 | 0.000000 | 113 | 0.000000 | 1.000000 |
| 82 | 1.000000 | 0.000001 | 114 | -1.000000 | 0.000000 |
| 83 | -1.000000 | -0.000001 | 115 | 0.000002 | -1.000000 |
| 84 | 1.000000 | 0.000000 | 116 | 1.000000 | 0.000000 |
| 85 | -0.866025 | 0.500000 | 117 | -0.000002 | 1.000000 |
| 86 | 0.500000 | -0.866025 | 118 | -1.000000 | 0.000000 |
| 87 | 0.000000 | 1.000000 | 119 | 0.000002 | -1.000000 |
| 88 | -0.500000 | -0.866025 | 120 | 1.000000 | 0.000000 |
| 89 | 0.866025 | 0.500001 | 121 | 0.500000 | 0.866025 |
| 90 | -1.000000 | -0.000001 | 122 | -0.500000 | 0.866025 |
| 91 | 0.866026 | -0.500000 | 123 | -1.000000 | 0.000000 |
| 92 | -0.500000 | 0.866025 | 124 | -0.500000 | -0.866026 |
| 93 | 0.000002 | -1.000000 | 125 | 0.500000 | -0.866026 |
| 94 | 0.499999 | 0.866026 | 126 | 1.000000 | 0.000001 |
| 95 | -0.866025 | -0.500001 | 127 | 0.499999 | 0.866026 |

**TABLE D-XXXII. In-phase and Quadrature components of 144 symbol Base Sequence used to form the 272 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 128 | -0.500001 | 0.866025 | 136 | -0.500000 | 0.866025 |
| 129 | -1.000000 | 0.000000 | 137 | -0.866025 | 0.500000 |
| 130 | -0.500001 | -0.866025 | 138 | -1.000000 | -0.000000 |
| 131 | 0.499998 | -0.866026 | 139 | -0.866025 | -0.500000 |
| 132 | 1.000000 | 0.000000 | 140 | -0.499999 | -0.866026 |
| 133 | 0.866025 | 0.500000 | 141 | 0.000000 | -1.000000 |
| 134 | 0.500000 | 0.866026 | 142 | 0.500000 | -0.866026 |
| 135 | -0.000001 | 1.000000 | 143 | 0.866025 | -0.500000 |

**TABLE D-XXXIII. In-phase and Quadrature components of 169 symbol Base Sequence used to form the 320 symbol mini-probe.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.000000 | 0.000000 | 32 | 0.885456 | -0.464723 |
| 1 | 1.000000 | 0.000000 | 33 | 0.885456 | 0.464723 |
| 2 | 1.000000 | 0.000000 | 34 | 0.120537 | 0.992709 |
| 3 | 1.000000 | 0.000000 | 35 | -0.748511 | 0.663123 |
| 4 | 1.000000 | 0.000000 | 36 | -0.970942 | -0.239316 |
| 5 | 1.000000 | 0.000000 | 37 | -0.354605 | -0.935016 |
| 6 | 1.000000 | 0.000000 | 38 | 0.568065 | -0.822984 |
| 7 | 1.000000 | 0.000000 | 39 | 1.000000 | 0.000000 |
| 8 | 1.000000 | 0.000000 | 40 | 0.120537 | 0.992709 |
| 9 | 1.000000 | 0.000000 | 41 | -0.970942 | 0.239316 |
| 10 | 1.000000 | 0.000000 | 42 | -0.354605 | -0.935016 |
| 11 | 1.000000 | 0.000000 | 43 | 0.885456 | -0.464723 |
| 12 | 1.000000 | 0.000000 | 44 | 0.568065 | 0.822984 |
| 13 | 1.000000 | 0.000000 | 45 | -0.748511 | 0.663123 |
| 14 | 0.885456 | 0.464723 | 46 | -0.748511 | -0.663123 |
| 15 | 0.568065 | 0.822984 | 47 | 0.568065 | -0.822984 |
| 16 | 0.120537 | 0.992709 | 48 | 0.885456 | 0.464723 |
| 17 | -0.354605 | 0.935016 | 49 | -0.354605 | 0.935016 |
| 18 | -0.748511 | 0.663123 | 50 | -0.970942 | -0.239316 |
| 19 | -0.970942 | 0.239316 | 51 | 0.120537 | -0.992709 |
| 20 | -0.970942 | -0.239316 | 52 | 1.000000 | 0.000000 |
| 21 | -0.748511 | -0.663123 | 53 | -0.354605 | 0.935016 |
| 22 | -0.354605 | -0.935016 | 54 | -0.748511 | -0.663123 |
| 23 | 0.120537 | -0.992709 | 55 | 0.885456 | -0.464723 |
| 24 | 0.568065 | -0.822984 | 56 | 0.120537 | 0.992709 |
| 25 | 0.885456 | -0.464723 | 57 | -0.970942 | -0.239316 |
| 26 | 1.000000 | 0.000000 | 58 | 0.568065 | -0.822984 |
| 27 | 0.568065 | 0.822984 | 59 | 0.568065 | 0.822984 |
| 28 | -0.354605 | 0.935016 | 60 | -0.970942 | 0.239316 |
| 29 | -0.970942 | 0.239316 | 61 | 0.120537 | -0.992709 |
| 30 | -0.748511 | -0.663123 | 62 | 0.885456 | 0.464723 |
| 31 | 0.120537 | -0.992709 | 63 | -0.748511 | 0.663123 |

**TABLE D-XXXIII. In-phase and Quadrature components of 169 symbol Base Sequence used to form the 320 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 64 | -0.354605 | -0.935016 | 96 | -0.354605 | -0.935016 |
| 65 | 1.000000 | 0.000000 | 97 | 0.120537 | 0.992709 |
| 66 | -0.748511 | 0.663123 | 98 | 0.120537 | -0.992709 |
| 67 | 0.120537 | -0.992709 | 99 | -0.354605 | 0.935016 |
| 68 | 0.568065 | 0.822984 | 100 | 0.568065 | -0.822984 |
| 69 | -0.970942 | -0.239316 | 101 | -0.748511 | 0.663123 |
| 70 | 0.885456 | -0.464723 | 102 | 0.885456 | -0.464723 |
| 71 | -0.354605 | 0.935016 | 103 | -0.970942 | 0.239316 |
| 72 | -0.354605 | -0.935016 | 104 | 1.000000 | 0.000000 |
| 73 | 0.885456 | 0.464723 | 105 | -0.748511 | -0.663123 |
| 74 | -0.970942 | 0.239316 | 106 | 0.120537 | 0.992709 |
| 75 | 0.568065 | -0.822984 | 107 | 0.568065 | -0.822984 |
| 76 | 0.120537 | 0.992709 | 108 | -0.970942 | 0.239316 |
| 77 | -0.748511 | -0.663123 | 109 | 0.885456 | 0.464723 |
| 78 | 1.000000 | 0.000000 | 110 | -0.354605 | -0.935016 |
| 79 | -0.970942 | 0.239316 | 111 | -0.354605 | 0.935016 |
| 80 | 0.885456 | -0.464723 | 112 | 0.885456 | -0.464723 |
| 81 | -0.748511 | 0.663123 | 113 | -0.970942 | -0.239316 |
| 82 | 0.568065 | -0.822984 | 114 | 0.568065 | 0.822984 |
| 83 | -0.354605 | 0.935016 | 115 | 0.120537 | -0.992709 |
| 84 | 0.120537 | -0.992709 | 116 | -0.748511 | 0.663123 |
| 85 | 0.120537 | 0.992709 | 117 | 1.000000 | 0.000000 |
| 86 | -0.354605 | -0.935016 | 118 | -0.354605 | -0.935016 |
| 87 | 0.568065 | 0.822984 | 119 | -0.748511 | 0.663123 |
| 88 | -0.748511 | -0.663123 | 120 | 0.885456 | 0.464723 |
| 89 | 0.885456 | 0.464723 | 121 | 0.120537 | -0.992709 |
| 90 | -0.970942 | -0.239316 | 122 | -0.970942 | 0.239316 |
| 91 | 1.000000 | 0.000000 | 123 | 0.568065 | 0.822984 |
| 92 | -0.970942 | -0.239316 | 124 | 0.568065 | -0.822984 |
| 93 | 0.885456 | 0.464723 | 125 | -0.970942 | -0.239316 |
| 94 | -0.748511 | -0.663123 | 126 | 0.120537 | 0.992709 |
| 95 | 0.568065 | 0.822984 | 127 | 0.885456 | -0.464723 |

**TABLE D-XXXIII. In-phase and Quadrature components of 169 symbol Base Sequence used to form the 320 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 128 | -0.748511 | -0.663123 | 149 | 0.885456 | 0.464723 |
| 129 | -0.354605 | 0.935016 | 150 | 0.885456 | -0.464723 |
| 130 | 1.000000 | 0.000000 | 151 | 0.120537 | -0.992709 |
| 131 | 0.120537 | -0.992709 | 152 | -0.748511 | -0.663123 |
| 132 | -0.970942 | -0.239316 | 153 | -0.970942 | 0.239316 |
| 133 | -0.354605 | 0.935016 | 154 | -0.354605 | 0.935016 |
| 134 | 0.885456 | 0.464723 | 155 | 0.568065 | 0.822984 |
| 135 | 0.568065 | -0.822984 | 156 | 1.000000 | 0.000000 |
| 136 | -0.748511 | -0.663123 | 157 | 0.885456 | -0.464723 |
| 137 | -0.748511 | 0.663123 | 158 | 0.568065 | -0.822984 |
| 138 | 0.568065 | 0.822984 | 159 | 0.120537 | -0.992709 |
| 139 | 0.885456 | -0.464723 | 160 | -0.354605 | -0.935016 |
| 140 | -0.354605 | -0.935016 | 161 | -0.748511 | -0.663123 |
| 141 | -0.970942 | 0.239316 | 162 | -0.970942 | -0.239316 |
| 142 | 0.120537 | 0.992709 | 163 | -0.970942 | 0.239316 |
| 143 | 1.000000 | 0.000000 | 164 | -0.748511 | 0.663123 |
| 144 | 0.568065 | -0.822984 | 165 | -0.354605 | 0.935016 |
| 145 | -0.354605 | -0.935016 | 166 | 0.120537 | 0.992709 |
| 146 | -0.970942 | -0.239316 | 167 | 0.568065 | 0.822984 |
| 147 | -0.748511 | 0.663123 | 168 | 0.885456 | 0.464723 |
| 148 | 0.120537 | 0.992709 | | | |

**TABLE D-XXXIV. In-phase and Quadrature components of 196 symbol Base Sequence used to form the 384 symbol mini-probe.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.000000 | 0.000000 | 32 | -0.900969 | -0.433884 |
| 1 | 1.000000 | 0.000000 | 33 | -0.222521 | -0.974928 |
| 2 | 1.000000 | 0.000000 | 34 | 0.623490 | -0.781831 |
| 3 | 1.000000 | 0.000000 | 35 | 1.000000 | 0.000000 |
| 4 | 1.000000 | 0.000000 | 36 | 0.623490 | 0.781831 |
| 5 | 1.000000 | 0.000000 | 37 | -0.222521 | 0.974928 |
| 6 | 1.000000 | 0.000000 | 38 | -0.900969 | 0.433884 |
| 7 | 1.000000 | 0.000000 | 39 | -0.900969 | -0.433884 |
| 8 | 1.000000 | 0.000000 | 40 | -0.222521 | -0.974928 |
| 9 | 1.000000 | 0.000000 | 41 | 0.623490 | -0.781831 |
| 10 | 1.000000 | 0.000000 | 42 | 1.000000 | 0.000000 |
| 11 | 1.000000 | 0.000000 | 43 | 0.222521 | 0.974928 |
| 12 | 1.000000 | 0.000000 | 44 | -0.900969 | 0.433884 |
| 13 | 1.000000 | 0.000000 | 45 | -0.623490 | -0.781831 |
| 14 | 1.000000 | 0.000000 | 46 | 0.623490 | -0.781831 |
| 15 | 0.900969 | 0.433884 | 47 | 0.900969 | 0.433884 |
| 16 | 0.623490 | 0.781831 | 48 | -0.222521 | 0.974928 |
| 17 | 0.222521 | 0.974928 | 49 | -1.000000 | 0.000000 |
| 18 | -0.222521 | 0.974928 | 50 | -0.222521 | -0.974928 |
| 19 | -0.623490 | 0.781831 | 51 | 0.900969 | -0.433884 |
| 20 | -0.900969 | 0.433884 | 52 | 0.623490 | 0.781831 |
| 21 | -1.000000 | 0.000000 | 53 | -0.623490 | 0.781831 |
| 22 | -0.900969 | -0.433884 | 54 | -0.900969 | -0.433884 |
| 23 | -0.623490 | -0.781831 | 55 | 0.222521 | -0.974928 |
| 24 | -0.222521 | -0.974928 | 56 | 1.000000 | 0.000000 |
| 25 | 0.222521 | -0.974928 | 57 | -0.222521 | 0.974928 |
| 26 | 0.623490 | -0.781831 | 58 | -0.900969 | -0.433884 |
| 27 | 0.900969 | -0.433884 | 59 | 0.623490 | -0.781831 |
| 28 | 1.000000 | 0.000000 | 60 | 0.623490 | 0.781831 |
| 29 | 0.623490 | 0.781831 | 61 | -0.900969 | 0.433884 |
| 30 | -0.222521 | 0.974928 | 62 | -0.222521 | -0.974928 |
| 31 | -0.900969 | 0.433884 | 63 | 1.000000 | 0.000000 |

**TABLE D-XXXIV. In-phase and Quadrature components of 196 symbol Base Sequence used to form the 384 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 64 | -0.222521 | 0.974928 | 96 | 0.623490 | 0.781831 |
| 65 | -0.900969 | -0.433884 | 97 | -0.900969 | -0.433884 |
| 66 | 0.623490 | -0.781831 | 98 | 1.000000 | 0.000000 |
| 67 | 0.623490 | 0.781831 | 99 | -1.000000 | 0.000000 |
| 68 | -0.900969 | 0.433884 | 100 | 1.000000 | 0.000000 |
| 69 | -0.222521 | -0.974928 | 101 | -1.000000 | 0.000000 |
| 70 | 1.000000 | 0.000000 | 102 | 1.000000 | 0.000000 |
| 71 | -0.623490 | 0.781831 | 103 | -1.000000 | 0.000000 |
| 72 | -0.222521 | -0.974928 | 104 | 1.000000 | 0.000000 |
| 73 | 0.900969 | 0.433884 | 105 | -1.000000 | 0.000000 |
| 74 | -0.900969 | 0.433884 | 106 | 1.000000 | 0.000000 |
| 75 | 0.222521 | -0.974928 | 107 | -1.000000 | 0.000000 |
| 76 | 0.623490 | 0.781831 | 108 | 1.000000 | 0.000000 |
| 77 | -1.000000 | 0.000000 | 109 | -1.000000 | 0.000000 |
| 78 | 0.623490 | -0.781831 | 110 | 1.000000 | 0.000000 |
| 79 | 0.222521 | 0.974928 | 111 | -1.000000 | 0.000000 |
| 80 | -0.900969 | -0.433884 | 112 | 1.000000 | 0.000000 |
| 81 | 0.900969 | -0.433884 | 113 | -0.900969 | -0.433884 |
| 82 | -0.222521 | 0.974928 | 114 | 0.623490 | 0.781831 |
| 83 | -0.623490 | -0.781831 | 115 | -0.222521 | -0.974928 |
| 84 | 1.000000 | 0.000000 | 116 | -0.222521 | 0.974928 |
| 85 | -0.900969 | 0.433884 | 117 | 0.623490 | -0.781831 |
| 86 | 0.623490 | -0.781831 | 118 | -0.900969 | 0.433884 |
| 87 | -0.222521 | 0.974928 | 119 | 1.000000 | 0.000000 |
| 88 | -0.222521 | -0.974928 | 120 | -0.900969 | -0.433884 |
| 89 | 0.623490 | 0.781831 | 121 | 0.623490 | 0.781831 |
| 90 | -0.900969 | -0.433884 | 122 | -0.222521 | -0.974928 |
| 91 | 1.000000 | 0.000000 | 123 | -0.222521 | 0.974928 |
| 92 | -0.900969 | 0.433884 | 124 | 0.623490 | -0.781831 |
| 93 | 0.623490 | -0.781831 | 125 | -0.900969 | 0.433884 |
| 94 | -0.222521 | 0.974928 | 126 | 1.000000 | 0.000000 |
| 95 | -0.222521 | -0.974928 | 127 | -0.623490 | -0.781831 |

**TABLE D-XXXIV. In-phase and Quadrature components of 196 symbol Base Sequence used to form the 384 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 128 | -0.222521 | 0.974928 | 162 | -0.222521 | 0.974928 |
| 129 | 0.900969 | -0.433884 | 163 | 0.900969 | 0.433884 |
| 130 | -0.900969 | -0.433884 | 164 | 0.623490 | -0.781831 |
| 131 | 0.222521 | 0.974928 | 165 | -0.623490 | -0.781831 |
| 132 | 0.623490 | -0.781831 | 166 | -0.900969 | 0.433884 |
| 133 | -1.000000 | 0.000000 | 167 | 0.222521 | 0.974928 |
| 134 | 0.623490 | 0.781831 | 168 | 1.000000 | 0.000000 |
| 135 | 0.222521 | -0.974928 | 169 | 0.623490 | -0.781831 |
| 136 | -0.900969 | 0.433884 | 170 | -0.222521 | -0.974928 |
| 137 | 0.900969 | 0.433884 | 171 | -0.900969 | -0.433884 |
| 138 | -0.222521 | -0.974928 | 172 | -0.900969 | 0.433884 |
| 139 | -0.623490 | 0.781831 | 173 | -0.222521 | 0.974928 |
| 140 | 1.000000 | 0.000000 | 174 | 0.623490 | 0.781831 |
| 141 | -0.222521 | -0.974928 | 175 | 1.000000 | 0.000000 |
| 142 | -0.900969 | 0.433884 | 176 | 0.623490 | -0.781831 |
| 143 | 0.623490 | 0.781831 | 177 | -0.222521 | -0.974928 |
| 144 | 0.623490 | -0.781831 | 178 | -0.900969 | -0.433884 |
| 145 | -0.900969 | -0.433884 | 179 | -0.900969 | 0.433884 |
| 146 | -0.222521 | 0.974928 | 180 | -0.222521 | 0.974928 |
| 147 | 1.000000 | 0.000000 | 181 | 0.623490 | 0.781831 |
| 148 | -0.222521 | -0.974928 | 182 | 1.000000 | 0.000000 |
| 149 | -0.900969 | 0.433884 | 183 | 0.900969 | -0.433884 |
| 150 | 0.623490 | 0.781831 | 184 | 0.623490 | -0.781831 |
| 151 | 0.623490 | -0.781831 | 185 | 0.222521 | -0.974928 |
| 152 | -0.900969 | -0.433884 | 186 | -0.222521 | -0.974928 |
| 153 | -0.222521 | 0.974928 | 187 | -0.623490 | -0.781831 |
| 154 | 1.000000 | 0.000000 | 188 | -0.900969 | -0.433884 |
| 155 | 0.222521 | -0.974928 | 189 | -1.000000 | 0.000000 |
| 156 | -0.900969 | -0.433884 | 190 | -0.900969 | 0.433884 |
| 157 | -0.623490 | 0.781831 | 191 | -0.623490 | 0.781831 |
| 158 | 0.623490 | 0.781831 | 192 | -0.222521 | 0.974928 |
| 159 | 0.900969 | -0.433884 | 193 | 0.222521 | 0.974928 |
| 160 | -0.222521 | 0.974928 | 194 | 0.623490 | 0.781831 |
| 161 | -1.000000 | 0.974928 | 195 | 0.900969 | 0.433884 |

**TABLE D-XXXV. In-phase and Quadrature components of 256 symbol Base Sequence used to form the 512 symbol mini-probe.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.000000 | 0.000000 | 32 | 1.000000 | 0.000000 |
| 1 | 1.000000 | 0.000000 | 33 | 0.707107 | 0.707107 |
| 2 | 1.000000 | 0.000000 | 34 | 0.000000 | 1.000000 |
| 3 | 1.000000 | 0.000000 | 35 | -0.707107 | 0.707107 |
| 4 | 1.000000 | 0.000000 | 36 | -1.000000 | 0.000000 |
| 5 | 1.000000 | 0.000000 | 37 | -0.707107 | -0.707107 |
| 6 | 1.000000 | 0.000000 | 38 | 0.000000 | -1.000000 |
| 7 | 1.000000 | 0.000000 | 39 | 0.707107 | -0.707107 |
| 8 | 1.000000 | 0.000000 | 40 | 1.000000 | 0.000000 |
| 9 | 1.000000 | 0.000000 | 41 | 0.707107 | 0.707107 |
| 10 | 1.000000 | 0.000000 | 42 | 0.000000 | 1.000000 |
| 11 | 1.000000 | 0.000000 | 43 | -0.707107 | 0.707107 |
| 12 | 1.000000 | 0.000000 | 44 | -1.000000 | 0.000000 |
| 13 | 1.000000 | 0.000000 | 45 | -0.707107 | -0.707107 |
| 14 | 1.000000 | 0.000000 | 46 | 0.000000 | -1.000000 |
| 15 | 1.000000 | 0.000000 | 47 | 0.707107 | -0.707107 |
| 16 | 1.000000 | 0.000000 | 48 | 1.000000 | 0.000000 |
| 17 | 0.923880 | 0.382683 | 49 | 0.382683 | 0.923880 |
| 18 | 0.707107 | 0.707107 | 50 | -0.707107 | 0.707107 |
| 19 | 0.382683 | 0.923880 | 51 | -0.923880 | -0.382683 |
| 20 | 0.000000 | 1.000000 | 52 | 0.000000 | -1.000000 |
| 21 | -0.382683 | 0.923880 | 53 | 0.923880 | -0.382683 |
| 22 | -0.707107 | 0.707107 | 54 | 0.707107 | 0.707107 |
| 23 | -0.923880 | 0.382683 | 55 | -0.382683 | 0.923880 |
| 24 | -1.000000 | 0.000000 | 56 | -1.000000 | 0.000000 |
| 25 | -0.923880 | -0.382683 | 57 | -0.382683 | -0.923880 |
| 26 | -0.707107 | -0.707107 | 58 | 0.707107 | -0.707107 |
| 27 | -0.382683 | -0.923880 | 59 | 0.923880 | 0.382683 |
| 28 | 0.000000 | -1.000000 | 60 | 0.000000 | 1.000000 |
| 29 | 0.382683 | -0.923880 | 61 | -0.923880 | 0.382683 |
| 30 | 0.707107 | -0.707107 | 62 | -0.707107 | -0.707107 |
| 31 | 0.923880 | -0.382683 | 63 | 0.382683 | -0.923880 |

**TABLE D-XXXV. In-phase and Quadrature components of 256 symbol Base Sequence used to form the 512 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 64 | 1.000000 | 0.000000 | 96 | 1.000000 | 0.000000 |
| 65 | 0.000000 | 1.000000 | 97 | -0.707107 | 0.707107 |
| 66 | -1.000000 | 0.000000 | 98 | 0.000000 | -1.000000 |
| 67 | 0.000000 | -1.000000 | 99 | 0.707107 | 0.707107 |
| 68 | 1.000000 | 0.000000 | 100 | -1.000000 | 0.000000 |
| 69 | 0.000000 | 1.000000 | 101 | 0.707107 | -0.707107 |
| 70 | -1.000000 | 0.000000 | 102 | 0.000000 | 1.000000 |
| 71 | 0.000000 | -1.000000 | 103 | -0.707107 | -0.707107 |
| 72 | 1.000000 | 0.000000 | 104 | 1.000000 | 0.000000 |
| 73 | 0.000000 | 1.000000 | 105 | -0.707107 | 0.707107 |
| 74 | -1.000000 | 0.000000 | 106 | 0.000000 | -1.000000 |
| 75 | 0.000000 | -1.000000 | 107 | 0.707107 | 0.707107 |
| 76 | 1.000000 | 0.000000 | 108 | -1.000000 | 0.000000 |
| 77 | 0.000000 | 1.000000 | 109 | 0.707107 | -0.707107 |
| 78 | -1.000000 | 0.000000 | 110 | 0.000000 | 1.000000 |
| 79 | 0.000000 | -1.000000 | 111 | -0.707107 | -0.707107 |
| 80 | 1.000000 | 0.000000 | 112 | 1.000000 | 0.000000 |
| 81 | -0.382683 | 0.923880 | 113 | -0.923880 | 0.382683 |
| 82 | -0.707107 | -0.707107 | 114 | 0.707107 | -0.707107 |
| 83 | 0.923880 | -0.382683 | 115 | -0.382683 | 0.923880 |
| 84 | 0.000000 | 1.000000 | 116 | 0.000000 | -1.000000 |
| 85 | -0.923880 | -0.382683 | 117 | 0.382683 | 0.923880 |
| 86 | 0.707107 | -0.707107 | 118 | -0.707107 | -0.707107 |
| 87 | 0.382683 | 0.923880 | 119 | 0.923880 | 0.382683 |
| 88 | -1.000000 | 0.000000 | 120 | -1.000000 | 0.000000 |
| 89 | 0.382683 | -0.923880 | 121 | 0.923880 | -0.382683 |
| 90 | 0.707107 | 0.707107 | 122 | -0.707107 | 0.707107 |
| 91 | -0.923880 | 0.382683 | 123 | 0.382683 | -0.923880 |
| 92 | 0.000000 | -1.000000 | 124 | 0.000000 | 1.000000 |
| 93 | 0.923880 | 0.382683 | 125 | -0.382683 | -0.923880 |
| 94 | -0.707107 | 0.707107 | 126 | 0.707107 | 0.707107 |
| 95 | -0.382683 | -0.923880 | 127 | -0.923880 | -0.382683 |

**TABLE D-XXXV. In-phase and Quadrature components of 256 symbol Base Sequence used to form the 512 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 128 | 1.000000 | 0.000000 | 160 | 1.000000 | 0.000000 |
| 129 | -1.000000 | 0.000000 | 161 | -0.707107 | -0.707107 |
| 130 | 1.000000 | 0.000000 | 162 | 0.000000 | 1.000000 |
| 131 | -1.000000 | 0.000000 | 163 | 0.707107 | -0.707107 |
| 132 | 1.000000 | 0.000000 | 164 | -1.000000 | 0.000000 |
| 133 | -1.000000 | 0.000000 | 165 | 0.707107 | 0.707107 |
| 134 | 1.000000 | 0.000000 | 166 | 0.000000 | -1.000000 |
| 135 | -1.000000 | 0.000000 | 167 | -0.707107 | 0.707107 |
| 136 | 1.000000 | 0.000000 | 168 | 1.000000 | 0.000000 |
| 137 | -1.000000 | 0.000000 | 169 | -0.707107 | -0.707107 |
| 138 | 1.000000 | 0.000000 | 170 | 0.000000 | 1.000000 |
| 139 | -1.000000 | 0.000000 | 171 | 0.707107 | -0.707107 |
| 140 | 1.000000 | 0.000000 | 172 | -1.000000 | 0.000000 |
| 141 | -1.000000 | 0.000000 | 173 | 0.707107 | 0.707107 |
| 142 | 1.000000 | 0.000000 | 174 | 0.000000 | -1.000000 |
| 143 | -1.000000 | 0.000000 | 175 | -0.707107 | 0.707107 |
| 144 | 1.000000 | 0.000000 | 176 | 1.000000 | 0.000000 |
| 145 | -0.923880 | -0.382683 | 177 | -0.382683 | -0.923880 |
| 146 | 0.707107 | 0.707107 | 178 | -0.707107 | 0.707107 |
| 147 | -0.382683 | -0.923880 | 179 | 0.923880 | 0.382683 |
| 148 | 0.000000 | 1.000000 | 180 | 0.000000 | -1.000000 |
| 149 | 0.382683 | -0.923880 | 181 | -0.923880 | 0.382683 |
| 150 | -0.707107 | 0.707107 | 182 | 0.707107 | 0.707107 |
| 151 | 0.923880 | -0.382683 | 183 | 0.382683 | -0.923880 |
| 152 | -1.000000 | 0.000000 | 184 | -1.000000 | 0.000000 |
| 153 | 0.923880 | 0.382683 | 185 | 0.382683 | 0.923880 |
| 154 | -0.707107 | -0.707107 | 186 | 0.707107 | -0.707107 |
| 155 | 0.382683 | 0.923880 | 187 | -0.923880 | -0.382683 |
| 156 | 0.000000 | -1.000000 | 188 | 0.000000 | 1.000000 |
| 157 | -0.382683 | 0.923880 | 189 | 0.923880 | -0.382683 |
| 158 | 0.707107 | -0.707107 | 190 | -0.707107 | -0.707107 |
| 159 | -0.923880 | 0.382683 | 191 | -0.382683 | 0.923880 |

**TABLE D-XXXV. In-phase and Quadrature components of 256 symbol Base Sequence used to form the 512 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 192 | 1.000000 | 0.000000 | 224 | 1.000000 | 0.000000 |
| 193 | 0.000000 | -1.000000 | 225 | 0.707107 | -0.707107 |
| 194 | -1.000000 | 0.000000 | 226 | 0.000000 | -1.000000 |
| 195 | 0.000000 | 1.000000 | 227 | -0.707107 | -0.707107 |
| 196 | 1.000000 | 0.000000 | 228 | -1.000000 | 0.000000 |
| 197 | 0.000000 | -1.000000 | 229 | -0.707107 | 0.707107 |
| 198 | -1.000000 | 0.000000 | 230 | 0.000000 | 1.000000 |
| 199 | 0.000000 | 1.000000 | 231 | 0.707107 | 0.707107 |
| 200 | 1.000000 | 0.000000 | 232 | 1.000000 | 0.000000 |
| 201 | 0.000000 | -1.000000 | 233 | 0.707107 | -0.707107 |
| 202 | -1.000000 | 0.000000 | 234 | 0.000000 | -1.000000 |
| 203 | 0.000000 | 1.000000 | 235 | -0.707107 | -0.707107 |
| 204 | 1.000000 | 0.000000 | 236 | -1.000000 | 0.000000 |
| 205 | 0.000000 | -1.000000 | 237 | -0.707107 | 0.707107 |
| 206 | -1.000000 | 0.000000 | 238 | 0.000000 | 1.000000 |
| 207 | 0.000000 | 1.000000 | 239 | 0.707107 | 0.707107 |
| 208 | 1.000000 | 0.000000 | 240 | 1.000000 | 0.000000 |
| 209 | 0.382683 | -0.923880 | 241 | 0.923880 | -0.382683 |
| 210 | -0.707107 | -0.707107 | 242 | 0.707107 | -0.707107 |
| 211 | -0.923880 | 0.382683 | 243 | 0.382683 | -0.923880 |
| 212 | 0.000000 | 1.000000 | 244 | 0.000000 | -1.000000 |
| 213 | 0.923880 | 0.382683 | 245 | -0.382683 | -0.923880 |
| 214 | 0.707107 | -0.707107 | 246 | -0.707107 | -0.707107 |
| 215 | -0.382683 | -0.923880 | 247 | -0.923880 | -0.382683 |
| 216 | -1.000000 | 0.000000 | 248 | -1.000000 | 0.000000 |
| 217 | -0.382683 | 0.923880 | 249 | -0.923880 | 0.382683 |
| 218 | 0.707107 | 0.707107 | 250 | -0.707107 | 0.707107 |
| 219 | 0.923880 | -0.382683 | 251 | -0.382683 | 0.923880 |
| 220 | 0.000000 | -1.000000 | 252 | 0.000000 | 1.000000 |
| 221 | -0.923880 | -0.382683 | 253 | 0.382683 | 0.923880 |
| 222 | -0.707107 | 0.707107 | 254 | 0.707107 | 0.707107 |
| 223 | 0.382683 | 0.923880 | 255 | 0.923880 | 0.382683 |

**TABLE D-XXXVI. In-phase and Quadrature components of 289 symbol Base Sequence used to form the 576 symbol mini-probe.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.000000 | 0.000000 | 32 | 0.739009 | -0.673696 |
| 1 | 1.000000 | 0.000000 | 33 | 0.932472 | -0.361242 |
| 2 | 1.000000 | 0.000000 | 34 | 1.000000 | 0.000000 |
| 3 | 1.000000 | 0.000000 | 35 | 0.739009 | 0.673696 |
| 4 | 1.000000 | 0.000000 | 36 | 0.092268 | 0.995734 |
| 5 | 1.000000 | 0.000000 | 37 | -0.602635 | 0.798017 |
| 6 | 1.000000 | 0.000000 | 38 | -0.982973 | 0.183750 |
| 7 | 1.000000 | 0.000000 | 39 | -0.850217 | -0.526432 |
| 8 | 1.000000 | 0.000000 | 40 | -0.273663 | -0.961826 |
| 9 | 1.000000 | 0.000000 | 41 | 0.445738 | -0.895163 |
| 10 | 1.000000 | 0.000000 | 42 | 0.932472 | -0.361242 |
| 11 | 1.000000 | 0.000000 | 43 | 0.932472 | 0.361242 |
| 12 | 1.000000 | 0.000000 | 44 | 0.445738 | 0.895163 |
| 13 | 1.000000 | 0.000000 | 45 | -0.273663 | 0.961826 |
| 14 | 1.000000 | 0.000000 | 46 | -0.850217 | 0.526432 |
| 15 | 1.000000 | 0.000000 | 47 | -0.982973 | -0.183750 |
| 16 | 1.000000 | 0.000000 | 48 | -0.602635 | -0.798017 |
| 17 | 1.000000 | 0.000000 | 49 | 0.092268 | -0.995734 |
| 18 | 0.932472 | 0.361242 | 50 | 0.739009 | -0.673696 |
| 19 | 0.739009 | 0.673696 | 51 | 1.000000 | 0.000000 |
| 20 | 0.445738 | 0.895163 | 52 | 0.445738 | 0.895163 |
| 21 | 0.092268 | 0.995734 | 53 | -0.602635 | 0.798017 |
| 22 | -0.273663 | 0.961826 | 54 | -0.982973 | -0.183750 |
| 23 | -0.602635 | 0.798017 | 55 | -0.273663 | -0.961826 |
| 24 | -0.850217 | 0.526432 | 56 | 0.739009 | -0.673696 |
| 25 | -0.982973 | 0.183750 | 57 | 0.932472 | 0.361242 |
| 26 | -0.982973 | -0.183750 | 58 | 0.092268 | 0.995734 |
| 27 | -0.850217 | -0.526432 | 59 | -0.850217 | 0.526432 |
| 28 | -0.602635 | -0.798017 | 60 | -0.850217 | -0.526432 |
| 29 | -0.273663 | -0.961826 | 61 | 0.092268 | -0.995734 |
| 30 | 0.092268 | -0.995734 | 62 | 0.932472 | -0.361242 |
| 31 | 0.445738 | -0.895163 | 63 | 0.739009 | 0.673696 |

**TABLE D-XXXVI. In-phase and Quadrature components of 289 symbol Base Sequence used to form the 576 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 64 | -0.273663 | 0.961826 | 96 | 0.092268 | 0.995734 |
| 65 | -0.982973 | 0.183750 | 97 | -0.982973 | -0.183750 |
| 66 | -0.602635 | -0.798017 | 98 | 0.445738 | -0.895163 |
| 67 | 0.445738 | -0.895163 | 99 | 0.739009 | 0.673696 |
| 68 | 1.000000 | 0.000000 | 100 | -0.850217 | 0.526432 |
| 69 | 0.092268 | 0.995734 | 101 | -0.273663 | -0.961826 |
| 70 | -0.982973 | 0.183750 | 102 | 1.000000 | 0.000000 |
| 71 | -0.273663 | -0.961826 | 103 | -0.602635 | 0.798017 |
| 72 | 0.932472 | -0.361242 | 104 | -0.273663 | -0.961826 |
| 73 | 0.445738 | 0.895163 | 105 | 0.932472 | 0.361242 |
| 74 | -0.850217 | 0.526432 | 106 | -0.850217 | 0.526432 |
| 75 | -0.602635 | -0.798017 | 107 | 0.092268 | -0.995734 |
| 76 | 0.739009 | -0.673696 | 108 | 0.739009 | 0.673696 |
| 77 | 0.739009 | 0.673696 | 109 | -0.982973 | 0.183750 |
| 78 | -0.602635 | 0.798017 | 110 | 0.445738 | -0.895163 |
| 79 | -0.850217 | -0.526432 | 111 | 0.445738 | 0.895163 |
| 80 | 0.445738 | -0.895163 | 112 | -0.982973 | -0.183750 |
| 81 | 0.932472 | 0.361242 | 113 | 0.739009 | -0.673696 |
| 82 | -0.273663 | 0.961826 | 114 | 0.092268 | 0.995734 |
| 83 | -0.982973 | -0.183750 | 115 | -0.850217 | -0.526432 |
| 84 | 0.092268 | -0.995734 | 116 | 0.932472 | -0.361242 |
| 85 | 1.000000 | 0.000000 | 117 | -0.273663 | 0.961826 |
| 86 | -0.273663 | 0.961826 | 118 | -0.602635 | -0.798017 |
| 87 | -0.850217 | -0.526432 | 119 | 1.000000 | 0.000000 |
| 88 | 0.739009 | -0.673696 | 120 | -0.850217 | 0.526432 |
| 89 | 0.445738 | 0.895163 | 121 | 0.445738 | -0.895163 |
| 90 | -0.982973 | 0.183750 | 122 | 0.092268 | 0.995734 |
| 91 | 0.092268 | -0.995734 | 123 | -0.602635 | -0.798017 |
| 92 | 0.932472 | 0.361242 | 124 | 0.932472 | 0.361242 |
| 93 | -0.602635 | 0.798017 | 125 | -0.982973 | 0.183750 |
| 94 | -0.602635 | -0.798017 | 126 | 0.739009 | -0.673696 |
| 95 | 0.932472 | -0.361242 | 127 | -0.273663 | 0.961826 |

**TABLE D-XXXVI. In-phase and Quadrature components of 289 symbol Base Sequence used to form the 576 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 128 | -0.273663 | -0.961826 | 160 | -0.273663 | -0.961826 |
| 129 | 0.739009 | 0.673696 | 161 | 0.092268 | 0.995734 |
| 130 | -0.982973 | -0.183750 | 162 | 0.092268 | -0.995734 |
| 131 | 0.932472 | -0.361242 | 163 | -0.273663 | 0.961826 |
| 132 | -0.602635 | 0.798017 | 164 | 0.445738 | -0.895163 |
| 133 | 0.092268 | -0.995734 | 165 | -0.602635 | 0.798017 |
| 134 | 0.445738 | 0.895163 | 166 | 0.739009 | -0.673696 |
| 135 | -0.850217 | -0.526432 | 167 | -0.850217 | 0.526432 |
| 136 | 1.000000 | 0.000000 | 168 | 0.932472 | -0.361242 |
| 137 | -0.982973 | 0.183750 | 169 | -0.982973 | 0.183750 |
| 138 | 0.932472 | -0.361242 | 170 | 1.000000 | 0.000000 |
| 139 | -0.850217 | 0.526432 | 171 | -0.850217 | -0.526432 |
| 140 | 0.739009 | -0.673696 | 172 | 0.445738 | 0.895163 |
| 141 | -0.602635 | 0.798017 | 173 | 0.092268 | -0.995734 |
| 142 | 0.445738 | -0.895163 | 174 | -0.602635 | 0.798017 |
| 143 | -0.273663 | 0.961826 | 175 | 0.932472 | -0.361242 |
| 144 | 0.092268 | -0.995734 | 176 | -0.982973 | -0.183750 |
| 145 | 0.092268 | 0.995734 | 177 | 0.739009 | 0.673696 |
| 146 | -0.273663 | -0.961826 | 178 | -0.273663 | -0.961826 |
| 147 | 0.445738 | 0.895163 | 179 | -0.273663 | 0.961826 |
| 148 | -0.602635 | -0.798017 | 180 | 0.739009 | -0.673696 |
| 149 | 0.739009 | 0.673696 | 181 | -0.982973 | 0.183750 |
| 150 | -0.850217 | -0.526432 | 182 | 0.932472 | 0.361242 |
| 151 | 0.932472 | 0.361242 | 183 | -0.602635 | -0.798017 |
| 152 | -0.982973 | -0.183750 | 184 | 0.092268 | 0.995734 |
| 153 | 1.000000 | 0.000000 | 185 | 0.445738 | -0.895163 |
| 154 | -0.982973 | -0.183750 | 186 | -0.850217 | 0.526432 |
| 155 | 0.932472 | 0.361242 | 187 | 1.000000 | 0.000000 |
| 156 | -0.850217 | -0.526432 | 188 | -0.602635 | -0.798017 |
| 157 | 0.739009 | 0.673696 | 189 | -0.273663 | 0.961826 |
| 158 | -0.602635 | -0.798017 | 190 | 0.932472 | -0.361242 |
| 159 | 0.445738 | 0.895163 | 191 | -0.850217 | -0.526432 |

**TABLE D-XXXVI. In-phase and Quadrature components of 289 symbol Base Sequence used to form the 576 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 192 | 0.092268 | 0.995734 | 224 | -0.273663 | 0.961826 |
| 193 | 0.739009 | -0.673696 | 225 | 0.932472 | 0.361242 |
| 194 | -0.982973 | -0.183750 | 226 | 0.445738 | -0.895163 |
| 195 | 0.445738 | 0.895163 | 227 | -0.850217 | -0.526432 |
| 196 | 0.445738 | -0.895163 | 228 | -0.602635 | 0.798017 |
| 197 | -0.982973 | 0.183750 | 229 | 0.739009 | 0.673696 |
| 198 | 0.739009 | 0.673696 | 230 | 0.739009 | -0.673696 |
| 199 | 0.092268 | -0.995734 | 231 | -0.602635 | -0.798017 |
| 200 | -0.850217 | 0.526432 | 232 | -0.850217 | 0.526432 |
| 201 | 0.932472 | 0.361242 | 233 | 0.445738 | 0.895163 |
| 202 | -0.273663 | -0.961826 | 234 | 0.932472 | -0.361242 |
| 203 | -0.602635 | 0.798017 | 235 | -0.273663 | -0.961826 |
| 204 | 1.000000 | 0.000000 | 236 | -0.982973 | 0.183750 |
| 205 | -0.273663 | -0.961826 | 237 | 0.092268 | 0.995734 |
| 206 | -0.850217 | 0.526432 | 238 | 1.000000 | 0.000000 |
| 207 | 0.739009 | 0.673696 | 239 | 0.445738 | -0.895163 |
| 208 | 0.445738 | -0.895163 | 240 | -0.602635 | -0.798017 |
| 209 | -0.982973 | -0.183750 | 241 | -0.982973 | 0.183750 |
| 210 | 0.092268 | 0.995734 | 242 | -0.273663 | 0.961826 |
| 211 | 0.932472 | -0.361242 | 243 | 0.739009 | 0.673696 |
| 212 | -0.602635 | -0.798017 | 244 | 0.932472 | -0.361242 |
| 213 | -0.602635 | 0.798017 | 245 | 0.092268 | -0.995734 |
| 214 | 0.932472 | 0.361242 | 246 | -0.850217 | -0.526432 |
| 215 | 0.092268 | -0.995734 | 247 | -0.850217 | 0.526432 |
| 216 | -0.982973 | 0.183750 | 248 | 0.092268 | 0.995734 |
| 217 | 0.445738 | 0.895163 | 249 | 0.932472 | 0.361242 |
| 218 | 0.739009 | -0.673696 | 250 | 0.739009 | -0.673696 |
| 219 | -0.850217 | -0.526432 | 251 | -0.273663 | -0.961826 |
| 220 | -0.273663 | 0.961826 | 252 | -0.982973 | -0.183750 |
| 221 | 1.000000 | 0.000000 | 253 | -0.602635 | 0.798017 |
| 222 | 0.092268 | -0.995734 | 254 | 0.445738 | 0.895163 |
| 223 | -0.982973 | -0.183750 | 255 | 1.000000 | 0.000000 |

**TABLE D-XXXVI. In-phase and Quadrature components of 289 symbol Base Sequence used to form the 576 symbol mini-probe.-Continued**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 256 | 0.739009 | -0.673696 | 273 | 0.932472 | -0.361242 |
| 257 | 0.092268 | -0.995734 | 274 | 0.739009 | -0.673696 |
| 258 | -0.602635 | -0.798017 | 275 | 0.445738 | -0.895163 |
| 259 | -0.982973 | -0.183750 | 276 | 0.092268 | -0.995734 |
| 260 | -0.850217 | 0.526432 | 277 | -0.273663 | -0.961826 |
| 261 | -0.273663 | 0.961826 | 278 | -0.602635 | -0.798017 |
| 262 | 0.445738 | 0.895163 | 279 | -0.850217 | -0.526432 |
| 263 | 0.932472 | 0.361242 | 280 | -0.982973 | -0.183750 |
| 264 | 0.932472 | -0.361242 | 281 | -0.982973 | 0.183750 |
| 265 | 0.445738 | -0.895163 | 282 | -0.850217 | 0.526432 |
| 266 | -0.273663 | -0.961826 | 283 | -0.602635 | 0.798017 |
| 267 | -0.850217 | -0.526432 | 284 | -0.273663 | 0.961826 |
| 268 | -0.982973 | 0.183750 | 285 | 0.092268 | 0.995734 |
| 269 | -0.602635 | 0.798017 | 286 | 0.445738 | 0.895163 |
| 270 | 0.092268 | 0.995734 | 287 | 0.739009 | 0.673696 |
| 271 | 0.739009 | 0.673696 | 288 | 0.932472 | 0.361242 |
| 272 | 1.000000 | 0.000000 | | | |

D.5.3 Coding and interleaving.

The interleaver used shall be a block interleaver. Each block of input data shall also be encoded using a block encoding technique with a code block size equal to the size of the block interleaver. Thus, the input data bits will be sent as successive blocks of bits that span the duration of the interleaver length selected. Tables D-XXXVII through D-XLVIII show the number of input data bits per block as function of both data rate and interleaver length, one table for each bandwidth. Note that the "Number of Input Bits" should not be confused with the "Number of Bits," which is the interleaver size. The bits from an input data block will be mapped through the coding and interleaving into a number of data frames and it is the number of bits per frame times the number of data frames that defines the interleaver length.

**TABLE D-XXXVII. Interleaver Parameters for 3kHz Bandwidth**

| Waveform Number | UltraShort | | | Short | | | Medium | | | Long | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits |
| 0 | - | - | - | 40 | 80 | 40 | 144 | 288 | 144 | 576 | 1152 | 576 |
| 1 | 4 | 192 | 24 | 16 | 768 | 96 | 64 | 3072 | 384 | 256 | 12288 | 1536 |
| 2 | 4 | 192 | 48 | 16 | 768 | 192 | 64 | 3072 | 768 | 256 | 12288 | 3072 |
| 3 | 2 | 192 | 64 | 8 | 768 | 256 | 32 | 3072 | 1024 | 128 | 12288 | 4096 |
| 4 | 2 | 192 | 128 | 8 | 768 | 512 | 32 | 3072 | 2048 | 128 | 12288 | 8192 |
| 5 | 1 | 256 | 192 | 4 | 1024 | 768 | 16 | 4096 | 3072 | 64 | 16384 | 12288 |
| 6 | 1 | 512 | 384 | 4 | 2048 | 1536 | 16 | 8192 | 6144 | 64 | 32768 | 24576 |
| 7 | 1 | 768 | 576 | 4 | 3072 | 2304 | 16 | 12288 | 9216 | 64 | 49152 | 36864 |
| 8 | 1 | 1024 | 768 | 4 | 4096 | 3072 | 16 | 16384 | 12288 | 64 | 65536 | 49152 |
| 9 | 1 | 1280 | 960 | 4 | 5120 | 3840 | 16 | 20480 | 15360 | 64 | 81920 | 61440 |
| 10 | 1 | 1536 | 1152 | 4 | 6144 | 4608 | 16 | 24576 | 18432 | 64 | 98304 | 73728 |
| 11 | 1 | 2160 | 1920 | 4 | 8640 | 7680 | 16 | 34560 | 30720 | 64 | 138240 | 122880 |
| 12 | 1 | 2880 | 2560 | 4 | 11520 | 10240 | 16 | 46080 | 40960 | 64 | 184320 | 163840 |
| 13 | 1 | 512 | 288 | 4 | 2048 | 1152 | 16 | 8192 | 4608 | 64 | 32768 | 18432 |

**TABLE D-XXXVIII. Interleaver Parameters for 6kHz Bandwidth**

| Waveform Number | UltraShort | | | Short | | | Medium | | | Long | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits |
| 0 | - | - | - | 80 | 160 | 80 | 288 | 576 | 288 | 1152 | 2304 | 1152 |
| 1 | 4 | 384 | 48 | 16 | 1536 | 192 | 64 | 6144 | 768 | 256 | 24576 | 3072 |
| 2 | 4 | 384 | 96 | 16 | 1536 | 384 | 64 | 6144 | 1536 | 256 | 24576 | 6144 |
| 3 | 2 | 408 | 136 | 8 | 1632 | 544 | 32 | 6528 | 2176 | 128 | 26112 | 8704 |
| 4 | 2 | 408 | 272 | 8 | 1632 | 1088 | 32 | 6528 | 4352 | 128 | 26112 | 17408 |
| 5 | 1 | 544 | 408 | 4 | 2176 | 1632 | 16 | 8704 | 6528 | 64 | 34816 | 26112 |
| 6 | 1 | 1088 | 816 | 4 | 4352 | 3264 | 16 | 17408 | 13056 | 64 | 69632 | 52224 |
| 7 | 1 | 1632 | 1224 | 4 | 6528 | 4896 | 16 | 26112 | 19584 | 64 | 104448 | 78336 |
| 8 | 1 | 2176 | 1632 | 4 | 8704 | 6528 | 16 | 34816 | 26112 | 64 | 139264 | 104448 |
| 9 | 1 | 2720 | 2040 | 4 | 10880 | 8160 | 16 | 43520 | 32640 | 64 | 174080 | 130560 |
| 10 | 1 | 3264 | 2448 | 4 | 13056 | 9792 | 16 | 52224 | 39168 | 64 | 208896 | 156672 |
| 11 | 1 | 3240 | 2880 | 4 | 12960 | 11520 | 16 | 51840 | 46080 | 64 | 207360 | 184320 |
| 12 | 1 | 4320 | 3840 | 4 | 17280 | 15360 | 16 | 69120 | 61440 | 64 | 276480 | 245760 |

**TABLE D-XXXIX. Interleaver Parameters for 9kHz Bandwidth**

| Waveform Number | UltraShort | | | Short | | | Medium | | | Long | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits |
| 0 | - | - | - | 120 | 240 | 160 | 432 | 864 | 576 | 1728 | 3456 | 2304 |
| 1 | 2 | 576 | 72 | 8 | 2304 | 288 | 32 | 9216 | 1152 | 128 | 36864 | 4608 |
| 2 | 2 | 576 | 144 | 8 | 2304 | 576 | 32 | 9216 | 2304 | 128 | 36864 | 9216 |
| 3 | 2 | 576 | 288 | 8 | 2304 | 1152 | 32 | 9216 | 4608 | 128 | 36864 | 18432 |
| 4 | - | - | - | - | - | - | - | - | - | - | - | - |
| 5 | 1 | 768 | 576 | 4 | 3072 | 2304 | 16 | 12288 | 9216 | 64 | 49152 | 36864 |
| 6 | 1 | 1536 | 1152 | 4 | 6144 | 4608 | 16 | 24576 | 18432 | 64 | 98304 | 73728 |
| 7 | 1 | 2304 | 1728 | 4 | 9216 | 6912 | 16 | 36864 | 27648 | 64 | 147456 | 110592 |
| 8 | 1 | 3072 | 2304 | 4 | 12288 | 9216 | 16 | 49152 | 36864 | 64 | 196608 | 147456 |
| 9 | 1 | 3840 | 2880 | 4 | 15360 | 11520 | 16 | 61440 | 46080 | 64 | 245760 | 184320 |
| 10 | 1 | 4608 | 3456 | 4 | 18432 | 13824 | 16 | 73728 | 55296 | 64 | 294912 | 221184 |
| 11 | 1 | 6480 | 5760 | 4 | 25920 | 23040 | 16 | 103680 | 92160 | 64 | 414720 | 368640 |
| 12 | 1 | 8640 | 7680 | 4 | 34560 | 30720 | 16 | 138240 | 122880 | 64 | 552960 | 491520 |

**TABLE D-XL. Interleaver Parameters for 12kHz Bandwidth**

| Waveform Number | UltraShort | | | Short | | | Medium | | | Long | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits |
| 0 | - | - | - | 160 | 320 | 160 | 576 | 1152 | 576 | 2304 | 4608 | 2304 |
| 1 | 3 | 576 | 72 | 12 | 2304 | 288 | 48 | 9216 | 1152 | 192 | 36864 | 4608 |
| 2 | 3 | 576 | 144 | 12 | 2304 | 576 | 48 | 9216 | 2304 | 192 | 36864 | 9216 |
| 3 | 2 | 768 | 256 | 8 | 3072 | 1024 | 32 | 12288 | 4096 | 128 | 49152 | 16384 |
| 4 | 2 | 768 | 512 | 8 | 3072 | 2048 | 32 | 12288 | 8192 | 128 | 49152 | 32768 |
| 5 | 1 | 1024 | 768 | 4 | 4096 | 3072 | 16 | 16384 | 12288 | 64 | 65536 | 49152 |
| 6 | 1 | 2048 | 1536 | 4 | 8192 | 6144 | 16 | 32768 | 24576 | 64 | 131072 | 98304 |
| 7 | 1 | 3072 | 2304 | 4 | 12288 | 9216 | 16 | 49152 | 36864 | 64 | 196608 | 147456 |
| 8 | 1 | 4096 | 3072 | 4 | 16384 | 12288 | 16 | 65536 | 49152 | 64 | 262144 | 196608 |
| 9 | 1 | 5120 | 3840 | 4 | 20480 | 15360 | 16 | 81920 | 61440 | 64 | 327680 | 245760 |
| 10 | 1 | 6144 | 4608 | 4 | 24576 | 18432 | 16 | 98304 | 73728 | 64 | 393216 | 294912 |
| 11 | 1 | 6480 | 5760 | 4 | 25920 | 23040 | 16 | 103680 | 92160 | 64 | 414720 | 368640 |
| 12 | 1 | 8640 | 7680 | 4 | 34560 | 30720 | 16 | 138240 | 122880 | 64 | 552960 | 491520 |

**TABLE D-XLI. Interleaver Parameters for 15kHz Bandwidth**

| Waveform Number | UltraShort | | | Short | | | Medium | | | Long | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits |
| 0 | - | - | - | 200 | 400 | 160 | 720 | 1440 | 576 | 2880 | 5760 | 2304 |
| 1 | 3 | 864 | 72 | 12 | 3456 | 288 | 48 | 13824 | 1152 | 192 | 55296 | 4608 |
| 2 | 3 | 864 | 144 | 12 | 3456 | 576 | 48 | 13824 | 2304 | 192 | 55296 | 9216 |
| 3 | 3 | 864 | 288 | 12 | 3456 | 1152 | 48 | 13824 | 4608 | 192 | 55296 | 18432 |
| 4 | 3 | 864 | 576 | 12 | 3456 | 2304 | 48 | 13824 | 9216 | 192 | 55296 | 36864 |
| 5 | 1 | 1280 | 960 | 4 | 5120 | 3840 | 16 | 20480 | 15360 | 64 | 81920 | 61440 |
| 6 | 1 | 2560 | 1920 | 4 | 10240 | 7680 | 16 | 40960 | 30720 | 64 | 163840 | 122880 |
| 7 | 1 | 3840 | 2880 | 4 | 15360 | 11520 | 16 | 61440 | 46080 | 64 | 245760 | 184320 |
| 8 | 1 | 5120 | 3840 | 4 | 20480 | 15360 | 16 | 81920 | 61440 | 64 | 327680 | 245760 |
| 9 | 1 | 6400 | 4800 | 4 | 25600 | 19200 | 16 | 102400 | 76800 | 64 | 409600 | 307200 |
| 10 | 1 | 7680 | 5760 | 4 | 30720 | 23040 | 16 | 122880 | 92160 | 64 | 491520 | 368640 |
| 11 | 1 | 6912 | 6144 | 4 | 27648 | 24576 | 16 | 110592 | 98304 | 64 | 442368 | 393216 |
| 12 | 1 | 9216 | 8192 | 4 | 36864 | 32768 | 16 | 147456 | 131072 | 64 | 589824 | 524288 |

**TABLE D-XLII. Interleaver Parameters for 18kHz Bandwidth**

| Waveform Number | UltraShort | | | Short | | | Medium | | | Long | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits |
| 0 | - | - | - | 240 | 480 | 320 | 864 | 1728 | 1152 | 3456 | 6912 | 4608 |
| 1 | 3 | 1344 | 168 | 12 | 5376 | 672 | 48 | 21504 | 2688 | 192 | 86016 | 10752 |
| 2 | 3 | 1344 | 336 | 12 | 5376 | 1344 | 48 | 21504 | 5376 | 192 | 86016 | 21504 |
| 3 | 3 | 1344 | 672 | 12 | 5376 | 2688 | 48 | 21504 | 10752 | 192 | 86016 | 43008 |
| 4 | - | - | - | - | - | - | - | - | - | - | - | - |
| 5 | 1 | 1536 | 1152 | 4 | 6144 | 4608 | 16 | 24576 | 18432 | 64 | 98304 | 73728 |
| 6 | 1 | 3072 | 2304 | 4 | 12288 | 9216 | 16 | 49152 | 36864 | 64 | 196608 | 147456 |
| 7 | 1 | 4608 | 3456 | 4 | 18432 | 13824 | 16 | 73728 | 55296 | 64 | 294912 | 221184 |
| 8 | 1 | 6144 | 4608 | 4 | 24576 | 18432 | 16 | 98304 | 73728 | 64 | 393216 | 294912 |
| 9 | 1 | 7680 | 5760 | 4 | 30720 | 23040 | 16 | 122880 | 92160 | 64 | 491520 | 368640 |
| 10 | 1 | 9216 | 6912 | 4 | 36864 | 27648 | 16 | 147456 | 110592 | 64 | 589824 | 442368 |
| 11 | 1 | 11520 | 10240 | 4 | 46080 | 40960 | 16 | 184320 | 163840 | 64 | 737280 | 655360 |
| 12 | 1 | 15360 | 12800 | 4 | 61440 | 51200 | 16 | 245760 | 204800 | 64 | 983040 | 819200 |

**TABLE D-XLIII. Interleaver Parameters for 21kHz Bandwidth**

| Waveform Number | UltraShort | | | Short | | | Medium | | | Long | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits |
| 0 | - | - | - | 280 | 560 | 160 | 1008 | 2016 | 576 | 4032 | 8064 | 2304 |
| 1 | 4 | 1280 | 80 | 16 | 5120 | 320 | 64 | 20480 | 1280 | 256 | 81920 | 5120 |
| 2 | 4 | 1280 | 160 | 16 | 5120 | 640 | 64 | 20480 | 2560 | 256 | 81920 | 10240 |
| 3 | 4 | 1280 | 320 | 16 | 5120 | 1280 | 64 | 20480 | 5120 | 256 | 81920 | 20480 |
| 4 | 4 | 1280 | 640 | 16 | 5120 | 2560 | 64 | 20480 | 10240 | 256 | 81920 | 40960 |
| 5 | 1 | 1344 | 896 | 4 | 5376 | 3584 | 16 | 21504 | 14336 | 64 | 86016 | 57344 |
| 6 | 1 | 2688 | 1792 | 4 | 10752 | 7168 | 16 | 43008 | 28672 | 64 | 172032 | 114688 |
| 7 | 1 | 4032 | 2688 | 4 | 16128 | 10752 | 16 | 64512 | 43008 | 64 | 258048 | 172032 |
| 8 | 1 | 5376 | 3584 | 4 | 21504 | 14336 | 16 | 86016 | 57344 | 64 | 344064 | 229376 |
| 9 | 1 | 6720 | 4480 | 4 | 26880 | 17920 | 16 | 107520 | 71680 | 64 | 430080 | 286720 |
| 10 | 1 | 8064 | 5376 | 4 | 32256 | 21504 | 16 | 129024 | 86016 | 64 | 516096 | 344064 |
| 11 | 1 | 15360 | 12288 | 4 | 61440 | 49152 | 16 | 245760 | 196608 | 64 | 983040 | 786432 |
| 12 | 1 | 20480 | 18432 | 4 | 81920 | 73728 | 16 | 327680 | 294912 | 64 | 1310720 | 1179648 |

**TABLE D-XLIV. Interleaver Parameters for 24kHz Bandwidth**

| Waveform Number | UltraShort | | | Short | | | Medium | | | Long | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits |
| 0 | - | - | - | 320 | 640 | 320 | 1152 | 2304 | 1152 | 4608 | 9216 | 4608 |
| 1 | 4 | 1088 | 136 | 16 | 4352 | 544 | 64 | 17408 | 2176 | 256 | 69632 | 8704 |
| 2 | 4 | 1088 | 272 | 16 | 4352 | 1088 | 64 | 17408 | 4352 | 256 | 69632 | 17408 |
| 3 | 2 | 1632 | 544 | 8 | 6528 | 2176 | 32 | 26112 | 8704 | 128 | 104448 | 34816 |
| 4 | 2 | 1632 | 1088 | 8 | 6528 | 4352 | 32 | 26112 | 17408 | 128 | 104448 | 69632 |
| 5 | 1 | 2176 | 1632 | 4 | 8704 | 6528 | 16 | 34816 | 26112 | 64 | 139264 | 104448 |
| 6 | 1 | 4352 | 3264 | 4 | 17408 | 13056 | 16 | 69632 | 52224 | 64 | 278528 | 208896 |
| 7 | 1 | 6528 | 4896 | 4 | 26112 | 19584 | 16 | 104448 | 78336 | 64 | 417792 | 313344 |
| 8 | 1 | 8704 | 6528 | 4 | 34816 | 26112 | 16 | 139264 | 104448 | 64 | 557056 | 417792 |
| 9 | 1 | 10880 | 8160 | 4 | 43520 | 32640 | 16 | 174080 | 130560 | 64 | 696320 | 522240 |
| 10 | 1 | 13056 | 9792 | 4 | 52224 | 39168 | 16 | 208896 | 156672 | 64 | 835584 | 626688 |
| 11 | 1 | 11520 | 10240 | 4 | 46080 | 40960 | 16 | 184320 | 163840 | 64 | 737280 | 655360 |
| 12 | 1 | 15360 | 12800 | 4 | 61440 | 51200 | 16 | 245760 | 204800 | 64 | 983040 | 819200 |

**TABLE D-XLV. Interleaver Parameters for 30 kHz Bandwidth**

| Waveform Number | UltraShort | | | Short | | | Medium | | | Long | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits |
| 0 | - | - | - | 400 | 800 | 320 | 1440 | 2880 | 1152 | 5760 | 11520 | 4608 |
| 1 | 3 | 1728 | 144 | 12 | 6912 | 576 | 48 | 27,648 | 2304 | 192 | 110,592 | 9216 |
| 2 | 3 | 1728 | 288 | 12 | 6912 | 1152 | 48 | 27,648 | 4608 | 192 | 110,592 | 18,432 |
| 3 | 3 | 1728 | 576 | 12 | 6912 | 2304 | 48 | 27,648 | 9216 | 192 | 110,592 | 36,864 |
| 4 | 3 | 1728 | 1152 | 12 | 6912 | 4608 | 48 | 27,648 | 18,432 | 192 | 110,592 | 73,728 |
| 5 | 1 | 2560 | 1920 | 4 | 10,240 | 7680 | 16 | 40,960 | 30,720 | 64 | 163,840 | 122,880 |
| 6 | 1 | 5120 | 3840 | 4 | 20,480 | 15,360 | 16 | 81,920 | 61,440 | 64 | 327,680 | 245,760 |
| 7 | 1 | 7680 | 5760 | 4 | 30,720 | 23,040 | 16 | 122,880 | 92,160 | 64 | 491,520 | 368,640 |
| 8 | 1 | 10,240 | 7680 | 4 | 40,960 | 30,720 | 16 | 163,840 | 122,880 | 64 | 655,360 | 491,520 |
| 9 | 1 | 12,800 | 9600 | 4 | 51,200 | 38,400 | 16 | 204,800 | 153,600 | 64 | 819,200 | 614,400 |
| 10 | 1 | 15,360 | 11,520 | 4 | 61,440 | 46,080 | 16 | 245,760 | 184,320 | 64 | 983,040 | 737,280 |
| 11 | 1 | 16,200 | 14,400 | 4 | 64,800 | 57,600 | 16 | 259,200 | 230,400 | 64 | 1,036,800 | 921,600 |
| 12 | 1 | 21,600 | 19,200 | 4 | 86,400 | 76,800 | 16 | 345,600 | 307,200 | 64 | 1,382,400 | 1,228,800 |

**TABLE D-XLVI. Interleaver Parameters for 36 kHz Bandwidth**

| Waveform Number | UltraShort | | | Short | | | Medium | | | Long | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits |
| 0 | - | - | - | 480 | 960 | 640 | 1728 | 3456 | 2304 | 6912 | 13824 | 9216 |
| 1 | 2 | 2304 | 288 | 8 | 9216 | 1152 | 32 | 36,864 | 4608 | 128 | 147,456 | 18,432 |
| 2 | 2 | 2304 | 576 | 8 | 9216 | 2304 | 32 | 36,864 | 9216 | 128 | 147,456 | 36,864 |
| 3 | 2 | 2304 | 1152 | 8 | 9216 | 4608 | 32 | 36,864 | 18,432 | 128 | 147,456 | 73,728 |
| 4 | 1 | 3072 | 1536 | 4 | 12,288 | 6144 | 16 | 49,152 | 24,576 | 64 | 196,608 | 98,304 |
| 5 | 1 | 3072 | 2304 | 4 | 12,288 | 9216 | 16 | 49,152 | 36,864 | 64 | 196,608 | 147,456 |
| 6 | 1 | 6144 | 4608 | 4 | 24,576 | 18,432 | 16 | 98,304 | 73,728 | 64 | 393,216 | 294,912 |
| 7 | 1 | 9216 | 6912 | 4 | 36,864 | 27,648 | 16 | 147,456 | 110,592 | 64 | 589,824 | 442,368 |
| 8 | 1 | 12,288 | 9216 | 4 | 49,152 | 36,864 | 16 | 196,608 | 147,456 | 64 | 786,432 | 589,824 |
| 9 | 1 | 15,360 | 11,520 | 4 | 61,440 | 46,080 | 16 | 245,760 | 184,320 | 64 | 983,040 | 737,280 |
| 10 | 1 | 18,432 | 13,824 | 4 | 73,728 | 55,296 | 16 | 294,912 | 221,184 | 64 | 1,179,648 | 884,736 |
| 11 | 1 | 19,440 | 17,280 | 4 | 77,760 | 69,120 | 16 | 311,040 | 276,480 | 64 | 1,244,160 | 1,105,920 |
| 12 | 1 | 25,920 | 23,040 | 4 | 103,680 | 92,160 | 16 | 414,720 | 368,640 | 64 | 1,658,880 | 1,474,560 |

**TABLE D-XLVII. Interleaver Parameters for 42 kHz Bandwidth**

| Waveform Number | UltraShort | | | Short | | | Medium | | | Long | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits |
| 0 | - | - | - | 560 | 1120 | 640 | 2016 | 4032 | 2304 | 8064 | 16128 | 9216 |
| 1 | 3 | 2304 | 288 | 12 | 9216 | 1152 | 48 | 36,864 | 4608 | 192 | 147,456 | 18,432 |
| 2 | 3 | 2304 | 576 | 12 | 9216 | 2304 | 48 | 36,864 | 9216 | 192 | 147,456 | 36,864 |
| 3 | 3 | 2304 | 1152 | 12 | 9216 | 4608 | 48 | 36,864 | 18,432 | 192 | 147,456 | 73,728 |
| 4 | 1 | 3456 | 1728 | 4 | 13,824 | 6912 | 16 | 55,296 | 27,648 | 64 | 221,184 | 110,592 |
| 5 | 1 | 3456 | 2304 | 4 | 13,824 | 9216 | 16 | 55,296 | 36,864 | 64 | 221,184 | 147,456 |
| 6 | 1 | 6912 | 4608 | 4 | 27,648 | 18,432 | 16 | 110,592 | 73,728 | 64 | 442,368 | 294,912 |
| 7 | 1 | 10,368 | 6912 | 4 | 41,472 | 27,648 | 16 | 165,888 | 110,592 | 64 | 663,552 | 442,368 |
| 8 | 1 | 13,824 | 9216 | 4 | 55,296 | 36,864 | 16 | 221,184 | 147,456 | 64 | 884,736 | 589,824 |
| 9 | 1 | 17,280 | 11,520 | 4 | 69,120 | 46,080 | 16 | 276,480 | 184,320 | 64 | 1,105,920 | 737,280 |
| 10 | 1 | 20,736 | 13,824 | 4 | 82,944 | 55,296 | 16 | 331,776 | 221,184 | 64 | 1,327,104 | 884,736 |
| 11 | 1 | 23,040 | 19,200 | 4 | 92,160 | 76,800 | 16 | 368,640 | 307,200 | 64 | 1,474,560 | 1,228,800 |
| 12 | 1 | 30,720 | 23,040 | 4 | 122,880 | 92,160 | 16 | 491,520 | 368,640 | 64 | 1,966,080 | 1,474,560 |

**TABLE D-XLVIII. Interleaver Parameters for 48 kHz Bandwidth**

| Waveform Number | UltraShort | | | Short | | | Medium | | | Long | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits | Number of Frames | Number of bits | Number of Input Bits |
| 0 | - | - | - | 640 | 1280 | 640 | 2304 | 4608 | 2304 | 9216 | 18432 | 9216 |
| 1 | 3 | 1536 | 192 | 18 | 9216 | 1152 | 72 | 36,864 | 4608 | 288 | 147,456 | 18,432 |
| 2 | 3 | 1536 | 384 | 18 | 9216 | 2304 | 72 | 36,864 | 9216 | 288 | 147,456 | 36,864 |
| 3 | 3 | 1536 | 768 | 18 | 9216 | 4608 | 72 | 36,864 | 18,432 | 288 | 147,456 | 73,728 |
| 4 | 1 | 2560 | 1280 | 6 | 15,360 | 7680 | 24 | 61,440 | 30,720 | 96 | 245,760 | 122,880 |
| 5 | 1 | 2560 | 1920 | 6 | 15,360 | 11,520 | 24 | 61,440 | 46,080 | 96 | 245,760 | 184,320 |
| 6 | 1 | 5120 | 3840 | 6 | 30,720 | 23,040 | 24 | 122,880 | 92,160 | 96 | 491,520 | 368,640 |
| 7 | 1 | 7680 | 5760 | 6 | 46,080 | 34,560 | 24 | 184,320 | 138,240 | 96 | 737,280 | 552,960 |
| 8 | 1 | 10,240 | 7680 | 6 | 61,440 | 46,080 | 24 | 245,760 | 184,320 | 96 | 983,040 | 737,280 |
| 9 | 1 | 12,800 | 9600 | 6 | 76,800 | 57,600 | 24 | 307,200 | 230,400 | 96 | 1,228,800 | 921,600 |
| 10 | 1 | 15,360 | 11,520 | 6 | 92,160 | 69,120 | 24 | 368,640 | 276,480 | 96 | 1,474,560 | 1,105,920 |
| 11 | 1 | 17,280 | 15,360 | 6 | 103,680 | 92,160 | 24 | 414,720 | 368,640 | 96 | 1,658,880 | 1,474,560 |
| 12 | 1 | 23,040 | 19,200 | 6 | 138,240 | 115,200 | 24 | 552,960 | 460,800 | 96 | 2,211,840 | 1,843,200 |

D.5.3.1 Block boundary alignment.
Each code block shall be interleaved within a single interleaver block of the same size. The boundaries of these blocks shall be aligned such that the beginning of the first data frame shall coincide with an interleaver boundary. The first data symbol from the first data frame in each interleaver set shall have as its MSB the first bit fetched from the interleaver. This is no different from what would normally be expected, but is a requirement.

D.5.3.2 Block encoding.
The full-tail-biting and puncturing techniques shall be used with either a rate 1/2 k=7 convolutional code or a rate 1/2 k=9 convolutional code to produce a block code that is the same length as the interleaver. For those data rates where the code is punctured to rate 9/10, 8/9, 5/6, 4/5, 3/4, 2/3, 9/16, 1/2, 2/5, 1/3, 2/7, 1/4, 1/6, 1/8, 1/12 and 1/16 the punctured block shall still fit exactly within the interleaver. Table D-XLIX indicates which code rates and modulations are used by the different waveform and bandwidths supported by this standard.

**TABLE D-XLIX. Code Rate and Modulation.**

| Waveform Number | **0** Walsh | **1** BPSK | **2** BPSK | **3** BPSK | **4** BPSK | **5** BPSK | **6** QPSK | **7** 8PSK | **8** 16QAM | **9** 32QAM | **10** 64QAM | **11** 64QAM | **12** 256QAM | **13** QPSK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Bandwidth** (kHz) | | | | | | | | | | | | | | |
| 3 | 1/2 | 1/8 | 1/4 | 1/3 | 2/3 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 8/9 | 8/9 | 9/16 |
| 6 | 1/2 | 1/8 | 1/4 | 1/3 | 2/3 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 8/9 | 8/9 | |
| 9 | 2/3 | 1/8 | 1/4 | 1/2 | - | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 8/9 | 8/9 | |
| 12 | 1/2 | 1/8 | 1/4 | 1/3 | 2/3 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 8/9 | 8/9 | |
| 15 | 2/5 | 1/12 | 1/6 | 1/3 | 2/3 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 8/9 | 8/9 | |
| 18 | 2/3 | 1/8 | 1/4 | 1/2 | - | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 8/9 | 5/6 | |
| 21 | 2/7 | 1/16 | 1/8 | 1/4 | 1/2 | 2/3 | 2/3 | 2/3 | 2/3 | 2/3 | 2/3 | 4/5 | 9/10 | |
| 24 | 1/2 | 1/8 | 1/4 | 1/3 | 2/3 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 8/9 | 5/6 | |
| 30 | 2/5 | 1/12 | 1/6 | 1/3 | 2/3 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 8/9 | 8/9 | |
| 36 | 2/3 | 1/8 | 1/4 | 1/2 | 1/2 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 8/9 | 8/9 | |
| 42 | 4/7 | 1/8 | 1/4 | 1/2 | 1/2 | 2/3 | 2/3 | 2/3 | 2/3 | 2/3 | 2/3 | 5/6 | 3/4 | |
| 48 | 1/2 | 1/8 | 1/4 | 1/2 | 1/2 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 3/4 | 8/9 | 5/6 | |

D.5.3.2.1 Constraint length 7, rate 1/2 convolutional code.
A constraint length 7, rate 1/2 convolutional code shall be used prior to puncturing. This shall be the same code as is used in the single-tone waveform described in section 5.3.2 of this standard. Figure D-9 is a pictorial representation of the encoder.

**Polynomials:**
**(b0)** $T_1 = x^6 + x^4 + x^3 + x^1 + 1$
**(b1)** $T_2 = x^6 + x^5 + x^4 + x^3 + 1$

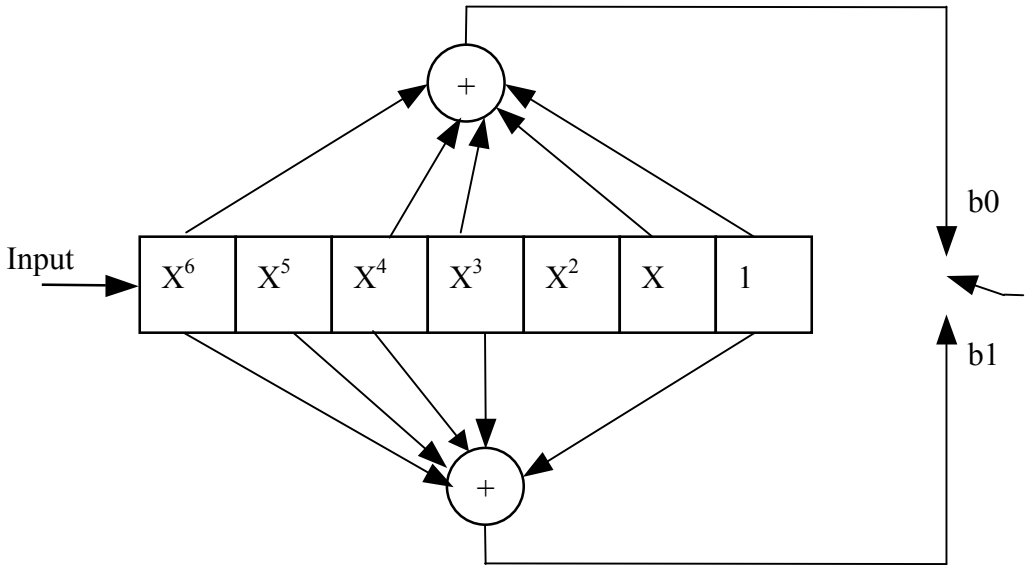


**FIGURE D-9. Constraint length 7, rate 1/2 convolutional encoder.**

The two summing nodes in the figure represent modulo 2 additions. For each bit input to the encoder, two bits are taken from the encoder, with the upper output bit b0, generated by polynomial $T_1(x)$, taken first.

D.5.3.2.2 Constraint length 9, rate 1/2 convolutional code.
A constraint length 9, rate 1/2 convolutional code shall be used prior to puncturing. Figure D-10 is a pictorial representation of the encoder.

**Polynomials:**
**(b0) T1 = $x^8+x^6+x^5+x^4+1$**
**(b1) T2 = $x^8+x^7+x^6+x^5+x^3+x^1+1$**

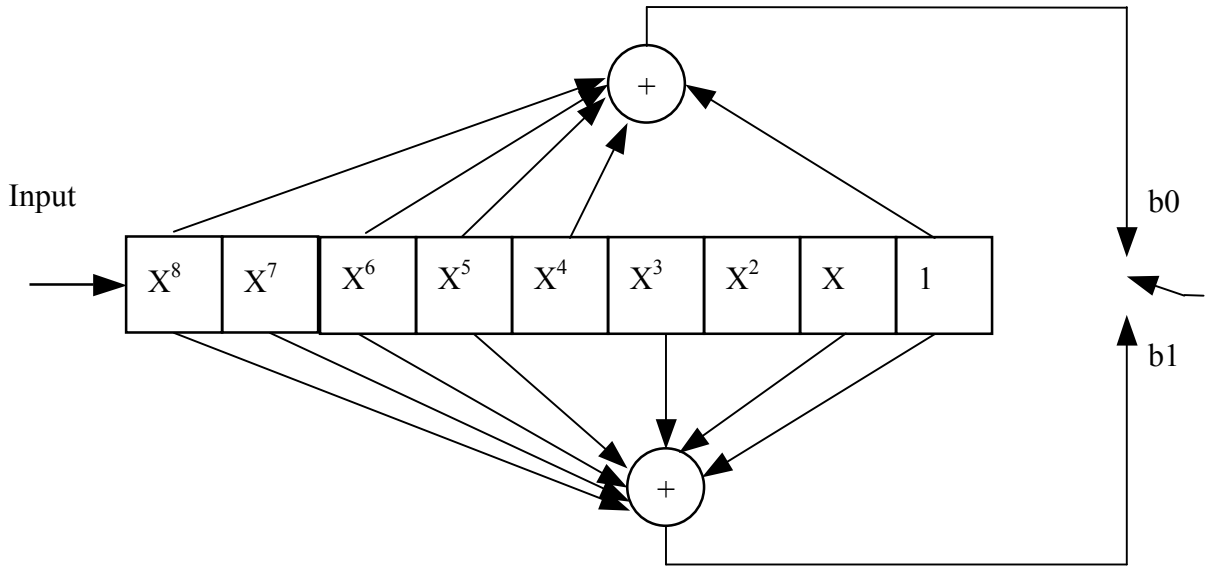


**FIGURE D-10. Constraint length 9, rate 1/2 convolutional encoder.**

The two summing nodes in the figure represent modulo 2 additions. For each bit input to the encoder, two bits are taken from the encoder, with the upper output bit b0, generated by polynomial $T_1(x)$, taken first.

D.5.3.2.3 Full-tail-biting encoding.
To begin encoding each block of input data, the encoder shall be preloaded by shifting in the first (k-1) input data bits without taking any output bits. These (k-1) input bits shall be temporarily saved so that they can be used to "flush" the encoder. The first two coded output bits shall be taken after the (kth) bit has been shifted in, and shall be defined to be the first two bits of the resulting block code. After the last input data bit has been encoded, the first (k-1) "saved" data bits shall be encoded. Note that the encoder shift register should not be changed before encoding these saved bits; i.e., it should be filled with the last seven input data bits. The (k-1) "saved" data bits are encoded by shifting them into the encoder one at a time, beginning with the earliest of the (k-1). The encoding thus continues by taking the two resulting coded output bits as each of the saved (k-1) bits is shifted in. These encoded bits shall be the final bits of the resulting (unpunctured) block code. Prior to puncturing, the resulting block code will have exactly twice as many bits as the input information bits. Puncturing of the rate 1/2 code to the other required rates shall be done prior to sending bits to the interleaver.

D.5.3.2.4 Puncturing and Repetition.

In order to obtain a higher rate code from a lower rate code, the output of the encoder must be punctured by not transmitting all of the encoder's output bits. Which bits are transmitted are defined by a puncturing mask. For example, when puncturing a rate ½ code to rate ¾ code one out of every 3 bits must not be transmitted. In this case puncturing shall be performed by using a puncturing mask of

110
101

In this notation the first row indicates the bits retained by the T1 branch, the second row indicates the bits retained by the T2 branch. A 1 indicates that the bit is transmitted and a 0 indicates that the bit is not transmitted. For an encoder generated sequence of

$T_1(k), T_2(k), T_1(k+1), T_2(k+1), T_1(k+2), T_2(k+2) \ldots$

the transmitted sequence shall be

$T_1(k), T_2(k), T_1(k+1), P, P, T_2(k+2) \ldots$

Defining $T_1(0)$, $T_2(0)$ to be the first two bits of the block code generated as defined in paragraph 5.3.2, then the value of k in the above sequences shall be an integral multiple of 3. The block code shall be punctured in this manner before being input to the interleaver.

In order to obtain a lower code rate from a higher code rate repetition can be used. For example to generate a rate ¼ code from a rate ½ code the two output bits

$T_1(k), T_2(k), T_1(k+1), T_2(k+1),$

Are repeated to yield four output bits for each input bit, giving

$T_1(k), T_2(k), T_1(k), T_2(k), T_1(k+1), T_2(k+1), T_1(k+1), T_2(k+1)$

For the cases that require a combination of repitition and puncturing the code words are first repeated and then the puncturing is applied. For example to generate a rate 1/3 code from a rate ½ code the two output, T1(k),T2(k) bits are repeated twice

T1(k), T2(k), T1(k), T2(k), T1(k+1), T2(k+1), T1(k+1), T2(k+1),

The Puncturing pattern from the Rate 2/3 code is now applied twice resulting in

T1(k), T2(k), T1(k), P, T1(k+1), T2(k+1), T1(k+1), P

**TABLE D-L. Puncture patterns.**

| Code Rate | K=7 Puncture Pattern | K=9 Puncture Pattern | Number of Repeats |
|---|---|---|---|
| 9 / 10 | 111101110<br>100010001 | 111000101<br>100111010 | n/a |
| 8 / 9 | 11110100<br>10001011 | 11100000<br>10011111 | n/a |
| 5 / 6 | 11010<br>10101 | 10110<br>11001 | n/a |
| 4 / 5 | 1111<br>1000 | 1101<br>1010 | n/a |
| 3 / 4 | 110<br>101 | 111<br>100 | n/a |
| 2 / 3 | 11<br>10 | 11<br>10 | n/a |
| 4/7 | 1111<br>0111 | 1111<br>0111 | n/a |
| 9/16 | 111101111<br>111111011 | 111101111<br>111111011 | n/a |
| 1 / 2 | n/a | n/a | n/a |
| 2 / 5 | 1110<br>1010 | 1110<br>1010 | ½ Repeated 2x |
| 1 / 3 | n/a | n/a | 2/3 Repeated 2x |
| 2 / 7 | 1111<br>0111 | 1111<br>0111 | ½ Repeated 2x |
| 1 / 4 | n/a | n/a | 1/2 repeated 2x |
| 1 / 6 | n/a | n/a | 1/2 repeated 3x |
| 1 / 8 | n/a | n/a | 1/2 repeated 4x |
| 1 / 12 | n/a | n/a | 1/2 repeated 6x |
| 1 / 16 | n/a | n/a | 1/2 repeated 8x |

D.5.3.3 Block interleaver structure.
The block interleaver used is designed to separate neighboring bits in the punctured block code as far as possible over the span of the interleaver with the largest separations resulting for the bits that were originally closest to each other.

D.5.3.3.1 Interleaver size in bits.
The interleaver shall consist of a single dimension array, numbered from 0 to its size in bits –1. The array size shall depend on both the data rate and interleaver length selected as shown in the Tables D-XXXVII through D-XLVIII, one for each bandwidth.

D.5.3.3.2 Interleaver load.
The punctured block code bits shall be loaded into the interleaver array beginning with location 0. The location for loading each successive bit shall be obtained from the previous location by

incrementing by the "Interleaver Increment Value" specified in Tables D-LI through D-LXII, modulo the "Interleaver Size in Bits."

Defining the first punctured block code bit to be B(0), then the load location for B(n) is given by:

Load Location = ( n * Interleaver Increment Value) Modulo (Interleaver Size in Bits)

Thus for Waveform 1 in Table D-XXXIII, using ultrashort interleaver (192 bit size with an increment of 25), the first 9 interleaver load locations are: 0, 25, 50, 75, 100, 125, 150, 175 and 8.

**TABLE D-LI. Interleaver increment value for 3 kHz waveform**

| WID | Interleaver Size | | | |
|---|---|---|---|---|
| | Ultrashort | Short | Medium | Long |
| 0 | - | 11 | 37 | 145 |
| 1 | 25 | 97 | 385 | 1543 |
| 2 | 25 | 97 | 385 | 1543 |
| 3 | 25 | 97 | 385 | 1549 |
| 4 | 25 | 97 | 385 | 1549 |
| 5 | 33 | 129 | 513 | 2081 |
| 6 | 65 | 257 | 1025 | 4161 |
| 7 | 97 | 385 | 1537 | 6241 |
| 8 | 129 | 513 | 2049 | 8321 |
| 9 | 161 | 641 | 2561 | 10403 |
| 10 | 193 | 769 | 3073 | 12481 |
| 11 | 271 | 1081 | 4321 | 17551 |
| 12 | 361 | 1441 | 5761 | 23401 |
| 13 | 65 | 257 | 1025 | 4161 |

**TABLE D-LII. Interleaver increment value for 6 kHz waveform**

| WID | Interleaver Size | | | |
|---|---|---|---|---|
| | Ultrashort | Short | Medium | Long |
| 0 | - | 21 | 73 | 289 |
| 1 | 49 | 193 | 769 | 3085 |
| 2 | 49 | 193 | 769 | 3085 |
| 3 | 53 | 205 | 817 | 3293 |
| 4 | 53 | 205 | 817 | 3293 |
| 5 | 69 | 273 | 1089 | 4421 |
| 6 | 137 | 545 | 2177 | 8841 |
| 7 | 205 | 817 | 3265 | 13261 |
| 8 | 273 | 1089 | 4353 | 17681 |
| 9 | 341 | 1361 | 5441 | 22103 |
| 10 | 409 | 1633 | 6529 | 26521 |
| 11 | 409 | 1621 | 6481 | 26329 |
| 12 | 553 | 2161 | 8641 | 35113 |

**TABLE D-LIII. Interleaver increment value for 9 kHz waveform**

| WID | Interleaver Size | | | |
|---|---|---|---|---|
| | Ultrashort | Short | Medium | Long |
| 0 | - | 31 | 109 | 433 |
| 1 | 73 | 289 | 1153 | 4645 |
| 2 | 73 | 289 | 1153 | 4645 |
| 3 | 73 | 289 | 1153 | 4645 |
| 4 | - | - | - | - |
| 5 | 97 | 385 | 1537 | 6241 |
| 6 | 193 | 769 | 3073 | 12481 |
| 7 | 289 | 1153 | 4609 | 18721 |
| 8 | 385 | 1537 | 6145 | 24961 |
| 9 | 481 | 1921 | 7681 | 31207 |
| 10 | 577 | 2305 | 9217 | 37441 |
| 11 | 811 | 3241 | 13771 | 52651 |
| 12 | 1081 | 4321 | 18361 | 70201 |

**TABLE D-LIV. Interleaver increment value for 12 kHz waveform**

| WID | Interleaver Size | | | |
|---|---|---|---|---|
| | Ultrashort | Short | Medium | Long |
| 0 | - | 41 | 145 | 577 |
| 1 | 73 | 289 | 1153 | 4633 |
| 2 | 73 | 289 | 1153 | 4633 |
| 3 | 97 | 385 | 1537 | 6193 |
| 4 | 97 | 385 | 1537 | 6193 |
| 5 | 129 | 513 | 2049 | 8321 |
| 6 | 257 | 1025 | 4097 | 16641 |
| 7 | 385 | 1537 | 6145 | 24961 |
| 8 | 513 | 2049 | 8193 | 33281 |
| 9 | 641 | 2561 | 10241 | 41603 |
| 10 | 769 | 3073 | 13057 | 49921 |
| 11 | 811 | 3241 | 13771 | 52651 |
| 12 | 1081 | 4321 | 18361 | 70201 |

**TABLE D-LV. Interleaver increment value for 15 kHz waveform**

| WID | Interleaver Size | | | |
|---|---|---|---|---|
| | Ultrashort | Short | Medium | Long |
| 0 | – | 51 | 181 | 721 |
| 1 | 109 | 433 | 1729 | 6949 |
| 2 | 109 | 433 | 1729 | 6949 |
| 3 | 109 | 433 | 1729 | 6949 |
| 4 | 109 | 433 | 1729 | 6949 |
| 5 | 161 | 641 | 2561 | 10401 |
| 6 | 321 | 1281 | 5121 | 20801 |
| 7 | 481 | 1921 | 7681 | 31201 |
| 8 | 641 | 2561 | 10241 | 41601 |
| 9 | 801 | 3201 | 13603 | 52003 |
| 10 | 961 | 3841 | 16321 | 62401 |
| 11 | 865 | 3457 | 14689 | 56161 |
| 12 | 1153 | 4609 | 19585 | 74881 |

**TABLE D-LVI. Interleaver increment value for 18 kHz waveform**

| WID | Interleaver Size | | | |
|---|---|---|---|---|
| | Ultrashort | Short | Medium | Long |
| 0 | - | 61 | 217 | 865 |
| 1 | 169 | 673 | 2689 | 10811 |
| 2 | 169 | 673 | 2689 | 10811 |
| 3 | 169 | 673 | 2689 | 10811 |
| 4 | - | - | - | - |
| 5 | 193 | 769 | 3073 | 12481 |
| 6 | 385 | 1537 | 6145 | 24961 |
| 7 | 577 | 2305 | 9217 | 37441 |
| 8 | 769 | 3073 | 13057 | 49921 |
| 9 | 961 | 3841 | 16327 | 62407 |
| 10 | 1153 | 4609 | 19585 | 74881 |
| 11 | 1441 | 5761 | 24481 | 93601 |
| 12 | 1921 | 7681 | 32641 | 124801 |

**TABLE D-LVII. Interleaver increment value for 21 kHz waveform**

| WID | Interleaver Size | | | |
|---|---|---|---|---|
| | Ultrashort | Short | Medium | Long |
| 0 | - | 71 | 253 | 1009 |
| 1 | 161 | 641 | 2561 | 10281 |
| 2 | 161 | 641 | 2561 | 10281 |
| 3 | 161 | 641 | 2561 | 10281 |
| 4 | 161 | 641 | 2561 | 10281 |
| 5 | 169 | 673 | 2689 | 10921 |
| 6 | 337 | 1345 | 5377 | 21841 |
| 7 | 505 | 2017 | 8065 | 32761 |
| 8 | 673 | 2689 | 11425 | 43681 |
| 9 | 841 | 3361 | 14293 | 54613 |
| 10 | 1009 | 4033 | 17137 | 65521 |
| 11 | 1921 | 7681 | 32641 | 124801 |
| 12 | 2561 | 10241 | 43521 | 166401 |

**TABLE D-LVIII. Interleaver increment value for 24 kHz waveform**

| WID | Interleaver Size | | | |
|---|---|---|---|---|
| | Ultrashort | Short | Medium | Long |
| 0 | - | 81 | 289 | 1153 |
| 1 | 137 | 545 | 2177 | 8739 |
| 2 | 137 | 545 | 2177 | 8739 |
| 3 | 205 | 817 | 3265 | 13159 |
| 4 | 205 | 817 | 3265 | 13159 |
| 5 | 273 | 1089 | 4353 | 17681 |
| 6 | 545 | 2177 | 8705 | 35361 |
| 7 | 817 | 3265 | 13873 | 53041 |
| 8 | 1089 | 4353 | 18497 | 70721 |
| 9 | 1361 | 5441 | 23123 | 88403 |
| 10 | 1633 | 6529 | 27745 | 106081 |
| 11 | 1441 | 5761 | 24481 | 93601 |
| 12 | 1921 | 7681 | 32641 | 124801 |

**TABLE D-LIX. Interleaver increment value for 30 kHz waveform**

| WID | Interleaver Size | | | |
|---|---|---|---|---|
| | Ultrashort | Short | Medium | Long |
| 0 | - | 119 | 431 | 1673 |
| 1 | 275 | 1259 | 4207 | 15445 |
| 2 | 275 | 1259 | 4207 | 15445 |
| 3 | 275 | 1259 | 4207 | 15445 |
| 4 | 275 | 1259 | 4207 | 15445 |
| 5 | 381 | 2951 | 8729 | 24989 |
| 6 | 781 | 5893 | 29161 | 49991 |
| 7 | 1207 | 8821 | 26221 | 71341 |
| 8 | 1529 | 11837 | 43733 | 142017 |
| 9 | 1941 | 14711 | 54541 | 221051 |
| 10 | 2257 | 17623 | 65557 | 288127 |
| 11 | 2473 | 18643 | 55669 | 281233 |
| 12 | 3281 | 25097 | 74329 | 374993 |

**TABLE D-LX. Interleaver increment value for 36 kHz waveform**

| WID | Interleaver Size | | | |
|---|---|---|---|---|
| | Ultrashort | Short | Medium | Long |
| 0 | - | 143 | 511 | 2011 |
| 1 | 901 | 1577 | 11843 | 22595 |
| 2 | 901 | 1577 | 11843 | 22595 |
| 3 | 901 | 1577 | 11843 | 22595 |
| 4 | 455 | 3557 | 17575 | 26663 |
| 5 | 455 | 3557 | 17575 | 26663 |
| 6 | 911 | 7027 | 35179 | 69763 |
| 7 | 1633 | 10867 | 52741 | 90013 |
| 8 | 1913 | 14245 | 70337 | 119977 |
| 9 | 2411 | 17831 | 87931 | 133351 |
| 10 | 2719 | 22267 | 105163 | 174025 |
| 11 | 2851 | 22381 | 110509 | 197491 |
| 12 | 4049 | 29977 | 148361 | 281057 |

**TABLE D-LXI. Interleaver increment value for 40 kHz waveform**

| WID | Interleaver Size | | | |
|---|---|---|---|---|
| | Ultrashort | Short | Medium | Long |
| 0 | - | 167 | 601 | 2371 |
| 1 | 1001 | 1687 | 5867 | 30619 |
| 2 | 1001 | 1687 | 5867 | 30619 |
| 3 | 1001 | 1687 | 5867 | 30619 |
| 4 | 593 | 4007 | 11789 | 33757 |
| 5 | 593 | 4007 | 11789 | 33757 |
| 6 | 1019 | 7993 | 23641 | 67505 |
| 7 | 1531 | 11995 | 35335 | 101203 |
| 8 | 2029 | 15965 | 47137 | 134965 |
| 9 | 2581 | 19901 | 58871 | 168701 |
| 10 | 3079 | 23995 | 70669 | 202411 |
| 11 | 3499 | 26539 | 78571 | 249943 |
| 12 | 4673 | 35281 | 104857 | 333113 |

**TABLE D-LXII. Interleaver increment value for 48 kHz waveform**

| WID | Interleaver Size | | | |
|---|---|---|---|---|
| | Ultrashort | Short | Medium | Long |
| 0 | - | 191 | 697 | 2693 |
| 1 | 943 | 1735 | 6805 | 14425 |
| 2 | 943 | 1735 | 6805 | 14425 |
| 3 | 943 | 1735 | 6805 | 14425 |
| 4 | 397 | 2941 | 8393 | 39551 |
| 5 | 397 | 2941 | 8393 | 39551 |
| 6 | 797 | 5881 | 16739 | 72607 |
| 7 | 1231 | 8827 | 25099 | 104197 |
| 8 | 1509 | 11729 | 46729 | 137413 |
| 9 | 1911 | 14701 | 41981 | 181541 |
| 10 | 2281 | 17623 | 70183 | 217873 |
| 11 | 2569 | 19831 | 56599 | 247963 |
| 12 | 3401 | 26449 | 105209 | 326729 |

These increment values have been chosen to ensure that the combined cycles of puncturing and assignment of bit positions in each symbol for the specific constellation being used is the same as if there had been no interleaving. For waveforms 7-12, this is important, because each symbol of a constellation contains “strong” and “weak” bit positions. Bit position refers to the location of the bit, ranging from MSB to LSB, in the symbol mapping. A strong bit position is one that has a large average distance between all the constellation points where the bit is a 0 and the closest point where it is a 1. Typically, the MSB is a strong bit and the LSB a weak bit. An interleaving strategy that does not evenly distribute these bits in the way they occur without interleaving could degrade performance.

D.5.3.3.3 Interleaver fetch.
The fetching sequence for all data rates and interleaver lengths shall start with location 0 of the interleaver array and increment the fetch location by 1. This is a simple linear fetch from beginning to end of the interleaver array.

D.5.4 Operational features and message protocols.
The format of this high-rate waveform has been designed to permit it to work well with most of the protocols used and planned for use with HF. The short length of the synchronization preamble, wide range of interleaving lengths, and the use of full-tail-biting coding is intended to provide efficient operation with ARQ protocols. To further enhance the operation with these protocols, the following operational features shall be included in the HF modem.

D.5.4.1 User interfaces.

D.5.4.1.1 Conventional synchronous interface.
A synchronous serial interface shall be provided IAW 4.2.3.

D.5.4.1.2 Conventional asynchronous interface.
In addition to the standard synchronous serial interface (see 4.2.3), the modem shall also be capable of interfacing with an asynchronous DTE. In this case the DTE provides (accepts) asynchronous Words consisting of a Start Bit, an N bit Character, and some minimum number of Stop Bits. Additional Stop Bits are provided (accepted) by the DTE between Words as necessary to accommodate gaps between their occurrence. Interoperability shall be provided for those cases where the value of N, the number of Bits in the Character, is 5,6,7, or 8 (including any parity bits), and the minimum number of Stop Bits is 1 or 2. Hence interoperability is defined for those cases where the number of Bits in the Word is N+2 and N+3. In these cases the entire N+2 or N+3 bits of the Word shall be conveyed in the modulated signal. Additional Stop Bits shall be conveyed as necessary to accommodate gaps in data from the DTE; there shall be no modem-defined null character incorporated into the modulated signal.

D.5.4.1.3 High speed asynchronous user interface with flow control.
Certain high speed user interfaces provide data to (and accept data from) the modem in units of 8 bit bytes. Furthermore, the Input Data Blocks shown in Tables D-XXXIII through D-XL are all multiples of 8 bit bytes. An optional mode shall be provided to accommodate the special case of an 8 bit character (which includes any parity check bits) and a 1.0 unit interval Stop Bit. In this optional mode, the 8 bit Character shall be aligned with the 256 symbol modem frame boundary, and no Start or Stop Bits shall be transmitted. In this mode of operation it is assumed that the DTE data rate is greater than that which can be accommodated by the modem. Consequently flow control shall be used to temporarily stop data flow from the DTE to the modem when the modem's input buffer becomes full. Conversely, when the modem's input buffer becomes empty, the modem shall assume that the DTE has finished its message, and the modem shall initiate its normal message-termination procedure. This method of operation obviates the need for the transmission of Null characters for the purpose of "rate padding." Consequently, no Null characters shall be transmitted for this purpose.

D.5.4.1.4 Ethernet interface.
The modem shall provide an Ethernet interface (see Appendix A) for byte oriented user data transfers (see D.5.4.1.2), and these bytes shall be aligned with the Input Data Block boundaries.

D.5.4.2 Onset of transmission.
The modem shall begin a transmission no later than 100 ms after it has received an entire input data block (enough bits to fill a coded and interleaved block), or upon receipt of the last input data bit, whichever occurs first. The latter would only occur when the message is shorter than one interleaver block. A transmission shall be defined as beginning with the keying of the radio, followed by the output of the preamble waveform after the configured pre-key delay, if any.

The delay between when the modem receives the first input data bit and the onset of transmission will be highly dependent on the means for delivery of the input data bits to the modem. A synchronous serial interface at the user data rate will have the greatest delay. For this reason it is recommended that a high speed asynchronous interface (serial or Ethernet port) with flow-control be used if this delay is of concern for the deployed application.

D.5.4.3 End of message.
The use of an end-of-message (EOM) in the transmit waveform shall be a configurable option. When the use of an EOM has been selected, a 32-bit EOM pattern shall be appended after the last input data bit of the message. The EOM, expressed in hexadecimal notation is 4B65A5B2, where the left most bit is sent first. If the last bit of the EOM does not fill out an input data block, the remaining bits in the input data block shall be set to zero before encoding and interleaving the block.

If the use of an EOM has been inhibited, and the last input data bit does not fill out an input data block, the remaining bits in the input data block shall be set to zero before encoding and interleaving the block. It is anticipated that the use of an EOM will only be inhibited when an ARQ data protocol uses ARQ blocks which completely fill (or nearly so) the selected input data block size (interleaver block). Without this feature, the use of an EOM would require the transmission of an additional interleaver block under these circumstances.

D.5.4.4 Termination of a transmission.
Upon receipt of a radio silence (or equivalent) command, the modem shall immediately un-key the radio and terminate its transmit waveform.

In normal operation, the modem shall terminate a transmission only after the transmission of the final data frame, including a mini-probe, associated with the final interleaver block. Note that a data frame consists of a 256 symbol data block followed by a mini-probe. Note that any signal processing and/or filter delays in the modem and the HF transmitter must be accounted for (as part of the key line control timing) to ensure that the entire final mini-probe is transmitted before the transmitter power is turned off.

An optional feature can be added to the end of each transmission. The transmitter can insert an end-of-transmission (EOT) marker following the last mini-probe sequence. The purpose of this EOT marker is to allow receiver implementations to detect the end of a transmission immediately, without having to wait for the EOM marker embedded within the data. The EOT will not be as robust an indicator of the end of a transmission as the embedded EOM. However, in relatively benign channels, this feature will reduce the time before the receiver is able to return to acquisition mode, with the result that in a TDMA system, back-to-back receptions can be scheduled with a significantly smaller guard time between them. The EOT shall consist of a cyclic extension of the last mini-probe, where the mini-probe sequence has been defined in Table D-XXI. The length of the cyclic extension shall be 13.333 ms (an integer multiple of 32 symbols for each symbol rate). Furthermore, it will be optional for the receiver to search for this EOT marker, so that operation on challenging multipath fading channels is not affected by the need to search for EOT marker.

For example, for the length 13 base sequence used with the 3 kHz bandwidth, the last mini-probe shall consist of the 24 symbols of the last mini-probe, plus 32 additional symbols formed by the cyclic extension of the 13 symbol Base Sequence. Thus, the final mini-probe will be 56 symbols in length and consist of 4 complete 13 symbol Base sequences plus the first 4 symbols of a fifth base sequence. This specific example is illustrated in Table D-LXIII.

**TABLE D-LXIII. In-phase and Quadrature components of 13 symbol Base Sequence used to form 24 symbol mini-probe and cyclically extended by 32 symbols to mark the EOT.**

| Symbol Number | In-Phase | Quadrature | Symbol Number | In-Phase | Quadrature |
|---|---|---|---|---|---|
| 0 | 1.00000 | 0.0 | 28 | 1.00000 | 0.0 |
| 1 | 1.00000 | 0.0 | 29 | 1.00000 | 0.0 |
| 2 | 1.00000 | 0.0 | 30 | 1.00000 | 0.0 |
| 3 | 1.00000 | 0.0 | 31 | -1.00000 | 0.0 |
| 4 | 1.00000 | 0.0 | 32 | -1.00000 | 0.0 |
| 5 | -1.00000 | 0.0 | 33 | 1.00000 | 0.0 |
| 6 | -1.00000 | 0.0 | 34 | 1.00000 | 0.0 |
| 7 | 1.00000 | 0.0 | 35 | -1.00000 | 0.0 |
| 8 | 1.00000 | 0.0 | 36 | 1.00000 | 0.0 |
| 9 | -1.00000 | 0.0 | 37 | -1.00000 | 0.0 |
| 10 | 1.00000 | 0.0 | 38 | 1.00000 | 0.0 |
| 11 | -1.00000 | 0.0 | 39 | 1.00000 | 0.0 |
| 12 | 1.00000 | 0.0 | 40 | 1.00000 | 0.0 |
| 13 | 1.00000 | 0.0 | 41 | 1.00000 | 0.0 |
| 14 | 1.00000 | 0.0 | 42 | 1.00000 | 0.0 |
| 15 | 1.00000 | 0.0 | 43 | 1.00000 | 0.0 |
| 16 | 1.00000 | 0.0 | 44 | -1.00000 | 0.0 |
| 17 | 1.00000 | 0.0 | 45 | -1.00000 | 0.0 |
| 18 | -1.00000 | 0.0 | 46 | 1.00000 | 0.0 |
| 19 | -1.00000 | 0.0 | 47 | 1.00000 | 0.0 |
| 20 | 1.00000 | 0.0 | 48 | -1.00000 | 0.0 |
| 21 | 1.00000 | 0.0 | 49 | 1.00000 | 0.0 |
| 22 | -1.00000 | 0.0 | 50 | -1.00000 | 0.0 |
| 23 | 1.00000 | 0.0 | 51 | 1.00000 | 0.0 |
| 24 | -1.00000 | 0.0 | 52 | 1.00000 | 0.0 |
| 25 | 1.00000 | 0.0 | 53 | 1.00000 | 0.0 |
| 26 | 1.00000 | 0.0 | 54 | 1.00000 | 0.0 |
| 27 | 1.00000 | 0.0 | 55 | 1.00000 | 0.0 |

D.5.4.5 Termination of receive data processing.

There are a number of events which shall cause the HF modem to cease processing the received signal to recover data, and return to the acquisition mode. These are necessary because a modem is not able to acquire a new transmission while it is attempting to demodulate and decode data.

D.5.4.5.1 Detection of EOM.
The HF modem shall always scan all of the decoded bits for the 32-bit EOM pattern defined in paragraph D.5.4.3. Upon detection of the EOM the modem shall return to the acquisition mode. The modem shall continue to deliver decoded bits to the user (DTE) until the final bit immediately preceding the EOM has been delivered.

D.5.4.5.2 Command to return to acquisition.
Upon receipt of a command to terminate reception, the HF modem shall return to the acquisition mode and terminate the delivery of decoded bits to the user (DTE).

D.5.4.5.3 Receipt of a specified number of data blocks.
The maximum message duration measured in number of Input Data Blocks (interleaver blocks) shall be a configurable parameter. One value of this parameter shall specify that an unlimited number may be received. Once the modem has decoded and delivered to the user (DTE), the number of bits corresponding to the configured maximum message duration, the HF modem shall return to the acquisition mode and terminate the delivery of decoded bits to the user (DTE). Note that for a given interleaver length, this parameter also specifies the maximum message duration in time, independent of the bit rate. Note that this parameter is the maximum duration and that the transmit end always has the option of using an EOM for shorter transmissions.

Operation with a specified number of input data blocks may be used by an ARQ protocol where the size of the ARQ packet is fixed, or occasionally changed to accommodate changing propagation conditions. In this case we anticipate that this parameter (maximum message duration) will be sent to the receiving end of the link as part of the ARQ protocol. It would then be sent to the receiving modem through the remote control interface (see 0 below), since it is not embedded in the waveform itself as the data rate and interleaver length parameters are.

D.5.4.5.4 Initiation of a transmission.
If, and only if, the HF Modem is configured to operate in half-duplex mode with transmit override, the initiation of a transmission by the user (DTE) shall cause the HF modem to terminate the receive processing and the delivery of decoded bits to the user (DTE).

D.5.4.6 Remote control.
The remote control interface (see section 5.3.1.5) shall provide the capability to specify the following parameters and commands:

a. waveform parameters:
   1) The bandwidth (from 3kHz through 24 kHz, in multiples of 3 kHz )
   2) The waveform ID (0 through 13)
   3) The Interleaver length (UltraShort, Short, Medium, or Long)
   4) The convolutional code constraint length (7 or 9)

b. A command to select the usage of the optional EOM in the transmit waveform. Note that the receiving modem must always scan for the EOM regardless of this setting.

c. A command to specify the maximum message duration measured in number of Input Data Blocks (interleaver blocks). The value of 0 (zero) for this parameter shall specify that an unlimited number may be received.

d. A command to cause the modem to terminate receive data processing and return to acquisition mode.

## D.6 PERFORMANCE

All MIL-STD-188-110C modem functionality testing should be performed at baseband. In the case of testing a modem embedded in an HF Radio, a baseband interface should be utilized if available. If no baseband interface is provided, care must be taken in the test set up to ensure that two radios, back to back, deliver a signal to Noise ratio (SNR) significantly higher than the condition under test so as to not compromise the measurement.

When testing a modem embedded in a radio with no baseband audio interface, the RF signals must be downconverted to baseband for processing by the channel simulator, and the result upconverted to RF for the receiver. In this case, transmit gain control (TGC), built-in analog and digital radio filters and automatic gain control (AGC) will affect the performance of the modems. Therefore, when testing embedded modems, the SNR values specified in Table D-LII shall be increased by 3 dB after verifying that the SNR condition mentioned in previous paragraph is met. Note that the SNR requirement mentioned in previous paragraph must also be met by the up/down conversion chain with the channel simulator set to non-fading path with 99 dB SNR.

### D.6.1 BER performance on AWGN and Multipath Fading Channels

The measured performance of the wideband waveform modes, using fixed-frequency operation and employing the maximum interleaving period (“Long” interleaver) and a 20-superframe preamble, shall achieve coded BER of no more than 1.0E-5 under each of the conditions listed in Table D-LXIV. Refer to Appendix E for channel simulator requirements. The channel conditions denoted “Poor Channel” in the tables shall comply with the ITU-R F.1487 Mid-Latitude-Disturbed Channel.

**TABLE D-LXIV. Data performance requirements, All Bandwidths.**

| Waveform Number | Average SNR (dB) for BER ≤ 1.0E-5 | | Exceptions (for specific bandwidths) |
|---|---|---|---|
| | AWGN Channel | "Poor" Channel | |
| 0 | -6 | -1 | 9 kHz Poor channel only: allow +1 dB |
| 1 | -3 | 3 | |
| 2 | 0 | 5 | |
| 3 | 3 | 7 | 9 kHz: allow extra 1 dB (both channels) |
| 4 | 5 | 10 | this waveform not available in 9 or 18 kHz |
| 5 | 6 | 11 | |
| 6 | 9 | 14 | |
| 7 | 13 | 19 | |
| 8 | 16 | 23 | |
| 9 | 19 | 27 | |
| 10 | 21 | 31 | 24 kHz Poor channel only: test for BER ≤ 1.0E-4 and allow 33 dB |
| 11 | 24 | - | |
| 12 | 30 | - | |
| 13 | 6 | 11 | this waveform available in 3 kHz only |

Performance shall be tested using a baseband HF simulator patterned after the Watterson Model in accordance with Appendix E.

- The AWGN channel shall consist of a single, non-fading path. Each condition shall be measured for at least 60 minutes.
- The "Poor" channel shall consist of two independent but equal average power Rayleigh fading paths, with a fixed 2 ms delay between paths, and with a fading (two sigma) bandwidth (BW) of 1 Hz. Each condition shall be measured for at least 5 hours.
- To compute SNR, both signal and noise power shall be measured *in the specified bandwidth*.

When testing a modem embedded with a radio, so that only radio frequency (RF) signals are available for testing, the RF signals must be downconverted to baseband for processing by the channel simulator, and the result upconverted to RF for the receiver. In this case, the built-in radio filters will affect the performance of the modems. Therefore, when testing embedded modems, the SNR values specified in Table D-LII shall be increased by 2 dB (3 dB at 9600 bps and above).

When the sending and receiving modems used in this test are not identical make and model, an extra dB of SNR shall be allowed due to potential degradation in mismatched filters.

D.6.2 BER performance on static multipath channels

The measured performance of the wideband waveform modes, using fixed-frequency operation and employing the maximum interleaving period ("Long" interleaver), shall achieve coded BER of no more than 1.0E-5 for an SNR of 50 dB under the static multipath channel conditions

shown in Table D-LXV. For all the static channels defined in table, all paths have equal power. The test period for each test should be 10 minutes. Due to possible alignment issues when acquiring channels with large delay spread, up to 3 opportunities are allowed per test to achieve a BER < 1e-5. Table shows the delay in milliseconds (ms) between the equal-power paths. For example, for WID 2 in 3 kHz, the second path is delayed 3.0 ms from the first path, and the third is delayed 9.0 ms from the first path.

**TABLE D-LXV. Static Channel Tests**

| Bandwidth | WID | Multipath Channel Delays (ms) |
|---|---|---|
| 3 KHz | 2 | 3-Path (0.0, 3.0, 9.0) |
| | 10 | 3-Path (0.0, 2.0, 4.5) |
| | 12 | 2-Path (0.0, 1.5) |
| 6 KHz | 2 | 3-Path (0.0, 2.0, 9.0) |
| | 10 | 4-Path (0.0, 1.5, 3.0, 5.0) |
| | 12 | 2-Path (0.0, 1.5) |
| 9 KHz | 3 | 3-Path (0.0, 3.0, 8.0) |
| | 10 | 3-Path (0.0, 2.0, 4.5) |
| | 12 | 2-Path (0.0, 1.5) |
| 12 KHz | 2 | 3-Path (0.0, 2.5, 8.5) |
| | 10 | 4-Path (0.0, 1.5, 3.0, 5.0) |
| | 12 | 2-Path (0.0, 1.5) |
| 24 KHz | 5 | 3-Path (0.0, 2.5, 5.5) |
| | 10 | 4-Path (0.0, 1.5, 3.0, 5.0) |
| | 12 | 2-Path (0.0, 1.5) |
| 48 KHz | 5 | 3-Path (0.0, 2.5, 4.0) |
| | 10 | 4-Path (0.0, 1.5, 3.0, 4.0) |
| | 12 | 2-Path (0.0, 1.5) |

D.6.3 Acquisition performance.
Not yet standardized.

D.6.4 Doppler shift test.

The modem shall acquire and maintain synchronization in 3, 6, 9, 12, 24, and 48 kHz channels for at least 5 minutes with a test signal having the following characteristics**:** WID 10/Long interleaver, 75 Hz frequency offset, 2 ms delay spread, a fading BW of 1 Hz, and an average SNR of 30 dB. The test shall be repeated with a –75 Hz frequency offset. No BER test is required.

D.6.5 Doppler sweep performance.

The AWGN BER test for WID 10 shall be repeated in 3, 6, 9, 12, 24, and 48 kHz channels with a test signal having a frequency offset that continuously varies at a rate of 3.5 Hz/s between the limits of -75 and +75 Hz, such that a plot of frequency offset vs. time describes a periodic "triangle" waveform having a period of (300/3.5) seconds. Over a test duration of 1 hour, the modem shall achieve a BER of 1.0E-5 or less at an SNR of 24 dB.

## D.7 ASSOCIATED COMMUNICATIONS EQUIPMENT

The QAM constellations specified in this appendix are more sensitive to equipment variations than the PSK constellations specified in section 5.3.2 of this standard. Because of this sensitivity, radio filters will have a significant impact on the performance of modems implementing the waveforms in this appendix. In addition, because of the level sensitive nature of the QAM constellations, turn-on transients, AGC, and ALC can cause significant performance degradation.

It is recommended that external modems (i.e., modems not integrated with the radio) implementing the waveforms in this appendix should include a variable pre-key feature, by which the user can specify a delay between the time when the transmitter is keyed and the modem signal begins. This allows for turn-on transient settling, which is particularly important for legacy radio equipment.

It is recommended that a slow AGC setting (e.g., the "nondata" mode in MIL-STD-188-141) be used when receiving the waveforms in this appendix.

# CHARACTERISTICS OF HF CHANNEL SIMULATORS

## TABLE OF CONTENTS

# FIGURES

FIGURE PAGE

# E.1 SCOPE

## E.1.1 Scope.

This appendix describes the characteristics of baseband HF channel simulators to be used in performance testing of modems that are intended for use in HF channels up to 24 kHz (nominally N x 3 kHz, where N is 1, 2, 3, 4, 5, 6, 7, or 8).

## E.1.2 Applicability.

This appendix is a nonmandatory part of MIL-STD-188-110B; however, channel simulators used to evaluate the compliance of modems with the performance requirements of this standard shall comply with this appendix.

# E.2 APPLICABLE DOCUMENTS

## E.2.1 Non-government documents.

The following documents form a part of this document to the extent specified herein..

1. C. C. Watterson, J. R. Juroshek, W. D. Bensema, “Experimental Confirmation of an HF Channel Model”, *IEEE Transactions On Communications Technology*, Vol. **COM-18**, No. 6, Dec. 1970

2. Michel C. Jeruchim, Philip Balaban, and K. Sam Shanmugan, “Simulation of Communication Systems”, ISBN 0-306-43989-1, Plenum Publishing

3. W. N. Furman, J. W. Nieto, “Understanding HF Channel Simulator Requirements in Order to Reduce HF Modem Performance measurement Variability,” *Proceedings of HF01, Nordic HF Conference*, Faro, Sweden, August 2001.

## E.2.2 Order of precedence.

In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless specific exemption has been obtained.

# E.3 DEFINITIONS

See section 3.

## E.4 GENERAL REQUIREMENTS

### E.4.1 Watterson Channel Model

The model of the HF channel to be implemented in simulators specified in this Appendix is the two-path model originally described by Watterson, et al, in "Experimental Confirmation of an HF Channel Model", *IEEE Transactions On Communications Technology*, Vol. COM-18, No. 6, Dec. 1970. In this model, the output of the channel consists of white Gaussian noise (WGN) added to two copies of the input signal which are delayed relative to each other by a fixed amount (the "delay spread"). The amplitudes of the two delayed copies of the input signal vary according to independent fading gains which have Gaussian power spectral densities with a specified "fading bandwidth." The two paths have equal power, averaged over a long period.

The Watterson model of a channel is completely specified by three parameters: the delay spread, the fading bandwidth per path, and the average signal-to-noise ratio (SNR) of the received signal.

### E.4.2 Implementation of the Watterson HF Channel Model

The Watterson model shall be implemented using a tap-delay line as shown in Figure E-1.

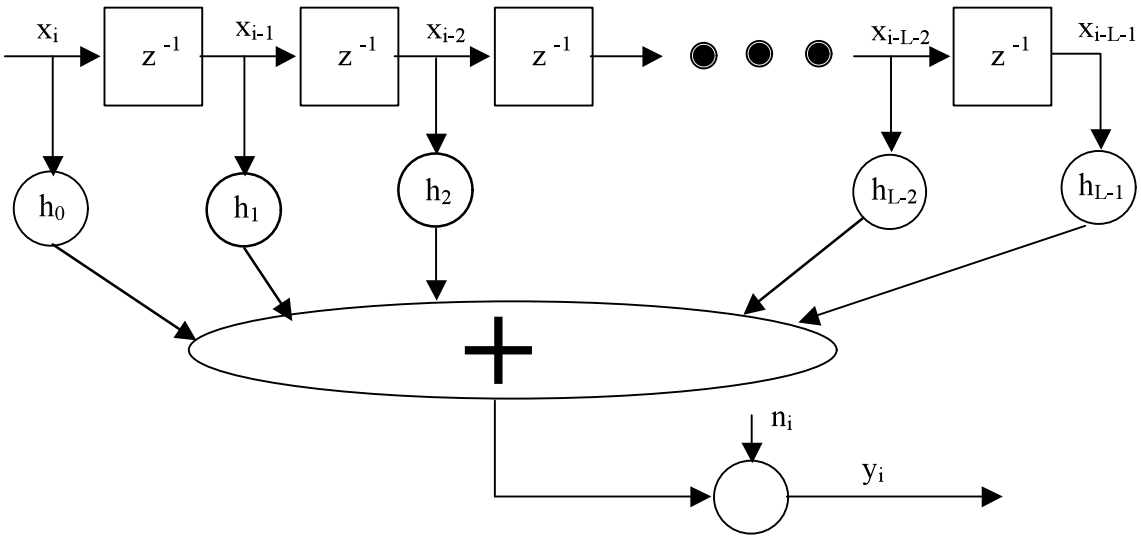


**Figure E-1. Implementation of the Watterson HF Channel Model**

The input $x_i$, output $y_i$, noise $n_i$, and filter tap gains $h_j$ are complex, time-varying quantities; *i* is the time index. For a two-path model with fixed delay spread, only two of the tap gains shall be non-zero: $h_0$ and $h_{L-1}$, where *L* is the specified delay spread of the channel divided by the sampling period. Mathematically, the relationship among these quantities is as follows:

$$f_j(t) = k\sqrt{2}e^{-\pi^2 t^2 d^2}, \quad -\tau < t < \tau$$

NOTE: when the external input to the channel simulator is a real audio signal, a Hilbert transform may be used to create the complex signal $x_i$.

NOTE: since the external output from the channel simulator is a real audio signal, only the real part of the resulting output signal yi is output.

E.4.3 Radio Filters
If radio filters are implemented within the channel simulator, they shall be disabled when the simulator is used for testing compliance with the performance requirements in this standard.

E.4.4 Latency
Delay through the channel simulator ($x_i$ to $y_i$) shall not exceed 25 ms (DO: 10 ms) when the simulator is used to test two-way (interactive) systems.

## E.5 DETAILED REQUIREMENTS

NOTE: "Simulation of Communication Systems," by Jeruchim, et al, and "Understanding HF Channel Simulator Requirements in Order to Reduce HF Modem Performance measurement Variability," by Furman and Nieto are useful references for implementers of channel simulators.

E.5.1 Sample rate.
The sample rate of the simulator shall be at least four times the symbol rate of the anticipated modem waveform to test. For example 9600 samples per second for the 3kHz bandwidth waveforms specified in Appendix C and 76800 samples per second for the 24kHz bandwidth waveforms specified in Appendix D.

The crystal used to generate the sample rate should be specified to drift no more than 500 parts per million (PPM) over its operating temperature range.

E.5.2 Delay spread simulation
The length of the simulated channel, $L$, shall be computed as the specified delay spread divided by the sample rate, and rounded to the nearest integer.

E.5.3 White gaussian noise generation.
The white noise generated for use in producing the channel noise ($n_i$ in Figure E-1) and the fading gains ($h_0$ and $h_{L-1}$ in Figure E-1) shall be independent random processes with power spectra that are uniform within ±1 dB up to the sampling rate /2.

E.5.4 Fading tap gain generation.
Fading tap gains (see Figure E-1) shall be obtained by filtering complex white Gaussian noise samples as shown in Figure E-2.

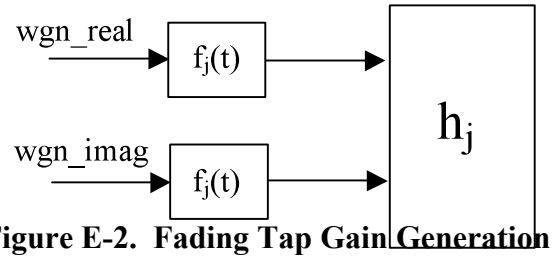


**Figure E-2. Fading Tap Gain Generation**

- Filters $f_j(t)$ used for fading process in the Watterson model have a Gaussian shaped power spectrum in the frequency domain whose standard deviation $\sigma_j$ is equal to half the fading bandwidth $d_j$ (also called the "Doppler spread") of each path:

$$\left|H_j(f)\right|^2 = \frac{e^{-2f^2/d_j^2}}{\sqrt{\frac{\pi d_j^2}{2}}} \qquad -\infty < f < \infty$$

  In the time domain, the equation for the $f_j(t)$ shall be as follows,

$$f_j(t) = k\sqrt{2}e^{-\pi^2 t^2 d^2}, \quad -\tau < t < \tau$$

  where $\tau$ (the truncation width) is selected so that the magnitude of the tap gain function at $\pm\tau$ is no greater than 1% of the peak value,

  $d$ is the desired fading bandwidth in Hz, and

  $k$ is set so that the total power gain of all paths is equal to 1.0 (i.e., so that the total average power output from the filters equals the average input power).

- Fading tap gains shall be computed at a rate of at least 32 times the specified fading bandwidth.

- Fading tap gains shall be interpolated to at least the symbol rate of the waveform to avoid introducing large discontinuities in the output of the simulator. (DO: the fading taps should be interpolated to the sample rate of the channel simulator.)

E.5.5 Signal-to-noise ratio

The power of $n_i$ shall be set to achieve the specified SNR in the bandwidth of the waveform under test with reference to the average power of the input signal $x_i$.

NOTE: Accurate measurement of the average power of the input signal may require several minutes in the case of higher data rate waveforms.

## E.6 IMPLEMENTATION DETAILS FOR WIDEBAND HF CHANNEL SIMULATORS

### E.6.1 Analog interface

The analog interface is of primary concern, especially for wideband HF waveform testing and evaluation. It should be noted that many PC soundcards have an analog filter on the audio input between 20 kHz and 24 kHz. Care should be taken to make sure that the pass band of the channel simulator is consistent with the waveform bandwidths to be tested.

An additional factor for consideration for wideband testing is the center or subcarrier frequency of the waveform under test. It may be beneficial to have the interface implemented at a common subcarrier frequency, for example 19.2 kHz, where all modem waveforms, independent of their bandwidth, would be centered at 19.2 kHz.

The sample rate of the simulator shall be at least four times the symbol rate of the anticipated modem waveform to test. For example 9600 samples per second for the 3kHz bandwidth waveforms specified in Appendix C and 76800 samples per second for the 24kHz bandwidth waveforms specified in Appendix D.

### E.6.2 Hilbert Transform Alternative

Baseband channel simulators generally employ a Hilbert transform to generate a complex baseband equivalent signal, from the real input signal in order to easily implement the amplitude and phase variations of the fading multipath channel. Hilbert transforms are often implemented as an FIR filter. As the sample rate is increased to support wider bandwidth signals the lower limit of the Hilbert pass band also increased, possibly to a point that would impact the lower frequencies of the modem waveform.

An alternate Hilbert architecture can be implemented by an overlapped FFT approach, where the phase and gain properties of the Hilbert transform are implemented in the frequency domain and an inverse FFT is utilized to return the signal to the time domain.

### E.6.3 Output LPF

Depending on the analog interface of the output of the channel simulator it may be beneficial to have a low-pass or band-pass filter that is slightly wider than the waveform signal under test. This will prevent the wider bandwidth noise signal, which may be present because of the higher sampling rate, from causing any aliasing issues with the waveform receive hardware.

A low-pass or band-pass filter can easily be implemented by an overlapped FFT approach similar in nature to the Hilbert transform described above.

## E.7 CHANNEL SIMULATOR VALIDATION

### E.7.1 Bandwidth

The frequency response of a channel simulator implementation should be within +/- 0.5 dB. This test should be performed at the band-center and repeated at the band-center +/- 25% of the waveform bandwidth.

### E.7.2 Signal-to-noise ratio – Single Non-fading path

The signal to noise ratio should be within 0.25 dB of the specified SNR. This is validated by measuring the channel simulator output power, consisting of signal and noise output power for an input tone in the center of the waveform bandwidth. The tone is then removed a noise power is measured. These two measurements can be combined to yield an estimate of SNR.
This test should be performed at the band-center and repeated at the band-center +/- 25% of the waveform bandwidth.
Each measurement should be an average taken over at least 20 minutes.

### E.7.3 Signal-to-noise ratio – Single fading path, Dual fading path

The signal to noise ratio should be within 0.5 dB of the specified SNR. The tests described in H 7.2 above should be repeated for a single fading path as well as a dual fading path channel with the paths separated by 2ms. Doppler spreads of 1.0 and 10.0 Hz should be tested. Each measurement should be an average taken over at least 2 hours.

### E.7.4 Doppler Spectrum

The Doppler spectrum can be evaluated by inputting a tone into the channel simulator and logging the output samples to a file. The long term windowed average of FFT bins can be used to approximate the output spectrum. A total number of samples representing at least 3 hours of operation is recommended. It is further recommended that a Kaiser window be utilized in the spectrum averaging process.

Figure E-3 displays the ideal Gaussian spectrum compared to an example measured fading spectrum obtained as recommended above. Table E-I recommends the maximum allowable deviation in dB, from the ideal spectrum at -20dB and -30dB from the center (0 Hz) gain.

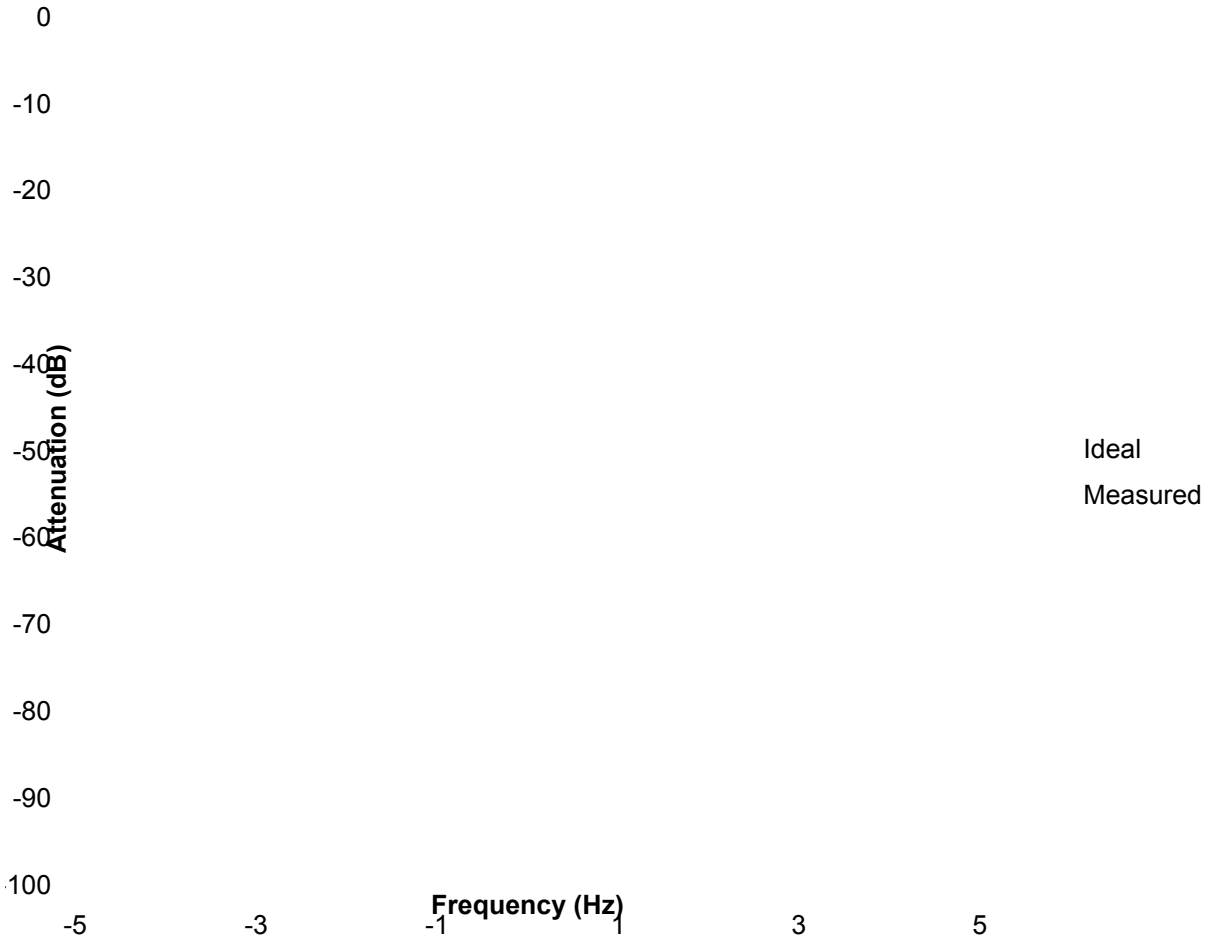


**Figure E-3. Doppler Spectrum**

**TABLE E-I – Allowed Deviation from Ideal Gaussian Fading Spectrum, Single path 1.0 Hz Doppler Spread**

| Attenuation | Deviation |
|---|---|
| -20 | +/-1.5dB |
| -30 | +/- 2.0dB |

# HF DATA MODEMS FOR MULTIPLE CHANNEL SYSTEMS

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# F.1 SCOPE

## F.1.1 Scope.

This appendix describes HF data modem operation over multiple discrete channels (including independent sidebands of a single carrier), and specifies a waveform that supports data rates of 9600 to 19,200 bps over two-independent-sideband (2-ISB) radios using the waveforms from Appendix C.

## F.1.2 Applicability.

This appendix is a nonmandatory part of MIL-STD-188-110B; however, systems using HF data modem waveforms on multiple discrete channels shall operate in accordance with this appendix.

# F.2 APPLICABLE DOCUMENTS

This section is not applicable to this appendix.

# F.3 DEFINITIONS

See section 3.

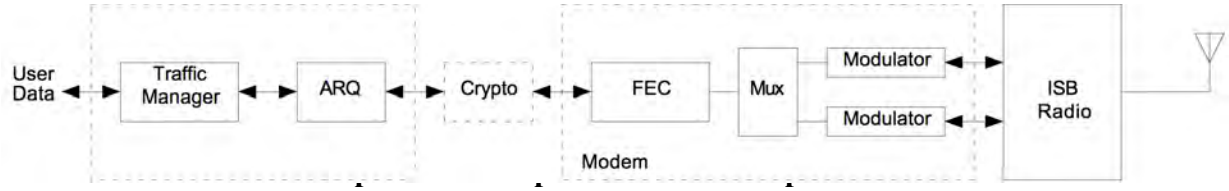
# F.4 GENERAL REQUIREMENTS

The use of multiple HF channels in parallel can provide data throughput greater than the use of a single sideband channel. Section F.4.1 describes a range of architectures for multiple channel operation that may be useful in specific applications. Section F.4.2 describes an independent sideband (ISB) modem waveform that may be used in any of these architectures.

## F.4.1 Architectures for multiple channel operation.

### F.4.1.1 Multiple channel operation with independent-sideband modem.

When ISB radios and channel allocations are available, the channels provided by the radio inherently have similar channel characteristics, and can support similar data rates. A modem that spreads coded symbols over the available channels takes full advantage of this capability. Such a modem is shown in Figure F-1 (with optional link-level encryption). The two-channel ISB (2-ISB) modem specified in sections F.4.2 and F.5 is the mandatory portion of this appendix. The ISB capability is currently limited to two channels per modem. Four-channel radios support two such 2-ISB modems using either of the techniques described in the following sections.




F.4.1.2 Multiple channel operation with multiple modems. (Optional)
When ISB radios and channel allocations are available, but ISB modems with a matching number of audio channels are not available, multiple modems may be employed as shown in Figure F-2. The upper diagram illustrates the case of unencrypted user data and link-level encryption (as in the previous section). The lower diagram depicts application-layer (end-to-end) encryption.

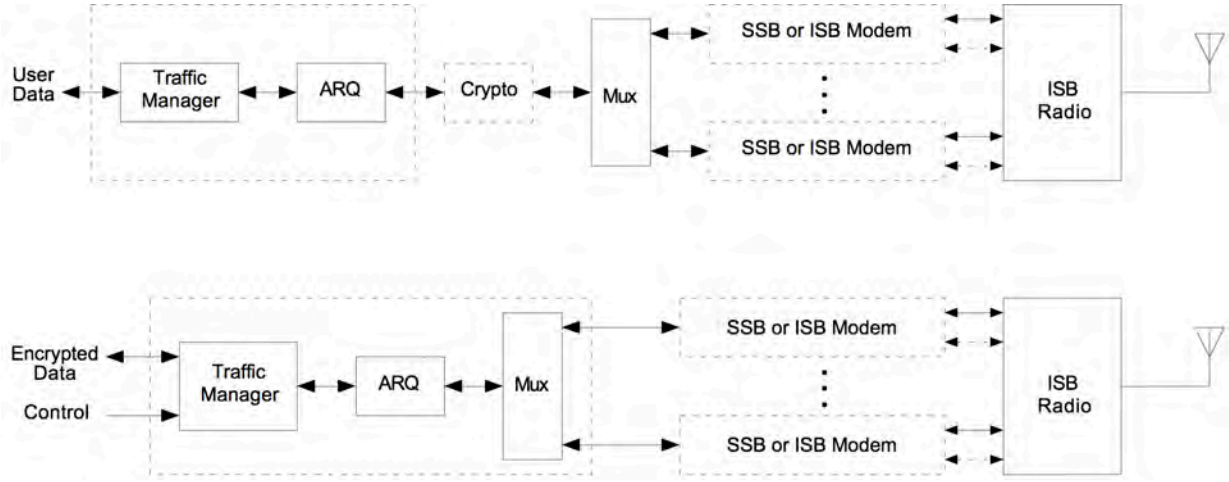



**FIGURE F-2. Multiple channel operation with single-sideband modems.**

The first bit of data to be sent shall be delivered to the modem associated with the highest over-the-air frequency, with succeeding bits delivered to modems with decreasing frequencies. When $M$ modems are attached to a single ISB radio ($M = 2$ shown), all modems shall operate at a single data rate, and modem $i$ ($i = 0 \,..\, M - 1$) shall carry bits numbered $i + nM$ ($n = 0, 1, \ldots$).

This architecture also may be applied to multiple radios operating on unrelated frequencies. However, performance may not be satisfactory if the characteristics of the various channels are not sufficiently similar to support a common maximum data rate. Bit ordering shall be as specified above, with the identity of the modem associated with the highest over-the-air frequency determined when the link is initially established, regardless of subsequent frequency changes while linked.

In the bit-synchronous approach described above, it is understood that the multiplexer and modems share a common clock. In addition, the multiplexer provides a short synchronization

header in the bit stream to each modem prior to the payload data. Note that this header is transparent to the ARQ or other modem-user process. The header is used by the multiplexer at the receive end to establish bit-order integrity. This header is required since a bit-synchronous Tx modem interface does not generally guarantee that the first bit out of the receiving modem is the first bit out of the transmitting DTE following assertion of CTS.

Alternatively, the High Speed Asynchronous Interface with Flow Control that is described in section C.5.4.1 may be used. In this case, data to successive modems from the multiplexer will be successive bytes rather than successive bits.

F.4.1.3 Multiple channel operation with parallel ARQ channels. (Optional)
The architecture shown in Figure F-3 accommodates any combination of radios and modems for multiple-channel operation. As above, the upper diagram illustrates link-level encryption while the lower diagram depicts application-layer (end-to-end) encryption.

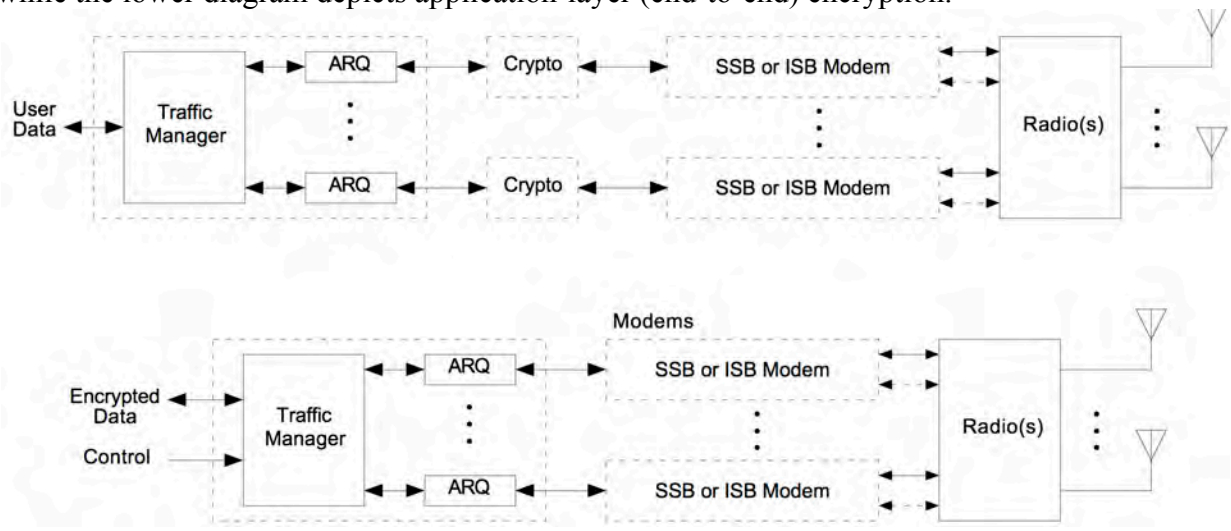



**FIGURE F-3. Multiple channel operation with parallel ARQ channels.**

A traffic manager process dynamically assigns packets to a separate ARQ protocol process associated with each modem. Each ARQ process adapts its modem's data rate to the channel conditions it encounters; the traffic manager likewise adapts the rate that it assigns packets to the ARQ processes based on their completion rates. Message reassembly relies on packet offset fields in the packet headers.

F.4.2 HF data modem waveform for two-independent-sideband applications.
This appendix presents a modem waveform and coding specification for data transmission over two HF sidebands for data rates from 9.6 up to 19.2 kbps. As in Appendix C, a block interleaver is used to obtain 6 interleaving lengths ranging from 0.12 s to 8.64 s. The waveforms in this appendix have been designed to be compatible with the Appendix C waveforms, and use identical preamble processing with the exception that these waveforms employ settings for specifying data rate and interleaver that are reserved in Appendix C.

Data rate and interleaver settings are explicitly transmitted as a part of the waveform, both as part of the initial preamble and then periodically as a reinserted preamble and in the periodic known symbol blocks ("mini-probes"). This "autobaud" feature is critical in developing an efficient (ARQ) protocol for high frequency (HF) channels. The receive modem is required to be able to deduce the data rate and interleaver setting from either the preamble or the subsequent data portion of the waveform.

A block diagram of the 2-ISB modem with 2-ISB radios is shown in Figure F-4. In all applications of this modem, the quasi-analog signal designated Channel 0 shall be connected to the radio equipment so that the sideband that it produces is higher in frequency than the sideband produced by the quasi-analog signal designated Channel 1. In particular, with 2-ISB radios Channel 0 shall use the upper sideband and Channel 1 shall use the lower sideband.

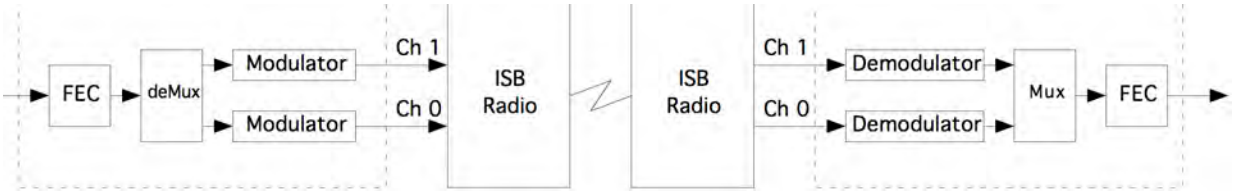



**FIGURE F-4. 2-ISB Modem.**

## F.5 DETAILED REQUIREMENTS

### F.5.1 Modulation.

Each of the channels shall be modulated independently. The modulation of each of the channels is identical, with a few specified exceptions, to that specified in appendix C for the high data rate single sideband option. The transmit data clock for both of the channels shall be synchronized so that there is no drift in the relative clocks for each of the channels.

The power spectral density of each modulator output signal should be constrained to be at least 20 dB below the signal level measured at 1800 Hz, when tested outside of the band from 200 Hz to 3400 Hz. The filter employed shall result in a ripple of no more than ±2 dB in the range from 800 Hz to 2800 Hz.

#### F.5.1.1 Known symbols.

For all known symbols, the modulation used shall be PSK, with the symbol mapping shown in Table C-I and figure C-1. No scrambling shall be applied to the known symbols.

F.5.1.2 Data symbols.
For data symbols, the modulation used depends upon the data rate as shown in Table F-I.

**TABLE F-I. Modulation used to obtain each data rate for 2-ISB operation.**

| Modulation | Code Rate | Data Rate (kbps) |
|---|---|---|
| 8PSK | 3/4 | 9.6 |
| 16QAM | 3/4 | 12.8 |
| 32QAM | 3/4 | 16.0 |
| 64QAM | 3/4 | 19.2 |

F.5.1.3 PSK data symbols.
For the PSK constellations, a distinction is made between the data bits and the symbol number. Transcoding is an operation which links a symbol to be transmitted to a group of data bits.

F.5.1.4 QPSK symbol mapping.
For QPSK symbols, used in the preamble and reinserted preamble to specify data rate and interleaving, transcoding shall be achieved by linking one of the symbols specified in Table C-I to a set of two consecutive data bits (dibit) as shown in Table C-III. In this Table, the leftmost bit of the dibit shall be the older bit; i.e., fetched from the interleaver before the rightmost bit.

F.5.1.5 8PSK symbol mapping.
For the 9600 bps user data rate, transcoding shall be achieved by linking one symbol to a set of three consecutive data bits (tribit) as shown in Table C-IV. In this Table, the leftmost bit of the tribit shall be the oldest bit; i.e., fetched from the interleaver before the other two, and the rightmost bit is the most recent bit.

F.5.1.6 QAM data symbols.
For the QAM constellations, no distinction is made between the number formed directly from the data bits and the symbol number. Each set of 4 bits (16QAM), 5 bits (32QAM) or 6 bits (64QAM) is mapped directly to a QAM symbol. For example, the four bit grouping 0111 would map to symbol 7 in the 16QAM constellation while the 6 bit grouping 100011 would map to symbol 35 in the 64QAM constellation. Again, in each case the leftmost bit shall be the oldest bit, i.e. fetched from the interleaver before the other bits, and the rightmost bit is the most recent bit.

F.5.1.7 The 16 QAM constellation.
See figure C-2 and Table C-V.

F.5.1.8 The 32 QAM constellation.
See figure C-3 and Table C-VI.

F.5.1.9 The 64QAM constellation.
See figure C-4 and Table C-VII.

F.5.1.10 Data scrambling.
Data symbols for the 8PSK symbol constellation shall be scrambled by modulo 8 addition with a scrambling sequence. The data symbols for the 16QAM, 32QAM, and 64QAM constellations shall be scrambled by using an exclusive or (XOR) operation. Sequentially, the data bits forming each symbol (4 for 16QAM, 5 for 32QAM, and 6 for 64QAM) shall be XOR'd with an equal number of bits from the scrambling sequence. In all cases, the scrambling sequence generator polynomial shall be $x^9 + x^4 + 1$ and the generator shall be initialized to 1 at the start of each data frame. A block diagram of the scrambling sequence generator is shown in figure C-5. Further details of the operation of the data scrambler may be found in C.5.1.3.

F.5.2 Frame structure.
The frame structure shall be as described in C.5.2 except that the data symbols $D_0$, $D_1$, and $D_2$ (used in the preambles and encoded in the mini-probes) take on values distinct from those used for the Appendix C SSB modes.

For the two sideband option, the 3 bits used for data rate in SSB are fixed at 000. The bits normally used for interleaver setting in SSB are employed as specified in Table F-II, using both channels, to select data rate and interleaver settings. Channel 0 carries the code for the combined data rate and Channel 1 carries the code for the common interleaver. Recall that channel 0 is always the higher frequency of the two sidebands. Unused codings are reserved and shall not be used until standardized.

**TABLE F-II. Data symbol patterns for specifying data rate and interleaver length for the 2-ISB modem.**

Channel 0

| Data Rate (kbps) | D0,D1,D2 | 3 Bit Mapping |
|---|---|---|
| 9.6 | 0,0,2 | 001 |
| 12.8 | 0,2,0 | 010 |
| 16.0 | 0,2,2 | 011 |
| 19.2 | 2,0,0 | 100 |

Channel 1

| Interleaver | D0,D1,D2 | 3 Bit Mapping |
|---|---|---|
| Ultra Short | 0,0,2 | 001 |
| Very Short | 0,2,0 | 010 |
| Short | 0,2,2 | 011 |
| Medium | 2,0,0 | 100 |
| Long | 2,0,2 | 101 |
| Very Long | 2,2,0 | 110 |

F.5.3 Coding and interleaving.
The interleaver used shall be a block interleaver. Each block of input data shall be encoded using a block encoding technique with a code block size equal to the size of the block interleaver. Thus, the input data bits will be sent as successive blocks of bits on both channels that together span the duration of the interleaver length selected.

Table F-III shows the number of input data bits per block as function of both data rate and interleaver length. Note that an "input data block" should not be confused with the 256 symbol data block that is part of a data frame in the waveform format. The bits from an input data block will be mapped through the coding and interleaving to the number of data frames, and thus 256 symbol data blocks, that define the interleaver length.

**TABLE F-III. Input data block size in bits as a function of data rate and interleaver length**

| Data Rate (kbps) | Interleaver Length in Frames | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 3 | 9 | 18 | 36 | 72 |
| | Number of Input Data Bits per Block | | | | | |
| 9.6 | 1,152 | 3,456 | 10,368 | 20,736 | 41,472 | 82,944 |
| 12.8 | 1,536 | 4,608 | 13,824 | 27,648 | 55,296 | 110,592 |
| 16.0 | 1,920 | 5,760 | 17,280 | 34,560 | 69,120 | 138,240 |
| 19.2 | 2,304 | 6,912 | 20,736 | 41,472 | 82,944 | 165,888 |

F.5.3.1 Block boundary alignment.
Each code block shall be interleaved within a single interleaver block of the same size. The boundaries of these blocks shall be aligned such that the beginning of the first data frame following each reinserted preamble shall coincide with an interleaver boundary. Thus for an interleaver length of 3 frames, the first three data frames following a reinserted preamble will contain all of the encoded bits for a single input data block. The first data symbol from the first data frame in each interleaver set shall have as its MSB the first bit fetched from the interleaver. This is no different from what would normally be expected, but is a requirement.

F.5.3.2 Block encoding.
See C.5.3.2.

F.5.3.3 F.5.3.3 Block interleaver structure.
The block interleaver used is designed to separate neighboring bits in the punctured block code as far as possible over the span of the interleaver with the largest separations resulting for the bits that were originally closest to each other.

F.5.3.4 Interleaver size in bits.
The interleaver shall consist of a single dimension array, numbered from 0 to its size in bits –1. The array size shall depend on both the data rate and interleaver length selected as shown in Table F-IV.

**TABLE F- IV. Interleaver size and increment in bits as a function of data rate and interleaver length.**

| Modulation | Data Rate (kbps) | Ultra Short 1 Frame | | Very Short 3 Frames | | Short 9 Frames | | Medium 18 Frames | | Long 36 Frames | | Very Long 72 Frames | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Size | Inc | Size | Inc | Size | Inc | Size | Inc | Size | Inc | Size | Inc |
| 8 PSK | 9.6 | 1536 | 229 | 4608 | 805 | 13,824 | 2089 | 27,648 | 5,137 | 55,296 | 10,273 | 110,592 | 17,329 |
| 16QAM | 12.8 | 2048 | 363 | 6144 | 1303 | 18,432 | 3281 | 36,864 | 6,985 | 73,728 | 11,141 | 147,456 | 28,007 |
| 32QAM | 16.0 | 2560 | 453 | 7680 | 1343 | 23,040 | 3481 | 46,080 | 8,561 | 92,160 | 14,441 | 184,320 | 34,907 |
| 64QAM | 19.2 | 3072 | 481 | 9216 | 1393 | 27,648 | 5137 | 55,296 | 10,273 | 110,592 | 17,329 | 221,184 | 47,069 |

F.5.3.5 Interleaver load.
The punctured block code bits shall be loaded into the interleaver array beginning with location 0. The location for loading each successive bit shall be obtained from the previous location by incrementing by the interleaver increment value “Inc” specified in Table F-IV, modulo the interleaver size in bits, “Size.”

Defining the first punctured block code bit to be B(0), then the load location for B(n) is given by:

$$\text{Load Location} = (n * \text{Inc}) \text{ modulo } (\text{Size})$$

F.5.3.6 Interleaver fetch.
The fetching sequence for all data rates and interleaver lengths shall start with location 0 of the interleaver array and increment the fetch location by 1. The first bit fetched from the interleaver (bit 0) shall be sent to the symbol formation module for channel 0, the second bit fetched (bit 1) shall be sent to the symbol formation module for channel 1, and this pattern shall continue until all bits have been fetched from the interleaver. This is a linear fetch from beginning to end of the interleaver array with even numbered bits delivered to channel 0 and odd numbered bits to channel 1.

F.5.4 Operational features and message protocols.
See C.5.4.

## F.6 PERFORMANCE

The measured performance of the 2-ISB high data rate mode, using fixed-frequency operation and employing the maximum interleaving period (the 72-frame "Very Long" interleaver), shall achieve coded BER of no more than 1.0E-5 under each of the conditions listed in Table F-V.

**TABLE F-V. Appendix F High data rate mode performance requirements.**

| User data rate (bps) | Average SNR (dB) for BER ≤ 1.0E-5 | |
|---|---|---|
| | AWGN Channel | ITU-R Poor Channel |
| 19200 | 21 | 34 |
| 16000 | 19 | 29 |
| 12800 | 16 | 25 |
| 9600 | 13 | 21 |

Performance shall be tested using a baseband HF simulator for each sideband patterned after the Watterson Model in accordance with Appendix H. SNR values specified in Table F-V are per sideband.

- Each AWGN channel shall consist of a single, non-fading path. Each condition shall be measured for at least 60 minutes.

- Each ITU-R Poor channel shall consist of two independent but equal average power Rayleigh fading paths per sideband, with a fixed 2 ms delay between paths, and with a fading (two sigma) bandwidth (BW) of 1 Hz. A separate simulator shall be used for each sideband (to avoid correlation among their fading processes). Each condition shall be measured for at least 5 hours.

- Both signal and noise power shall be measured in a 3 kHz bandwidth. Note that the average power of QAM symbols is different from that of the 8PSK mini-probes and

reinserted preambles; the measured signal power shall be the long-term average of user data, mini-probe, and reinserted preamble symbols.

When testing a modem embedded with a radio, so that only radio frequency (RF) signals are available for testing, the RF signals must be down-converted to baseband for processing by the channel simulator, and the result up-converted to RF for the receiver. In this case, the built-in radio filters will affect the performance of the modems. Therefore, when testing embedded modems, the SNR values specified in Table F-xyz shall be increased by 3 dB for all data rates.

## F.7 ASSOCIATED COMMUNICATIONS EQUIPMENT

See C.7 “ASSOCIATED COMMUNICATIONS EQUIPMENT”

CONCLUDING MATERIAL

Custodians:
Army - CR
Navy - EC
Air Force – 71

Preparing Activity:
Air Force – 71

(Project TCSS-2018-003)

Review Activities:
Navy – MC
Air Force – 02, 07
DoD – DC1, NS

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