STANAG N° 4539
(Edition 1)

NORTH ATLANTIC TREATY ORGANIZATION
(NATO)

NATO STANDARDIZATION AGENCY
(NSA)

STANDARDIZATION AGREEMENT
(STANAG)

SUBJECT: **TECHNICAL STANDARDS FOR NON-HOPPING HF COMMUNICATIONS WAVEFORMS**

Promulgated on 8 June 2005

J. MAJ
Brigadier General, POL(A)
Director, NSA

RECORD OF AMENDMENTS

No.	Reference/date of Amendment	Date Entered	Signature

EXPLANATORY NOTES

AGREEMENT

1. This NATO Standardization Agreement (STANAG) is promulgated by the Director NATO Standardization Agency under the authority vested in him by the NATO Standardization Organisation Charter.

2. No departure may be made from the agreement without informing the tasking authority in the form of a reservation. Nations may propose changes at any time to the tasking authority where they will be processed in the same manner as the original agreement.

3. Ratifying nations have agreed that national orders, manuals and instructions implementing this STANAG will include a reference to the STANAG number for purposes of identification.

RATIFICATION, IMPLEMENTATION AND RESERVATIONS

4. Ratification, implementation and reservation details are available on request or through the NSA websites (internet http://nsa.nato.int; NATO Secure WAN http://nsa.hq.nato.int).

FEEDBACK

5. Any comments concerning this publication should be directed to NATO/NSA – Bvd Leopold III - 1110 Brussels - BE.

STANAG 4539
Edition 1

NAVY / ARMY / AIR

NATO STANDARDISATION AGREEMENT
(STANAG)

TECHNICAL STANDARDS FOR NON-HOPPING HF COMMUNICATIONS WAVEFORMS

Annexes :

A. Functional Characteristics and Technical Overview of Non-Hopping HF Communications Waveforms (for information only)

B. Technical Specifications to Ensure Interoperability of Serial Waveforms for Non-Hopping Multiple Application Operation on HF Channels (mandatory)

C. Performance Characteristics of Waveforms for Non-Hopping Multiple Application Operation on HF Channels (for information only)

D. Technical Specifications to Ensure Interoperability of Serial Waveforms for Non-Hopping TDMA Operation on HF Channels (optional)

Related Documents :

[1] STANAG 4203 ‘Technical Standard for Single Channel HF Radio Equipment’

[2] STANAG 4285 ‘Characteristics of 1200/2400/3600 Bits Per Second Single Tone Modulators/Demodulators for HF Radio Links’.

[3] STANAG 4197 ‘Modulation and Coding Characteristics that must be Common to ensure interoperability of 2400 bps Linear Predictive Encoded Digital Speech transmitted over HF Radio Facilities’.

[4] STANAG 4415 ‘Characteristics of a Robust Non-Hopping Serial Tone Modulator/ Demodulator for Severely Degraded HF Radio Links’

[5] STANAG 4444 ‘Technical Standards for a Slow-Hop HF EPM Communications System’

[6] STANAG 5066 ‘Profile for High Frequency (HF) Radio Data Communications’

[7] STANAG 4538 ‘Technical Standards for an Automatic Radio Control System for HF Communication Links’

[8] MIL-STD-188-110 ‘Interoperability and Performance Standards for Data Modems’

[9] MIL-STD-188-141 ‘Interoperability and Performance Standards for Medium and High Frequency Radio Equipment’

AIM

1. The aim of this agreement is to define the technical standards required to ensure the interoperability of land, air and maritime HF radio modems.

AGREEMENT

2. Participating nations agree to use the standards defined in this STANAG where interoperability is required for HF radio modems.

GENERAL

3. This agreement is divided into four parts.

- The functional characteristics and technical overview of HF radio modems is described in Annex A (for information only).
- The technical specifications to ensure interoperability of HF modems in multiple application mode, operating from 75 bps to 9600 bps are specified in Annex B (mandatory).
- Performance characteristics of these waveforms are described in Annex C (for information only).
- The technical specifications to ensure interoperability of HF modems for TDMA operation are detailed in Annex D (optional).

IMPLEMENTATION OF THE AGREEMENT

4. This STANAG is implemented by a nation when the HF radio equipment in the nation’s forces complies with the standards described in this STANAG and is placed in service.

ANNEX A TO STANAG 4539

(FOR INFORMATION ONLY)

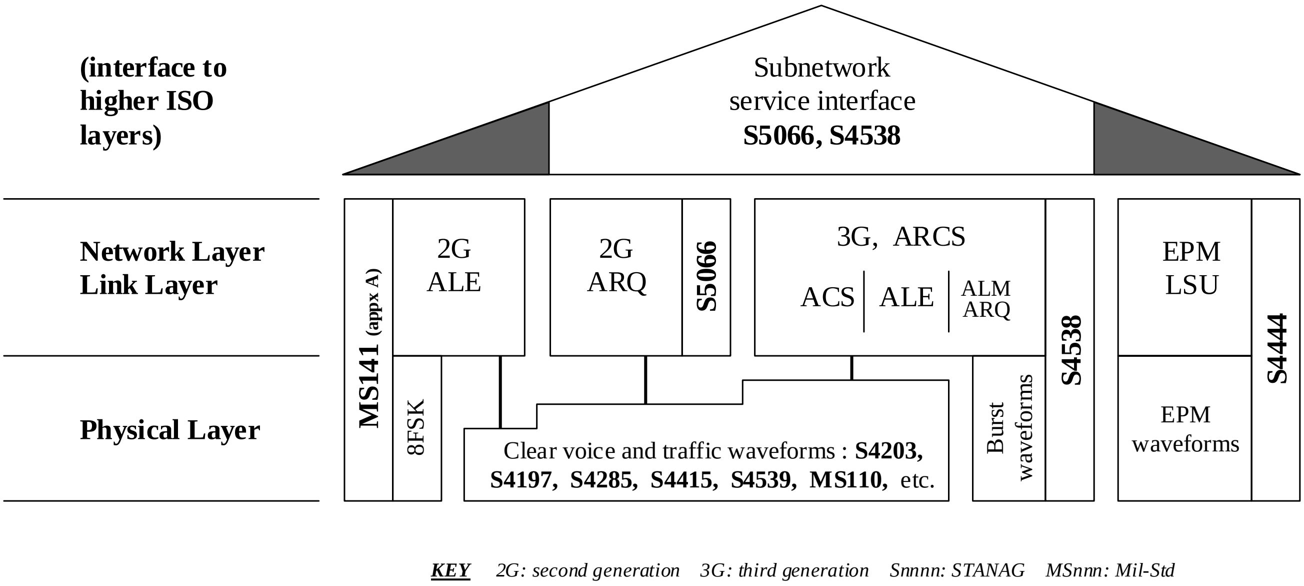
FUNCTIONAL CHARACTERISTICS AND TECHNICAL OVERVIEW OF NON-HOPPING HF COMMUNICATIONS WAVEFORMS

1. INTRODUCTION

1.1 Purpose

(NU) This Annex provides an introduction to modem waveforms to ensure interoperability within complying HF radio networks.

(NU) This document addresses NATO non-EPM requirements, as illustrated in Figure 1.1-1. EPM requirements are addressed in STANAG 4444. Non-EPM multi-application mode requirements are addressed in Annex B of this STANAG. Non-EPM TDMA mode requirements are addressed in Annex D.



(NU) FIGURE 1.1-1. Relationship of STANAG 4539 to HF House

(NU) This document also supports interoperability between the HF House and the U.S. MIL-STD-188-110B Appendix C high data rate waveform, as well as interoperability with MIL-STD-188-110B medium rate serial tone waveform.

1.2 Approach and Structure of Annex A

(NU) The system described in STANAG 4539 is designed to satisfy NATO requirements.

(NU) This standard reflects the NATO emphasis on the International Standards Organisation Open Systems Interconnect (ISO/OSI) model. The system attributes defined in STANAG 4539 are considered to lie within the physical layer of the OSI reference model. The structure of the Annex is as follows.

(NU) Section 1 is an introduction.

(NU) Section 2 presents an overview of the multi-waveform concept.

(NU) Section 3 addresses link setup waveforms.

2. MULTI-WAVEFORM CONCEPT

(NU) The HF House system includes a flexible multi-waveform concept which not only permits the appropriate waveforms (WFs) to be used in a wide variety of propagation/interference conditions but also permits new WFs to be added as advances in communications permit.

(NU) There are 2 modes of operation, a non-EPM mode and an EPM mode. EPM mode waveforms are specified in STANAG 4444. Waveforms for the non-EPM mode are described in this STANAG.

(NU) Specific waveforms are included for the multi-application mode of operation (Annex B) and for TDMA operation (Annex D).

3. LINK SETUP WAVEFORMS

(NU) Waveforms for link setup (LSU) are specified in STANAG 4538.

ANNEX B TO STANAG 4539

(MANDATORY)

TECHNICAL SPECIFICATIONS TO ENSURE INTEROPERABILITY OF SERIAL WAVEFORMS FOR NON-HOPPING MULTIPLE APPLICATION OPERATION ON HF CHANNELS

1. INTRODUCTION

1.1 Purpose

(NU) This Annex provides a detailed description of modem waveforms to ensure interoperability within complying HF radio networks. A family of self-identifying waveforms is specified for operation from 75 bps to 9600 bps (with optional operation at 12800 bps). The self-identifying feature[1] of this family of waveforms enables rapid adaptation of the modulation to respond to changing channel conditions. Additional waveforms are specified for backward interoperability.

(NU) This Annex addresses NATO non-EPM multi-application requirements. Non-EPM TDMA mode requirements are addressed in Annex D of this STANAG. EPM requirements are addressed in STANAG 4444.

(NU) This Annex supports interoperability between the HF House and the U.S. MIL-STD-188-110B Appendix C high data rate waveforms, as well as interoperability with MIL-STD-188-110B low and medium rate serial tone waveforms.

1.2 Approach and Structure of Annex B

(NU) The waveforms described in STANAG 4539 are designed to satisfy NATO requirements.

(NU) This Annex specifies waveforms for general applications, including broadcast and ARQ operation. The structure of the Annex is as follows.

(NU) Section 1 is an introduction.

(NU) Section 2 addresses the very robust traffic waveform.

(NU) Section 3 addresses low to medium data rate traffic waveforms.

(NU) Section 4 addresses high data rate traffic waveforms.

(NU) Section 5 addresses waveforms for backward interoperability.

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[1] Symbols sent in the preamble and channel probe phases specify data rate and interleaver depth.

2. VERY ROBUST TRAFFIC WAVEFORM (75 BPS)

(NU) A self-identifying waveform for conveying data continuous traffic over severely degraded channels is fully specified in STANAG 4415. This waveform is required for 75 bps operation for systems complying with this STANAG.

3. LOW TO MEDIUM DATA RATE TRAFFIC WAVEFORMS (150 TO 2400 BPS)

(NU) A self-identifying family of low to medium rate waveforms for conveying traffic at data rates of 150, 300, 600, 1200, and 2400 bps is fully specified in MIL-STD-188-110 (section 5.3). This waveform family is required for 150 to 2400 bps operation for systems complying with this STANAG.

4. HIGH DATA RATE TRAFFIC WAVEFORMS (3200 TO 12800 BPS)

4.1 Overview

(NU) This section presents a modem waveform and coding specification for data rates of 3200, 4800, 6400, 8000 and 9600 bps. Uncoded operation at 12800 bps is described but is optional. This self-identifying waveform family is required for 3200 to 9600 bps operation for systems complying with this STANAG.

(NU) 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.

(NU) 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 self-identifying 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.

4.2 Modulation

(NU) The symbol rate for all symbols shall be 2400 symbols-per-second, which shall be accurate to a minimum of ±0.024 symbols-per-second (10 ppm) 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 centred 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).

(NU) The power spectral density of the 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. The recommended filter is a square root Nyquist filter with alpha = 0.35.

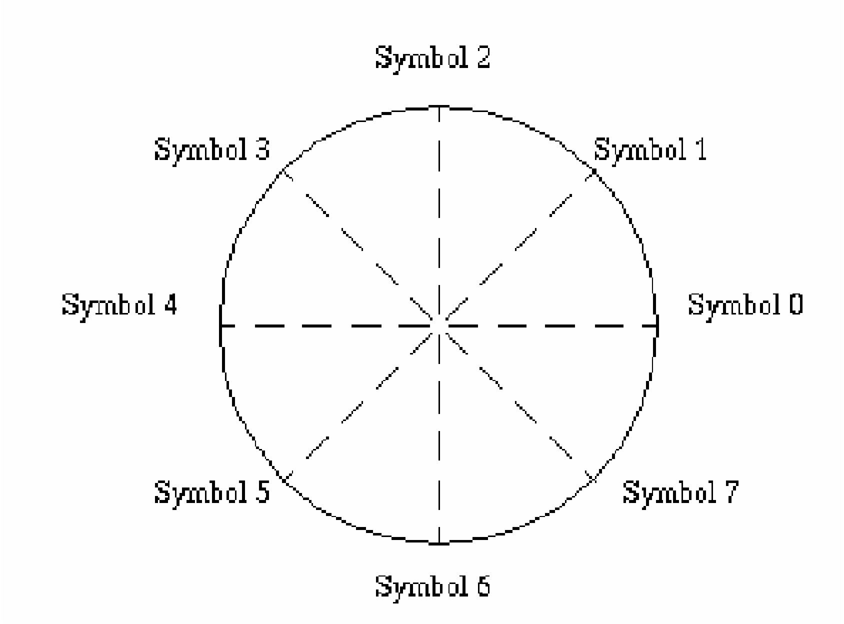
4.2.1 Known symbols

(NU) For all known symbols, the modulation used shall be PSK, with the symbol mapping shown in Table 4.2.1-1 and Figure 4.2.1-1. No scrambling shall be applied to the known symbols.

(NU) TABLE 4.2.1-1. 8PSK symbol mapping

Symbol Number	Phase	In-Phase	Quadrature
0	0	1.000000	0.000000
1	π/4	0.707107	0.707107
2	π/2	0.000000	1.000000
3	3π/4	-0.707107	0.707107
4	π	-1.000000	0.000000
5	5π/4	-0.707107	-0.707107
6	3π/2	0.0000000	-1.000000
7	7π/4	0.707107	-0.707107

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



(NU) FIGURE 4.2.1-1. 8PSK signal constellation and symbol mapping

4.2.2 Data symbols

(NU) For data symbols, the modulation used shall depend upon the data rate. Table 4.2.2-1 specifies the modulation that shall be used with each data rate.

(NU) TABLE 4.2.2-1. Modulation used to obtain each data rate.

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

(NU) 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.

4.2.2.1 PSK data symbols

(NU) 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.

4.2.2.1.1 QPSK symbol mapping

(NU) For the 3200 bps user data rate, transcoding shall be achieved by linking one of the symbols specified in Table 4.2.1-1 to a set of two consecutive data bits (dibit) as shown in Table 4.2.2.1.1-1. In this table, the leftmost bit of the dibit shall be the older bit; i.e., fetched from the interleaver before the rightmost bit.

(NU) TABLE 4.2.2.1.1-1. Transcoding for 3200 bps

Dibit	Symbol
00	0
01	2
11	4
10	6

4.2.2.1.2 8PSK symbol mapping

(NU) 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 4.2.2.1.2-1. 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.

(NU) TABLE 4.2.2.1.2-1. Transcoding for 4800 bps

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

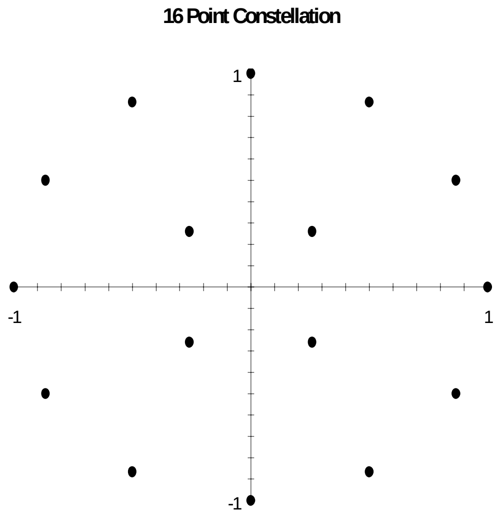
4.2.2.1.3 QAM data symbols

(NU) 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.

(NU) The mapping of bits to symbols for the QAM constellations has been selected to minimise the number of bit errors incurred when errors involve adjacent signalling points in the constellation.

4.2.2.1.4 The 16QAM constellation

(NU) The constellation points which shall be used for 16QAM are shown in Figure 4.2.2.1.4-1 and specified in terms of their In-phase and Quadrature components in Table 4.2.2.1.4-1. As can be seen in the figure, the 16 QAM constellation comprises two PSK rings: 4 PSK inner and 12 PSK outer symbols.



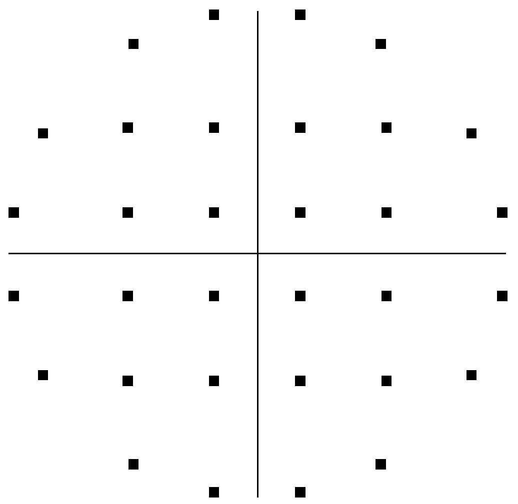
(NU) FIGURE 4.2.2.1.4-1. 16QAM Signalling Constellation

(NU) TABLE 4.2.2.1.4-1. 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

4.2.2.1.5 The 32QAM constellation

(NU) The constellation points which shall be used for 32QAM are shown in Figure 4.2.2.1.5-1 and specified in terms of their In-phase and Quadrature components in Table 4.2.2.1.5-1. This constellation contains an outer ring of 16 symbols and an inner square of 16 symbols.



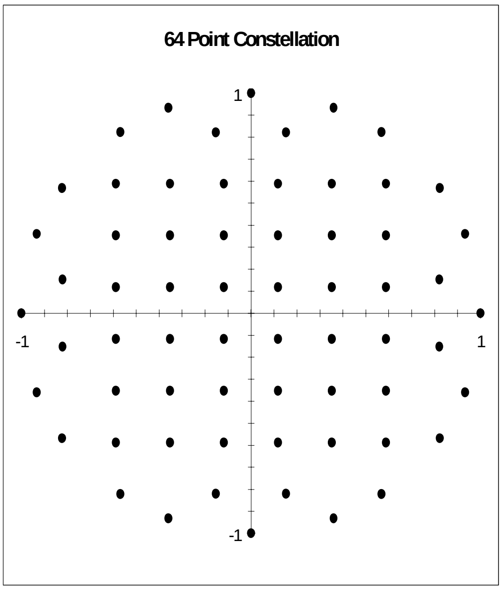
(NU) FIGURE 4.2.2.1.5-1. 32 Signalling Constellation

(NU) TABLE 4.2.2.1.5-1. 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

4.2.2.1.6 The 64QAM constellation

(NU) The constellation points which shall be used for the 64QAM modulation are shown in Figure 4.2.2.1.6-1 and specified in terms of their In-phase and Quadrature components in Table 4.2.2.1.6-1. This constellation is a variation on the standard 8 x 8 square constellation, which achieves a better peak-to-average ratio without sacrificing the very good pseudo-Gray code properties of the square constellation.



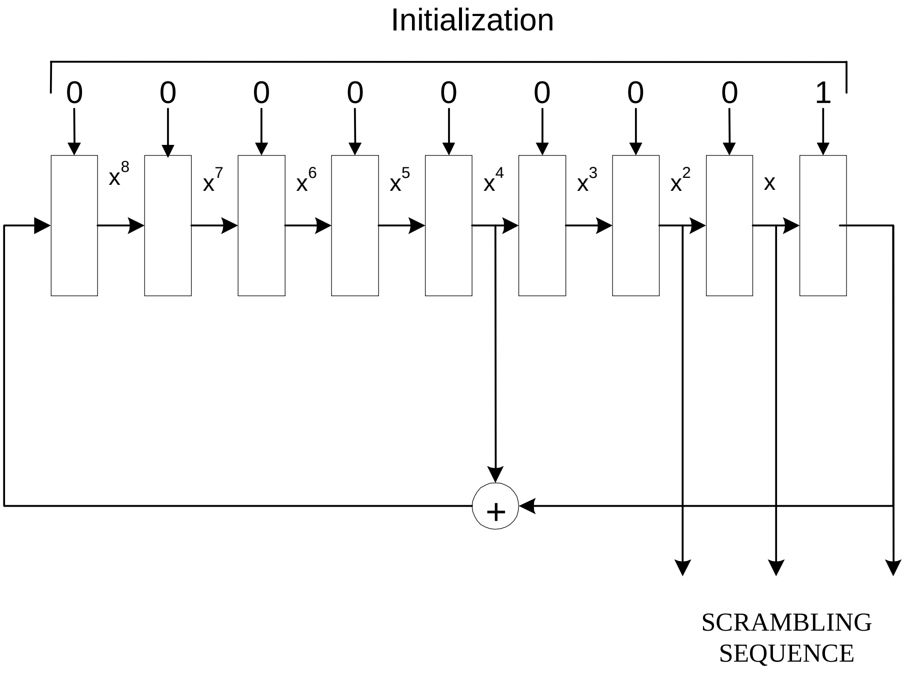
(NU) FIGURE 4.2.2.1.6-1. 64QAM signalling constellation

(NU) TABLE 4.2.2.1.6-1. 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

4.2.3 Data scrambling

(NU) 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 initialised to 1 at the start of each data frame. A block diagram of the scrambling sequence generator is shown in Figure 4.2.3-1.



(NU) FIGURE 4.2.3-1. Scrambling sequence generator illustrating scrambling generator for 8PSK symbols

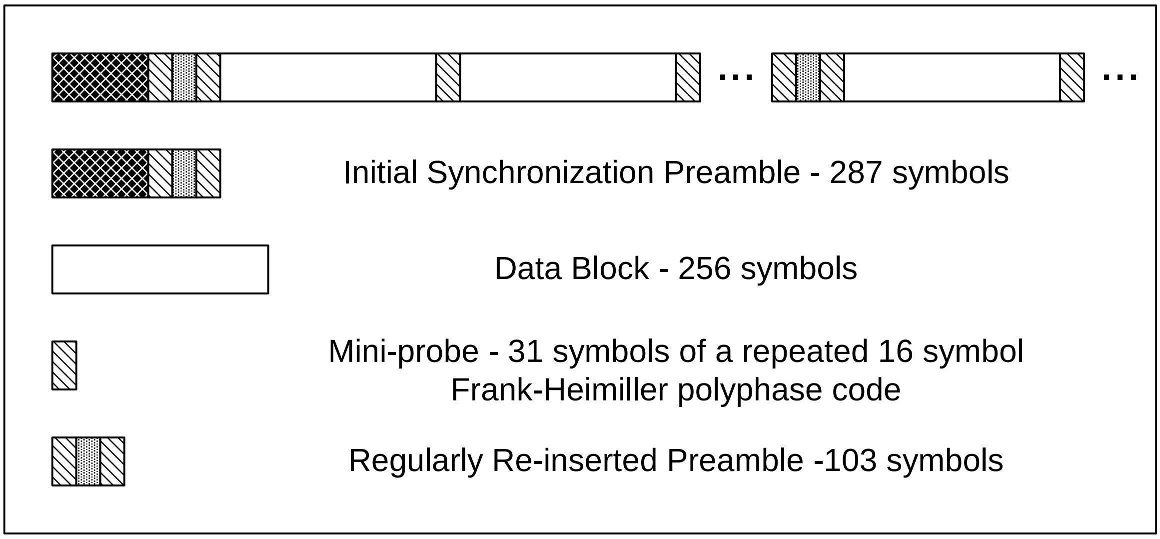
(NU) For 8PSK symbols (3200 bps and 4800 bps), the scrambling shall be carried out taking the modulo 8 sum of the numerical value of the binary triplet consisting of the last (rightmost) three bits in the shift register, and the symbol number (transcoded value). For example, if the last three bits in 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.

(NU) 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 used, the first data symbol of every data frame shall, therefore, be scrambled by the appropriate number of bits from the initialisation value of 00000001.

(NU) 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.

4.3 Frame structure

(NU) The frame structure that shall be used for the waveforms specified in this section is shown in Figure 4.3-1. 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.



(NU) FIGURE 4.3-1. Frame structure for all waveforms

4.3.1 Synchronisation and reinserted preambles

(NU) The synchronisation preamble is used for rapid initial synchronisation. The reinserted preamble is used to facilitate acquisition of an ongoing transmission (acquisition on data).

4.3.1.1 Synchronisation preamble

(NU) The synchronisation 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.

(NU) The second section shall consist of 287 symbols. The first 184 symbols are intended exclusively for synchronisation 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 4.2.1-1 the second section of the synchronisation preamble shall be as follows:

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 4.3.1.1-1 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.

(NU) TABLE 4.3.1.1-1. D0, D1, D2 8 PSK symbol values as a function of data rate and interleaver length

Data Rate (bps)	Interleaver Length in Frames (256 Symbol Data Blocks)					
	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*	N/A	N/A	N/A	N/A	N/A

*For 12800 bps 1 frame interleaver interpreted as no interleaving.

(NU) The mapping chosen to create Table 4.3.1.1-1 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 4.2.2.1.1-1, the dibit transcoding table. The 3 bit data rate and interleaver length mappings are shown in Table 4.3.1.1-2. Note that the transcoding has the effect of placing the 3 interleaver length bits in quadrature with the 3 data rate bits.

(NU) TABLE 4.3.1.1-2. Bit patterns for specifying data rate and interleaver length.

Data	3 Bit Mapping
3200	001
4800	010
6400	011
8000	100
9600	101
12800	110

Interleaver Length	3 Bit Mapping	Name
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)

(NU) Since the Barker code is unbalanced in terms of the number of 0s and 1s, these 3-bit patterns have been chosen to avoid the 000 or 111 patterns in order to minimise the unbalance in the combined three symbols. More specifically, one of the three repeats of the Barker code that appears on each of the quadrature components is always phase shifted by 180 degrees with respect to the other two. This results in a net imbalance in each quadrature component of the 39 symbols that is always 17 to 22, rather than ever being 12 to 27.

4.3.1.2 Reinserted preamble

(NU) The reinserted preamble shall be identical to the final 72 symbols of the synchronisation preamble. In fact, the final 103 symbols are common between the synchronisation 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:

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 again take one of 30 sets of values chosen from Table 4.3.1.1-1 to indicate the data rate and interleaver settings as described in the Synchronisation Preamble section above. Note that the first 31 of these symbols are the immediately preceding mini-probe, which follows the last of the 72 data blocks.

4.3.2 Mini-probes

(NU) 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.

(NU) 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 '+'.

(NU) 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 synchronisation and reinserted preambles shall also be encoded into mini-probes 1 to 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 18th mini-probe, in each of the first three sets, is also the 1st 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.

(NU) 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).

(NU) 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 4.3.2-1. Note that these 6 bit patterns (+ is a 0) correspond to the concatenation of the 3 bit mappings from Table 4.3.1.1-2 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 4.3.2-2.

(NU) TABLE 4.3.2-1. 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

(NU) TABLE 4.3.2-2. 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
+ + -	+ - +	+ - -	- + +

(NU) The first 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).

4.4 Coding and interleaving

(NU) 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 4.4-1 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.

(NU) TABLE 4.4-1. 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	1152	3456	6912	13824	27648
4800	576	1728	5184	10368	20736	41472
6400	768	2304	6912	13824	27648	55296
8000	960	2880	8640	17280	34560	69120
9600	1152	3456	10368	20736	41472	82944

4.4.1 Block boundary alignment

(NU) 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.

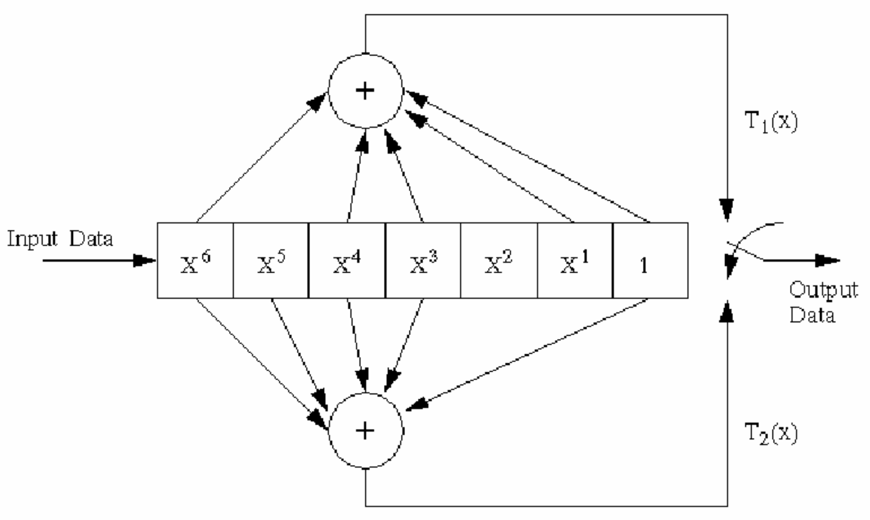
4.4.2 Block encoding

(NU) 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.

4.4.3 Rate 1/2 convolutional code

(NU) A constraint length 7, rate ½ convolutional code shall be used prior to puncturing. Figure 4.4.3-1 is a pictorial representation of the encoder. The two generator polynomials used shall be:

$T_1 = x^6 + x^4 + x^3 + x + 1$
$T_2 = x^6 + x^5 + x^4 + x^3 + 1$



(NU) FIGURE 4.4.3-1. Constraint length 7, rate 1/2 convolutional encoder

(NU) 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.

4.4.3.1 Full-tail-biting encoding

(NU) 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.

4.4.3.2 Puncturing to rate 3/4

(NU) In order to obtain a rate 1/2 code from the rate 3/4 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:

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

(NU) Defining $T_1(0)$, $T_2(0)$ to be the first two bits of the block code generated as defined in paragraph 4.4.2, 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.

4.4.4 Block interleaver structure

(NU) The block interleaver used is designed to separate neighbouring 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 flexible interleaver structure is needed.

4.4.4.1 Interleaver size in bits

(NU) 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 4.4.4.1-1.

(NU) TABLE 4.4.4.1-1. 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	18432	36864
4800	768	2304	6912	13824	27648	55296
6400	1024	3072	9216	18432	36864	73728
8000	1280	3840	11520	23040	46080	92160
9600	1536	4608	13824	27648	55296	110592

4.4.4.2 Interleaver load

(NU) 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 4.4.4.2-1, modulo the “Interleaver Size in Bits.”

(NU) 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)

(NU) 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.

(NU) TABLE 4.4.4.2-1. 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	6985
4800	145	361	1045	2089	5137	10273
6400	189	481	1393	3281	6985	11141
8000	201	601	1741	3481	8561	14441
9600	229	805	2089	5137	10273	17329

(NU) 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.

4.4.4.3 Interleaver fetch

(NU) 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.

4.5 Operational features and message protocols

(NU) 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 reinserted preamble facilitates acquisition (or re-acquisition) of an ongoing broadcast transmission. The short length of the synchronisation 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.

4.5.1 User interfaces

4.5.1.1 Conventional asynchronous interface

(NU) The modem shall 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.

4.5.1.2 High speed asynchronous user interface with flow control

(NU) 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 4.4-1 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 modems input buffer becomes full. Conversely, when the modems 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.

4.5.1.3 Ethernet interface

(NU) The modem shall provide an Ethernet interface. The bytes shall be aligned with Input Data Block boundaries.

4.5.2 Onset of transmission

(NU) 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.

(NU) 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.

4.5.3 End of message

(NU) 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.

(NU) 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.

4.5.4 Termination of a transmission

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

(NU) 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.

4.5.5 Termination of receive data processing

(NU) 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.

4.5.5.1 Detection of EOM

(NU) The HF modem shall always scan all of the decoded bits for the 32-bit EOM pattern defined in paragraph 4.5.3. 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.

4.5.5.2 Command to return to acquisition

(NU) 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).

4.5.5.3 Receipt of a specified number of data blocks

(NU) The maximum message duration measured in number of Input Data Blocks (interleaver blocks) shall be a configurable parameter. Setting this parameter to zero 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.

(NU) 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 since it is not embedded in the waveform itself as the data rate and interleaver length parameters are.

4.5.5.4 Initiation of a transmission

(NU) 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).

4.6 Performance Requirements

(NU) The minimum performance requirements for the high data rate mode are specified in this section. These requirements are not exhaustive, but are intended to ensure that equipment contains a high-quality implementation of the standard.

4.6.1 Simulator Characteristics

(NU) Performance of the high data rate mode shall be tested using a baseband HF simulator patterned after the Watterson Model in accordance with ITU-R 520-2.

- Multipath shall be modelled using a delay line.
- The fading gain of each tap on the delay line shall be obtained by filtering complex Gaussian noise samples.
- The power spectral density (frequency domain) of the fading gains shall be Gaussian. The standard deviation of the Gaussian distribution shall equal half of the specified Doppler spread. The spectrum of the actual filters must match a true Gaussian shape over a range of at least 35 dB (i.e., from the peak out to at least 35 dB below the peak).
- Fading gains shall be computed at least 30 times faster than the desired fade rate (which is the reciprocal of the Doppler spread), and shall be interpolated to at least the symbol rate of the waveform (i.e., 2400 samples per second) to avoid introducing large discontinuities in the output of the simulator.
- Additive white Gaussian noise (AWGN) shall be used as the noise source. 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.

4.6.2 Radio Filters

(NU) Finite impulse response (FIR) filters that reflect STANAG 4203 radio passband requirements shall be used. The filter shall be an N=63 FIR filter with the following coefficients (read across, then down):

3.4793306E-04	-4.6615634E-05	3.6863006E-05	6.8983925E-04
1.2186785E-03	7.1322870E-04	-6.2685051E-04	-1.1305640E-03
3.8082659E-04	2.2257954E-03	1.0150929E-03	-3.6258003E-03
-6.9094691E-03	-4.2534569E-03	1.1371180E-03	-1.0868903E-04
-1.1312117E-02	-2.2036370E-02	-1.8856425E-02	-4.9115933E-03
-1.3025356E-03	-2.1579735E-02	-4.8379221E-02	-4.8040411E-02
-1.4815010E-02	9.8565688E-03	-2.0275153E-02	-9.0223589E-02
-1.1587973E-01	-2.2672007E-02	1.6315786E-01	3.1537800E-01
3.1537800E-01	1.6315786E-01	-2.2672007E-02	-1.1587973E-01
-9.0223589E-02	-2.0275153E-02	9.8565688E-03	-1.4815010E-02
-4.8040411E-02	-4.8379221E-02	-2.1579735E-02	-1.3025356E-03
-4.9115933E-03	-1.8856425E-02	-2.2036370E-02	-1.1312117E-02
-1.0868903E-04	1.1371180E-03	-4.2534569E-03	-6.9094691E-03
-3.6258003E-03	1.0150929E-03	2.2257954E-03	3.8082659E-04
-1.1305640E-03	-6.2685051E-04	7.1322870E-04	1.2186785E-03
6.8983925E-04	3.6863006E-05	-4.6615634E-05	3.4793306E-04

4.6.3 BER performance

(NU) BER performance shall be measured using radio filters, with the channel simulator programmed to simulate the following channels:

- The AWGN channel shall consist of a single, non-fading path. Each condition shall be measured for at least 15 minutes for 1.0E-4 BER, and at least 60 minutes for 1.0E-5 BER.
- The Rician channel shall consist of two independent but equal average power paths, with a fixed 2 ms delay between paths. The first path shall be non-fading. The second shall be a Rayleigh fading path with a two sigma fading BW of 2 Hz. Each condition shall be measured for at least 2 hours for 1.0E–4 BER, and at least 5 hours for 1.0E-5 BER.
- 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 two sigma fading BW of 1 Hz. Each condition shall be measured for at least 2 hours for 1.0E-4 BER, and at least 5 hours for 1.0E-5 BER.

(NU) The measured performance, 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-4 under each of the conditions listed in Table 4.6.3-1. Design objective (DO) figures are indicated in the table, reflecting the performance that is known to be achievable; these levels of performance are non-mandatory.

(NU) TABLE 4.6.3-1. High data rate mode performance requirements for 1.0E-4 BER

User data rate (bps)	Average SNR (dB) for BER not to exceed 1.0E-4		
	AWGN Channel	Rician Channel	Poor Channel
12800*	27	-	-
9600	21 (DO: 19)	30 (DO: 27)	30 (DO: 27)
8000	19 (DO: 17)	25 (DO: 22)	26 (DO: 23)
6400	16 (DO: 14)	21 (DO: 18)	23
4800	13 (DO: 11)	17 (DO: 14)	20 (DO: 17)
3200	9 (DO: 7)	12	14

* optional data rate

(NU) The measured performance, 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 4.6.3-2. Design objective (DO) figures are indicated in this table, reflecting the performance that is known to be achievable.

(NU) TABLE 4.6.3-2. High data rate mode performance requirements for 1.0E-5 BER

User data rate (bps)	Average SNR (dB) for BER not to exceed 1.0E-5		
	AWGN Channel	Rician Channel	Poor Channel
12800*	28	-	-
9600	22 (DO: 20)	32 (DO: 29)	32 (DO: 29)
8000	19 (DO: 17)	26 (DO: 23)	28 (DO: 25)
6400	16 (DO: 14)	22 (DO: 19)	24
4800	14 (DO: 12)	18 (DO: 15)	21 (DO: 18)
3200	9 (DO: 7)	13	15

* optional data rate

4.6.4 Doppler shift test.

(NU) The modem shall acquire and maintain synchronisation 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.

4.6.5 Doppler sweep performance.

(NU) The AWGN BER test at 9600 bps from Table 4.6.1-1 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.

4.7 Associated communications equipment

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

(NU) It is recommended that modems implementing these waveforms should include a variable pre-key feature, whereby 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.

(NU) Radios for use with the high rate data waveforms described in this section are to be compliant with STANAG 4203.

5. LOW TO MEDIUM DATA RATE TRAFFIC WAVEFORMS FOR BACKWARD INTEROPERABILITY

(NU) Additional low to medium rate waveforms are specified in STANAG 4285 and STANAG 4529. These waveforms are required for backward interoperability for systems complying with this STANAG.

(NU) ARQ applications may wish to avoid use of these waveforms, as they lack the self-identifying feature.

ANNEX C TO STANAG 4539

(FOR INFORMATION ONLY)

PERFORMANCE ASPECTS OF WAVEFORMS FOR NON-HOPPING MULTIPLE APPLICATION OPERATION ON HF CHANNELS

1. INTRODUCTION

1.1 Purpose

(NU) This Annex illustrates operational performance aspects of the self-identifying family of waveforms from 75 to 9600 bps detailed in Annex B. This Annex does not contain any mandatory requirements, but is provided for information only.

(NU) The information provided in this Annex is intended to illustrate the tradeoffs that exist between waveform robustness (i.e. resilience against a range of HF channel conditions) and user data rate. This is the basis for the rationale within Annex B for providing a suite of waveforms which range from very robust low data rate to less robust high data rate waveforms.

1.2 Limitations

(NU) Waveform performance is presented in the form of characterisation plots which illustrate the operating region of a waveform against a set of baseline criteria related to bit error rate (BER) and HF channel conditions. The information conveyed by these plots is limited in the following ways :

- A single BER metric is used in the plots. The plots would be scaled for other BER metrics. The plots do not directly illustrate the data throughput of the waveforms when using ARQ protocols.
- Simplified HF channel criteria are used in the plots. These criteria can be mapped on to a range of HF channel conditions, but the complexity of certain propagation conditions would affect accuracy. The effects of non-Gaussian channel noise (e.g. interference) is not represented.
- Characterisation plots are derived from a single implementation of the waveforms. Some characterisation details are expected to vary in other compliant implementations of the STANAG. (Note. All implementations must meet the minimum mandatory performance requirements detailed in Annex B.)

1.3 Approach and structure of Annex C

(NU) The structure of Annex C is as follows.

(NU) Section 1 is an introduction.

(NU) Section 2 describes the technique used for obtaining the performance characterisations.

(NU) Section 3 details the characterisation plots.

2. DESCRIPTION OF CHARACTERISATION TECHNIQUE

(NU) STANAG 4539 waveform characteristations have been obtained using a HF channel simulator compliant with ITU-R F.520-2 “Use of High Frequency Ionospheric Channel Simulators employing the C.C. Watterson Model” . The simulator is used in a configuration which produces two independently fading skywave modes. Both modes have equal mean attenuation, equal Doppler shifts and spreads, and are separated by a multipath delay.

(NU) Doppler shift is held fixed at zero, and the performance of the waveform under test is measured by varying the Doppler spread, multipath and signal to noise ratio (SNR) channel parameter combinations over the ranges indicted in Table 2-1 below.

(NU) TABLE 2-1. Channel parameter test ranges

Input parameter	Range	Step size
Multipath delay	0 to 4.0 ms 4.0 to 10.0 ms	0.5 ms 1.0 ms
Doppler spread	0.5 to 4.0 Hz 4.0 to 20.0 Hz	0.5 Hz 2 Hz
SNR in 3kHz	-10 to 45 dB	1 dB

(NU) Bit error rate (BER) is used as the measure of waveform performance. At each Doppler spread / multipath delay combination the SNR which produces the required BER is determined. The resultant data can be presented as a three dimensional (3D) plot, whereby SNR, Doppler spread and multipath delay are attributed to the three orthogonal axes. Within the three dimensional space, the locus of points of constant BER describes a surface which indicates the waveform performance across the range of tested channel conditions.

(NU) A typical characterisation produced in this way (see section 3) will have a low level, relatively flat operating region, surrounded by a plateau which defines the non-operating region where the Doppler and multipath spreads are beyond the waveform’s capabilities for the specified BER.

(NU) This 3D characterisation is performed in accordance with the characterisation procedure in ITU Recommendation ITU-R F.1487.

3. CHARACTERISATION PLOTS

(NU) Illustrative waveform characterisation plots are presented in this section. In all cases a BER metric of 10^{-3} has been used (i.e. an uncorrected error rate of 1 error in 1000 bits of user data). The region above the surface in each plot is where a BER of 10^{-3} or lower (better) is experienced - apart from the plateau at the maximum measured SNR. The region below the surface in each plot is where a BER of 10^{-3} or higher (worse) is experienced.

(NU) Table 3-1 lists the selection of high data rate waveform plots which are provided. These waveforms are specified in Section 4 of Annex B to this STANAG. Each plot has been produced with STANAG 4203 filtering (nominal 350 – 3050Hz) in use.

(NU) Table 3-2 lists the selection of low to medium data rate waveform plots which are provided. These waveforms are described in Section 3 of Annex B to this STANAG. Each plot has been produced with 3kHz filtering (nominal 0 – 3000Hz) in use. The scale range used in the plots differs from that used in the high data rate waveform plots.

(NU) Table 3-3 details the very robust waveform plot which is provided. This waveform are described in Section 2 of Annex B to this STANAG. The plot has been produced with 3kHz filtering (nominal 0 – 3000Hz) in use. The scale range used in the plot differs from that used in the high data rate waveform plots.

(NU) TABLE 3-1. List of high data rate waveform characterisation plots

Figure No.	**User data rate (bps)**	**Interleaver depth (s)**
3-1	9600	0.36
3-2	9600	8.64
3-3	8000	0.36
3-4	8000	8.64
3-5	6400	0.36
3-6	6400	8.64
3-7	4800	0.36
3-8	4800	8.64
3-9	3200	0.36
3.10	3200	8.64

(NU) TABLE 3-2. List of low to medium data rate waveform characterisation plots

Figure No.	**User data rate (bps)**	**Interleaver depth (s)**
3-11	2400	4.80
3-12	1200	4.80
3-13	300	4.80

(NU) TABLE 3-3. Details of very robust waveform waveform characterisation plot

Figure No.	**User data rate (bps)**	**Interleaver depth (s)**
3-14	75	4.80

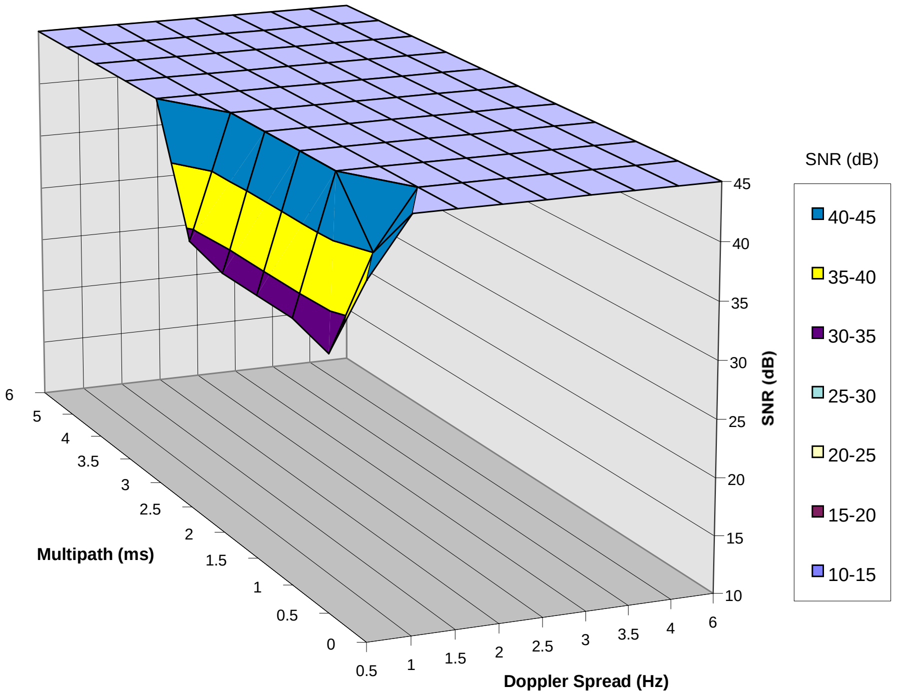


FIGURE 3-1. Characterisation plot: 10^{-3} BER, 9600bps, 0.36s interleaver.

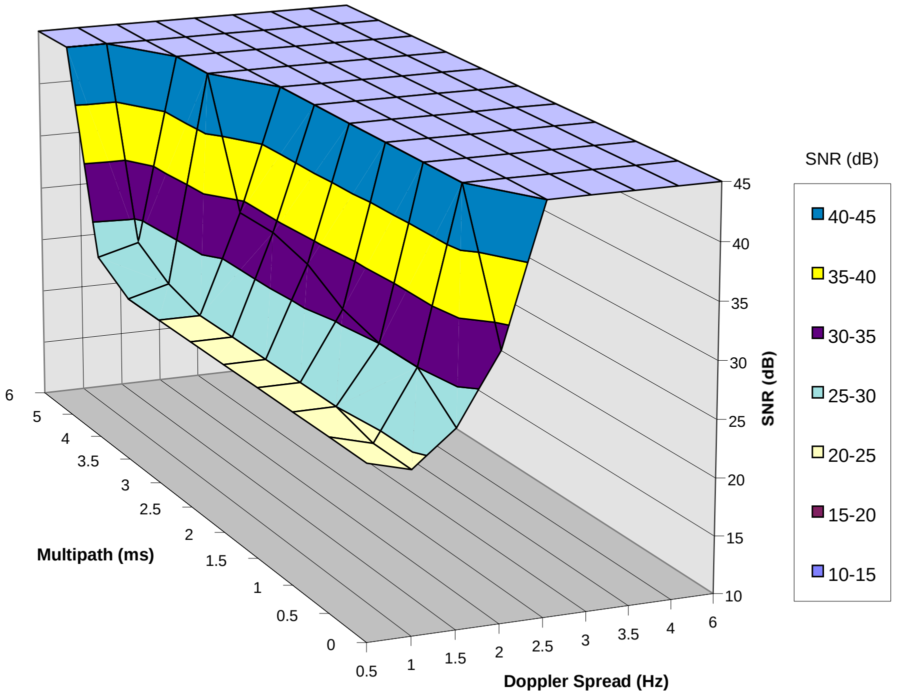


FIGURE 3-2. Characterisation plot: 10^{-3} BER, 9600bps, 8.64s interleaver.

FIGURE 3-3. Characterisation plot: 10^{-3} BER, 8000bps, 0.36s interleaver.

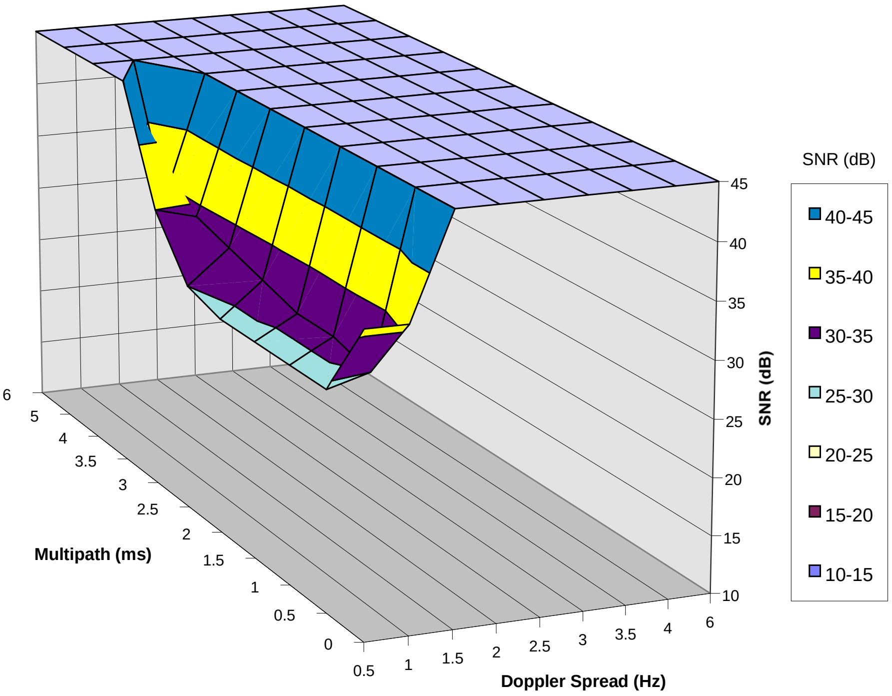
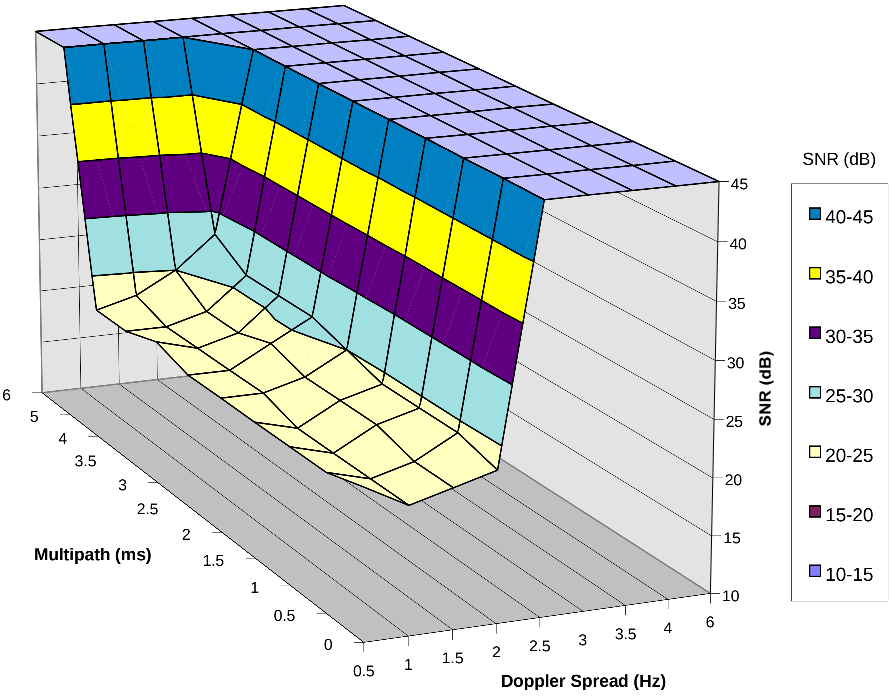


FIGURE 3-4. Characterisation plot: 10^{-3} BER, 8000bps, 8.64s interleaver.



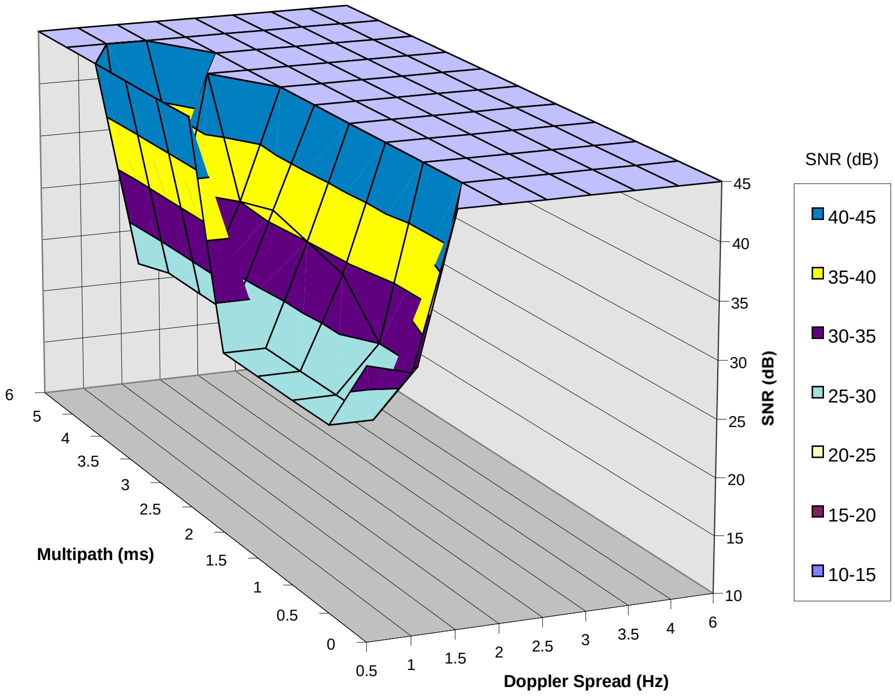


FIGURE 3-5. Characterisation plot: 10^{-3} BER, 6400bps, 0.36s interleaver.

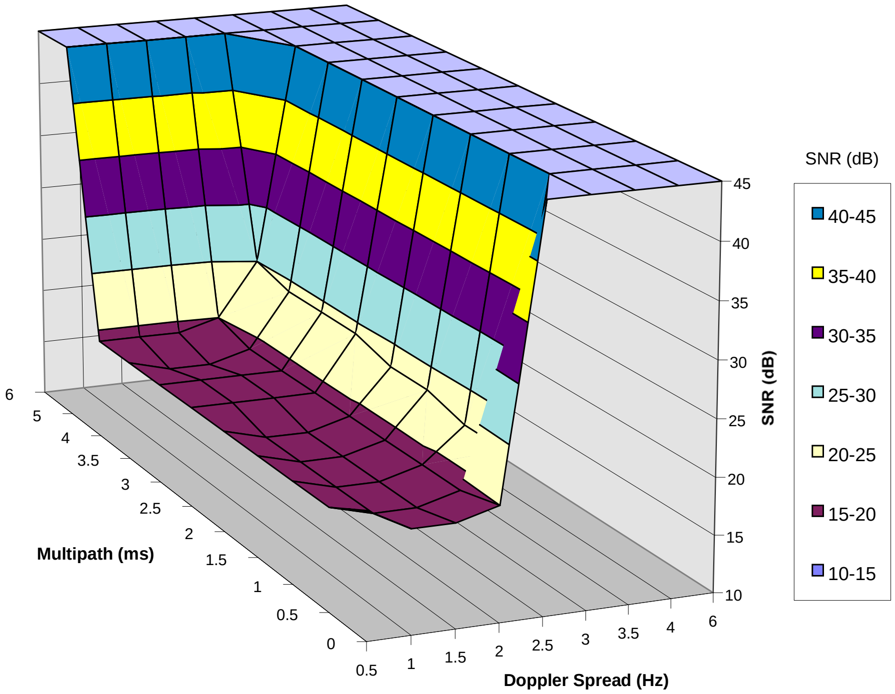


FIGURE 3-6. Characterisation plot: 10^{-3} BER, 6400bps, 8.64s interleaver.

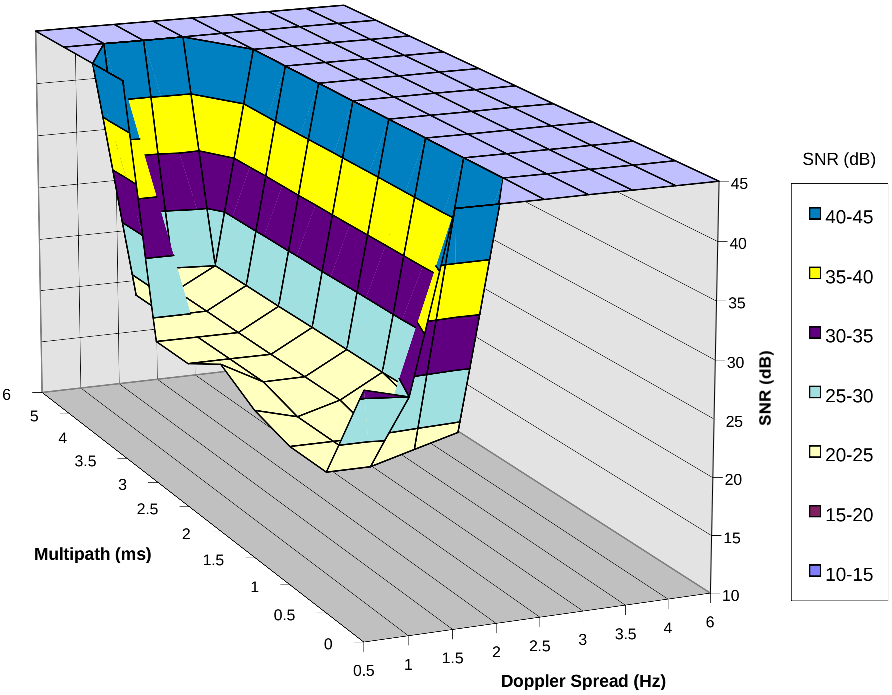


**FIGURE 3-7.
Characterisation
plot: 10^{-3} BER,
4800bps,
0.36s interleaver.**

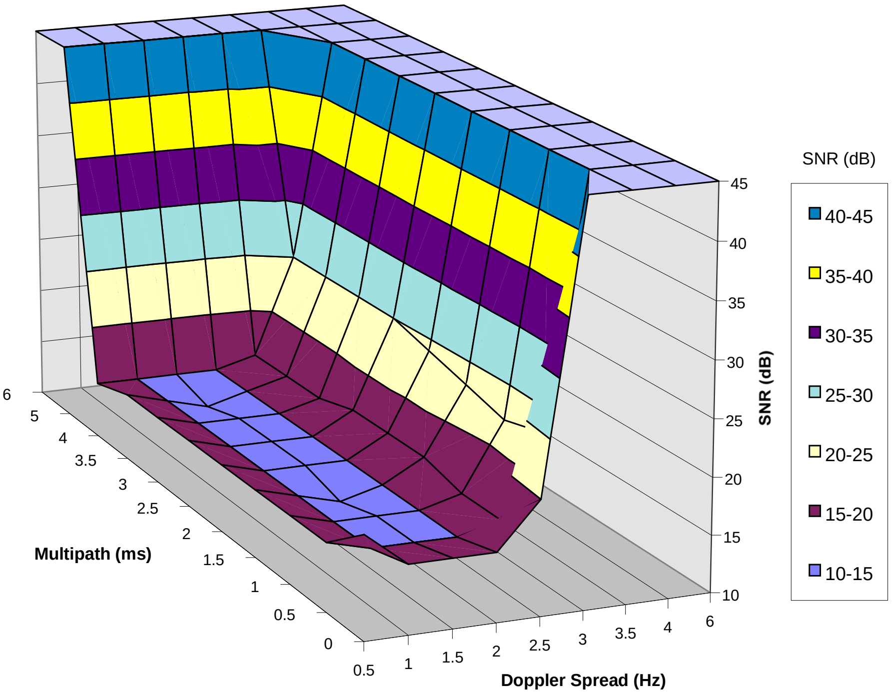


**FIGURE 3-8.
Characterisation
plot: 10^{-3} BER,
4800bps,
8.64s interleaver.**

FIGURE 3-9. Characterisation plot: 10^{-3} BER, 3200bps, 0.36s interleaver.

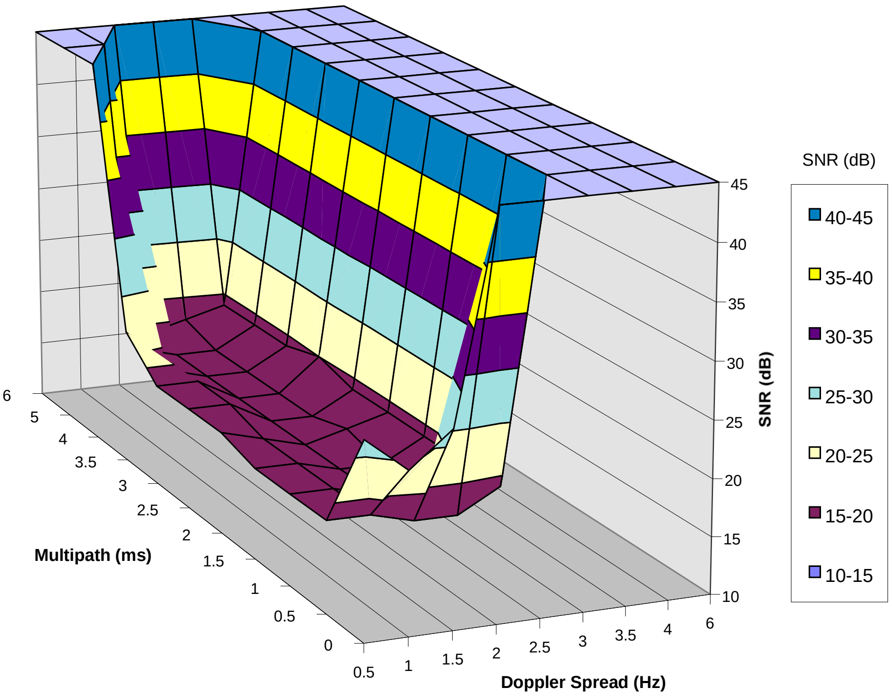


FIGURE 3-10. Characterisation plot: 10^{-3} BER, 3200bps, 8.64s interleaver.

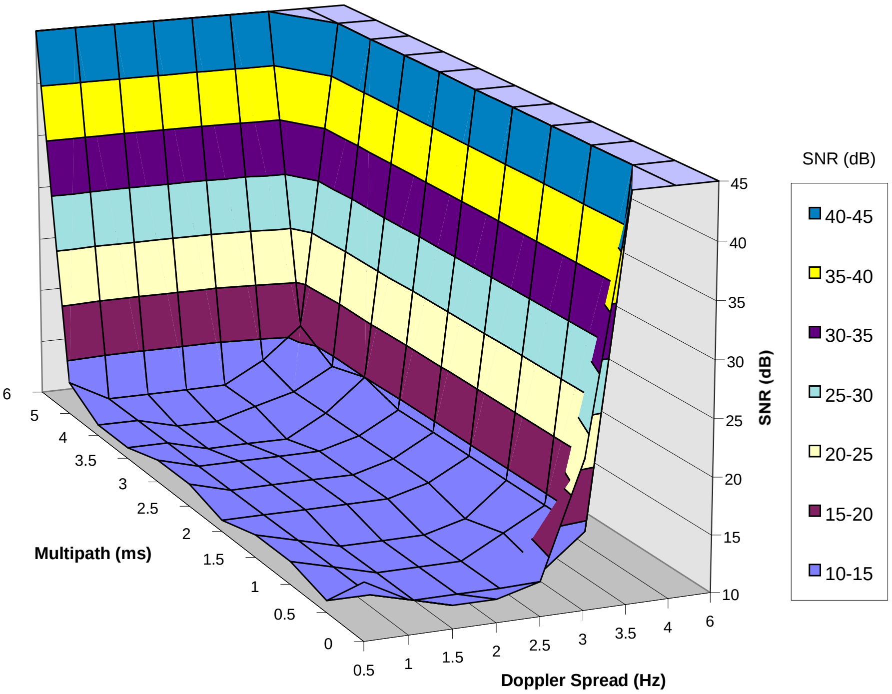


FIGURE 3-11. Characterisation plot: 10^{-3} BER, 2400bps, 4.80s interleaver.

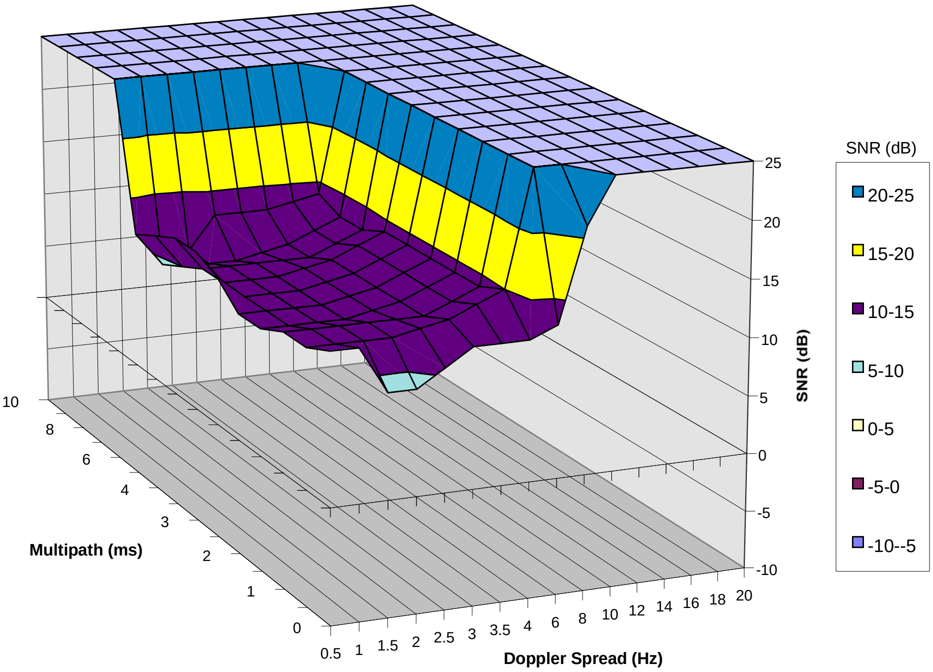
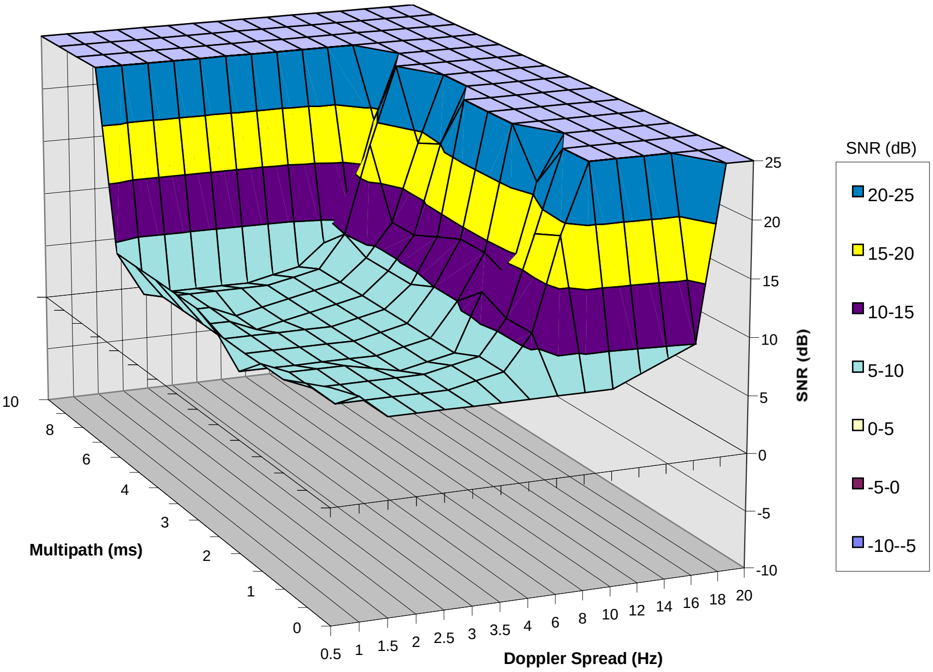


FIGURE 3-12. Characterisation plot: 10^{-3} BER, 1200bps, 4.80s interleaver.



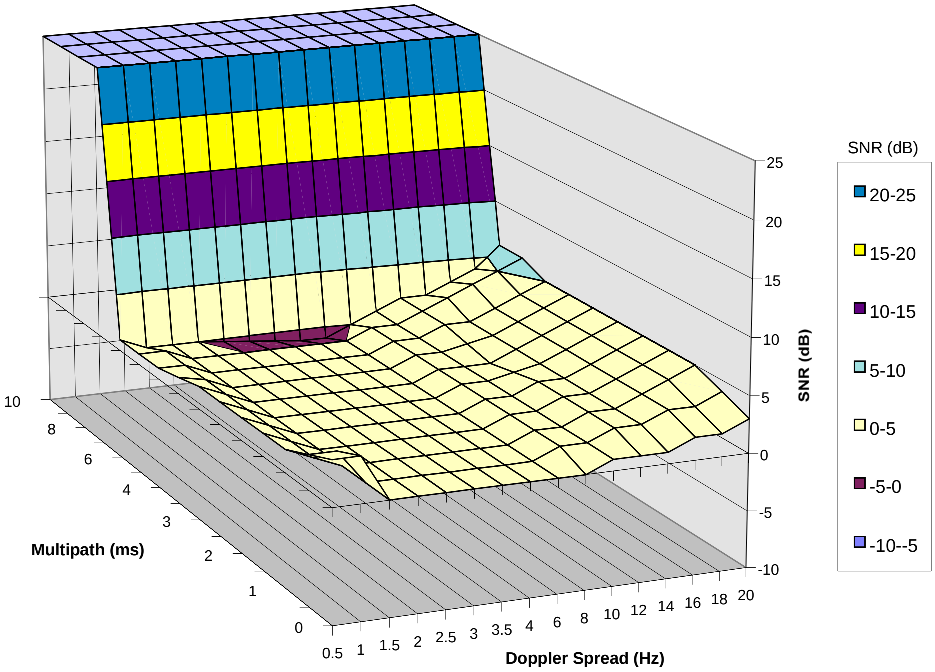


FIGURE 3-13. Characterisation plot: 10^{-3} BER, 300bps, 4.80s interleaver.

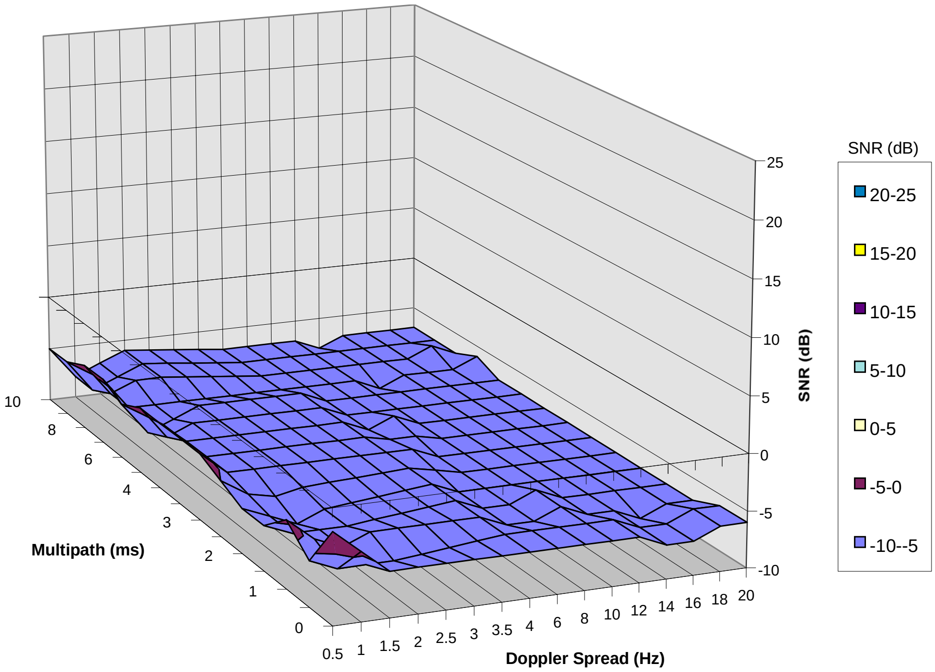


FIGURE 3-14. Characterisation plot: 10^{-3} BER, 75bps, 4.80s interleaver.

ANNEX D TO STANAG 4539

(OPTIONAL)

TECHNICAL SPECIFICATIONS TO ENSURE INTEROPERABILITY OF SERIAL WAVEFORMS FOR NON-HOPPING TDMA OPERATION ON HF CHANNELS

1. INTRODUCTION

1.1 Purpose

(NU) This Annex provides a detailed description of modem waveforms to ensure interoperability within complying HF radio networks.

(NU) This annex addresses NATO non-EPM TDMA mode requirements.

1.2 Approach and Structure of Annex D

(NU) The system described in STANAG 4539 is designed to satisfy NATO requirements.

(NU) This standard reflects the NATO emphasis on the International Standards Organisation Open Systems Interconnect (ISO/OSI) model. The system attributes defined in STANAG 4539 are considered to lie within the physical layer of the OSI reference model. The structure of the Annex is as follows.

(NU) Section 1 is an introduction.

(NU) Section 2 presents TDMA mode waveforms.

2. TDMA MODE WAVEFORMS

(NU) This section specifies the modem to be used in HF Fixed Frequency for TDMA operations. The aim of this section is to define all the technical characteristics in order to ensure interoperability among participants in a TDMA network.

2.1 Modulation

(NU) The modulation technique shall consist of phase shifting of a 1800 Hz sub-carrier. The modulation speed shall be 2400 baud with a minimum accuracy of $3*10^{-5}$.

(NU) The accuracy of the sub-carrier frequency shall be $3*10^{-5}$.

(NU) The phase shift of the modulated signal relative to a reference signal may assume one of the following values:

TABLE 2.1-1. Symbol number assignment

Symbol number	Phase(rad)
0	0
1	π/4
2	π/2
3	3π/4
4	π
5	5π/4
6	3π/2
7	7π/4

(NU) In the complex notation each symbol can be represented by the following notation:

$$e^{jn\frac{\pi}{4}} \qquad \begin{array}{c} n = symbol \quad number \\ 0 \le n \le 7 \end{array} \qquad (2.1\text{-}1)$$

(NU) There are two different types of PSK modulations: QPSK and 8PSK. The QPSK modulation is used for preamble transmission. QPSK or 8PSK are used for Media Code Frame transmission.

(NU) The symbol mapping to be used shall be according to the following tables:

(NU) TABLE 2.1-2. QPSK symbol coding

Bits		symbol
earlier bit	later bit	
0	0	0
0	1	2
1	0	6
1	1	4

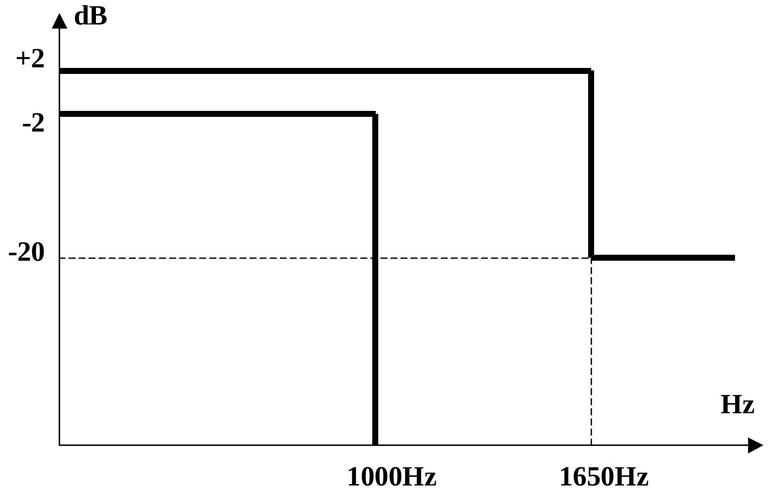
(NU) TABLE 2.1-3. 8PSK symbol coding

Bits			symbol
earliest bit	....	latest bit	
0	0	0	1
0	0	1	0
0	1	0	2
0	1	1	3
1	0	0	6
1	0	1	7
1	1	0	5
1	1	1	4

2.2 Power spectral density

(NU) The audio frequency mask that the modulated signal spectrum must fall within is shown in Figure 2.2-1. The mask is presented relative to the sub-carrier of 1800 Hz, about which the mask is symmetric.

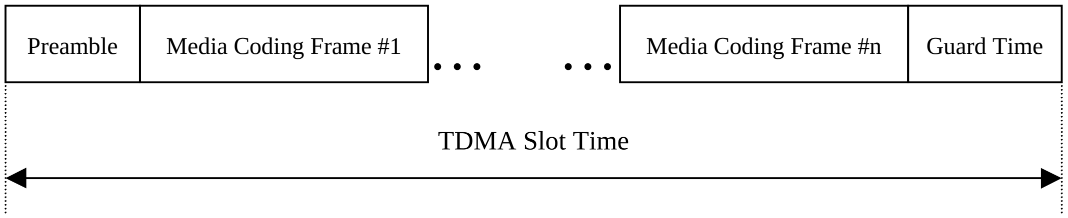
(NU) This audio frequency mask is consistent with traditional square-root-raised cosine pulse shape responses, with rolloffs between the 20% and 30%, suffering severe rectangular windowing (i.e. spanning as few as 3 symbol periods).



(NU) FIGURE 2.2-1. Audio Frequency Spectrum Mask

2.3 Slot structure

(NU) A TDMA slot is the high level structure in which information will be transmitted/received. A TDMA slot is composed of a Preamble, a certain number of Media Code Frames (specified to the modem by the System Network Controller prior to transmission of the first Media Code Frame) and a Guard Time. The duration of the Preamble plus the duration of the Guard time is equal to a Media Code Frame time. The structure is shown in Figure 2.3-1. The TDMA slot starts with the Preamble transmission/reception.



(NU) FIGURE 2.3-1. TDMA Slot Structure

2.3.1 Preamble structure

(NU) The preamble consists of 203 Symbols transmitted in QPSK at the modulation rate of 2400 baud. The preamble duration is ≈ 84.58 ms.

(NU) In Table 2.3.1-1 the preamble symbols are specified. The transmission shall start from the top-left symbol following the table by rows.

(NU) TABLE 2.3.1-1. Symbols composing the Preamble

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

2.3.2 Media Code Frame structure

(NU) A Media Code Frame is composed of 270 symbols to be transmitted/ received at the modulation rate of 2400 baud and following a certain waveform structure.

(NU) The possibility of accommodating different waveforms in a Media Code Frame has been provided to optimise performance for various channel conditions. Each waveform is composed of a sequence of different DATA blocks and Mini Probe (MP) blocks.

(NU) The DATA block contains coded user information symbols. The MP block contains known training symbols to be used by the equaliser. These symbols allow for updates of the equaliser to handle varying propagation conditions (Doppler spread and delay spread).

(NU) By varying the waveform structure and the modulation (quaternary phase shift keying (QPSK) or octal phase shift keying (8PSK)) multiple waveforms can be designed to optimise system performance for a variety of channel conditions.

(NU) Three waveforms are used for HF Fixed Frequency TDMA applications. Each of the waveform symbols shall be scrambled as described in section 2.3.2.2.

2.3.2.1 Waveform Modulation and Content

(NU) The three different waveforms are shown in Tables 2.3.2.1-1, 2.3.2.1-2, and 2.3.2.1-3.

(NU) The Mini Probes symbols, prior to scrambling, are all symbols number 0.

(NU) TABLE 2.3.2.1-1. Modulation Type and Contents for WF1

WF's sections	Duration in Modulation Symbols	Modulation Type
DATA1	48	QPSK
MP1	19	QPSK
DATA2	48	QPSK
MP2	20	QPSK
DATA3	48	QPSK
MP3	19	QPSK
DATA4	48	QPSK
MP4	20	QPSK

(NU) TABLE 2.3.2.1-2. Modulation Type and Contents for WF2

WF's sections	Duration in Modulation Symbols	Modulation Type
DATA1	18	QPSK
MP1	16	QPSK
DATA2	18	QPSK
MP2	15	QPSK
DATA3	18	QPSK
MP3	16	QPSK
DATA4	18	QPSK
MP4	16	QPSK
DATA5	18	QPSK
MP5	16	QPSK
DATA6	18	QPSK
MP6	15	QPSK
DATA7	18	QPSK
MP7	16	QPSK
DATA8	18	QPSK
MP8	16	QPSK

(NU)□ TABLE 2.3.2.1-3. Modulation Type and Contents for WF3

WF's sections	Duration in Modulation Symbols	Modulation Type
DATA1	48	8PSK
MP1	19	8PSK
DATA2	48	8PSK
MP2	20	8PSK
DATA3	48	8PSK
MP3	19	8PSK
DATA4	48	8PSK
MP4	20	8PSK

2.3.2.2 Scrambling

(NU)□ Each of the 270 symbols of a Media Code Frame are scrambled by the modulo 8 addition of the Data or Mini Probe symbol number with the corresponding scrambling symbol number.

(NU)□ The scrambling symbol number generator is shown in Figure 2.3.2.2-1. The numbers are formed using a pseudo-random code of length 511, whose polynomial generator may be written as

$$x^9 + x^4 + 1 \qquad (2.3\text{-}1)$$

(NU)□ The generator is initialised to 1FF Hex at the start of each Media Code Frame.

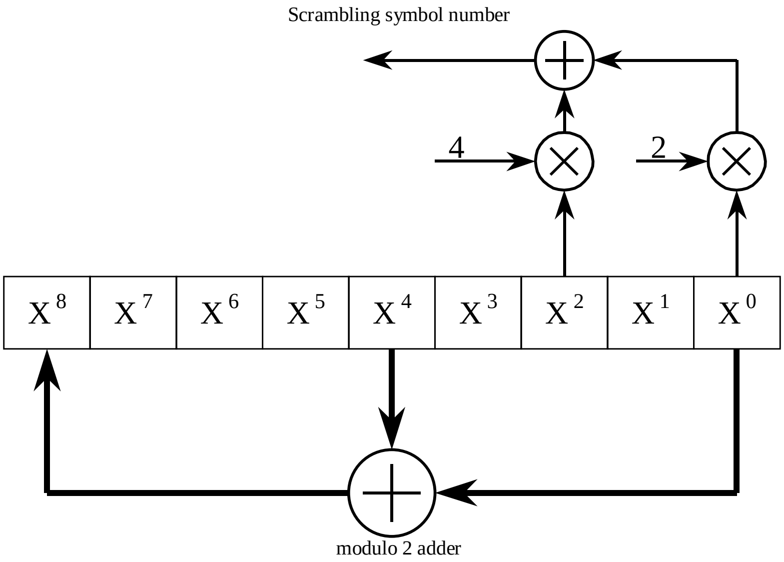
(NU)□ A scrambling symbol number is derived from the pair of bits that occupy positions 0 and 2 (i.e. x^0, and x^2) in the shift register of Figure 2.3.2.2-1. Specifically:

$$\text{scrambling symbol number} = \exp(j\ N\ \pi\ /4) \qquad (2.3\text{-}2)$$

where N is the scrambling symbol number given by:

$$N = 4 \bullet x^2 + 2 \bullet x^0 \qquad x^2 \quad \{0,1\} \quad x^0 \quad \{0,1\} \qquad (2.3\text{-}3)$$

(NU)□ Hence N is restricted to the four values 0,2,4, and 6. This restriction applies to both QPSK and 8PSK modulation types.



(NU) FIGURE 2.3.2.2-1. Scrambling Symbol Number Generator

(NU) Generation from one symbol to the next is by successive shifting (toward the LSB) of the register by 3 positions. The resulting sequence of 270 Scrambling symbols is {6,6,6,0,4,......,4,0,0,6,6,6} where numbers to the left of this sequence scramble symbols are used earlier in the Media Code Frame scrambling, and numbers to the right are used later.

2.3.3 Guard time Packet

(NU) The Guard time is ≈ 27.92 ms. corresponding to the duration of 67 Symbols at the data rate of 2400 baud.

(NU) During this time the TDMA slot owner does not transmit. This time is provided to allow the receiving units to compensate for the propagation delay time (composed of propagation delay time over the air and through the electronics).

2.4 Coding scheme

(NU) Shortened modifications of the maximum length Reed-Solomon (RS) coding scheme are applied in order to give the requested error detection and correction capabilities accordingly to the following rules:

- All the Data portions of the same Media Code Frame shall belong to the same codeword.
- The codeword length depends on the waveform to which the code is applied.
- The RS symbols belong to a GF(2^8) field. The unshortened code word length N is equal to:

$$N = 2^8 - 1 = 255 \qquad (2.4\text{-}1)$$

- The number of RS information symbols, k, is programmable and depends on the waveform and on the robustness that a Network Management function (outside the modem) wants to have. These parameters can be changed before the beginning of the first Media Code Frame in a new TDMA slot. Thus, the encoder/decoder set/reset operations shall be performed anytime during the preamble time. Of course the encoder/decoder must be ready and synchronised for operation at the beginning of the first Media Code Frame in the TDMA slot.

- The encoder input is a set of k RS symbols each made of 8 bits.
- The encoder output is a set of n RS symbols each made of 8 bits. The value of n depends on the selected waveform.
- The possible coding schemes are given in Table 2.4-1 for each waveform.

(NU) TABLE 2.4-1. Possible combination of WFs and coding

	RS: symbol size 8 bits	
	n	k
WF1	48	39
	48	30
WF2	36	30
	36	21
WF3	72	57
	72	48

2.4.1 Field generator

(NU) The polynomial generator of the Galois Field GF(2^8) is:

$$p(z) = z^8 + z^5 + z^3 + z + 1 \qquad (2.4\text{-}2)$$

(NU) The elements of the field generated by p(z) are:

$$0, 1, \alpha, \alpha^2, \ldots, \alpha^{254} \qquad (2.4\text{-}3)$$

(NU) Alternatively, each element in equation 2.4-2 may be represented as an 8 bit number.

(NU) In the RS code word, any symbol is an element of GF(2^8).

2.4.2 User bits mapping

(NU) Let the following k 8 bits be provided by the user in the order of arrival:

$$b_{1,0}, \ldots, b_{1,7}; b_{2,0}, \ldots, b_{2,7}; \ldots \ \ldots; b_{k,0}, \ldots, b_{k,7} \qquad (2.4\text{-}4)$$

where $b_{1,0}$ is the earliest bit and $b_{k,7}$ is the latest bit.

(NU) The mapping between each block of 8 bits

$$b_{i,0},\ldots,b_{i,7} \qquad \forall\ i \in [1,\ldots,k] \tag{2.4-5}$$

and the corresponding RS information symbol I_i shall be done on the field described in the para 2.4 considering $b_{i,0}$ as MSB and $b_{i,7}$ as LSB.

(NU) After the mapping the bit sequence can be written as:

$$I_1, I_2, \ldots\ \ldots, I_k \tag{2.4-6}$$

2.4.3 Code generator polynomial

(NU) Let (n,k) be the parameters of the RS codeword we are considering, and define R as: R=n-k.

(NU) The corresponding code shall be generated by the following code generator polynomial:

$$g(x) = (x-\alpha)(x-\alpha^2)\ldots(x-\alpha^R) \tag{2.4-7}$$

2.4.4 Systematic encoding

(NU) Let i(x) be a polynomial representing the k information symbols to be coded as they were described in para 2.3.2. We can write:

$$i(x) = I_1 x^{k-1} + I_2 x^{k-2} + \ldots\ldots + I_{k-1}x + I_k \tag{2.4-8}$$

(NU) The RS(n,k) code word can be represented in systematic form by the polynomial c(x) as:

$$c(x) = i(x)x^{n-k} + r(x) \tag{2.4-9}$$

where

$$\begin{aligned} r(x) &= \left[i(x)x^{n-k}\right]\mathrm{mod}\left[g(x)\right] \\ &= R_1 x^{n-k-1} + R_2 x^{n-k-2} + \ldots\ \ldots R_{n-k} \end{aligned} \tag{2.4-10}$$

(NU) After calculation, we will have:

$$c(x) = I_1 x^{n-1} + I_2 x^{n-2} + \ldots + I_k x^{n-k} + R_1 x^{n-k-1} + R_2 x^{n-k-2} + \ldots + R_{n-k-1}x + R_{n-k} \tag{2.4-11}$$

(NU) Using a vectorial notation the codeword can be represented as:

$$C_w = (I_1, I_2, \ldots, I_k, R_1, R_2, \ldots, R_{n-k-1}, R_{n-k}) \tag{2.4-12}$$

where each symbol belongs to the Galois Field defined in para 2.4.

2.4.5 Code word transmission

(NU) The transmission order of the code word shall be in accordance with the decreasing order of its polynomial representation (equation 2.4-11). Consequently the transmission order of the Reed Solomon symbols is:

$$I_1, I_2, \ldots, I_k, R_1, R_2, \ldots, R_{n-k-1}, R_{n-k} \tag{2.4-13}$$

from I_1 to R_{n-k}.

(NU) The symbol sequence can be written in terms of bits as:

$$b_{1,0},\dots,b_{1,7};b_{2,0},\dots,b_{2,7};\dots\ \dots;b_{n,0},\dots,b_{n,7} \qquad (2.4\text{-}14)$$

where the bits $b_{i,j}$ $\quad \forall\ i \in \{1,\dots,k\}$
$\quad \forall\ j \in \{0,\dots,7\}$
are the information bits provided by the user,

and the bits $b_{i,j}$ $\quad \forall\ i \in \{k+1,\dots,n\}$
$\quad \forall\ j \in \{0,\dots,7\}$
are the redundancy bits provided by the encoder.

(NU) For the purposes of modulation, the sequence in (2.4-14) is partitioned into consecutive group of q bits, where q is the number of bits in a modulation symbol. Note that n•8 is exactly divisible by q, so there are n•8/q such groups. The conversion of any q bit group to the corresponding PSK symbol number is performed using the appropriate Table 2.1-2 or 2.1-3. To use a table, the convention is employed that the left-most bit in any group (information or redundancy) is the "earliest" bit, and the right-most bit is the "latest". Hence, for example, $b_{1,0}$ is the earliest bit of the left-most group, and $b_{n,7}$ is the latest bit of the right-most group.

(NU) Transmission shall proceed beginning with the symbol formed from the left-most group, and ending with the symbol formed from the right-most group.

2.4.6 Decoding

(NU) The decoder shall perform error detection and correction on the received code word. It also shall provide distance information for each code word as Link Quality Indicator.

2.5 Waveform summary (for information only)

(NU) Characteristics of the TDMA waveforms are summarized in Table 2.5-1. The user bits per second figures are upper bounds, which will be approached only as the number of Media Coding Frames per TDMA slot approaches infinity.

(NU) TABLE 2.5-1. Waveform Summary

	n	k	user bits per symbol	user symbols per frame	user bits per frame	user bits per second
WF1	48	39	2	192	312	2773
	48	30	2	192	240	2133
WF2	36	30	2	144	240	2133
	36	21	2	144	168	1493
WF3	72	57	3	192	456	4053
	72	48	3	192	384	3413

2.6 Pulse shaping (for information only)

(NU) A pulse shaping filter shall be used which will constrain the bandwidth of the modulated signal without increasing the Inter Symbol Interference (ISI) in the demodulator. The following constraints are stated:

- The band of the transmitter modulation filter and receiver demodulation filter shall be compatible with the receiver/transmitter bandwidth: 300 Hz to 3300 Hz.
- To maximise the Signal to noise ratio a filter matched to the pulse signal shall be used on the receiver side.

(NU) A class of filter that meets such constraints is the class of raised cosine filters. The global transfer function of modulation filter (or shaping filter) plus demodulation filter shall be:

$$H(f) = 1 \qquad |f| \leq Wo(1-\rho) \qquad (2.6\text{-}1)$$

$$H(f) = \cos^2\left(\frac{\pi}{4}\frac{(|f| - Wo(1-\rho))}{\rho Wo}\right) \qquad Wo(1-\rho) < |f| < Wo(1+\rho) \qquad (2.6\text{-}2)$$

$$H(f) = 0 \qquad |f| \geq Wo(1+\rho) \qquad (2.6\text{-}3)$$

where

Wo is the Nyquist frequency **Wo** = baud rate/2 = 1200 Hz
ρ is the roll-off factor **ρ** = 0.25
and |f| is the absolute value of the frequency.

(NU) The transfer function of modulation filter shall be, in this case, equal to the transfer function of demodulation filter:

$$H(f)_{\text{mod.}} = H(f)_{de\,\text{mod.}} = \sqrt{H(f)} \qquad (2.6\text{-}4)$$

(NU) The total delay introduced by the modulation filter plus demodulation filter shall be less then the time equivalent to the transmission of 10 Symbols at the nominal baud rate (≈ 4.1666 ms.).