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See Distribution List No. 2

STANAG 4529 EL (EDITION 1) - CHARACTERISTICS OF SINGLE TONE MODULATORS/DEMODULATORS FOR MARITIME HF RADIO LINKS WITH 1240 Hz BANDWIDTH

Reference:
AC/302-D/756 of 31 January 1996

1. The enclosed NATO Standardization Agreement which has been ratified by nations as reflected in page iii is promulgated herewith.

2. The reference listed above is to be destroyed in accordance with local document destruction procedures.

3. AAP-4 should be amended to reflect the latest status of the STANAG.

ACTION BY NATIONAL STAFFS

4. National staffs are requested to examine page iii of the STANAG and, if they have not already done so, advise the NHQC3A through their national delegation as appropriate of their intention regarding its ratification and implementation.

A. GRØNHEIM
Major General, NOAF
Chairman MAS

Enclosure:
STANAG 4529

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STANAG No. 4529
(Edition 1)

NORTH ATLANTIC TREATY ORGANIZATION

(N A T O)

MILITARY AGENCY FOR STANDARDIZATION

(M A S)

STANDARDIZATION AGREEMENT

(STANAG)

SUBJECT : CHARACTERISTICS OF SINGLE TONE MODULATORS/DEMODULATORS FOR MARITIME HF RADIO LINKS WITH 1240 Hz BANDWITH

Promulgated on 20 January 1998

A. GRØNHEIM
Major General, NOAF
Chairman, MAS

RECORD OF AMENDMENTS

No.	Reference/Date of amendment	Date Entered	Signature

EXPLANATORY NOTES

AGREEMENT

1. This NATO Standardization Agreement (STANAG) is promulgated by the Chairman MAS under the authority vested in him by the NATO Military Committee.

2. No departure may be made from the agreement without consultation with the tasking authority. 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.

DEFINITIONS

4. Ratification is "In NATO Standardization, the fulfilment by which a member nation formally accepts, with or without reservations, the content of a Standardization Agreement" (AAP-6).

5. Implementation is "In NATO Standardization, the fulfillment by a member nation of its obligations as specified in a Standardization Agreement" (AAP-6).

6. Reservation is "In NATO Standardization, the stated qualification by a member nation that describes the part of a Standardization Agreement that it will not implement or will implement only with limitations" (AAP-6).

RATIFICATION, IMPLEMENTATION AND RESERVATIONS

7. Page iii gives the details of ratification and implementation of this agreement. If no details are shown, it signifies that the nation has not yet notified the tasking authority of its intentions. Page iv (and subsequent) gives details of reservations and proprietary rights that have been stated.

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NAVY

NATO STANDARDIZATION AGREEMENT
(STANAG)

CHARACTERISTICS OF SINGLE TONE MODULATORS / DEMODULATORS FOR MARITIME HF RADIO LINKS WITH 1240 Hz BANDWIDTH

ANNEXES : A. Required characteristics of single tone modulators / demodulators for maritime HF radio links with 1240 Hz bandwidth

B. Comments accompanying STANAG 4529

RELATED DOCUMENTS :

STANAG 4285 - Characteristics of 1200/2400/3600 Bits Per Second Single Tone Modulators / Demodulators for HF Radio Links

STANAG 4203 - Technical Standards for Single Channel HF Radio Equipment

STANAG 4481 - Minimum Technical Equipment Standards for Naval HF Shore-to-Ship Broadcast Systems

AIM

1. The aim of this agreement is to define the technical interoperability characteristics for a means of digital communications over maritime HF radio channels having a bandwidth of 1240 Hz. The effective bit rate of the communication can be 75, 150, 300, 600, or 1200 bits per second, by means of a single tone modulator / demodulator in combination with error correction techniques. In addition, uncoded data transmission modes at 600, 1200, and 1800 bps are defined. This STANAG has been developed with the objective of implementation of the capability by upgrading existing STANAG 4285 or STANAG 4481 equipments to contain this means as another user-selectable mode.

AGREEMENT

2. The participating nations agree to use the characteristics contained in this STANAG (Annex A and Appendix 1 to Annex A) for their single tone modems for data communications over maritime HF radio circuits with a bandwidth of 1240 Hz.

IMPLEMENTATION OF THE AGREEMENT

3. This STANAG is implemented by a nation when single tone modems for data communications over maritime HF radio circuits with a bandwidth of 1240 Hz comply with the characteristics detailed in this agreement and are placed in service.

4. This reduced bandwidth STANAG waveform has well-established technical performance limitations with respect to those occupying a 3 kHz bandwidth (e.g. STANAG 4285), particularly on difficult skywave paths and to small mobile platforms. These limitations result in a restriction that STANAG 4529 should only be used when no 3 kHz allocations are available under the "Complan".

This STANAG is not suitable for use at high latitudes or on air/ground circuits, and should not be used in those roles.

It is intended that this waveform is used as an interim measure, and that it will not be fully supported by the new waveform family being designed under STANAG 4539 or by STANAG 4538.

REQUIRED CHARACTERISTICS OF SINGLE TONE MODULATORS/DEMODULATORS FOR MARITIME HF RADIO LINKS WITH 1240 HZ BANDWIDTH

APPENDICES:
APPENDIX 1: Performance of associated communications equipment
APPENDIX 2: Modem dialogues and interfaces with transmitter, receiver and data terminals
APPENDIX 3: Modulator/Demodulator Filtering

INTRODUCTION

1. (a) This document describes the modulation, call establishment processes, and data correction coding required to insure interoperability between modems transmitting data over HF radio links where the data rate at the digital interface may be 75, 150, 300, 600 or 1200 bps. The rate at which data (user data bits plus bits for error correction coding) are transmitted (ie, the channel data rate) may be 600 bps (when the user data rate is 75, 150, or 300 bps), 1200 bps (when the user data rate is 600 bps), or 1800 bps (when the user data rate is 1200 bps).

(b) The equipment may also be used for uncoded data transmission in which data input to a modulator's digital interface is transmitted without the addition of the error correction coding and interleaving described in section 10. The uncoded modes provide data rates of 600, 1200, and 1800 bps.

MODULATION

2. (a) the modulation technique consists of phase shifting of a subcarrier frequency that is selectable in 100 Hz steps from 800 Hz to 2400 Hz inclusive. Modulation speed is 1200 bauds with a minimum accuracy of 1 part in 10^5.

(b) the accuracy of the clock linked with the generation of the subcarrier frequency is 1 part in 10^5.

(c) the phase shift of the modulated signal relative to the unmodulated reference subcarrier may take one of the following values (see figure A-1).

Symbol Number	Phase
0	0
1	$\pi/4$
2	$\pi/2$
3	$3\pi/4$
4	π
5	$5\pi/4$
6	$3\pi/2$
7	$7\pi/4$

The complex number $\exp[jn\pi/2]$ is linked with the symbol number n.

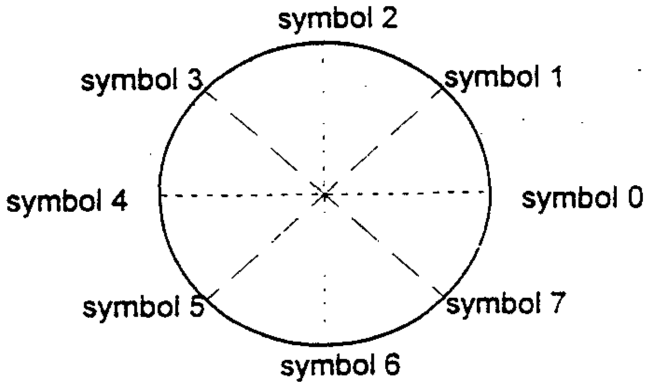

Figure A-1: Phase State Encoding

TRANSCODING

3. Transcoding is an operation involving linking a symbol to be transmitted to a group of bits.

(a) for the 600 bps channel data rate (75, 150, and 300 bps user data rates), transcoding is achieved by linking one symbol to one bit according to the following rule:

Bit	Symbol
0	0
1	4

(b) for the 1200 bps channel data rate (600 bps user data rate), transcoding is achieved by linking one symbol to a set of two consecutive bits (dibit) according to the following rule:

Dibit	Symbol
0 0	0
0 1	2
1 1	4
1 0	6

⇑
Most recent bit

(c) for the 1800 bps channel data rate (1200 bps user data rate), transcoding is achieved by linking one symbol to a set of two consecutive bits (tribit) according to the following rule:

Tribit	Symbol
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

⇑
Most recent bit

POWER SPECTRAL DENSITY

4. The power spectral density of the modulated signal shall be centered on a frequency that is selectable in 100 Hz steps from 800 Hz to 2400 Hz inclusive, with a default value of 1700 Hz. Filtering shall be applied as necessary so that 99% of the output power is within 1240 Hz.

FRAME STRUCTURE

5. (a) The frame structure is shown in Figure A-2;

(b) The symbols to be transmitted are structured in recurrent frames 213.3 ms in length;

(c) a frame consists of 256 symbols. A frame can be broken down into: 80 symbols for synchronization, 48 reference symbols and 128 data symbols;

(d) the 176 reference and data symbols are scrambled by a scrambling sequence with eight phase states of length 176 ;

(e) the modem makes use of the synchronization sequence to detect the presence of the signal and for correction of the frequency shift resulting from doppler effect or the difference between the transmit and receive pilots, bit synchronization and either equalizer training in the case of equalizing by recursive filtering, or HF channel estimation in the case of detection according to the maximum likelihood method;

(f) the reference and data symbols are formed into 4 blocks: the first 3 consist of 32 data symbols followed by 16 reference symbols; the last block consists of 32 data symbols. The reference symbols are all symbol number 0.

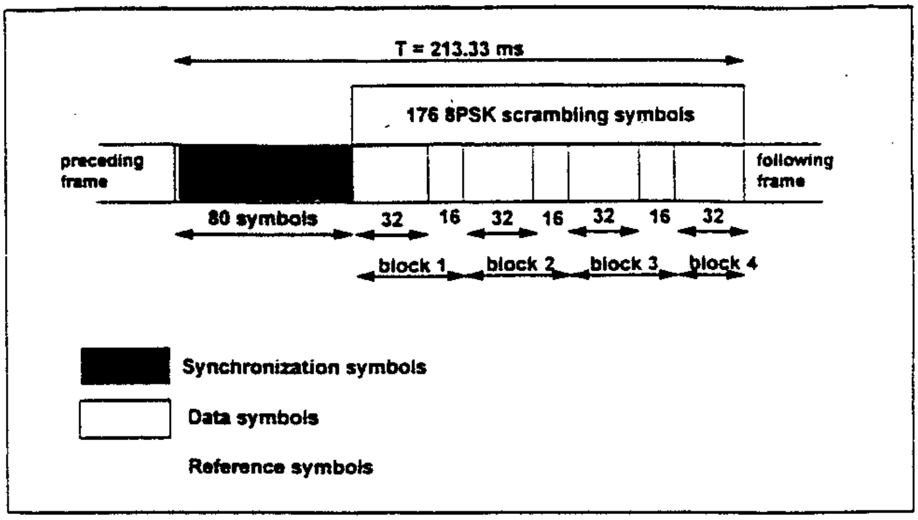

Figure A-2: Frame Structure

SYNCHRONIZATION SEQUENCE GENERATOR

6. (a) The synchronization consists of 80 symbols and is transmitted recurrently every 213.3 ms. This sequence uses 2PSK modulation and the modulation rate is equal to 1200 bauds;

(b) The sequence is identical to a pseudo random sequence of length 31, which is repeated periodically within the 80 symbol window, i.e. the synchronization sequence consists of 2 periods of length 31 plus the first 18 symbols of another period;

(c) a generator for the synchronization sequence is described in Figure A-3. The generator polynomial is:

$$x^5 + x^2 + 1$$

(d) at the beginning of every frame the generator is initially set to the following value:

1 1 0 1 0

(e) the first symbol of the synchronization sequence is identical to the least significant bit of this initial value. The remaining 79 symbols are obtained by applying the clock 79 times.

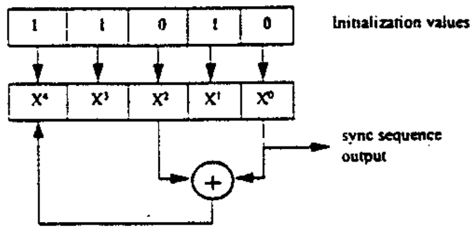

Figure A-3. Synchronization Sequence Generator

GENERATION OF THE DATA BLOCK SCRAMBLING SEQUENCE

7. (a) the scrambling sequence is composed of 176 symbols and is repeated every 213.3 ms. This sequence is transmitted in eight-phase-state modulation at the rate of 1200 bauds;

(b) data scrambling by an eight-phase-state sequence is done to maintain commonality with STANAG 4285 implementations;

(c) the scrambling symbol generator is shown in Figure A-4. The symbols are formed by means of a pseudo-random code of length 511, the generator polynomial of which is:

$$x^9 + x^4 + 1$$

(d) the generator is initialized to 1 at the start of each frame;

(e) a symbol is derived from the triplet consistng of the last three bits in the PN register, i.e. $x_0 \cdot x_1\ x_2$ by the following relationship:

Scrambling symbol $B_k = \exp[jn\pi/4]$

where:

$n = 4x_2 + 2x_1 + x_0$

$x_0 = 0$ or 1

$x_1 = 0$ or 1

$x_2 = 0$ or 1

(f) generation from one symbol to the next is by successive shifting of the PN register by three positions.

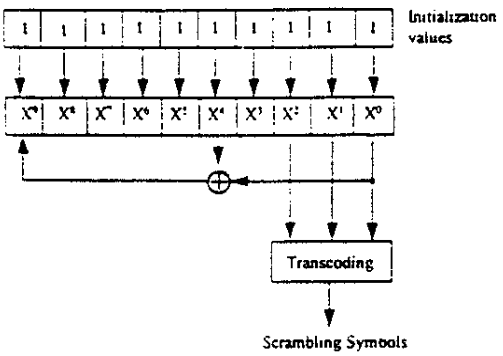

Figure A-4. . **Generation of Scrambling Sequence**

DATA BLOCK SCRAMBLING

8. The scrambling operation is carried out on reference and data symbols only, not on the synchronization sequence. This operation consists of modulo 8 addition of the data symbol number to the scrambling symbol number; this amounts to complex multiplication of the data symbol by the scrambling symbol.

TOLERANCE OF ERRORS IN FREQUENCY BETWEEN HF TRANSMISSION AND RECEPTION CARRIERS

9. The modem must be capable of tolerating a frequency error of +/- 37.5 Hz between the transmission and reception of HF carriers (transmitter/receiver frequency error and Doppler shift included) and rate of frequency change of up to 3.5 Hz/sec.

ERROR CORRECTION CODING, INTERLEAVING, AND MESSAGE PROTOCOLS

10. For the error correcting modes defined in this STANAG, the error correction coding used shall be the rate 1/2, constraint length 7 convolutional coding as described STANAG 4285 Annex E. For each user data rate described in this STANAG (ie, 75, 150, 300, 600 and 1200 bps), the coding, interleaving, and flush bits shall be as described for the next higher data rate in STANAG 4285 Annex E. The changes necessary to allow 1240 Hz operation are explicitly shown below.

The error correction coding used shall be as in STANAG 4285 Annex E section 2 with the following changes:

Coded data rate	Waveform	Effective code rate	Coding method
1200 bps	8 phase (1800 bps)	2/3	Rate 1/2 punctured to rate 2/3
600 bps	4 phase (1200 bps)	1/2	Rate 1/2 code
300 bps	2 phase (600 bps)	1/2	Rate 1/2 code
150 bps	2 phase (600 bps)	1/4	Rate 1/2 code repeated 2x
75 bps	2 phase (600 bps)	1/8	Rate 1/2 code repeated 4x

The interleaving shall be as described in STANAG 4285 Annex E section 3 with the following different parameters:

Number of rows: I = 32 for all data rates

	Delay increment "j" for each successive row: Total Interleaving Delay: 20.48 sec	1.706 sec
Data rates		
1200 bps	48	4
600 bps	24	2
300, 150 and 75 bps	12	1

Interleaver synchronization shall be as described in STANAG 4285 Annex E part 4 with no changes.

The initialization and message protocol for use with coding and interleaving shall be as described in STANAG 4285 Annex E part 5 with the following difference:

the number of flush zeros for each of the data rates and the two interleaver lengths are as follows:

	Interleaver Delay	
Data rate	20.48 sec	1.706 sec
1200 bps	24678	2150
600 bps	12390	1126
300 bps	6246	614
150 bps	3174	358
75 bps	1638	230

UNCODED DATA TRANSMISSION MODES

11. Modems shall provide uncoded data transmission modes, in which the coding, interleaving, and associated initialization and message protocols (described in section 10) are not applied to the data transmitted. Uncoded data modes shall retain all other characteristics described in this STANAG. Uncoded data rates of 600, 1200, and 1800 bps shall be provided.

PERFORMANCE OF ASSOCIATED COMMUNICATIONS EQUIPMENT

To obtain optimal performance, transmitters and receivers must perform in accordance with STANAG 4203 or STANAG 4481.

MODEM DIALOGUES AND INTERFACES WITH TRANSMITTER, RECEIVER AND DATA TERMINALS
(For Information Only)

Modem dialogues and interfaces with transmitter, receiver, and data terminals are described in Appendix 2 to Annex A to STANAG 4285. Additional information of this subject is available in Annex F to STANAG 4481.

MODULATOR/DEMODULATOR FILTERING
(For Information Only)

The forming filters used by the modulator and demodulator must test the following criteria:

(a) reception filter matched to transmission filter (to maximize the signal-to-noise ratio in the demodulator);

(b) putting the transmission and reception filters in series should form a filter minimizing inter-symbol modulation in the demodulator. Because the 99% band occupancy requirement of 1240 Hz is only 3.3% greater than the symbol rate, attaining a true Nyquist response is impractical. An acceptable compromise between maximizing stop band rejection and minimizing filter length and inter-symbol interference can be achieved by the following filter:

$$H(f) = 1 \qquad f \le f_n - pf_n$$

$$H(f) = 0.5\left(1 - \sin\left[\left(\frac{f - f_n}{pf_n}\right)\frac{\pi}{2}\right]\right) \qquad f_n - pf_n < f \le f_n + pf_n$$

$$H(f) = 0 \qquad f > f_n + pf_n$$

where f_n = 535 Hz and the roll-off factor p = 0.159.

Such filters are synthesized by Finite Impulse Response (FIR) filters with a sampling rate of 8/T. An example of filtering obtained with a transmission filter with 64 coefficients is given in Figure A-3-1. The impulse response of such a filter is shown in Figure A-3-2, and the inpulse response of a series combination of such a transmit filter and a matching receive filter is shown in figure A-3-3.

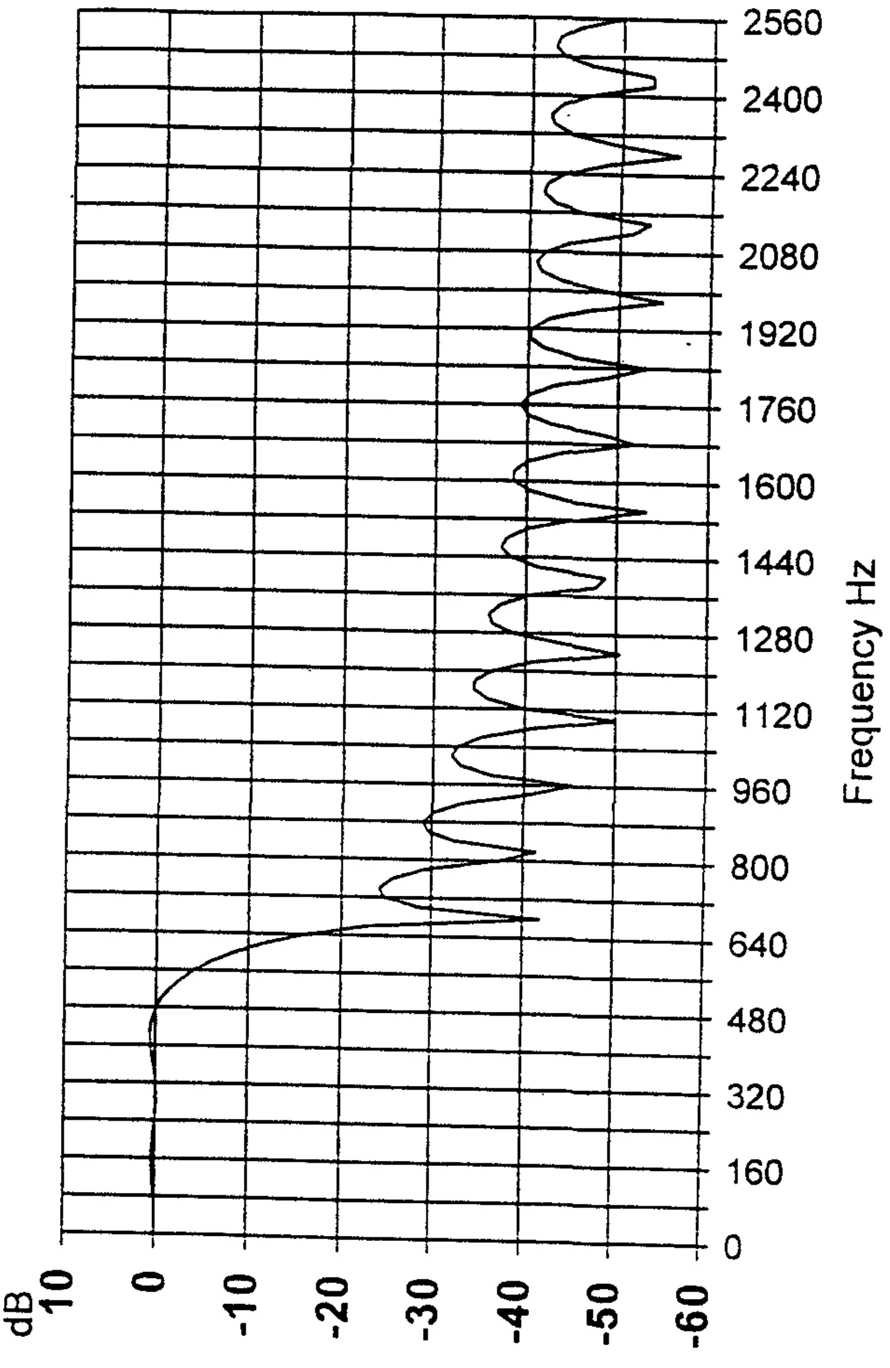

Figure A-3-1: 64 tap FIR Filter Response

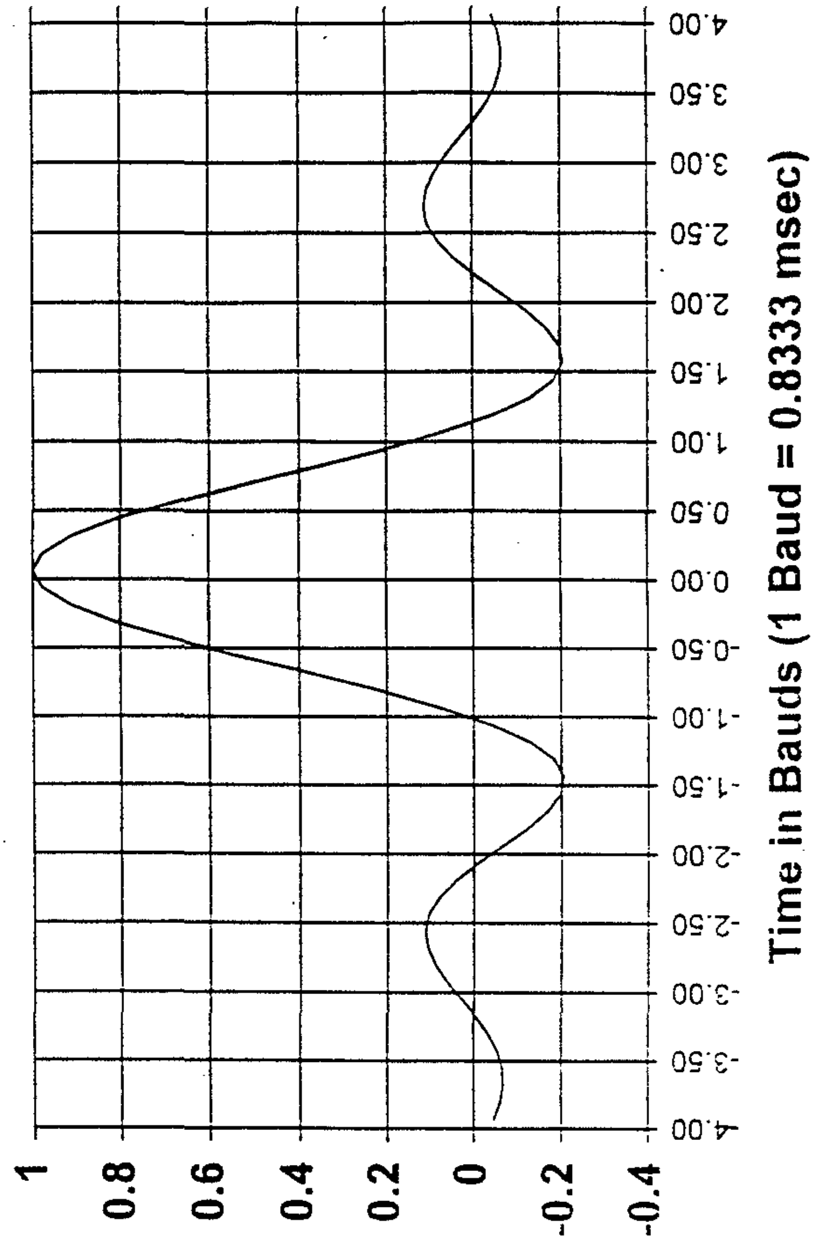

Figure A-3-2: Transmit Filter Impulse Response

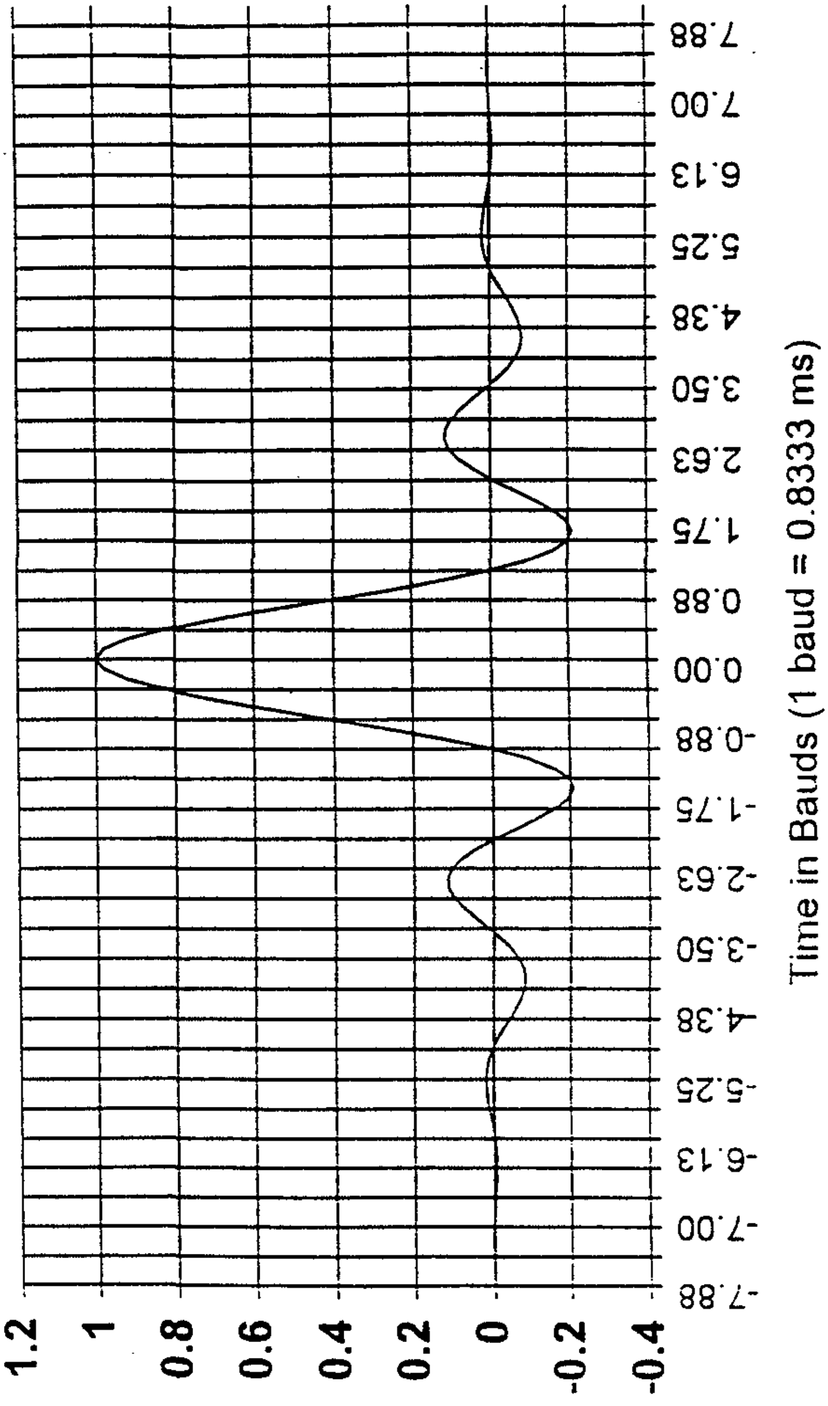

Figure A-3-3. Impulse Response of Transmit and Receive Filters in Series

Comments Accompanying STANAG 4529
(For Information Only)

Rationale and Development Approach

The development of the waveform described in this STANAG was guided by two goals. first, to allow operation on existing 1240 Hz channels; and second, to facilitate implementation in existing STANAG 4285 modems. This new waveform is intended to complement STANAG 4285 in situations where a narrower bandwidth is necessary or convenient. In many cases, existing FSK RATT systems operate on 1240 Hz frequency assignments. A modern, equalized modem able to make use of such frequencies will have extensive practical utility.

The existing STANAG 4285 single tone modem has been modified to operate in a narrower bandwidth by reducing the symbol rate from the current 2400 baud to 1200 baud. The original STANAG 4285 format was not changed; each 1240 Hz data rate employs the STANAG 4285 baseband processing for twice that data rate.

To achieve a 99% power bandwidth of 1240 Hz requires additional filtering, which will have some effects on performance (discussed below).

Performance Implications

The new 1240 Hz waveform can be compared to a recording of the STANAG 4285 waveform played at half speed. To the receive modem, time events in the HF channel appear to be half the duration (relative to same event with a STANAG 4285 receive modem, the event will affect half the symbols) and frequency shifts appear twice the value (relative to the same shift received by a STANAG 4285 modem). The tighter spectral confinement relative to the baud rate requires longer (in terms of number of symbols) transmit and receive low-pass filter impulse responses. The net effect of these changes relative to the original STANAG 4285 performance is described in the following paragraphs.

The interleaving duration is doubled, thus the delay with the long interleaver is approximately 20 seconds. The benefits of using a 20 second interleaver, rather than modifying this STANAG to maintain the 10 second long interleaving delay of STANAG 4285, is debatable. Certainly, for short transmissions, a 20 second interleaving delay will significantly reduce the effective throughput. Much of the recently disseminated measured data on benign channels tends to indicate that Doppler spreads of 0.1 Hz are fairly common. The 20 second interleaver should be 2 to 3 dB better than a 10 second one against such slow fading. Channel simulator testing of the 1240 Hz waveform with the 20 second interleaver has shown very good performance on fading channels with multipath.

The tighter relative spectral confinement and resulting non-Nyquist matched filter output results in increased intersymbol interference. This results in a slight decrease in SNR performance. This effect will be greatest with the 8-PSK constellation, which is used for the 1200 bps data rate. The utility of this data rate may be limited on skywave channels. It has been included because of the higher throughput which may be possible on surface wave propagation paths.

As a result of the doubled symbol duration, the phase rotation between successive symbols is thus doubled for any given frequency offset. The transmit-receive frequency offset capability is therefore halved.. To meet a 75 Hz offset requirement, significant changes would be required. For applications which demand a 75 Hz offset capability, the original STANAG 4285 is available.

The Doppler spread capability is reduced to less than half that of STANAG 4285. A reduction to one half results from doubling the frame duration. A further reduction results from the fact that for any given data rate, the waveform used is that for twice the data rate in STANAG 4285. This means that, for example, the Doppler spread performance of the 1240 Hz waveform at 300 bps will correspond to half that of the STANAG 4285 at 600 bps.

If the receive equalizer signal processing is not changed from that used for STANAG 4285, then the total signal dispersion (includes filtering and multi-path) accomodated will be doubled. The actual multi-path spread capability, however, will not fully double since the impulse response of the spectral confinement filters will have slightly more than doubled.