Data Modem Primer v1.00
FINAL DRAFT 08-19-12

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MIL-STD/STANAG

Data Modem Primer

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NOTE: Military data modem serial tone waveforms use 1200bps and 2400bps symbol rates and are **NOT** legal for Amateur Radio use under current FCC rules.

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ABSTRACT

The purpose of this paper is to provide the MARS member with a better understanding of Serial Tone (ST) waveforms available in Military Standard (MIL-STD) HF Data Modems conforming to U.S. Military standard MIL-STD-188-110A[1] (110A), MIL-STD-188-110B[2] (110B) and MIL-STD-188-110C[3] (110C) as well as Standard NATO (STANAG) S4285[4], S4415[5], S4529[6] and S4539[7] waveforms that many such modems also support. In addition insight is provided into the use of these waveforms for basic Forward Error Corrected (FEC) based Broadcast and Multicast use as well as Data Link Protocol (DLP) based ARQ and Non-ARQ Mutlicast, Point-to-point and Point-to-multipoint communications to include tactical chat and client/server networking use of these modems.

The above referenced MIL-STD and STANAG documents provide specifications for each waveform by describing the on the air signaling used to transmit the digital data signal over a radio channel. Each waveform description in their respective standard includes a complete specification of the modulation used and the known symbols used for initial training (a.k.a. the preamble), that are sent to establish synchronization as well as any additional known symbols which may be inserted with the data (a.k.a. the payload) to aid in the demodulation process. Also included are the details of forward error correction coding, bit redundancy, bit interleaving as an integral part of the definition.

The ST waveform is widely used by all NATO forces for most HF digital communications and has been carried forward in MIL-STD-188-110C (110C) and modified for Naval use in Link-22 (STANAG 5522). It is the ST waveform which has found the most favor with Military users over the last 20 plus years, out performing the MIL-STD FSK RTTY and optional parallel 16 tone DPSK and 39 tone QDPSK Orthogonal Frequency-Division Multiplexing (OFDM) (which are similar to PACTOR II and III) waveforms found in appendix A and B of 110A and 110B (also used for digital voice per STANAG 4197). The 16 tone waveform is now officially obsolete having been removed from 110C. The 39 tone modem although retained in 110C is also obsolete according to Dr. Eric Johnson's HF Industry Association (HFIA) "MIL-STD Technical Advisory Committee" presentations on the continuing revisions of "U.S. Military HF Radio Standards". It is the ST waveform with its synchronous or asynchronous auto-detect (or autobaud) capability for data transmission at speeds of 75bps and higher which is used today as the basis of a number of Military waveforms from the basic MIL-STD-188-110A ST through the STD-188-110B Appendix C (S4539 being nearly identical) waveforms using Forward Error Correction (FEC) (PACTOR IV is also a serial tone waveform). Being Auto-detect waveforms, the 110A/B/C and S4539 serial tone waveforms are also more popular for Automatic Request Query (ARQ) than non-autobaud S4285 when using FED-STD-1052 Appendix B Data Link Protocol (DLP)[8] and STANAG 5066 Data Link Protocol (DLP)[9], a.k.a. 5066-ARQ as detailed in MIL-STD-188-110B Appendix E.

In recent years, there has been a growing need for higher data rates by the Military than the MIL-STD-188-110A 75bps through 2400bps coded and 4800bps with no FEC or interleaving (unencoded) which has led to MIL-STD-188-110B and 9600bps coded in a 3Khz channel and most recently MIL-STD-188-110C (110C). In 110C a new family of wideband waveforms are defined that extend the high performance serial tone modem technology beyond the 110B 9600bps coded limit using a single 3Khz channel to wider bandwidths and much higher data rates. These new waveforms can occupy bandwidths from 3Khz up to 24Khz in increments of 3Khz channels while providing user data rates up to 120,000bps coded throughput with multiple

HF Independent Sideband (ISB) channels. A single 3Khz channel will support ST data rates through 9600bps, whereas an ISB channel (6Khz) doubles that throughput, a 2ISB channel doubles it again and a 4ISB channel (24Khz) achieves 120,000bps coded throughput. This increase in throughput with each additional 3Khz channel can be thought of as being similar to OFDM in that each 3Khz channel represents and additional PSK carrier of modulation. MARS however is limited to a single SSB channel (3Khz) and 9600bps at present, as more MARS members move to SDR transceivers perhaps at some point we can start using ISB and Left and Right Channel audio to double our throughput as well.

MARS members for the most part, when it comes to MIL-STD ST hardware modems have surplus 110A modems, some also have 110B hardware modems, most if not all have only dumb terminal software for FEC use of their hardware modems. However the bulk of the MARS membership shall have to rely on PC Sound Device based software solutions, such as MARS-ALE and its current MIL-STD-188-110A support and the MARS M110A Data Modem Terminal software. In addition a Portable Virtual Software Modem is planned which will lead to additional software Client and Server application development to include ARQ in support of MARS down the road. Thus the software MIL-STD 110A modem and FEC operation will amount to the bulk of MARS interoperability capability with MARS customers at first.

REFERENCES

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[3] MIL-STD-188-110C, "INTEROPERABILITY AND PERFORMANCE STANDARDS FOR DATA MODEMS", 23 SEPTEMBER 2011

[4] NATO STANAG 4285, "CHARACTERISTICS OF 1200/2400/3600 BITS PER SECOND SINGLE TONE MODULATORS/DEMODULATORS FOR HF RADIO LINKS", BRUSSELS, EDITION 1, 17 FEBRUARY 1989

[5] NATO STANAG 4415, "CHARACTERISTICS OF A ROBUST, NON-HOPPING, SERIAL-TONE MODULATOR/DEMODULATOR FOR SEVERELY DEGRADED HF RADIO LINKS", EDITION 1, 21 JUNE 1999

[6] NATO STANAG 4529, "CHARACTERISTICS FOR SINGLE TONE MODULATORS/ DEMODULATORS FOR MARITIME HF RADIO LINKS WITH 1240 HZ BANDWIDTHS", EDITION 1, 20 JANUARY 1998

[7] STANAG 4539 C3 (EDITION 1), TECHNICAL STANDARDS FOR NON-HOPPING HF COMMUNICATIONS WAVEFORMS, 8 JUNE 2006

[8] FED-STD-1015 TELECOMMUNICATIONS: ANALOG TO DIGITAL CONVERSION OF VOICE BY 2400 BIT/SECOND LINEAR PREDICTIVE CODING, 11 AUGUST 1995

[9] FED-STD-1052 APPENDIX B, "TELECOMMUNICATIONS: HF RADIO MODEMS", 7 AUGUST 1996

[10] FED-STD-3005 ANALOG-TO-DIGITAL CONVERSION OF VOICE BY 2,400 BIT/SECOND MIXED EXCITATION LINEAR PREDICTION (MELP), 20 December 1999

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[12] STANAG 4197 EDITION 1, MODULATION AND CODING CHARACTERISTICS THAT MUST BE COMMON TO ASSURE INTEROPERABILITY OF 2400 BPS LINEAR PREDICTIVE ENCODED DIGITAL SPEECH TRANSMITTED OVER HF RADIO FACILITIES, 2 APRIL 1984

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[14] STANAG 4481 EDITION 1, MINIMUM TECHNICAL STANDARDS FOR NAVAL HF SHORE-TO-SHIP BROADCAST SYSTEMS, 19 JULY 2002

[15] STANAG 4591 EDITION 1, 600 BIT/S, 1200 BIT/S AND 2400 BIT/S NATO INTEROPERABLE NARROW BAND VOICE CODER, 3 OCTOBER 2008

[16] STANAG 4203 C3 (EDITION 3), TECHNICAL STANDARDS FOR SINGLE CHANNEL HF RADIO EQUIPMENT, 27 APRIL 2007, ANNEX B and ANNEX C.

[17] MIL-STD-188-141C, INTEROPERABILITY AND PERFORMANCE STANDARDS FOR MEDIUM AND HIGH FREQUENCY RADIO SYSTEMS, 25 July 2011

[18] MIL-STD-188-141B, Interoperability and Performance Standards for Medium and High Frequency Radio Systems, Notice 1, 31 August 2001; Appendix C "Third-Generation HF Link Automation."

[19] STANAG 4538 (EDITION 1) - TECHNICAL STANDARDS FOR AN AUTOMATIC RADIO CONTROL SYSTEM (ARCS) FOR HF COMMUNICATION LINKS, 24 February 2009

[20] ACP-142(A) - P_MUL - A PROTOCOL FOR RELIABLE MULTICAST IN BANDWIDTH CONSTRAINED AND DELAYED ACKNOWLEDGEMENT (EMCON) ENVIRONMENTS, October 2008

[21] ACP-127(G) COMMUNICATIONS INSTRUCTIONS TAPE RELAY PROCEDURES, NOVEMBER 1988

NOTE: Many of the above referenced documents can be found at many places on the Internet, to include:

https://assist.daps.dla.mil/quicksearch/

http://groups.yahoo.com/group/MARS-ALE/files/

LIST OF ABBREVIATIONS

2G - Second Generation
3G - Third Generation
AGC - Automatic Gain Control
ALC - Automatic Level Control
ALE - Automatic Link Establishment
ALM - Automatic Link Management
AQC-ALE - Alternate Quick Call ALE
ARQ - Automatic Repeat Request
AWGN - Additive White Gaussian Noise
BER - Bit Error Rate
bps - bits per second
BCAST - Broadcast
BRASS - Broadcast And Ship-Shore
BRD - Broadcast
BW - Bandwidth
CPU - Central Processing Unit
DLP - Data Link Protocol
DPSK - differential phase shift keying
DSSS - Direct Sequence Spread Spectrum
DTE - Data Terminal Equipment
dB - Decibels
DSP - Digital Signal Processor
EMCON - Emission Control
FEC - Forward Error-Correction
FED-STD - U.S. Federal Standard
FTP - File Transfer Protocol
HF - High Frequency (referring to radio waves 2-28 MHz for normal MARS operations)
Hz - Hertz
HTML - Hyper Text Message Language
ISB - Independent Single Sideband
Khz - Kilohertz
MIL-STD - U.S. Military Standard
NATO - North Atlantic Treaty Organization
NRQ - Non-ARQ
PSK - phase shift keyed
QAM - quadrature amplitude modulation
QDPSK - quadrature differential phase shift keying
QPSK - quaternary phase shift keyed
ST - Serial Single Tone
STANAG - Standard NATO
TNC - Terminal Node Controller
TXCO - Crystal Controlled Oscillator

DEFINITIONS

Broadcast And Ship-Shore (BRASS): NATO Naval broadcast network of shore-based stations to support and improve naval broadcast and ship-shore service for HF naval communications. BRASS is described as a system that broadcasts data and messages to ships, while traffic in the reverse direction is unicast.

Broadcast: 1. The transmission of signals that may be simultaneously received by stations that usually make no acknowledgement. 2. Broadcast, in subnetworks, is when a single device is transmitting a message to all other devices in a given address range. This broadcast could reach all hosts on the subnet, all subnets, or all hosts on all subnets. Broadcast packets have the host (and/or subnet) portion of the address set to all ones. By design, most modern routers will block IP broadcast traffic and restrict it to the local subnet.

Data Rate: The throughput speed in bits per second at which data is transmitted.

Datagram: In packet switching, a self-contained packet, independent of other packets, that contains information sufficient for routing from the originating data terminal equipment (DTE) to the destination DTE without relying on prior exchanges between the equipment and the network. Note: Unlike virtual call service, when datagram’s are sent there are no call establishment or clearing procedures. Thus, the network may not be able to provide protection against loss, duplication, or miss-delivery.

Emission Control: Emission Control (EMCON) is a military term for Radio Silence, where nodes can receive data but not send for hours or days or perhaps at all. ACP 142 is a standard for multicast data transport used for Normal and EMCON support. An ACP 142 sender will handle Non-EMCON and EMCON destinations as specified in ACP 142. For disabled receivers, no transmissions will be made. This saves resource and allows transmissions to other destinations. The standard ACP 142 EMCON mechanism is for the sender to transmit the message a configurable number of times at intervals. It then retains the message and waits for the destination to leave the EMCON state, when the destination is expected to acknowledge the message. This model works well for systems that are in EMCON for a relatively short period of time, and ensures that the originator will always receive error information.

Interleaver: The level of shuffling of coded symbols or message bits out of their naturally occurring order prior to transmission for the purpose of making the distribution of symbol errors in the deinterleaved stream of symbols in their natural order as reconstructed at the receiver more uniform than may occur without the interleaving and deinterleaving steps.

Multicast: Multicast: 1. In a network, a technique that allows data, including packet form, to be simultaneously transmitted to a selected set of destinations. Note: Some networks, such as Ethernet, support multicast by allowing a network interface to belong to one or more multicast groups. 2. To transmit identical data simultaneously to a selected set of destinations in a network, usually without obtaining acknowledgement of receipt of the transmission.

P_MUL: P_MUL as detailed in ACP-142 and ACP-142A is a reliable multicast protocol for messaging in subnetworks with bandwidth constraints and delayed acknowledgements. As an application-layer protocol, P_MUL runs on top of a connectionless transport protocol such as the User Datagram Protocol (UDP). P_MUL is emerged as the standard reliable multicast protocol for military messaging in bandwidth-constrained subnetworks. The initial work in using P_MUL over HF channels used 2G protocols in ACP-142 and later 3G in ACP-142A.

Protocol Data Unit: 1. Information that is delivered as a unit among peer entities of a network and that may contain control information, address information, or data. 2. In layered systems, a unit of data that is specified in a protocol of a given layer and that consists of protocol-control information of the given layer and possible user data of that layer.

Subnetwork: A collection of nodes. As a whole, a subnetwork provides a reliable networked data-transport service for external users or clients. An Ethernet LAN behaves similar to a STANAG 5066 HF subnet.

Symbol Rate: Symbol rate (also known as baud or modulation rate) is the number of symbol changes (waveform changes or signalling events) made to the transmission medium per second.

Unicast: Unicast packets are sent from host to host. The communication is from a single host to another single host. There is one device transmitting a message destined for one reciever.

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INTRODUCTION

For MARS members unfamiliar with the subject, this paper will put MIL-STD Data Modem waveforms and the protocols they provide into perspective. The basic use of MIL-STD modems are for peer-to-peer and broadcast communications using Forward Error Correction (FEC) and Interleaving to combat the effects of channel Fading, Doppler spread, Multipath and Noise bursts. This use of ST waveforms is similar to the use of PACTOR FEC or MT-63 as use in MARS peer-to-peer and broadcast operations.

HF transmission and reception is subject to varying levels and types of noise and interference which cause data errors. MIL-STD HF waveforms use coding and redundancy techniques in the transmitted waveform that allow the receiving modem to recover the original data in the case of errors caused by hits and fading throughout the HF path. The ST waveform FEC adds redundant data into the data stream to allow the demodulator to detect and correct errors. If errors are detected, the FEC accurately reproduces the data without notifying the data sender that there was a problem. The FEC coding technique is most effective if errors occur randomly in a data stream. However, errors usually occur in bursts on HF, where during a given period of time there is a high Bit Error Rate (BER) on the channel along with periods of low BER.

To enhance FEC performance a process called interleaving is used to spread the data about during transmission to randomize the errors that occur during the high BER periods. FEC methods perform more efficiently than they would without the interleaving and deinterleaving steps. Interleaver selections of ZERO, SHORT and LONG are usually provided where LONG interleaving spreads the data about more and thus provides more robust operation, while adding more time to the data transmission, SHORT is quicker and ZERO is the quickest for a given coded data rate. Additional shorter and longer interleaver selections are provided for in the latest 110B appendix C and S4539 waveforms mainly in support of Adaptive ARQ application.

When using 110A in basic FEC application vs. Adaptive ARQ application, it is up to the user to select the proper data rate based on the channel conditions for reliable broadcast or two-way communications. Just as with any other FEC protocol when no ARQ is being used, if a data rate is selected with an FEC protocol that is too high to support channel conditions, the results will be less than optimal. The transmitting station must consider the RX station(s) being targeted at the time and their location relative to the transmitting station, whether there is one or many. Also, whether all receiving stations are all within NVIS or if some are on the edge or outside NVIS range on a NVIS range frequency or if we are talking a Skyware scenario. Another consideration is the transmitting station power level and whether 100w or less or perhaps higher power levels is being used and the effect of the power level providing a strong enough signal to meet the required SNR for the AWGN channel conditions at the data rate selected at the receiving station end. For a correlation to data rates and SNR required for channel conditions see Appendix A of this document. The use of LONG interleaver is likely the best choice for all channel conditions, the use of SHORT (and none when available) will speed throughput but for FEC only applications should only be used under the best channel conditions. You can't go wrong with 75bps if your sound device and all other stations have the required low sample clock error, however 75bps is slow and is usually only used when conditions are very poor or when the sending station has no idea from the receiving station as to their receiving conditions. When making selections above 75bps you must really consider the channel conditions as to Signal to Noise Ratio (SNR) under Additive White Gaussian Noise (AWGN) channel conditions for basic FEC use of ST waveforms.

When an FEC waveform such as MIL-STD-188-110A (110A) is coupled with a Data Link Protocol (DLP) via an embedded controller or controlling software application the modem provides for Station Identification (Callsign Exchange), Link Creation and Adaptive Automatic Request Query (ARQ) and Broadcast (BRD) communications. DLP layers are heavily used for Tactical and Client/Server radio-to-radio communications networks for HF e-mail using ARQ such as with STANAG 5066 networks which can be thought of as being an HF radio based version of the Internet as they can be configured to support e-mail, HTML, FTP and more, using many of the same standards or standards similar to those used via the Internet, such as RFC 821, “SIMPLE MAIL TRANSFER PROTOCOL”. This use of the ST waveform with ARQ is similar to PACTOR ARQ or WINMOR ARQ used in MARS operations.

MIL-STD modems can be used stand alone or in conjunction with Automatic Link Establishment (ALE). ALE/110A/DLP combined, can be used as an Automatic Link Maintenance (ALM) system configuration, which is the case with STANAG 4538 and optionally STANAG 5066. Link maintenance involves the automatic selection of new channel parameters, to include some or all of: frequency, waveform modulation, and bandwidth. This may be initiated from either side of the link as conditions degrade, or may be automatically scheduled to occur after a specified time period of channel use. STANAG 4539 ALM operation provides for faster link establishment, linking at lower SNR (estimated 8-10dB improvement in AWGN and fading channels), improved channel efficiency leading to higher DLP throughput for short and long messages in HF e-mail networks.

In addition to data, MIL-STD modems using STANAG 4285 and other waveforms at 600, 800, 1200 and 2400bps data rates are commonly used for Digital Voice communications per LPC-10 (STANAG 4198), LPC-10e (FED-STD-1015), MELP (MIL-STD-3005) and MELPe (STANAG 4591) standards. Such operation in the Military usually involves Secure Voice using an embedded Crypto or external Crypto terminal or software. For U.S. Government and NATO applications of MELP/MELPe, the Interlectual Property (IP) licensing royalties were waived by the IP holders, the same would be required before any thought of MELP/MELPe implementation using a software modem for MARS.

In the MIL-STD hardware modem world, 110A/110B modems mostly exist as external hardware units similar to an Amateur Radio TNC. They can also exist internal to an ALE transceiver as an embedded modem, such as the 110B/S4539 modem capability in the Harris AN/PRC-150(C) and RF-5800H-MP radius which provide 2G ALE/AQC-ALE/FS-1052B DLP (for ARQ and BRD) and 3G ALE/S4538. MARS-ALE is a 2G ALE/AQC-ALE modem/controller and 110A modem solution with FS-1052 DLP for BRD, ARQ and FTP. The new Harris RF-7800H transceiver is the first 2G/3G tactical radio to provide support of the new wideband high speed waveforms found in 110C.

A hardware 110A modem can be used with anything from a dumb ASCII RS-232 DTE ASYNC terminal and front panel setup (or RS-232 SYNC DTE terminal for certain application) to software specifically written to control the modem for Client/Server applications requiring DLP support for ARQ. Most hardware modems do not provide anything other than FEC, where as an Amateur TNC itself can provide for ARQ operation in its firmware, most hardware MIL-STD modems rely on software or dedicated messages terminals for ARQ operation. In addition, hardware modems use both front panel user selected setup and mode parameter selection as well as remote control. The remote control may be ASCII like commands or not and may be proprietary or to a standard such as STANAG 5066 ANNEX E. The remote control and the data flow for message payload require two separate serial ports when using PC software for both. For MARS applications, developers of software applications shall have to specifically support each make/model of hardware modem for ARQ applications and even FEC operation if full remote control is desired.

The 110A PC Sound Device modems to date, such as MARS-ALE, have been tightly integrated with the end application, however a stand alone Virtual MIL-STD modem similar in concept to the WINMOR Virtual TNC is planned for development, which will run on the same PC as the user application or a separate PC platform. A Virtual MIL-STD modem and DLP support could then be added to existing client and server applications used by MARS while new client and server applications are developed.

To achieve ARQ operation with 110A modems, DLP application software rather than dumb terminal software is required for the DLP implementation and command and control of the data modem for Adaptive ARQ, this is especially true for message traffic automation with HF e-mail. However some ALE transceivers with internal MIL-STD data modems offer some DLP capabilities without external software control. The current level of MARS 110A interoperability required is at the dumb terminal level and in certain cases encrypted terminal software applications for peer-to-peer FEC based communications with the customer.

HF TRANSCEIVER REQUIREMENTS

The 110A ST waveform puts more demand on the HF transceiver than does MT-63, PACTOR or WINMOR which were all designed to work within typical Amateur or Commercial HF radio 2.4Khz or less filtering. To achieve full performance with 110A the filtering requirements of STANAG 4203[10] along with radio performance specifications detailed in MIL-STD-188-141C[17].are referenced. In summation the notable items are:

- TXCO is recommended for long data transmissions.
- Radio bandpass of 3Khz is required where variations in attenuation at most are +/-2db and a Group Delay time over 80% of passband must not be more than .5ms.
- AGC time constant must be less than 10ms on desensitization and less than 25ms on resensitization for full ST performance.

The 110A ST waveform uses an 1800hz PSK Carrier requiring a sample clock accuracy of 1 Part Per Million (ppm). The carrier is modulated by a fixed 2400bps Symbol Rate resulting in a passband of 300-3300hz. As the Symbol Rate is fixed at 2400bps, the passband never changes regardless of the user selected data rate, thus radios with lower than 3Khz IF BW will not be able to obtain the full range of user throughput data rate selections.

Some 110A modems allow for the use of a non-standard 1650hz or 1500hz ST PSK carrier where all stations in the net uses the non-standard carrier or where a station with a less than 3Khz IF filter can tune off dial frequency by 300hz to move the signal lower into the passband of their radio while operating data. As most Amateur Grade radios have only a 2.4Khz or 2.7Khz SSB filter, the 1500hz carrier allows moving further down into the passband of the radios filter. However the use of a 1500hz carrier makes mixed Data/Voice channel communications more complicated.

MODES: ASYNC and SYNC

Stand alone firmware based MIL-STD Hardware Data Modems and HF SSB Tactical Radios with internal Data Modems have a number of benefits over the MIL-STD software modems, however they still require a proper HF SSB transceiver with IF filters and other characteristics suitable for their use.

These hardware modems also have additional requirements when it comes to their use that software modems do not. The selection of SYNC vs. ASYNC mode with hardware modems when using their serial port interface requires specific SYNC vs. ASYNC wired cabling. In addition an RS-232 Synchronous port or adapter is required to operate in standard SYNC mode as today's PC's only have asynchronous ports if any serial port is provided as standard as USB ports have come into being as standard. Some hardware modems provide configuration in accordance with an optional MIL-STD-188-110B Appendix C, section C.5.4.1.2 capability of using an Asynchronous Serial Port interface to provide SYNC compatible operation over the air.

The transmission of data over the air occurs in either the Asynchronous (ASYNC) or Synchronous (SYNC) mode. In ASYNC or SYNC, depending on the modem mode in use, there may be a Start of Message (SOM) sequence sent prior to the message characters and an End of Message (EOM) sequence or just an EOM as standard after the data. In addition the EOM may optionally be disabled in the configuration of some modems. When the EOM is not sent, the receiving modem must be configured so as to reset on either a specific number of interleaver blocks for the mode in use or on the flush bits or some other means.

In conventional ASYNC operation, each character (5, 7 or 8 bits) uses framing where both a start and (1 or 2) stop bits are sent with selections of Even, Odd or No parity options. The start bit prepares the data receiver to accept the character. The stop bit brings the data receiver back to the wait state and the character is displayed. Asynchronous systems eliminate the need for complex and now costly synchronization interfaces, but at the cost of higher overhead than synchronous systems. With asynchronous systems the start and stop bits increase the length of the character by 25 percent or more over synchronous due to this framing.

In SYNC mode data transmissions as with Synchronous serial ports, the start and stop bits are eliminated over the air. SYNC is mostly used for binary data with ARQ. Digital Voice (Vocoder) and Cryto, but does support sending ASCII messages as well. The use of an EOM is standard but is often inhibited when as ARQ and Digital Voice protocols use blocks which completely fill (or nearly so) the selected input data block size (interleaver block). If the use of an EOM has been inhibited, and the last input data bit does not fill out an input data block, the remaining bits in the input data block shall be set to zero before encoding and interleaving the block. Without this feature, the use of an EOM would require the transmission of an additional interleaver block under these circumstances. This type of system typically uses the preamble (a known sequence of bits at the start of the message) to synchronize the receiver's internal clock and to alert the data receiver that a message is coming.

A modem that supports the optional so called High Speed ASYNC 8 bit operation as detailed in MIL-STD-188-110B Appendix C, section C.5.4.1.2, provides the capability of using an Asynchronous Serial Port interface to provide SYNC compatible operation over the air is wired to the PC serial port just as if standard ASYNC mode was being used. Most hardware modem manufacturers that provide this support recommend its use over standard ASYNC due not using start and stop bit framing as it provides greater data throughput and is much less susceptible to disastrous framing errors when the channel introduces errors in the data stream just as SYNC mode is, yet only a standard Asynchronous serial port is all that is required.

In conventional ASYNC operation, a standard RS-232 Asynchronous port or USB to RS-232 ASYNC adapter works just fine with a hardware modem. However in traditional SYNC operation the serial port connection to a hardware modem must be a Synchronous serial port from the computer to the modem for the required Transmit and Receive Clocks on the serial bus. Most hardware modems support synchronous serial data interface using an EIA RS-232 standard DCE interface. Some support MIL-STD-188-114, EIA-422 (RS-422) can interoperate with interfaces designed to MIL-STD-188-114 but they are not identical. EIA-422 uses a nominal 0 to 5 volt signal while MIL-STD-188-114B uses a signal symmetric about 0 V. However the tolerance for common mode voltage in both specifications allows them to interoperate. RS-423 devices generally operate at +/- 6 VDC and are compatible with RS-232 devices. Receivers are very sensitive, capable of detecting Mark/Space states at +/- 0.4 VDC and operate with the same Ground potential differences as RS-422 and are generally compatible with MIL-STD 188-114, ITU V.10, and RS-232.

As today's common PC's do not have Synchronous serial ports any longer and some don't even have Asynchronous serial ports. This means the use of an expensive Synchronous serial port adapter that is USB, PCcard or Firewire based is required for serial interfaced SYNC based ARQ, Digital Voice and other uses. Many recent hardware modems have started to provide TCP/IP ports as standard or options and MIL-STD-188-110C Appendix A now details a non-mandatory Asynchronous and Synchronous TCP/IP remote control and data port interface. Some embedded radio data modems can also be controlled via point-to-point protocol (PPP), PPP is commonly used as a data link layer protocol for connection over synchronous and asynchronous circuits

In 110A ASYNC mode the data transmission usually provides for the End of Message (EOM) sequence of bytes sent at the end of the unknown payload (message characters), however it can be disabled should the modem provide for doing such in setup. As ASYNC is commonly used to send ASCII data with framing the EOM is usually used.

In 110A SYNC the End of Message (EOM) sequence is often disabled to support ARQ and other uses where turn around time is important and where the data link layer being used provides its own end of block turn around indicator. To disable or enable EOM often requires access to the remote control port which for many modems requires modem specific configuration software or at a minimum the required commands and a dumb terminal wired to the remote control port as it's not usually a front panel menu selection.

When a user of a hardware modem is configured for ASYNC or SYNC with or without EOM, that is the mode they are using, period, so for a MARS members using a hardware modem its best to configure for what is commonly being used the most in their MARS operations. For the software modem user life is much more simple as the various modes can be selected on the fly.

WAVEFORMS

MIL-STD-188-110A

MIL-STD-188-110A details FSK Radio Teletype (RATT), PSK Single (Serial) tone and both 16 tone Differential Phase-Shift Keying (DPSK) and 39 tone Quadrature Differential Phase-shift Keying (QDPSK) parallel modems. Our main interest herein is detailed in MIL-STD-188-110A section 5.3.1.1 the 110A serial tone waveform, which is the same waveform also detailed in FED-STD-1052. The serial tone waveform is the baseline for all current U.S. Military and Standard NATO waveforms and has been found to be superior to both the 16 tone DPSK and 39 tone QDPSK parrallel waveforms to the point where the 16 tone has become obsolete as of MIL-STD-188-110C.

The 110A serial tone waveform is an M-ary Phase Shift Keying (PSK) modulated waveforms on a single carrier frequency designed for data rates from 75bps up to 2400bps with convolutional coding (Coded) and 4800bps in an uncoded form (Uncoded). The 8-ary appearing PSK modulation of an 1800hz PSK carrier is at a constant symbol rate or 2400 symbols per second regardless of the data rate selected for throughput.

The 75bps Robust data rate uses a Direct Sequence Spread Spectrum (DSSS) scheme where a low data rate signal is modulated with a high rate pseudorandom sequence producing a 3Kkz signal with a small amount of noise for the conventionally modulated signal. The 110A actual user selectable data rates are Coded Walsh at 75bps and PSK at 150, 300, 600, 1200 and 2400bps and Uncoded PSK at 4800bps.

Data Rate	Interleaver	FEC Encoding	Data Modulation
75 bps	0.6 or 4.8 sec	$\frac{1}{2}$	Multiple PSK symbols per channel symbol
150 bps	0.6 or 4.8 sec	$\frac{1}{2}$	2-ary PSK scrambled to appear 8-ary
300 bps	0.6 or 4.8 sec	$\frac{1}{2}$	2-ary PSK scrambled to appear 8-ary
600 bps	0.6 or 4.8 sec	$\frac{1}{2}$	2-ary PSK scrambled to appear 8-ary
1200 bps	0.6 or 4.8 sec	$\frac{1}{2}$	4-ary PSK scrambled to appear 8-ary
2400 bps	0.6 or 4.8 sec	$\frac{1}{2}$	8-ary PSK scrambled to appear 8-ary
4800 bps	0 sec	None	8-ary PSK scrambled to appear 8-ary

The Forward Error Correction (FEC) in conjunction with the wide range of data rates copes with a correspondingly wide range of SNR conditions. During fades and other channel conditions, more symbols may be lost than the FEC can correct, even though the average SNR suggests that the error rate should be manageable. Thus interleaving is therefore employed to spread burst errors over longer symbol sequences so that the resulting error density is suitable for FEC. Interleaver selections are Short or Long and Zero, where Long provides for the best error rate performance in poor channel conditions. Interleaving is a method of taking data packets, chopping them up into smaller bits and then rearranging them so that once contiguous data is now spaced further apart into a non-continuous stream and more immune to channel disturbances. Data packets are re-assembled by the modem when received and FEC is applied to deal with any data lost. The Short vs. Long is the depth to which the data is rearranged and the time is takes to rearrange and re-assemble which affects the throughput of the data transmission in addition to the data rate selected.

Data Rate	Modulation scheme	Coding
75	Walsh	1/2
150	2-PSK	1/8
300	2-PSK	1/4
600	2-PSK	1/2
1200	4-PSK	1/2
2400	8-PSK	1/2
4800	8-PSK	None

Modems designed to meet 110A must meet error correction requirements including transmitter/receiver frequency variations and channel doppler shift of +/- 75hz @ +/- 3.5hz/sec slope on channels presenting up to 5 milliseconds of Multipath and 5hz of Doppler spread. At the constant symbol rate of 2400bps modulation known data symbols are periodically inserted into the data stream to aid in the estimation of channel characteristics to allow the receiving modem to adaptively equalize for channel degradation.

The 110A standard uses the concept of "autobaud" for its waveforms. This feature embeds known information (a constant pattern defined in the modem standard) into the waveforms preamble about its data rate and interleaver depth. The modems can then automatically detect the characteristics of the incoming waveform rather than having to be preset with the waveform type being used as with MT-63. However this preamble negotiation only happens on the initial radio link and it is not re-negotiated during data transfer in basic 110A operation. Thus the link could be lost on a channel operated over a period of time with ever degrading channel conditions. There is also "known" or "probe" blocks sent after the preamble which provide 1/100th of the amount of data symbols as does the preamble to equalize on to maintain sync or to attempt to sync on when coming on frequency late if the modem posses "Acquisition on Data", a.k.a. "Sync on Data" or "Late Acquisition" capabilities.

The "unknown" or "data" portion of the waveform containing the data payload or message, is Forward Error Corrected (FEC) to produce error protection on the data stream. Lower data rates generally have higher levels of FEC.

110A when operated in ASYNC the EOM sequence is usually used.

When operated in SYNC the EOM sequence is not usually used when the use of a Data Link Protocol for ARQ operation is controlling the modem. FED-STD-1052 Appendix B is used with 110A however 5066-ARQ is replacing it.

110A being an auto-detect waveforms lends itself to the modem's parameters being adapted to meet changing channel conditions in ARQ operation where the modems settings due to supporting autobaud operation can be changed for TX automatically and independently on each side of the connection.

MIL-STD-188-110B

MIL-STD-188-110B includes the same ST performance requirements as MIL-STD-188-110A where 75bps is the low speed data rate and 150-2400bps are the medium speed rate waveforms. However the 110B standard adds the optional Appendix C (nearly the same as STANAG 4539 Annex E.) with high speed data rates of 3200, 6400, 4800 (replacing 110A uncoded), 8000 and 9600bps coded and 12800bps uncoded. The ST waveforms specified in this appendix use modulation techniques of greater complexity and data blocks larger than those found in 110B section 5.3.2 and 110A section 5.3.1.1 in order to achieve the efficiencies necessary to obtain the required data rates. These waveforms are both autobaud and preamble reinserting during transmission to maintain sync.

Data Rate	Modulation scheme	Coding
75	Walsh	1/2
150	2-PSK	1/8
300	2-PSK	1/4
600	2-PSK	1/2
1200	4-PSK	1/2
2400	8-PSK	1/2
3200	4-PSK	3/4
4800	8-PSK	3/4
6400	16-QAM	3/4
8000	32-QAM	3/4
9600	64-QAM	3/4
12800	64-QAM	None

Modulation types added are Quadrature Phase-Shift Keying (QPSK) used at the 3200bps data rate which is scrambled to appear on-air as an 8PSK constellation. In addition Quadrature Amplitude Modulation (QAM) techniques where added where 16QAM is used at 6400bps, 32QAM is used at 8000bps and 64QAM is used at 9600 and 12800bps. The 4800bps data rate uses 8PSK.

The symbol rate for all symbols shall be 2400 symbols-per-second. The subcarrier (or pair of quadrature sub-carriers in the case of QAM) are centered at 1800 Hz and 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 is achieved by making the In-phase sub-carrier cos(1800 Hz) and the Quadrature sub-carrier -sin(1800 Hz).

The QAM constellations specified in this appendix are more sensitive to equipment variations than the PSK constellations specified in 110B section 5.3.2 (and 110A). Because of this sensitivity, radio filters will have a significant impact on the performance of modems implementing the waveforms in 110B Appendix C. In addition, because of the level sensitive nature of the QAM constellations, turn-on transients, AGC, and ALC can cause significant performance degradation, AGC SLOW must be used. In addition the standard recommends that modems implementing the waveforms in this appendix should include a variable pre-key feature, by which the user can specify a delay between the time when the transmitter is keyed and the modem signal begins. This allows for turn-on transient settling, which is particularly important for legacy radio equipment.

The Interleaver choices are Ultra Short (US), Very Short (VS), Short (S), Medium (M), Long (L) and Very Long (VL). 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.

110B when operated in ASYNC the EOM sequence is usually used just as with 110A.

When operated in SYNC the EOM is disabled as with 110A when a Data Link Protocol software is controlling the modem. 5066-ARQ is usually used at 3200bps and higher, the modem's parameters can be adapted to meet changing channel conditions in ARQ operation where the modems settings due to supporting autobaud operation can be changed for TX automatically independently on each side of the connection over the entire coded range through 9600bps.

These 110B High Speed waveforms are the limit for single 3Khz channel operation which is the current configuration of MARS FAU's. The use of these waveforms will require radios that have TXCO's and 3Khz filters and both accurate and stable PC Sound Devices for modems.

MIL-STD-188-110C

MIL-STD-188-110C provides for two new waveforms within a 3Khz channel that are of potential interest for MARS. Those being 64-QAM 12,000bps coded and 256-QAM 16,000bps coded as seen in the waveform lineup chart below.

MIL-STD-188-110C
APPENDIX D

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

Waveform Number	0 Walsh	1 BPSK	2 BPSK	3 BPSK	4 BPSK	5 BPSK	6 QPSK	7 8PSK	8 16QAM	9 32QAM	10 64QAM	11 64QAM	12 256QAM	13 QPSK
Bandwidth (kHz)														
3	75	150	300	600	1200	1600	3200	4800	6400	8000	9600	12000	16000	2400

STANAG 4285

S4285 is specified in MIL-STD-188-110A section 5.3.1.3. The S4285 waveform uses an 1800hz PSK carrier and 2400bps Symbol Rate as does 110A. This waveform does not provide an autobaud capability and both transmitter and receiver must be set to the same data rate and interleaver settings before transmission begins, as is the case with MT-63.

The 110A waveform uses a block interleaver where the rearrangement of bits is performed on a whole block of data at a time whereas S4285 uses a convolutional interleaver. 4285 has a short 80 symbol preamble verses 110A however it is inserted every 106.7 msec (every 256 symbols) thus providing many opportunities to acquire, re-aquire and maintain sync which is very useful for broadcast applications. However the overhead for the reinserted preamble results in lower effective data rates and weaker FEC as well as limiting its usefulness for ARQ applications. Signal quality can be assessed from the number of errors being detected in the 80-bit preamble sequence and from a Mean Viterbi Confidence (MVC) algorithm.

S4285 selectable data rates are Coded at 75, 150, 300, 600, 1200 and 2400bps with Interleaver selections of Short or Long and Zero and Uncoded at 1200, 1800, 2400 and 3600bps.

Data Rate	Modulation scheme	Coding
75	1-BPSK	1/16
150	1-BPSK	1/8
300	1-BPSK	1/4
600	1-BPSK	1/2
1200	2-QPSK	1/2
2400	8-PSK	2/3
1200	1-QPSK	None
2400	2-QPSK	None
3600	8-PSK	None

S4285 provides for both Start of Message (SOM) begin decoding and End of Message (EOM) reset modem receiver sequence support. If the receiver is not setup to display only if SOM is received then any legitimate S4285 transmission will cause the receiver to print regardless or not if the terminal is set to the same parameters of the sending station and thus gibberish will be printed. If the receiver is not setup to reset on EOM, then printing will continue after the transmission ceases.

A large number of modem suppliers have implemented this standard in their MIL-STD modems for use in NATO operations. S4285 in its sub mode STANAG 4481-PSK, is used by for the NATO Naval BRASS (BRoadcast And Ship-Shore) project, BRASS is described as a system that broadcasts data and messages to ships using ACP-127[21] formatted messages, while traffic in the reverse direction is unicast. BRASS uses 300bps for continuous broadcasting over wide coverage areas due to its repeated preamble data for which supports maintaining sync during long transmissions as well as late entry where a station can start to receive at any point during the transmission as long as their terminal is not set to begin on the SOM sequence. These features make S4285 a prime candidate for MARS broadcast use.

STANAG 4415

STANAG 4415 is the same waveform defined as 75bps in 110A on transmit and thus S4415 and 110A at 75bps are interoperable. However in 110A the 75bps waveform receive performance is defined as 2db SNR @ 3khz AWGN 5ms multipath and 5hz fading channel. The performance requirements for the S4415 receiver are much stricter, requiring S4415 to perform well under more severe channel conditions and thus using S4415 on both ends is required for the full robust benefits.

S4415 is the “NATO Robust Waveform” that works down to -6db SNR @ 3Khz AWGN heavy multipath/fading channel using a direct sequence spread spectrum waveform at 75bps using a 2400bps Symbol Rate. Interleaver selections are Short or Long and Zero and are auto detected. This very robust HF data waveform will operate effectively almost 10 dB below the noise floor in a noise dominated environment, nearly 40 dB below the level of a tonal interferer, and tolerate extremes of delay and Doppler spreading.

The difference between 110A 75bps and S4415 are that there are no known symbols except for an initial synchronization preamble, and that the code bits are modulated by orthogonal Walsh functions in S4415. A different set of Walsh functions is used for the last Walsh symbol in each interleaver block for synchronization purposes. A convolutional encoder (as in S4285) provides a code rate of Rc=1/2. For every 2 code bits are generated 32 BPSK channel symbols, called one Walsh symbol. This means that the number of code bits per channel symbol is Q = 2/32 = 1/16. Because there are no training symbols, the frame pattern efficiency is Rf = 1, and we can verify that the information data rate is fa = RcQRf fs = 75 bps.

STANAG 4481

STANAG 4481 defines the minimum technical standards for NATO naval shore-to-ship broadcast (shore transmitting and ship receiving) equipment that will permit interoperable communication using HF transmissions.

Refer to S4285 for details as the PSK mode detailed in S4481 are the 75-300bps waveforms of S4285 using the LONG Interleaver.

STANAG 4529

The S4529 waveform is basically a Narrowband Version of 4285 Single Tone Appendix A with a few differences. S4529 was developed for use in narrower 1240Hz NATO Naval channels. The narrower occupied bandwidth is achieved by reducing the baud rate of the S4285 waveform from 2400bps to 1200bps and changing the filtering to reduce the occupied bandwidth which also provides improved SNR performance over S4285. The PSK carrier is selectable in 100Hz steps from 800Hz to 2400Hz, with a default value of 1700Hz. This waveform would easily support full throughput with all MARS members radios IF filters regardless of the selected PSK carrier.

As with S4285, the modem transmitter and receiver must be set to the same data rate and interleaver settings S4529 is not autobaud. An S4529 modem must be capable of dealing with a Transmitter/Receiver/Doppler frequency error of 37.5hz (only half that of S4285 and 110A) at a slope rate of 3.5hz/sec. In addition interleaver duration is double that of S4285 to achieve 2 to 3db better SNR performance on slow fading channels, which also slows data throughput.

Coded at 75, 150, 300, 600 and 1200bps with Interleaver selections of Short or Long and Zero and Uncoded at 600, 1200, 1800bps.

Data Rate	Modulation scheme	Coding
75	1-BPSK	1/8
150	1-BPSK	1/4
300	1-BPSK	1/2
600	2-QPSK	1/2
1200	8-PSK	2/3
600	1-BPSK	None
1200	2-QPSK	None
1800	8-PSK	None

S4529 provides for both Start of Message (SOM) begin decoding and End of Message (EOM) reset modem receiver sequence support. If the receiver is not setup to display only if SOM is received then any legitimate S4529 transmission will cause the receiver to print regardless or not if the terminal is set to the same parameters of the sending station and thus gibberish will be printed. If the receiver is not setup to reset on EOM, then printing will continue after the transmission ceases.

S4529 was designed for use by NATO BRASS Naval Broadcast over wide coverage area due to its repeated preamble data for which supports maintaining sync during long transmissions as well as late entry where a station can start to receive at any point during the transmission as long as their terminal is not set to begin on Start of Message (SOM). These features make S4529 a prime candidate for MARS broadcast use.

STANAG 4538

STANAG 4538[19] and MIL-STD-188-141B[18] Appendix C, which are almost identical (except that 141B excludes Fast Link Set Up (FLSU) mode), represent serial tone PSK burst waveform based 3G ALE and define the concept of an Automatic Radio Control System (ARCS) for HF communication links supporting an Internet Protocol (IP) interface for tactical communications. The ARCS concept consists of three main functions: Automatic Channel Selection (ACS), Automatic Link Establishment (ALE) and Automatic Link Maintenance (ALM). 3G ALE uses all serial tone waveforms where backward compatibility with 2G ALE is also supported. An ARCS system is typically implemented as an embedded system in tactical HF radios.

An ARCS 3G ALE or Synchronous ALE (where 2G FSK ALE is an Asynchronous ALE) based system is designed to establish quickly and efficiently one-to-one and one-to-many (broadcast and multicast) tactical links. It supports trunked-mode operation (separate calling and traffic channels) as well as sharing any subset of the frequency pool between calling and traffic. It uses a specialized carrier-sense-multiple-access (CSMA) scheme for calling channel access control, and regularly monitors traffic channels to avoid interference.

STANAG 4538 and MIL-STD-188-141B Appendix C are located at the data link protocol layer and the link setup layer of the OSI model. The data link protocol is closely connected with the burst waveforms defined in the standard, and cannot be run with other waveforms. On the other hand, the link set up, which is also located at layer two, can be run in conjunction with other data link protocols, for example STANAG 5066 with all supported waveforms. In this case, ARCS establishes a line-switched connection which STANAG 5066 or the waveforms make use of.

3G ALE is based on efficient ARQ data link protocols using six robust 2400bps symbol rate 1800Hz PSK carrier serial tone modem waveforms which is the focus of interest within this document Burst Waveforms (BW) known as BW0-BW5 which are optimized for the data link protocols. The 2G advanced 8FSK Alternate Quick Call (AQC) ALE also uses the BW2 PSK waveform for its optional burst mode operation. These properties of 3G ALE provide for an Automatic Link Management (ALM) system and are heavily used in support of both STANAG 5066 networks and Tactical Chat point-to-point communications.

The S4538 data link protocol is an ARQ protocol which can only be run in a point-to-point data packet connection. The difference in robustness between HDL and LDL as detailed later herein, is the result of the different waveforms which are used. The data link protocol is closely associated with the burst waveforms defined in the standard. There are six Burst Waveforms (BW) defined which are used in different aspects of the protocol:

- BW0 for Robust Link Set Up
- BW1 for management traffic and HDL ACK
- BW2 for HDL traffic
- BW3 for LDL traffic
- BW4 for LDL ACK
- BW5 for Fast Link Set Up (Note: Does not existing in 141B)

The six waveforms have different characteristics in terms of data rate, interleaving, frame pattern and synchronization which provides for different degrees of robustness and application. The ACK signals use the most robust waveforms along with link being more robust than the traffic waveforms, which means it may be impossible to pass the payload after a link if channel conditions are poor enough.

Prob Link Success	Gaussian	ITU-R F.250-2 Good	ITU-R F.250-2 Poor
25%	-10	-8	-6
50%	-9	-6	-3
85%	-8	-3	0
95%	-7	1	3

The HDL BW2 waveform must have positive SNR values to work, while the LDL BW3 can handle an SNR down to -5dB AWGN channel. The data rates, symbol patterns and interleaving of a burst varies for the different waveforms as follows:

- BW2, up to 4800bps data rate with average throughput of 767-4409bps, 32 symbol data and 16 symbol known probe frame pattern using 8PSK, variable 0.96s - 6.93s block interleaving,
- BW3, 600bps data rate with average throughput of 219-573bps, 16ary orthogonal Walsh function frame pattern like S4415 using 8PSK, 0.6s / 4.8s block interleaver selections,

The burst waveforms employ code combining for data transmissions: complete channel coding is computed for each data block before transmission, but only a subset (one half or one quarter) of the code bits are sent in each transmission. If a packet is received with uncorrectable errors, the soft decisions are saved and additional code bits are requested in a retransmission of the packet. After each new reception, the additional received signal is combined in the FEC decoder with the earlier reception(s) until an error-free result is obtained. Since the retransmission of additional code bits is requested on a packet-by-packet basis, the code rate (and therefore the effective data rate) of each packet is reduced from the initial high rate only so far as is necessary for correct reception. Thus, with no more overhead than is already required for ARQ operation, data rate can adapt as required for each individual packet in a message.

In 3G ALE all stations in the network are equipped with accurate clocks (referenced to GPS and other time servers) and perform synchronous scanning of a set of pre-assigned frequencies based on their clocks. All stations change frequency simultaneously, and the current dwell channel of every station is always known, enabling very rapid linking where there are no need for ALE Soundings due to the synchronous scanning, however the protocol and packet format are defined in S4538 for use when Link Quality Assessment (LQA) would be useful. For example, when in scanning mode, 3G ALE stations shall also be able to detect 2G ALE calls from MIL-STD-188-141A based systems and respond.

One of the functions of the sub network layer is translation of upper-layer addresses (e.g., IP addresses) into whatever peculiar addressing scheme the local subnet uses. The addresses used in 3G ALE protocol data units (PDUs) are 11-bit binary numbers. In a network operating in synchronous mode, these addresses are partitioned into a 5-bit dwell group number and a 6-bit member number within that dwell group. Up to 32 dwell groups of up to 60 members each are supported (1920 stations per net). Four additional unassignable addresses in each group (1111xx) are available for temporary use by stations calling into the network. When it is desired to be able to reach all network members with a single call, and traffic on the network is expected to be light, up to 60 network member stations may be assigned to the same dwell group. However, this arrangement does not take full advantage of the 3G calling channel congestion avoidance techniques. To support heavier call volume than the single group scheme will support, the network members should be distributed into multiple dwell groups. This results in spreading simultaneous calls more evenly over the available frequencies.

STANAG 4539

STANAG 4539 and MIL-STD-188-110B differ in some areas but are substantially the same and interoperable. S4539 uses S4415 requirements at 75bps and MS110A requirements for 150-2400bps. However the performance requirements above 2400bps are higher for STANAG 4539 than for 110B Appendix C. Thus S4539 and 110B can communicate with each other, but a modem in compliance with 110B Appendix C does not necessarily exhibit as good communication performance as a S4539 modem.

DATA LINK PROTOCOLS

In NATO emphasis is on the International Standards Organisation Open Systems Interconnect (ISO/OSI) model defined in ISO/IEC 8886.3 for Open Systems Interconnection (OSI) compatibility.

For Error Free delivery Automatic Repeat Request (ARQ) control makes use of the FEC waveforms, however the error free delivery provided by ARQ protocols comes at the cost of variable delays due to any required retransmissions thus decreasing throughput.

Also, in non-ARQ operations, the Forward Error Correction (FEC) used with the various MIL-STD/STANAG waveforns in current use offer a wide range of data rates to cope with a correspondingly wide range of SNR conditions. During fades, of course, more symbols may be lost than the FEC can correct, even though the average SNR suggests that the error rate should be manageable. Interleaving is therefore also employed to spread burst errors over longer symbol sequences so that the resulting error density is suitable for FEC. However, as the connection to hardware modems for ARQ is a synchronous serial interface, the end-to-end delay through the sending and receiving modems is at least two times the interleaver depth. The Link turnaround times are at least twice that long, so ARQ systems typically only use the shortest interleaver possible, which is SHORT on 110A and VERY SHORT on 110B.

FED-STD-1052B DLP

FED-STD-1052 is basically the equivalent of MIL-STD-188-110A just as FED-STD-1045A is basically the equivalent of MIL-STD-188-141A when it comes to ALE. However FED-STD-1052 Appendix B specifies a first generation Data Link Protocol layer with priority messaging and multiple pre-emptive resume queuing ARQ that is not included in MIL-STD-188-110A. The DLP supports a data link layer protocol as defined by the International Organization for Standardization (ISO) network reference model. This protocol, when used in conjunction with an appropriate modem, provides a method for transmitting error-free data over an HF radio circuit. The DLP provides the functionality required to support a data link service defined in ISO/IEC 8886.3 for Open Systems Interconnection (OSI) compatibility.

The DLP protocol includes the possibility of changing data rate, such that if the channel conditions can support a data rate higher than the one currently used, the data rate may be increased. And similarly, if almost all packets fail because the data rate is too high, the data rate may be decreased. In this way, the data rate is adapted to changing channel conditions in ARQ.

There are three modes of FS-1052 DLP operation:

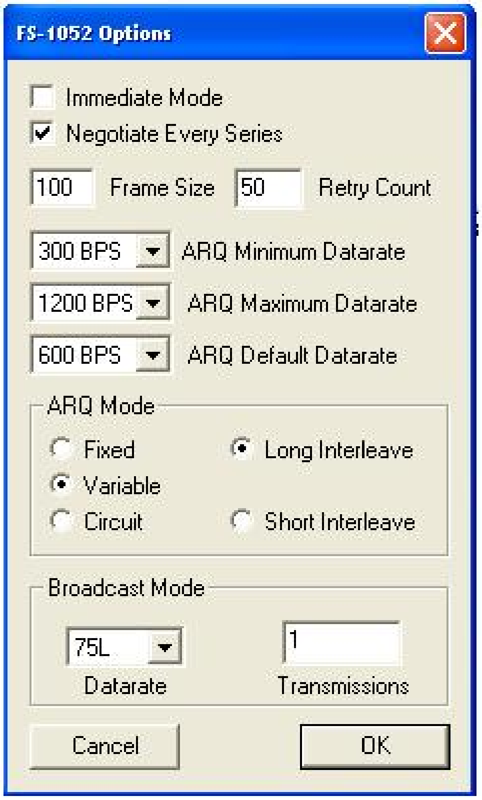
1. ARQ: The primary mode of operation (mandatory) is the automatic repeat request (ARQ) mode, which provides for basic go-back-N ARQ error-free point-to-point data transfer. One alternative of this mode uses fixed-length control frames and a minimum of link reversals. The other alternative provides additional functionality and flexibility by employing variable length control frames. Both alternatives employ a control frame acknowledgment scheme. The ARQ protocol is “Adaptive”, which is to say that it includes the possibility of changing the data rate, such that if the channel conditions can support a data rate higher than the one currently used, the data rate may be increased, the shortest interleaver setting for the given waveform being used is normally used. Similarly, if almost all packets fail because the data rate is too high, the data rate may be

decreased. In this way, the data rate is adapted to changing channel conditions. The data rate can be different for both sides of the connection depending on the changing channel conditions. The 110A auto-detect waveform is used starting with 600bps SHORT normally and ARQ Immediate mode normally followed by adaptive data rate changes during data exchange.

2. BRD or BCAST: A secondary mode of operation (mandatory) is the Broadcast (non-ARQ) mode. The Broadcast mode allows unidirectional data transfer using fixed-length frames to multiple (as well as to single) receivers. No transmissions from the receiving terminal are desired or required.

3. CIRCUIT: The other secondary mode, the Circuit mode (optional), allows a link to be established and maintained in the absence of traffic. The ARQ variable-length frame protocol is used along with a technique to maintain the data link connection in the absence of user data.

When Adaptive ARQ is used, the educated user selection of the data rate required with FEC use for serial tone waveforms is taken out of the equation. A starting data rate as configured is use, say 600bps and based on ACK/NAK exchanges the data rate is ramped up and down on each side, where both stations may remain at the starting data rate or both may go lower or higher or one may stay at the starting data rate and the other may go higher or lower or the two stations may go in opposite directions where one may end up sending at the lowest configured data rate and the other may end up sending at the highest configured data rate. As an example of configuration see the screen cap below from the MARS-LP-ALE tool, the data rate selections start off with 600bps and will never go lower than 300bps and never go higher than 1200bps as configured using 1052-ARQ and the 110A modem.



FS-1052 DLP is typically implemented in computer software applications and not in the hardware modem, however some tactical radios do implement an embedded 1052 ARQ and BRD capability. 1052-ARQ is limited to a 2400bps maximum data rate, 5066-ARQ detailed below has no such limitation.

STANAG 5066

5066-ARQ

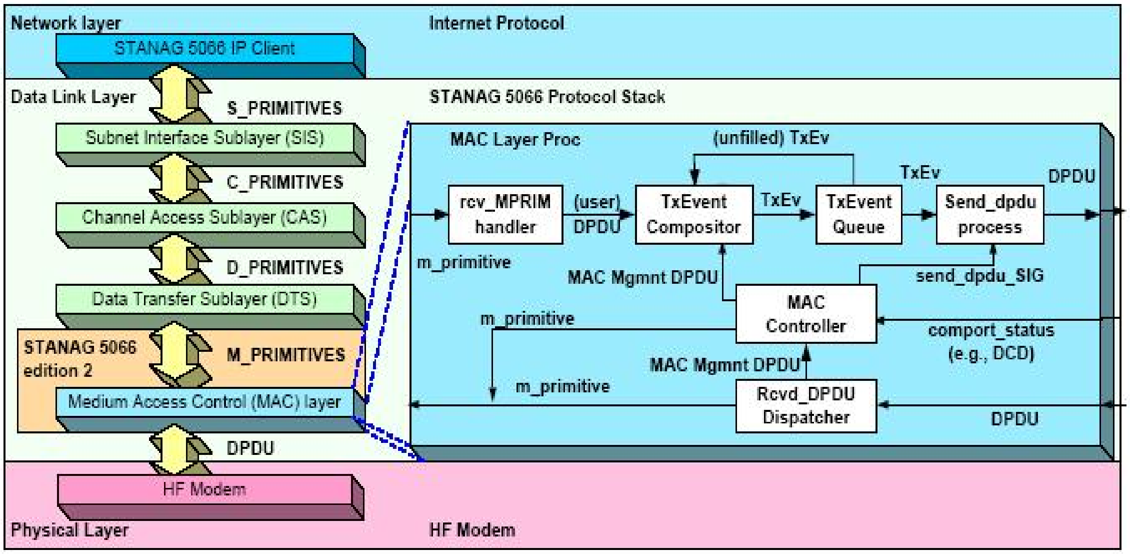
The STANAG 5066 standard provides data transfer using ARQ as well as non-ARQ point-to-point, broadcast or multicast data transfer. In contrast to STANAG 4538, STANAG 5066 is a pure data link standard and does require Automatic Link Establishment (ALE). Either, a fixed frequency operation or an ALE 2G or 3G system can be used with STANAG 5066.

MIL-STD-188-110B, Appendix E specifies 5066-ARQ as the optional DLP in E.4.2, “Channel access protocol as specified in STANAG 5066 Annex B.” and E.4.3, “Data Transfer Protocol as specified in STANAG 5066 Annex C”. These two annexes of STANAG 5066 describe the Sub Network Interface operating in ARQ mode after data link setup, are collectively denoted as 5066-ARQ in military circles. 5066-ARQ can be used with 110A, 110B, 110C, S4539 auto-detect waveforms and STANAG non-autobaud waveforms. All aspects of 5066, the second generation DLP, are implemented in computer software applications external to the modem.

The full STANAG 5066 was originally developed for the ship-shore part of NATO’s BRASS project which needed a link layer ARQ protocol. STANAG 5066 is located at the data link layer and defines an interface to applications (clients) which will use the network. It also defines an interface to the HF data modem. The standard describes a general purpose, open and interoperable sub network protocol stack for data communications over HF radio and beyond.

Although STANAG 5066 Edition 1 can transmit Internet Protocol (IP) based traffic, the standard did not originally define a direct IP interface, instead, for STANAG 5066 networks to serve IP packets, they need to arrive at the Subnetwork Interface Sublayer of STANAG 5066 as part of a service primitive. A STANAG 5066 IP client is responsible for the conversion between IP packets and the standardized SIS primitives, acting as a gateway between an IP network and the STANAG 5066 radio network. However STANAG 5066 Edition 2 now directly supports IP based HF wide area networking. The main new functionality in Edition 2 concerns media access control (MAC) to allow multiple nodes in a small network (up to 8 nodes) to share a single frequency. One new annex describes random access control protocols and another annex describes a wireless token ring protocol. Still another annex is reserved for a future definition of TDMA.

5066-ARQ which is depicted below in the “5066 Protocol Stack” as the first layer above the HF modem, as the second generation NATO data link protocol, as described in Annex C of STANAG 5066. 5066-ARQ is a Selective Repeat ARQ protocol, with some special features such as an end-of-transmission announcement to simplify link turnaround timing, meaning that only the packets in error are retransmitted and not all packets after the error, as in the case of the basic go-back-N ARQ of FS-1052 Appendix B. In addition to the Selective ARQ and Non-ARQ services provided to the upper sublayers, the Data Transfer Sublayer shall provide an Idle Repeat Request service for peer-to-peer communication with the Data Transfer Sublayer of other nodes which supports Multi-casting. STANAG 5066 is a connectionless bi-directional protocol (like IP) with every D_PDU containing both source and destination addresses.



The 5066-ARQ protocol, as is FED-STD-1052 Appendix B, represents Adaptive ARQ, which is to say that it includes the possibility of changing the data rate, such that if the channel conditions can support a data rate higher than the one currently used, the data rate may be increased. If almost all packets fail because the data rate is too high, the data rate may be decreased. In this way, the data rate is adapted to changing channel conditions. The 5066-ARQ controller uses Data Rate Change Request algorithm based Frequency of Error and other factors in conjunction with an autobaud FEC waveform to bring about Adaptive ARQ. The data rate can be different for both sides of the connection depending on the changing channel conditions, the shortest interleaver setting for the given waveform being used is normally used to speed data transfer.

5066-NRQ

In STANAG 5066 section "C.1 Data Transfer Sublayer Service Definition", it states that depending on the application and service-type requested by higher sublayers, the user service provided by the Data Transfer Sublayer shall be either a simple non ARQ service, commonly known as broadcast mode and technically known as "No Repeat-Request (NRQ) Protocol" or a reliable selective ARQ service, commonly known as 5066-ARQ.

The Data Transfer Sublayer provides "sub-modes" for non ARQ and reliable selective ARQ delivery services, which influence the characteristics of the particular service. In addition to the Selective ARQ and Non-ARQ services provided to the upper sublayers, the Data Transfer Sublayer shall provide an Idle Repeat Request service for peer-to-peer communication with the Data Transfer Sublayer of other nodes.

The non-ARQ service is as specified in "C.1.1 Non-ARQ Service" as follows:

In the non ARQ service error-check bits (i.e., cyclic-redundancy-check or CRC bits) applied to the D_DPU shall (1) be used to detect errors, and any D_PDUs that are found to contain transmission errors shall (2) be discarded by the data transfer sublayer protocol entity.

A special mode of the non-ARQ service shall (3) be available to reconstruct C_PDUs from D_PDUs in error and deliver them to the Channel Access Sublayer.

In the non-ARQ mode, the following sub modes may be specified:

- regular data service.
- expedited data service.
- “in order” delivery of C_PDUs is not guaranteed.
- delivery of complete or error free C_PDUs is not guaranteed.

The NRQ protocol shall only operate in a simplex mode since the local node, after sending Information Frames (I-frames), does not wait for an indication from the remote node as to whether or not the I-frames were correctly received. Multiple repetitions of I-frames can be transmitted in order to increase the likelihood of reception under poor channel conditions, in accordance with the requested service characteristics.

STANAG 4538 and MIL-STD-188-141B

See STANAG 4538 under WAVEFORMS above for general details of the waveforms that the third generation data link protocols operate over.

LOW-LATENCY DATA LINK

Low-latency Data Link (LDL) protocol as detailed in MIL-STD-188-141B Appendix C and STANAG 4538 is a stop-and-wait ARQ protocol tightly integrated with a very robust burst BW2 (of the BW0-BW5 waveforms available) serial tone modem waveform with the data rate and interleaver settings of S4285. It uses code combining to dynamically adapt FEC coded data rate frame-by frame and provides a useful throughput at –10 dB SNR. The size of the LDL transmission frame can vary from 32 bytes (LDL_32) to 512 bytes (LDL_512). As only one packet is sent, no selective ACK is available in this system, and if an error occurs, the whole frame is retransmitted. The maximum throughput for LDL is approximately 500bps. LDL is optimized for delivering small datagrams in all channel conditions and also longer datagrams in poor channel conditions for broadcast and multicast tactical chat applications over STANAG 5066 sub nets using ACP-142(A)[20] P_MUL protocol.

P_MUL, as a reliable multicast protocol, requires an underlying connectionless network infrastructure with multicast routing functionality. The P_MUL protocol may be understood as a transport layer protocol. P_MUL utilizes lower layer protocols to transmit its PDUs (Protocol Data Units) over a multicast network. The non-responsive mode is also known as emission control or radio silence, where the receivers are incapable of or disallowed to provide any feedback. That aside, different messages may have different priorities and different characteristics. All these factors constrain the design of an efficient error recovery scheme for P Mul. Military networks find multicast an ideal tool to match the needs of an all-informed subnetwork for bandwidth efficient communications for strategic and tactical messaging where users under radio silence need not respond for hours or days yet can still get resends at that later time.

HIGH-THROUGHPUT DATA LINK

High-throughput Data Link (HDL) protocol as detailed in MIL-STD-188-141B[18] and STANAG 4538[19] is a selective repeat ARQ protocol, tightly integrated with a code-combining burst BW3 (of the BW0-BW5 waveforms available) serial tone modem waveform with the data rate and interleaver settings of S4285 that emphasizes high throughput rather than low-SNR performance. HDL is optimized for delivering large datagrams in medium to good channel conditions for broadcast and multicast tactical chat applications over STANAG 5066 sub nets using ACP-142(A) P-Mul protocol same as with Low-latency Data Link (LDL) protocol.

HDL is the preferred protocol for transmitting large amounts of data over good channels. Prior to transmission, the data to be sent is divided into packets of a given size. The number of packets contained in one transmitted frame in the HDL protocol is designated by a number attached to the protocol name e.g. HDL_24 will transmit 24 HDL packets (233 bytes in one packet). Available frame sizes for HDL are 3, 6, 12 and 24 packets. The receiving PU decodes each packet separately, and is able to send an ACK message with information about which packets contained errors (selective ACK). This enables retransmission of failed packets only. The maximum data rate, not considering protocol overhead, is 4800 bps (bit/s) which gives an approximate throughput of 3200 bps when the highest amount of packets (24) are sent in each frame.

NATO HF GENERATIONS

The current NATO definition of 2nd Generation HF (2G) is embodied by the following standards:

- Data Modems - STANAG 4285/4539/MIL-STD-188-110B
- DLP ARQ - STANAG 5066
- ALE - MIL-STD-188-141A/MIL-STD-188-141B
- Subnetwork - STANAG 5066
- HF Clients - STANAG 5066

The current NATO definition of 3rd Generation HF (3G) is embodied in the following standards:

- Waveforms - BW1-5 from STANAG 4538
- DLP ARQ - HDL & LDL from STANAG 4538
- ALE - STANAG 4538
- Subnetwork - STANAG 5066
- HF Clients - STANAG 5066

NATO states that neither 2G HF or 3G HF meet the needs of all users due to the characteristics of each generation and users needs, therefore both will continue to be components of future NATO HF communications.

In both 2G HF and 3G HF the use of single channel or multi-channel ALE operation is supported where 2G HF can utilize legacy non-ALE radios. However 3G HF for NATO requires a 3G ALE radio with embedded S4538 support, which for MARS operations would need to be implemented in software.

In the current STANAG 5066 the only mandatory HF Clients per Annex F are the Raw Subnetwork Interface Sublayer (SIS) Socket Server and the Internet Protocol (IP) client where the requirement is for HF-subnetwork support of the Internet Protocol (Version 4), Internet Standard 5, Request for Comments (RFC) 791. Over the HF subnetwork interface, the IP client shall be capable of sending and receiving encapsulated IP datagrams with unicast (i.e., point-to-point) IP addresses, using both ARQ and non-ARQ-transmission modes in STANAG 5066. Over the HF subnetwork interface, the IP client shall be capable of sending and receiving encapsulated IP datagrams with multicast (i.e., point-to-multipoint) IP addresses, using non-ARQ-transmission modes.

The implementation of HF-email with support for attachments, File Transfer and other capabilities over STANAG 5066 as detailed in Annex F, are accomplished by using the same or similar standards and protocols as used via the Internet, with or without IP, where MARS developers familiar with TCP/IP, POP3/SMTP, HMTP, GZIP, MIME, ZMODEM will be at home adapting or developing open source tools in support of a MARS STANAG 5066 stack.

APPENDIX A

Data Rate
and
Interleaver Selection

S4415 which only supports one data rate makes life simpler for the user and provides very robust operation under all channel conditions, but it is slow and thus not the best choice if the channel supports faster data rates. S4285 and S4529 which are not autobaud compliant require that both the TX and RX stations to be configured the to the same data rate and interlever settings in advance and thus do not support Adaptive ARQ not being autobaud. However due to their near constant re-sync known data transmitted during the payload, it makes them the better suited modes for FEC Broadcast applications.

As 110A is autobaud compliant, data rate and interleaver settings are only required on the transmit side and thus bi-lateral data rate selections are supported in that both stations can be at different data rates and interleaver settings. In Adaptive ARQ operation using 110A which only sends short known data probes during the payload, software controls data rate via selection based on channel conditions automatically and where SHORT interleaver is normally used. In Adaptive ARQ operation the linking call will usually start at 600bps and based on SNR and BER data exchanged ramp up or down or if no link is established ramp down to attempt a re-link and will continue to base parameter changes on ongoing SNR and BER readings where each side can be working at the same settings or completely opposite sides of the data rate settings spectrum.

However for FEC only use, the user must select the data rate and interleaver for FEC operation based on channel conditions manually. The use of serial tone modem waveforms in FEC modes by stations in attended operation, unlike in unattended guard channel operations permits a voice exchange to determine receive conditions on both ends, this holds true for Regional Broadcast use as well, as the NCS or directed sending station can poll the net for signal report. In two-way use of 110A serial tone FEC modes both stations can send at the same or different data rate and Interleaver settings, where it is best to just make use of the LONG interleaver setting to deal with any channel issues and minimum performance characteristics of the waveform data rates. For guard channel operations the broadcast station can only to take into account TOD propagation characteristics for the wavelength being used, seasonal effects and minimum performance characteristics of the waveform data rates, thus 75-300bps should be used for CONUS wide or OCONUS broadcasts and 75-600bps for regional broadcasts.

Most MARS-to-MARS peer-to-peer and regional broadcast communications takes place within 2-12Mhz NVIS where the 3-7Mhz range sees the most use and where the 3 and 4Mhz range sees the bulk of the use and which has the highest noise levels and fading conditions next to 2Mhz. As such the recommended Interleaver setting is always LONG. Data rates beyond 600bps will not yield reliable good results even if one has an S4203 compliant radio system and hardware modem unless very good to excellent channel conditions exist, which can be determined if two-way contact with the audience stations is part of the scenario.

Below are sections from both MIL-STD-188-110B pertaining to 110A ASYNC and from STNANAG 4415 pertaining to S4415 regarding Performance Requirements taking into account the use of an S4203 compliant HF radio. Then further below is information regarding the calibration of S-meters which combined should give all users of 110A ASYNC an idea of how to best select the data rate and in consideration of prevailing an possibly changing channel conditions.

MIL-STD-188-110B

5.3.2.5 Performance requirements.

The measured performance of the serial (single-tone) mode, using fixed-frequency operation and employing the maximum interleaving period, shall be equal to or better than the coded BER performance in table XX. Performance verification shall be tested using a baseband HF simulator patterned after the Watterson Model in accordance with International Telecommunications Union (ITU) Recommendation ITU-R F.520-2. The modeled multipath spread values and fading (two sigma) bandwidth (BW) values in table XX shall consist of two independent but equal average power Rayleigh paths. For frequency-hopping operation, an additional 2 dB in signal-to-noise ratio (SNR) shall be allowed.

TABLE XX. Serial (single-tone) mode minimum performance.

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

NOTES:

1. Per ITU-R F520-2.
2. Both signal and noise powers are measured in a 3-kHz bandwidth.

STANAG 4415 Edition 1, Annex A

MINIMUM REQUIRED PERFORMANCE

24. The performance specified in the following paragraphs is required when the modem is operating in the long interleaver mode. The HF simulator used shall be in accordance with CCIR Report 549-3. Doppler spread shall be Gaussian and specified as a 2 Sigma power bandwidth. Signal and noise powers shall be measured in a 3 kHz bandwidth.

25. Single Path, non-fading - The modem shall achieve a BER<10^{-3} at -9.00 dB SNR (3kHz) in an additive white Gaussian noise environment.

26. Dual Path, Multipath delay = 10.0ms. - The modem shall achieve a BER < 10^{-4} at the following SNRs (3kHz).

Doppler Spread (both paths) (Hz)	Required SNR[dB] to achieve 10^{-4}BER
0.5	0.0
1.0	-1.0
2.0	-1.0
5.0	-1.0
10.0	-1.0
20.0	-1.0
30.0	-1.0
40.0	-0.5
50.0	0.0

Table 3.1 - Fading Multipath Performance

27. Delay Spread Tolerance - The modem shall be capable of achieving synchronisation and providing BER of less than 10^{-5} for multipath delay spreads up to 10 milliseconds in a 0 dB SNR channel with Doppler spreads of 2 Hz and 20 Hz.

28. Interference Tolerance - Table 3.2 specifies Signal to Interference Ratio (SIR) that shall be accommodated by the modem while maintaining a BER of 10^{-4} for several different types of interference. In order to obtain the stated performance it may be necessary to implement excision filters in the demodulator.

The signal to noise ratio (SNR) is defined as the ratio between the signal and noise levels, and is usually expressed in decibels (dB). 0 dB means the ratio is 1, the signal and noise power levels are the same. a 10 dB SNR means the signal power is 10 times the noise power, 20 dB means the signal is 100 times (it is a log based scale). These are for power values, for voltage ratios the SNR is twice the power value. A SNR of 0 dB would just be barely detectable, in practice you need a few dBs for even a weak signal, and a SNR of 30 or 40 dB is considered an excellent quality signal.

For a correlation to MIL-STD-188-110B 5.3.2.5 Performance requirements. TABLE XX. In terms of S meter reading only, the International Amateur Radio Union (IARU) Region 1 agreed on a technical recommendation for S Meter calibration for HF and VHF/UHF transceivers in 1981. IARU Region 1 Technical Recommendation R.1 defines S9 for the HF bands to be a receiver input power of -73 dBm. This is a level of 50 microvolts at the receiver's antenna input assuming the input impedance of the receiver is 50 ohms.

S-reading	HF		Signal Generator emf
	µV (50Ω)	dBm	dB above 1uV
S9+10dB	160.0	-63	44
S9	50.2	-73	34
S8	25.1	-79	28
S7	12.6	-85	22
S6	6.3	-91	16
S5	3.2	-97	10
S4	1.6	-103	4
S3	0.8	-109	-2
S2	0.4	-115	-8
S1	0.2	-121	-14

APPENDIX B

MIL-STD-188-110x
Software available and supported at
http://groups.yahoo.com/group/MARS-ALE/

MARS-M110A: The M110A Data Message Terminal (DMT) started life as a test bed tool for development and testing of the MIL-STD-188-110A modem core as used in PC-ALE and MARS-ALE. It is now being developed into a full featured application for the needs of MARS. At present it provides for MIL-STD-188-110A ASYNC and SYNC modes with data rates from 75bps through 2400bps coded and 4800bps uncoded and is being developed to fully meet the modem performance requirements of MIL-STD-188-110A section 5.3.1.1.

MARS-ALE: The MARS-ALE toolset contains an integrated MIL-STD-188-110A section 5.3.1.1 modem and FED-STD-1052 Appendix B, Data Link Protocol (DLP) controller capability. The DLP is available for use with all modes (ARQ, BRD, FTP) currently supported during an ALE inlink state and the BRD is also supported when in MARS Immediate Link State (MILS). The DLP has never been verified for interoperability with any hardware system. For testing the MARS-M110A DMT tool, basic ASYNC has recently been added, but is not fully coded beyond a basic useable level and has not been released for ALE follow on use.