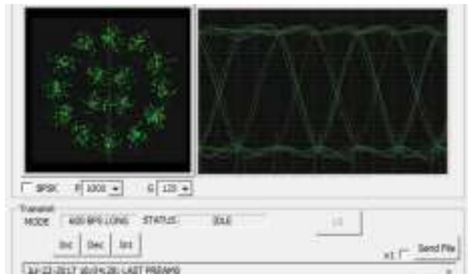

# MIL-STD/STANAG
# Data Modem Primer

Version 1.09
POC for this document is:

support@marsale.org

**Data Modem Primer v1.09**

## ABSTRACT

This document is written for the benefit of the MARS member in gaining a better understanding of U.S. Military and NATO HF Data Modem standards. However the reading of this document is not required for the use of any hardware or software defined military modem solutions applicable to support of the MARS mission.

The majority of MARS members are Amateur Radio licensees which serves as a very good basis of HF radio knowledge and experience. An Amateur Radio license is also a prerequisite for becoming a MARS member. However, few Amateur Radio practices, equipment and digital modes intersect with MARS operational needs and the interoperable requirements of our MARS Military sponsors which are vastly different.

In addition data encryption is not authorized on the Amateur Radio bands. However when you are operating as a MARS member, you are operating as a DoD radio station. In that regard, in MARS the goal is that every digital transmission sent over the HF radio be encrypted for transmission to provide Operational Security (OPSEC). As such the data being handled by MARS may be sent in the clear as Plain Text (PT) or Encrypted Text (CT) and in the future by using Secure Voice (SV).

The MARS primary mission is to provide contingency HF communications support to DoD and the Military Services. MARS also performs HF communications training with active duty, reserve and National Guard units. The HF SSB transceiver predominately available to these units is the AN/PRC-150(C) HF-ALE tactical transceiver, where the new AN/PRC-160(V) is also now being fielded. It is a level of digital communications interoperability with these HF-ALE tactical transceivers that is a focus of MARS interoperability.

As such the MARS member most strive to learn and be proficient in Military HF communications procedures and work to achieve interoperability to the Military Standards for both voice and digital communications in order to directly support the MARS mission.

The purpose of this paper is to provide the MARS member with a better understanding of the Military digital waveforms detailed in both U.S. Military Standard (MIL-STD) and Standardized Agreement NATO (STANAG) requirements as normally implemented in hardware based HF Data Modems and HF Tactical Radios used by both MARS Military sponsors and MARS customers.

Also covered in passing for familiarity are Data Link Protocol (DLP) based ARQ and Non-ARQ Multicast, Client/Server based HF e-mail, FAX and Digital Secure Voice use of these data modem waveforms and where applicable how HF-ALE in both 2G and 3G implementations ties into the picture. Then too the use of in the clear and encrypted communications is brought into perspective.

The Military waveforms data modem standards, in particular MIL-STD-188-110A[1] (MS110A) Serial Tone (ST) waveforms, provide for Point-to-point and Point-to-multipoint communications in MARS directed Net operations and scheduled Broadcast application.

MARS heavily relies upon the MS110A ST Forward Error Correction (FEC) coded 75bps through 2400bps data rates along with tactical chat header use for interoperability and data

encryption for OPSEC with use of MARS specific external terminal software applications without the use of ARQ overhead.

The Military HF waveforms of interest to MARS conform to a number of U.S. MIL-STD and STANAG standards. In addition to the legacy MS110A serial tone 75..2400bps coded waveforms, also of interest are the MIL-STD-188-110B[2] (MS110B) Appendix C waveforms providing 3200..9600bps throughput. In addition MIL-STD-188-110C[3] (MS110C) Appendix D 3kHz waveforms now being fielded in PRC-160(V) tactical radios and some COTS hardware modem offerings will be of interest to MARS in the near future. Also of interest are STANAG standards S4285[4], S4415[5] and S4539[7] where S4415 is a much more robust 75bps only standard as to modem the receiver capability and is interoperable with MS110A at 75bps.

Although this document provides some level of technical details regarding many of the Military waveforms of interest. It does so for the purpose of a basic understanding of how the waveforms work and to explain the differences and enhanced features of the various waveforms in comparison for the benefit of the reader.

The actual modem waveform descriptions 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) 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 ongoing synchronization or late entry and the demodulation process. Also included are the details of forward error correction coding, bit redundancy and bit interleaving as an integral part of the definition.

The referenced MIL-STD and STANAG waveform documents herein combined with other Military standards which detail Data Link Protocols (DLP) layers and Cryptography (CRYPTO) provide the specifications for Military communications systems by describing the on-the-air signaling used to transmit the digital data signal over a radio channel for intercept and decoding by the intended receiving station(s).

## REFERENCES

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**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/

## Data Modem Primer v1.09

## 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
BLOS - Beyond Line of Sight
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

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## DEFINITIONS

Broadcast And Ship-Shore (BRASS): NATO Naval broadcast network of shore-based stations to support and improve naval BLOS 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.

Differential Phase Shift Keying: Modulation scheme that conveys data by changing the phase of the carrier wave.

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/ACP-142A are standards for multicast data transport used for Normal and EMCON support. An ACP-142x sender will handle Non-EMCON and EMCON destinations as specified in ACP-142x. For disabled receivers, no transmissions will be made. This saves resource and allows transmissions to other destinations. The standard ACP-142x 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 de-interleaved stream of symbols in their natural order as reconstructed at the receiver more uniform than may occur without the interleaving and de-interleaving steps.

Late Entry: Synchronization after the start of the data transmission.

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.

Parallel tone modem: Carries information on simultaneous audio tones, where each tone is modulated at a low keying (symbol) rate per carrier tone.

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.

Quadrature Differential Phase Shift Keying (QDPSK): Modulation scheme where the data is represented as a shift in the phasing of an audio tone that can take 4 (quadrature) possible states, modulates each of these tones. These phase shifts are then distributed, interleaved, and synchronized over the sub-carrier tones contained in the narrow band (voice) channel

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 signaling events) made to the transmission medium per second.

Time Diversity: Time Diversity is obtained by interleaving and coding over symbols across different coherent time periods within the waveform.

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 receiver.

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## INTRODUCTION

For MARS members unfamiliar with the subject matter, this paper will put Military HF waveforms and data link protocols used with them into perspective. The high speed Serial Tone (ST) modem waveforms are of particular interest given their use in data communications for the bulk of current MARS HF digital communications. These ST waveforms provide robust Forward Error Correction (FEC) with selectable interleaving which effectively combat the effects of channel Fading, Doppler spread, Multipath and Noise bursts.

The use of the MS110A serial tone waveforms in basic FEC only application by MARS is the current workhorse. MS110A ST is similar in application within MARS to the use past use in MARS of MT-63, however MS110A provides for much faster throughput in comparison. In addition the MS110A ST waveforms are Autobaud detect which means the users do not need to setup in advance to the proper configuration to decode the sending station and two or more stations sending can make use of different data rates and interleave selections.

Military data modems do not include Data Link Protocol (DLP) support for Automatic Request Query (ARQ) or Broadcast (BRD) mode based error free communications. This is an area where Military modems are much more versatile than Commercial modems or Amateur Radio Terminal Node Controllers (TNC). By design a Military modem can be wired for land line or two-way application. A Military modem can then be used to carry any type of data using its FEC waveforms that can be coded into a binary data stream to include voice and imagery.

The MS110A ST waveforms when coupled with the 1996 FED-STD-1052 Appendix B. DLP will provide for Automatic Station Identification in the Link Creation for either Adaptive ARQ or Broadcast (BRD) mode based error free communications. The use of MS110A with FS-1052 ARQ can be compared to the use of PACTOR III for one-to-one linked station error free messaging. Whereas the use of MS110A with FS-1052 ARQ and an IP based Tactical Chat protocol that provides for messaging and file attachments and can be compared to the use of PACTOR III or WINMOR coupled with WL2K/FBB2.

The legacy MS110A ST waveforms, which are also defined in FED-STD-1052, are widely used by all NATO forces for HF digital communications. The MS110A legacy waveforms have been carried forward through the new MIL-STD-188-110D[24] and have been modified for Naval use in Link-22 (STANAG 5522). It is the ST waveforms which have found the most favor with Military users over the last 25 plus years due to outperforming MIL-STD FSK RTTY and the optional MS110A Appendix A parallel 16 tone DPSK (1.8kHz BW) and the Appendix B 39-tone QDPSK (2.5kHz BW) Orthogonal Frequency-Division Multiplexing (OFDM) waveforms. The OFDM waveforms are similar in many respects to later development of the 16 tone PACTOR III OFDM waveforms.

The 39 tone modem is also defined in FED-STD-1052 Appendix A. The 39 tone modem can be used for Data, Image or Digital Voice. A derivative 16/39 tone waveform detailed in STANAG 4197 was developed specifically for Linear Predictive digital voice within NATO where the 16 tone modem is used as the preamble and the 39 tone for the data.

The MIL-STD Appendix A, 16 tone waveform is now officially obsolete having been removed from MS110C. However the MIL-STD 39 tone modem although retained through the new MS110D, has been deemed to be obsolete according to Dr. Eric Johnson in an HF Industry Association (HFIA) “MIL-STD Technical Advisory Committee” presentation on the continuing revisions of “U.S. Military HF Radio Standards”. However the 39 tone modem is still found in current U.S. Military HF tactical radios manufactured by Harris and airborne HF radios manufactured by Rockwell and some external hardware modems such as the Rockwell MDM-Q9604 are still being fielded with the 39 tone modem as it is widely available in U.S. Government equipment still in use and the basis of HF Frequency Hopping. The MS110A ST waveforms have been proven to perform twice as good as the 39 tone modem in dealing with multipath channel conditions.

In the tactical HF radio world today it is serial tone waveforms that are most common in Military use, both with data modems and with the 3G ALE modem burst waveforms which are for the most part based on the MS110A 600bps coded and MS110B 4800bps coded waveforms. The benefits of serial tone waveforms and burst mode operation has been recognized by SCS with their PACTOR IV modem implementation which provides serial tone modem burst waveforms using an 1800 baud symbol rate centered on 1500hz to achieve a 2.4kHz BW and throughput approaching that of the 3G ALE waveforms in single channel operation.

In the MIL-STD hardware modem world, MS110A/B modems mostly exist as external hardware units similar to an Amateur Radio TNC. They can also exist as internal options for COTS HF-ALE transceivers and as embedded modems such as the MS110B modem capability in the Harris AN/PRC-150(C) (and non-ITAR RF-5800H-MP) family of radios which also provide STANAG 4285, 2G ALE/AQC-ALE/pFS-1052B DLP (for ARQ and BRD) and 3G ALE to S4538. The new Harris RF-7800H and AN/PRC-160(V) family has added MIL-STD-188-110C main body support to include Wide Band Appendix D from 3kHz through 24kHz waveforms.

It is the legacy MS110A ST waveforms of 75bps through 2400bps coded and 4800bps un-coded (no FEC or interleaving) and in many cases no other ST waveform that are found in the MIL-STD hardware modems and HF-ALE radios that many MARS members have acquired as both used and new acquisitions. In MARS the MARS-ALE software defined solution provides both 2G ALE/AQC-ALE modem/controller capability and MS110A ST modem with FS-1052B DLP for BRD, ARQ and FTP.

MARS members for the most part use MS-DMT and MARS-ALE. Many have purchased surplus modems, some only MS110A capable and some capable of various STANAG waveforms, where some also have MS110B class modems. Most of the new hardware modems being purchased are upgradable to more than MS110A, but due to the cost new, they are usually purchased with just MS110A installed. The use of these hardware modems at present within MARS are being limited MS110A FEC application at present due to no terminal software being implemented in MARS with support for ARQ.

The MS-DMT and MARS-ALE tools that the bulk of the MARS membership rely on currently use an AC'97 compliant PC Sound Device as the hardware modem component in their software defined modem solution approach. At present these two tools provide support for MS110A and are S4415 compliant at 75bps. However S4285 and MS110B/S4539 are under development and 3kHz MS110C Appendix D waveforms are planned for development.

The use of a hardware MS110A modem can be coupled with anything from a dumb ASCII RS-232 DTE ASYNC terminal to an RS-232 SYNC DTE Secure Voice terminal application. Hardware modems are usually wired via their data port using RTS for PTT where the modem front panel is used for setup and operating parameter control. In addition to front panel control for setup and operating parameter selection, remote control is also provided. Some new external hardware modems offer now front panel control. The remote modem control may be ASCII like commands or binary, usually proprietary command sets even though STANAG 5066 ANNEX E proposes a command set. The remote control and the data flow for message payload require two separate serial ports when using PC software for both. Most MIL-STD hardware modems do not provide anything other than coded and un-coded FEC operation, whereas an Amateur TNC itself provides for ARQ operation in its firmware. A hardware MIL-STD modem relies on software or dedicated messages terminals for ARQ operation aside from tactical HF radios and Tactical Terminals with embedded modems.

The MS-110A ST waveforms with their auto-detect (or autobaud) capability have served as the basis of both new MIL-STD and STANAG Military as well as Commercial serial tone waveforms. This lineage is evident in S4415, MIL-STD-188-110B Appendix C (S4539 being nearly identical) and ARINC 635[23] HF Data Link (HFDL) at 1800 baud symbol rate with 300, 600, 1200 or 1800 bps waveforms. Being Auto-detect waveforms, the MS110A/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.

The 150bps through 4800bps MS110A ST waveforms use 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 baseband modulated signal of 300-3300hz prior to radio filtering. At 75bps there is no PSK carrier as it is WALSH modulation Direct Digital Synthesis (DDS). The 2400 baud symbol rate and 1800hz PSK carrier has been retained in the need for higher data rates by the Military than those provided by the legacy MS110A waveforms.

The MIL-STD-188-110B (and later STANAG 4539) standard added a number of new coded waveforms from 3200bps to a top end of 9600bps within a 3kHz channel. The release of MS110C, in Appendix D., detailed a new family of serial tone waveforms that also extended the high performance serial tone modem technology beyond the MS110B 9600bps coded limit in a single 3kHz channel to 16,000bps coded using a 256-QAM waveform. These new MS110C Appendix D 3kHz waveforms start at 75bps and have all the data rates of MS110A and MS110B but are not interoperable, they provide for very much improved performance over the previous waveforms at each data rate as well.

The MS110C Appendix D wideband waveforms can also occupy bandwidths from 3kHz up to 24kHz providing up to 120,000bps coded throughput by stacking multiple HF Independent Sideband (ISB) channels. The use of an ISB channel (6kHz) doubles the throughput of SSB channel. A 2ISB channel doubles it again and a 4ISB channel (24kHz) achieves the top end 120,000bps coded throughput. The increase in throughput with each additional 3kHz channel is similar to the OFDM approach in that each 3kHz channel represents and additional PSK carrier of modulation. The new MS110D Appendix D extends the wideband support to 48kHz. MARS however is limited to a single SSB channel (3kHz) at present, perhaps as more MARS members move to SDR transceivers, at some point we too can approach the use of ISB with Left and Right Channel PC sound device audio to double our throughput for server forwarding applications.

HF transmission and reception is subject to varying levels and types of noise and interference which cause data errors. Military HF waveforms use data spreading 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 waveforms 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 time diversity is applied in real time using a process called interleaving 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 de-interleaving steps. Interleave 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 interleave selections are provided for in MS110B and MS110C Appendix C. and S4539 waveforms mainly in support of Adaptive ARQ application. It is interesting that in MS110C Appendix D the settled on only 4 interleave selections.

When using MS110A in basic FEC ASYNC or SYNC RATT application vs. Adaptive ARQ, 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 by the MS110A transmitting station is their power level and whether 100w or less or perhaps higher power levels are being used and the effect of the power level providing a strong enough signal to meet the required SNR for the AWGN channel conditions for the data rate selected taking into consideration 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 interleave is likely the best choice for all channel conditions using MS110A ST for RATT, 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.

In Military application the use of a Data Link Protocol for either ARQ or Non-ARQ is used for error free communications. ARQ is used Tactical Chat and Client/Server applications run over it to provide for either one-on-one linked or IP based networks to facilitate Messaging or HF e-mail with the option of file transfers. The use of STANAG 5066 IP based networks which can be thought of as being an HF radio based version of the Internet is a prime example where for HF e-mail, HTML, FTP and more can be configured using many of the same standards or standards similar to those used via the Internet, such as RFC 821, “SIMPLE MAIL TRANSFER PROTOCOL”. However we are not to the point of using STANAG 5066 in MARS and may never use it for the MARS mission due to the complications involved.

MIL-STD modems can be used stand alone or in conjunction with Automatic Link Establishment (ALE) for follow on communications. ALE/MS110A/DLP can be used as an Automatic Link Maintenance (ALM) system configuration, which is the case with 3G STANAG 4538 and optionally 2G ALE/STANAG 5066. ALE 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 4538 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. It is S4538 3G ALE which the author sees as having the most potential in MARS operations, many of the complications of STANAG 5066 do not exist, but the capabilities are very similar as to network transport of data.

In addition to data, MS110A, STANAG 4285 and other waveforms operating at 600, 800, 1200 and 2400bps data rates are used for Digital Voice communications per LPC-10 (STANAG 4198), LPC-10e (FED-STD-1015), MELP (MIL-STD-3005) and MELPe (STANAG 4591) standards. MELP and MELP-e are interoperable. Digital Voice 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.

The MS110A software defined modem running on the PC Sound Device provided by MARS-ALE and MS-DMT have been tightly integrated with the application. However MS-DMT is now basically being used as standalone Virtual MIL-STD modem similar in concept to the WINMOR Virtual TNC. It supports use on the same PC terminal applications being used by MARS on the same PC using a VSP null modem or via a separate PC platform over a physical Null modem cable. As a Virtual MIL-STD modem it can be used to provide support for any application that a hardware modem can be used under external software control. This can range from ARQ for Client/Server applications to Digital Voice using MELPe. For MARS applications, developers of software applications shall have to specifically support each make/model of hardware modem for ARQ applications and the same is true of MS-DMT where a full remote control command set is provided. MARS-ALE will soon be updated to provide the needed features developed in MS-DMT to provide for external terminals to utilize its MS110A modem capability.

## HF TRANSCEIVER REQUIREMENTS

The MS110A ST waveform places 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 IF BW filtering. To achieve full performance with MS110A the 2.75kHz and group delay 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.

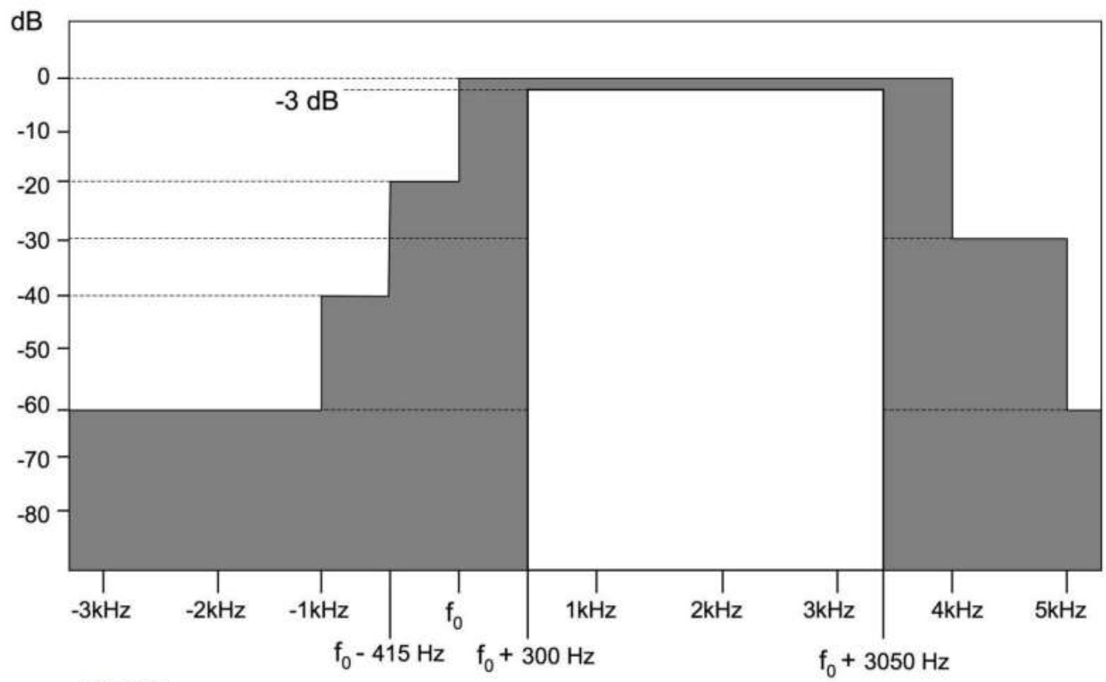
- Radio bandpass of 2.75kHz (3kHz nominal military channel) is required where variations in attenuation at most are +/-2db and a Group Delay time over 80% of passband must not be more than .5ms.

- AGC time constant must be less than 10ms on desensitization and less than 25ms on re-sensitization for full ST performance.

As the Symbol Rate is fixed at 2400bps, the passband never changes regardless of the user selected data rate, thus radios with lower than STANAG 4203 filtering will not be able to obtain the full range of performance in data rate selections and will be limited to lower data rates.

The nominal Military HF 3 kHz channel is to NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management. Where Single-channel SSB operation in 3 kHz channels is specified as: The amplitude vs. frequency response between (f0 + 300 Hz) and (f0 + 3050 Hz) shall be within 3 dB (total) where f0 is the carrier frequency. The attenuation shall be at least 20 dB from f0 to (f0 - 415 Hz), at least 40 dB from (f0 - 415 Hz) to (f0 - 1000 Hz), and at least 60 dB below (f0 - 1000 Hz). Attenuation shall be at least 30 dB from (f0 + 4000 Hz) to (f0 + 5000 Hz) and at least 60 dB above (f0 + 5000 Hz) as detailed in the following graphic from MIL-STD-188-141C.

MIL-STD-188-141C
w/CHANGE 1




NOTES:

1. Channel response shall be within shaded portion of curve.
2. $f_0$ for a single channel is the carrier frequency.
3. $f_0$ for 2-channel ISB is the center frequency.

The Military Serial Tone modem waveforms using 2400 baud symbol rate inclusive of MIL-STD-188-110A/B/C, STANAG 4285, 4415, 4539 and 3G ALE at their audio baseband modulating an 1800hz carrier for a baseband modulated signal of 300-3300hz (3kHz) bandwidth that is then passed through a STANAG 4203 compliant filter of 2750hz to be compliant with the nominal 3khz HF channel.

As such it is only S4203 filters that provide the proper filtering for the best performance of these Military waveforms. Filters that are greater in bandwidth with the same S4203 characteristics otherwise will not adhere to the spectral emission requirements. Filters that are narrower in bandwidth or of proper bandwidth but otherwise not meet S4203 requirements will adhere to the spectral requirements but will not provide for optimal results in passing these waveforms. The 2.75kHz passband where variations in attenuation at most are +/-2db and a Group Delay time over 80% of passband must not be more than .5ms are key factors in the waveforms performance.

Some Military modems allow for the use of a non-standard 1650hz or 1500hz PSK carrier selection where all stations in the net either use the non-standard carrier or where a station with a less than 3kHz IF filter can tune off dial frequency, e.g. by 300hz when using the 1500hz alternate selection to move the signal lower into the passband of their radio while operating data to pass more of the waveform through their narrow filter. As most analog Amateur Grade radios have 2.1 to 2.4 kHz SSB ceramic filter, using the optional PSK carrier allows moving further down into the passband of the radios filter, those with IF DSP and SDR radios may have more options. The use of an optional carrier selection makes mixed Data/Voice channel communications more complicated due to the need of changing frequency between data and analog voice operation.

## 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 verses just a mode selection at the click of the mouse. 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 USB ports have come into being as the standard. Some hardware modems provide configuration in accordance with the 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 known as "High Speed Async".

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 standard in use, there may be a Start of Message (SOM) sequence sent prior to the message characters, which if being looked for, will preclude decoding if not present. An End of Message (EOM) sequence or just EOM, is sent as standard after the data payload has been sent and the terminal drops its PTT signal. The EOM may optionally be disabled in the configuration of some modems. When the EOM is not sent, the receiving modem must be configured to reset on either a specific number of interleaver blocks for the modem standard 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 bit 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 or held in a buffer until the entire block is received. Asynchronous systems eliminate the need for complex and now costly synchronization interfaces, but at the cost of higher overhead than synchronous systems. With ASYNC the start and stop bits increase the length of the character by 25 percent or more over SYNC operation due to this framing, which not only makes SYNC more efficient in that regard, but also less prone to poor channel conditions.

In SYNC mode data transmissions as with Synchronous serial ports, the start and stop bits are eliminated and thus not sent over the air. SYNC is used for binary data streams such as with ARQ, Crypto terminals and Digital Voice (Vocoder). However it does support sending ASCII messages as well.

The use of EOM is standard with SYNC as with ASYNC but can be inhibited when any DLP is used for BRD, ARQ and Digital Voice protocols which completely fill blocks (or nearly so) of the selected data block size (interleaver block) and provide for their own EOM in the DLP. 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.

MIL-STD modems require two ports for interfacing, one for Data and one for Remote control. 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 that for Synchronous operation, use of an expensive serial port adapter is required that is USB, PCcard or Firewire based is required for serial interfaced SYNC based ARQ, Digital Voice and other uses. Asynchronous serial adapters are much more common and thus inexpensive. Many recent hardware modems have also started to provide TCP/IP ports as standard or optional and the new 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. The remote control protocol for most hardware modems and embedded modems in tactical radios is usually an ASCII based protocol, however some modems make use of structured binary handshaking protocol and some manufacturers do not provide the details of their protocol as they consider it to be proprietary.

In MS110A 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 MS110A 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 sending the EOM sequence that is the mode they are using period, they don't just use their mouse or radio menu to select modes, they physically need to re-cable and reconfigure. Thus for a MARS members using a hardware modem its best to configure for what is commonly being used the most in their MARS operations as they can't change on the fly. For the software modem, a user's life is much simpler as the various modes can be selected by a mouse click.

## 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.

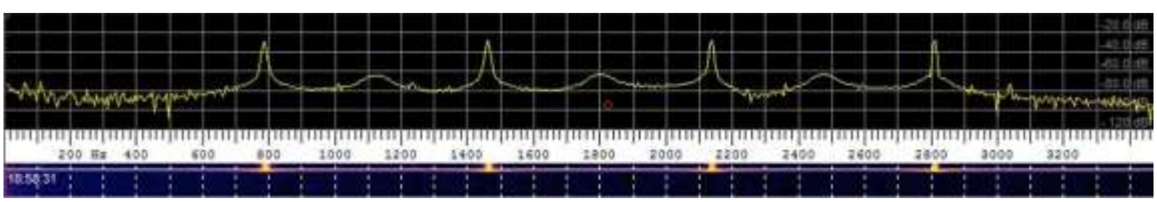
In MARS our main interest at present is the MIL-STD-188-110A section 5.3.1.1 Serial Tone waveforms, which are the same serial tone waveforms detailed in FED-STD-1052. These legacy serial tone waveforms have been found superior to both the 16 tone DPSK and 39 tone QDPSK parallel waveforms to the point where the 16 tone has become obsolete as of MIL-STD-188-110C with the 39 tone modem being retained for now although also noted as being obsolete.

Fundamentally the 16 and 39 tone modems are similar, however the addition of the error control code gives the 39 tone modem a significant performance advantage. The 16 tone OFDM (75 baud symbol rate per carrier with 2 bits of data per symbol) modem is uncoded only and transmits data at a rate of 2400 bps (16 x 75 x 2) offering user selected data rates of 75, 150, 300, 600, 1200 and 2400bps.  As to stand alone used the 16 modem is obsolete, however in some standards its used as a preamble signaling mechanism prior to use of the 39 tone modem.

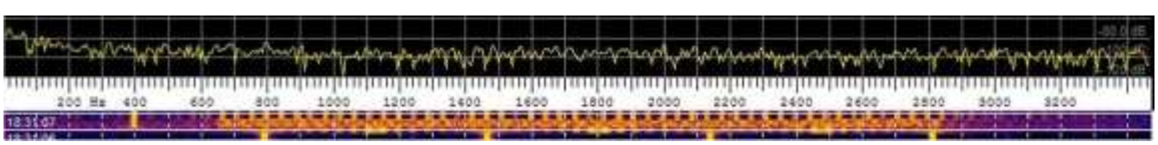
### MS110A 39 Tone Modem

As of the new MS110D standard, the Appendix B, 39 tone OFDM modem still exists. It operates at a 44.44 baud symbol rate per carrier tone with 2 bits per symbol. The modem uses 3.5-ms guard time frequency separation set to the inverse of the symbol rate to prevent modulation on one tone from interfering with reception of another.

The screen capture below is of the Preamble prior to transmission of the data, a three-part preamble is transmitted. The first part of the preamble as depicted here consists of 14 signal elements (symbol periods) long, and consists of four equal-amplitude unmodulated data tones of 787.5, 1462.5, 2137.5 and 2812.5 Hz.



Then During data transmission a 40th tone, an un-modulated 393.75hz Doppler correction tone is sent at 6 dB ±1 dB higher than the normal level of any of the data tones as seen below immediately after the preamble completes.



The modem uses shortened (14,10) Reed-Solomon block coding to provide strong Forward Error Correction (FEC) and selectable diversity interleaving of SHORT (0.0 s) which equates to NONE in other modem standards, LONG (6.0 s), ALTERNATE SHORT (0.50 s) and ALTERNATE LONG (2.0 s) are also specified. The Digital Voice use interleave options which are only valid for SYNC mode operation are SHORT (0.0 s) and LONG (0.15 s) with ALTERNATE SHORT (0.30 s) and ALTERNATE LONG (0.45 s).

The modem provides a raw rate of 3466bps (39 tones x 44.44 baud x 2 symbols) which after the inclusion of Reed–Solomon (14,10) block code error-control coding results in a final rate of 2400bps. The modem provides user selectable over-the-air data rates of 75, 150, 300, 600, 1200 and 2400bps for bit synchronous data transmission and asynchronous operation. The 39 tone modem achieves high data rates without having to perform equalization on the channel as does the MS110A serial tone modem, which would result in a significant drop in CPU processing power needed for the 39 modem DSP. In addition the 44.44 baud symbol rate results in less demand on the common 16 bit PC sound device, another potential benefit for the PC sound device use as the data modem under MS-Windows.

**MS110A Serial Tone Modem**

The MS110A serial tone waveforms, also current as of MS110D, are 8 level M-ary Phase Shift Keying (8-PSK) modulated waveform structures on a single carrier frequency 150bps through 2400bps with convolutional coding (Coded) and 4800bps in an un-coded form. 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.

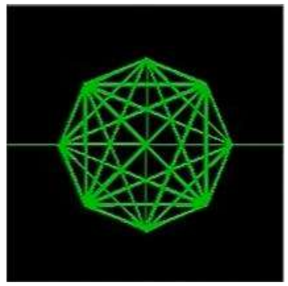
The MS110A ST 75bps data rate provides robust performance, uses a Direct Sequence Spread Spectrum (DSSS) scheme where a low data rate signal is modulated with a high rate pseudorandom sequence producing a 3kHz signal with a small amount of noise for the conventionally modulated signal. Some MS110A hardware modems provide S4415 performance at 75bps, as does MS-DMT and MARS-ALE.

| 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 |

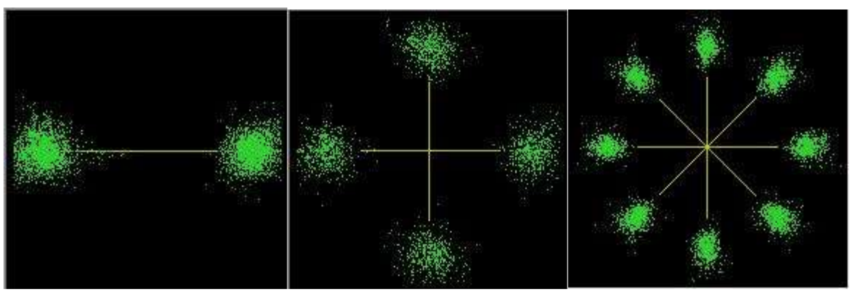
The MS110A user selectable over-the-air data rates are coded Walsh modulation at 75bps and coded BPSK at 150bps, 300bps, 600bps, QPSK at 1200bps and 8-PSK at 2400bps all scrambled to appear as 8-ary PSK over-the-air and un-coded 8-PSK at 4800bps.

The PREAMBLE phase at the beginning of an MS110A transmission is used to determine the condition of the channel and the required synchronization factors as well as to convey the data rate and interleave selection for autobaud detection to the receiving terminal. During the PREAMBLE phase coding is common to all waveforms and robust Walsh modulation is used to punch through the worst channel conditions.

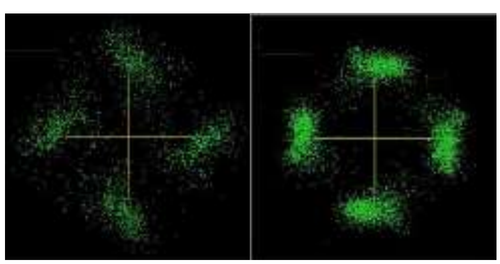
The modes 150..4800bps are always sent as 8-psk over-the-air for the Data phase, even though the modulation may not be 8-psk. The data symbols can be displayed on a Constellation display for all but the 75bps mode. A Constellation line mode display is seen below as captured from MS-DMT. The 75bps WALSH modulation being Direct Digital Synthesis does not correlate to a display of symbols on a conventional Constellation symbol display.



The Constellation display captures from MS-DMT below are of incoming data symbols during the data phase from left to right in their actual BPSK/2-PSK, QPSK/4-PSK and 8-PSK representation for each data rate where 150, 300 and 600bps is BPSK, 1200bps is QPSK and both 2400 and 4800bps are 8-PSK. In MS-DMT the user can select to display in 8-PSK for all data rates or the actual modulation being used.



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. The QPSK constellation display captures from MS-DMT below depict such fading and rotation of symbols.



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 MS110A 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 MS110A wavefom structure has 3 main sections, the Preamble, the “unknown data” (which is the message data payload), and the known data (the probe data to maintain sync) and supports the concept of “autobaud” for its waveform detection. The autobaud feature embeds known information (a constant pattern defined in the modem standard) into the waveforms preamble about its data rate and interleaver depth. The modem receiver 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 and STANAG 4285 or 4529. The “unknown data” of the waveform when such blocks are populated, is Forward Error Corrected (FEC) to produce error protection on the data stream where the lower data rates generally have higher levels of FEC.

However this preamble negotiation only happens on the initial radio link and it is not re-negotiated during data transfer in basic MS110A operation. Thus the link could be lost on a channel operated over a period of time with ever degrading channel conditions. The preamble length is 1440 symbols for SHORT interleave whose time duration at 2400 baud is 0.6 seconds. The preamble length is 11520 symbols for LONG interleave, whose time duration is 4.8 seconds.

The “known data” or “probe data“ sequence blocks are sent alternating with the “unknown data” (message payload data) after the preamble which only provide 1/100$^{th}$ of the amount of data symbols as does the preamble as a means to equalize to maintain sync or to attempt to sync on. These on-going probe blocks allow the modem receiver to touch up the sync. The probes are a series of zeros that are scrambled by the same pseudo-random sequence as the unknown data and mapped to an 8-PSK constellation. The length of the unknown data frame and the probe are determined by the selected over-the-are data throughput rate.

| Data Rate | Bits/Symbol | Unknown Data Length | Probe Data Length |
|---|---|---|---|

| | | | |
|---|---|---|---|
| 75 | 2 | ALL | 0 |
| 150 | 1 | 20 | 20 |
| 300 | 1 | 20 | 20 |
| 600 | 1 | 20 | 20 |
| 1200 | 2 | 20 | 20 |
| 2400 | 3 | 32 | 16 |
| 4800 | 3 | 32 | 16 |

Some hardware modem vendors have also provided the ability to sync on the unknown data which has been called “Acquisition on Data” or “Sync on Data” or “Late Acquisition”. This adds in maintaining sync as well as providing for late entry support when coming on frequency late or rather after the preamble has been sent.

The S4285 and S4529 coded data rates, although in common at a certain point to MS110A, e.g. no 2400bps in S4529 as found in MS110A, have greater interleaver time lengths, thus actual throughput will be slower for the same given data rate when compared with MS110A

MS110A when operated in ASYNC or SYNC RATT, the EOM sequence is usually used. When operated in SYNC with a Data Link Protocol the EOM sequence is not required as the DLP resets the modem.

MS110A being auto-detect waveforms lends itself to the modem’s parameters being adapted to meet changing channel conditions in Adaptive ARQ operation where the modems settings due to supporting auto baud operation can be changed for TX automatically and independently on each side of the connection.

## MIL-STD-188-110B

MIL-STD-188-110B includes all of the waveforms defined in MS110A where the ST 75bps waveform is considered the Low Speed Robust data rate and 150-2400bps are the Medium Speed data rate waveforms. The 75-2400bps ST waveforms are considered the Legacy ST waveforms, as originally defined in MS110A. The legacy waveforms are held to the same performance requirements detailed in MS110A. Some MS110B modems provide S4415 performance at 75bps.

However MS110B Appendix C (which is nearly identical to STANAG 4539 Annex E.) defines High Speed waveforms with data rates of 3200, 6400, 4800 (replacing the MS110A un-coded) 8000 and 9600bps coded and the 12800bps un-coded waveform. The ST waveforms specified in Appendix C use modulation techniques of greater complexity and data blocks larger than those found in MS110B section 5.3.2 and MS110A section 5.3.1.1 in order to achieve the efficiencies necessary to obtain the required data rates. These new waveforms are both auto baud and preamble reinserting during transmission to maintain sync and provide for late entry.

| 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 |

The modulation types added in MS110B Appendix C, are Quadrature Phase-Shift Keying (QPSK) used at the 3200bps data rate which is scrambled to appear on-air as an 8-PSK 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 8-PSK and is coded vs. being uncoded as in MS110A.

The symbol rate for all MS110B waveforms is retained as 2400 baud (symbols-per-second) as found in MS110A. The subcarrier (or pair of quadrature sub-carriers in the case of QAM) are centered at 1800hz and accurate to a minimum of 0.018hz (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 MS110B section 5.3.2 (and MS110A). Because of this sensitivity, radio filters will have an even more significant impact on the performance of modems implementing the new waveforms in MS110B 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 MS110C 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 which means VOX PTT systems that work with MS110A waveforms may be out of the question in software defined modem implementations.

The Interleaver choices for the new waveforms 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 as with MS110A, since the time delays would not be reduced. At 3200bps and above the Short and Long selections having different time durations compared to MS110A legacy waveforms of 0.6s for Short and 4.8s for Long.

| | | |
|---|---|---|
| **ULTRA SHORT** | **US** | **0.11958333s** |
| **VERY SHORT** | **VS** | **0.35875s** |
| **SHORT** | **S** | **1.07625s** |

| | | |
|---|---|---|
| **MEDIUM** | **M** | **2.1525s** |
| **LONG** | **L** | **4.305s** |
| **VERY LONG** | **VL** | **8.61s** |

With MS110B when operated in ASYNC and SYNC RATT, the EOM sequence is usually used. When operated in SYNC with a Data Link Protocol the EOM sequence is not required as the DLP resets 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 auto-baud operation can be changed for TX automatically independently on each side of the connection over the entire coded range through 9600bps.

## MIL-STD-188-110C

MIL-STD-188-110C (MS110C) retains the legacy MS110A ST waveforms as well as the MS110B Appendix C waveforms in the MS110C Appendix C for backward interoperability.

However MS110C Appendix D provides for new, more robust autobaud ST waveforms within a 3kHz channel at all of the existing MS110B data rates and three additional data rates, 1600bps (BPSK) coded, 12,000bps (64-QAM) and the lightly coded 16,000bps (256-QAM) for ground wave use only.

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 |

In MS110C Appendix D, even the 75bps is still WALSH modulated, but doesn't retain interoperability with MS110A or S4415 in 3kHz operation. Which brings up the point that the PREAMBLE for each waveform is still sent using WALSH modulation as in MS110A and MS110B.

However the subsequent waveforms that correlate to MS110A and MS110B as to the given data rates have different modulation types, code rates, frame data symbols count and frame known symbols count for more robust performance.

The data rates of 150bps through 600bps remain as BPSK modulation, where 1200bps is now BPSK vs. QPSK, 2400bps is now QPSK vs. 8PSK and all higher data rates remain as QAM modulation.

In addition to SHORT and LONG interleave selections as found in MS110A, there exists ULTRA SHORT and MEDIUM which equate to 0.12s (US), 0.48s (S), 1.92s (M) and 7.68s (L) seconds respectfully. This is in contrast to the eight selections found in MS110B Appendix C where the additional selections beyond SHORT and LONG only applied to 3200bps and higher waveforms.

| | | |
|---|---|---|
| **ULTRA SHORT** | **US** | **0.12s** |
| **SHORT** | **S** | **0.48s** |
| **MEDIUM** | **M** | **1.92s** |
| **LONG** | **L** | **7.68s** |

| Data Rate | Modulation Type | Code Rate | Frame Data Symbols | Frame Known Symbols |
|---|---|---|---|---|
| 75 | Walsh | 1/2 | N/A | N/A |
| 150 | BPSK | 1/8 | 48 | 48 |
| 300 | BPSK | 1/4 | 48 | 48 |
| 600 | BPSK | 1/3 | 96 | 32 |
| 1200 | BPSK | 2/3 | 96 | 32 |
| 1600 | BPSK | 3/4 | 256 | 32 |
| 2400 | QPSK | 9/16 | 256 | 32 |
| 3200 | QPSK | 3/4 | 256 | 32 |
| 4800 | 8PSK | 3/4 | 256 | 32 |
| 6400 | 16QAM | 3/4 | 256 | 32 |
| 8000 | 32QAM | 3/4 | 256 | 32 |
| 9600 | 64QAM | 3/4 | 256 | 32 |
| 12000 | 64QAM | 8/9 | 360 | 24 |
| 16000 | 256QAM | 8/9 | 360 | 24 |

The reason for the US and M interleaver selections are obvious as to use in ACK/NAK DLP applications, however it would really have been nice if they implemented the MS110B VERY LONG (VL) as well or made LONG (L) the same 8.6s for 3kHz channel FEC only applications.

These waveforms feature a configurable constraint length parameter for two options: standard constraint length 7 (K=7) and a more robust constraint length 9 (K=9) coding which according to Rockwell Collins excels at digital voice application in CCIR poor channel conditions at 600bps by 3db over MS110B, at 1200bps by 0.5db and at 2400bps by 5db as seen in the chart below.

These new MS110C coded waveforms seem to be the limit for single 3kHz SSB channel operation, which is the current configuration of all MARS FAU's. The use of Independent Single Sideband (ISB) authorized FAU's will be required to increase throughput beyond that of 9600bps coded use on Skywave channels.

MS110C Appendix D provides for stacking ISB (ISB/6kHz BW, 2ISB/12kHz BW, 4ISB/24kHz BW, 8ISB/48kHz BW) channels out to 24kHz BW (120,000bps throughput) and the new MS110D Appendix D out to 48kHz (240,000bps throughput). The standard allows for incremental bandwidth steps of 3kHz vs. the full 6khz with each added ISB channel. However the use of an ISB 6kHz channel supports up to 19,200bps coded on Skywave, which is the maximum throughput that can be achieved on Skywave paths regardless of channel bandwidth. The RapidM company has an excellent visual chart breakdown published on their RM9 WBHF modem slick as seen below.

| Waveform Standards | B/width | Data Rates [bps] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 256-QAM | 64-QAM | | 32-QAM | 16-QAM | 8-PSK | Q-PSK | B-PSK | Walsh |
| MIL-STD-188-110C (Groundwave & Sky-wave) | 24 kHz | 120000 | 96000 | 76800 | 64000 | 51200 | 38400 | 25600 | 12800, 9600, 4800, 2400, 1200 | 600 |
| | 21 kHz | 115200 | 76800 | 57600 | 48000 | 38400 | 28800 | 19200 | 9600, 4800, 2400, 1200, 600 | 300 |
| | 18 kHz | 90000 | 72000 | 57600 | 51200 | 38400 | 28800 | 19200 | 9600, 4800, 2400, 1200 | 600 |
| | 15 kHz | 76800 | 57600 | 48000 | 51200 | 32000 | 24000 | 16000 | 8000, 4800, 2400, 1200, 600 | 300 |
| | 12 kHz | 64000 | 48000 | 38400 | 32000 | 25600 | 19200 | 12800 | 6400, 4800, 2400, 1200, 600 | 300 |
| | 9 kHz | 48000 | 36000 | 28800 | 25600 | 19200 | 14400 | 9600 | 4800, 2400, 1200, 600 | 300 |
| | 6 kHz | 32000 | 24000 | 19200 | 16000 | 12800 | 9600 | 6400 | 3200, 2400, 1200, 600, 300 | 150 |
| | 3 kHz | 16000 | 12000 | 9600 | 8000 | 6400 | 4800 | 3200, 2400 | 1600, 1200, 600, 300, 150 | 75 |

Groundwave Operation Only — Skywave Operation

The largest benefit in throughput with this 4G wideband technology is only achieved when ground wave propagation is possible. However the use of ISB/6kHz bandwidth provides a boost in throughput on both ground wave and skywave channels that would benefit back channel routing in an IP network between servers should MARS ever aspire to such an automated message system.

An analog ISB radio and standard stereo channel sound device such as the TI C5535 ezDSP board using LEFT and RIGHT channel would provide for the LSB and USB channels of the ISB mode. The use of ISB doubles the symbol rate from 2400 to 4800 baud and moves the PSK carrier from 1800hz to 3300hz. An SDR radio with VAC would however likely be the more common MARS user approach.

## MIL-STD-188-110D

At this time all things of interest to MARS regarding the technical aspects of the modem waveforms defined in MIL-STD-188-110D[24] are detailed in the preceding section on MIL-STD-188-110C. The wideband support of MS110D Appendix D has been extended beyond that of 24kHz in MS110C to 48kHz for a maximum of 240,000bps throughput, which is currently of no interest in MARS communications.

However there is interest in the now more mature non-mandatory MS110D Appendix A that originated in MS110C. At present it is being reviewed for consideration of implementation in both the MS-DMT and MARS-ALE applications for remote Data Modem support.

The interface detailed in Appendix A is designed to enable a Data Terminal Equipment (DTE) to interact with a modem via a data network over TCP/IP and UDP packets. The interface supports one DTE connection at a time for control the modem. All attempts by a second DTE to establish a connection shall be rejected by the modem.

The TCP-based protocol is specified in support of higher-performance networks, whereas the UDP-based protocol is geared for data networks that experience long delays or non-negligible packet loss rates. The standard states that both protocols shall be supported in all implementations of this appendix, even though it is a non-mandatory aspect of the standard.

## STANAG 4285

The S4285 waveform uses an 1800hz PSK carrier and 2400bps Symbol Rate as does MS110A, The performance criteria as to SNR are similar, however S4285 as better ongoing synchronization, which comes at a price. This waveform does not provide an autobaud capability. As such both transmitter and receiver must be coordinated between stations to the same data rate and interleaver settings before transmission begins as is the case with MT-63 used by MARS.

The MS110A 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. S4285 has a short 80 symbol preamble verses MS110A however it is inserted every 106.7 ms (every 256 symbols) thus providing many opportunities to acquire, re-acquire 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 transmission decoding and End of Message (EOM) reset modem receiver end sequence support. If the receiver is not setup to decode on SOM being 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 until manually reset or some period timeout or symbol count is exceeded as implemented.

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 and 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 “go to” NATO “Robust” waveform. In addition to being robust can also be considered the NATO weak signal mode. S4415 works down to -9db SNR @ 3kHz AWGN in heavy multipath/fading channels. Using direct sequence spread spectrum Walsh modulation at 75bps over-the-air and a fixed 2400bps Symbol Rate. The S4415 waveform is compatible with the 75bps waveform in MS110A, as such both are interoperable. However use of S4415 on both ends is required for the full robust weak signal benefit.

S4415 Interleave selections are SHORT, LONG and ZERO (if implemented) and are autobaud detected as with MS110A. However in MS110A the 75bps Rake receiver decoding performance is defined as only 2db SNR @ 3kHz AWGN 5ms multipath and 5hz fading channel. Whereas the performance requirements for the S4415 receiver are much stricter, requiring S4415 to perform well under much more severe channel conditions.

This very robust HF data waveform will operate effectively almost 10 dB below the noise floor in a noise dominated environment. The Narrow-Band Interfering (NBI) performance specification of S4415 requires the waveform handle interfering signals up to 40 dB larger than the signal of interest being decoded at down to -9db SNR in a 3kHz AWGN channel and tolerate extremes of delay and doppler spread up to 40 Hz and multipath spread approaching 12ms. This is all well beyond the performance requirements of MS110A 75bps.

The difference between MS110A 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.

The S4415 requirements are applied to the 75bps mode of STANAG 4539 which is the NATO version of MS110B but having more stringent modem receiver decoding requirements. S4415 is mentioned in MS110B when it comes to 75bps if robust operation is required, but it is not mandated. Those who have MS110B hardware modems need to read the docs to determine if their modem's 75bps is to the MIL-STD performance requirements or to the STANAG requirements. There is no guessing when it comes to the 75bps selection of S4539 in a hardware modem. In MS-DMT v2.00 the MS110A 75bps performance is now to S4415 requirements.

Full S4415 technical details:

Walsh modulation uses the bits, in groups of two, coming from the coder and the block interleaver structure to select one of four orthogonal Walsh functions of length four. Then, these Walsh functions are repeated eight times, resulting in a 32-symbol 8-PSK sequence. The interleaved data also decides which of the four Walsh functions is used to rotate 180 (in case of 1) or 0 (in case of 0) each of the 8-PSK symbols of the underlying PN sequence. Finally, the scrambled PN sequence is mapped to the in-phase and quadrature components of the carrier signal (1800 Hz) at a rate of 2400 symbols per second.

The minimum required performance of STANAG 4415 is defined as (modem operating in LONG interleaving mode (4.8 seconds) and with a convolutional encoder (code rate=1/2, constraint length=7)):

- In a single path and non-fading channel, the modem shall achieve BER< 10E3 at

-9.00 dB SNR (3 kHz) in an additive white Gaussian noise environment.

- In a dual path channel, with multipath delay spread equal to 10.0 ms the modem shall achieve BER< 10E4 with a Doppler spread ranging from 0.5 Hz to 50.0 Hz, in both paths, and SNR between -1.00 dB and 0.00 dB (3 kHz).

- The modem shall be capable of achieving synchronization and providing BER<10E5 for multipath delay spreads up to 10.0 ms in a 0 dB SNR (3 kHz) channel with Doppler spreads of 2 Hz and 20 Hz.

- The modem shall be able to cope with a signal to interference ratio (SIR) of -6 dB, -25 dB and -40 dB, while maintaining BER< 104 with SNR=+10 dB, for the following types of interference: self interference where S4415 is the interfering source, SSB voice and swept CW.

## 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 as S4529 is also 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 MS110A) 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 a Start of Message (SOM) sequence to begin decoding on and an End of Message (EOM) sequence to reset the modems receiver. 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 of gibberish 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 4539

STANAG 4539 and MIL-STD-188-110B differ in some areas but are substantially the same and interoperable. S4539 uses S4415 requirements applied to the 75bps waveform and MS110A requirements for 150-2400bps legacy waveforms. However the receiver performance requirements above 2400bps are higher for STANAG 4539 than for MS110B Appendix C. Thus S4539 and MS110B can communicate with each other, but a modem in compliance with MS110B Appendix C does not necessarily exhibit as good communication performance as a S4539 modem.

## NON-STANDARD ST WAVEFORMS

There are numerous non-standard serial tone data modem waveforms available from various hardware modem manufactures in addition to or in some cases instead of standard waveforms.

In most cases the non-standard waveforms are slightly modified versions of standard waveforms, usually with a reduced symbol rate to support Naval or Airborne narrow channel bandwidths or to provide for best operation with Commercial or Humanitarian use of SSB radio equipments having lesser SSB bandwidth filtering.

In the case of MARS, with its overwhelming use of Amateur Radio SSB gear, many of these non-standard waveforms would make sense for MARS-to-MARS communications in addition to S4529, such as a MS110A like autobaud waveform but with the S4529 symbol rate.

Some of these waveforms are proprietary however (e.g. PACTOR 4), while others are not and are simple changes to existing standard waveforms or hybrids with the best features from two standard waveforms being utilized to achieve interoperability with these non-standard waveforms found in some MIL-STD hardware modems.

## STANAG 4538

3G ALE as defined by STANAG 4538[19] and MIL-STD-188-141B[18] Appendix C, has traditionally only been found in Military tactical HF-ALE systems, however it has now shown up in Military Airborne transceivers and as an option in some COTS HF-ALE systems from a few vendors. In addition 3G ALE to STANAG 4538 specifications is being studied for potential implementation in MARS-ALE.

The two 3G ALE standards are almost identical protocols (except that 141B excludes the Fast Link Set Up (FLSU) mode) and represent the application of serial tone modem 8PSK burst waveforms where backward compatibility with 2G ALE 8-ary FSK is also supported.

3G ALE defines 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). 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 Asynchronous ALE) is an system 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 Burst Waveforms (BW's) known as BW0-BW5 which are optimized for the data link protocols. All burst waveforms use the basic 8-PSK modulation at 2400 baud centered at 1800hz also used in the MIL-STD 188-110A serial tone modem waveform. The 2G advanced 8-ary FSK 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. HDL is used for large messages and/or good channel conditions whereas LDL is used for short messages and/or poor channel conditions.

BW breakdown:

- 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 or better making it a true weak signal performer for 20 watt Military man pack radio use. 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.

## HDL+

Harris Radio Corporation has developed an extended proprietary data link protocol known as HDL+, which they have incorporated into their S4538 implementation FALCON II and later line of HF-ALE tactical radio families.

The HDL+ protocol achieves a maximum throughput of up to 10000bps within a 3kHz channel by incorporating higher data rate waveforms based on S4539. Each HDL+ forward transmission begins with an informational header transmitted in the more robust new BW6 waveform. The actual data transmission of the HDL+ is performed with the new BW7 waveform. BW7 actually consists of seven different waveforms based on S4539, and two packet sizes (280 or 568 bytes). In order for the receiving PU to demodulate and decode correctly, the waveform and packet size is described in the header.

Harris proposed a solution known as “IPR-free HDL+” for interoperability with the patented HDL+ protocol for third parties. The IPR-free solution is not allowed to communicate channel information in the ACK message or utilize the highest data rate. By following these rules, the maximum data rate of the IPR-free solution is limited to 7,900bps while the patented version Harris radios will be able to communicate at up to 10,000bps. The IPR-free represents twice the maximum of approximately 3500bps achievable using HDL.

## HF 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 wavefonrs 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 MS110A and VERY SHORT on MS110B.

## FED-STD-1052B DLP

FED-STD-1052 Appendix B specifies a first generation Data Link Protocol (DLP) layer with priority messaging and multiple pre-emptive resume queuing ARQ. FED-STD-1052 (FS-1052) is basically the equivalent of MS110A as to the modems, which similar to FED-STD-1045A being the equivalent of MIL-STD-188-141A when it comes to ALE.

In MIL-STD-187-721C, "Interface and Performance Standard for Automated Control Applique for HF Radio," 30 November 1994 (which details ALE Automatic Link Maintenance (ALM) based communications) Appendix A, USAISEC TECHNICAL REPORT "HF DATA LINK PROTOCOL" is provided which specifies FS-1052B DLP HF-DLP for use with MS110A. At this point in time the FS-1052B DLP is thought of as a legacy DLP since MIL-STD-188-141B Appendix G refers to MIL-STD-188-110B Appendix E. where the specified the HF DLP from STANAG 5066 is the required HF DLP for interoperability with NATO.

The FS-1052B HF DLP as designed will work with other data modems and not just the FS-1052 and MS110A ST modems. However FS-1052 it is optimized for use with a data modem having the same data rates from 75-2400bps and also supporting auto-baud.

The FS-1052 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.

## Data Modem Primer v1.09

MARS-ALE provides an implementation of FS-1052 Appendix B. DLP running over the integral software defined MS110A modem on the PC Sound Device. However it is also planned to support hardware based MS110A modems. What is unknown at this time is what systems used by MARS Military sponsors also implement the published FS-1052 DLP.

The popular Harris family of tactical HF radios includes models that implement a draft Proposed FS-1052B DLP (pFS-1052) they adopted and fielded years prior to the published 1996 FS-1052 standard.

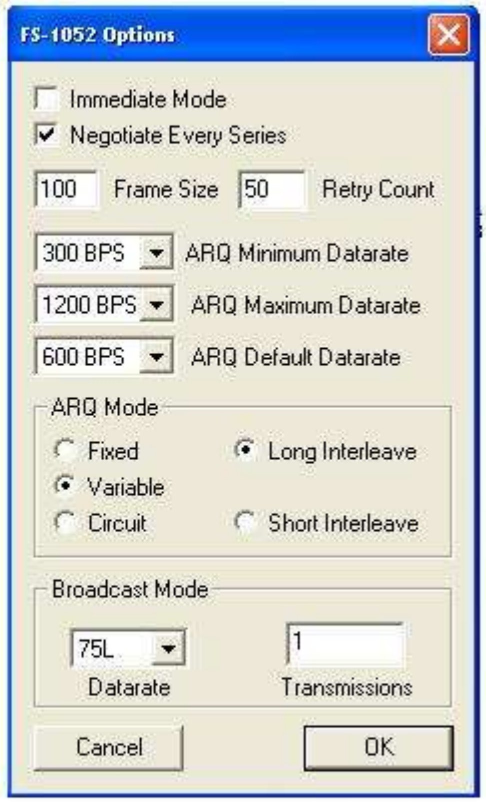
There are three modes of DLP operation in the published FS-1052 standard:

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 MS110A 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 but mandatory mode of operation, 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. Broadcast mode is essentially ARQ mode with fixed-length control frames and no acknowledgments from receive terminals.

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 can be ramped up and down on each side as configured on each terminal, 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 MS110A 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. FS-1052 DLP is limited to a 2400bps maximum data rate by design, whereas the newer STANAG 5066 DLP detailed here has no such limitation.

## STANAG 5066

### 5066-ARQ

The STANAG 5066 standard and its second generation DLP 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 not require Automatic Link Establishment (ALE). STANAG 5066 can be implemented as either a fixed frequency operation or as follow on to a 2G ALE or 3G link setup.

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 is best used with can be used with auto-detect waveforms (e.g. MS110A, MS110B, MS110C or S4539) however non-autobaud STANAG (S4285 and S4529) waveforms can also be used. All aspects of 5066 are implemented in computer software applications external to the hardware modem.

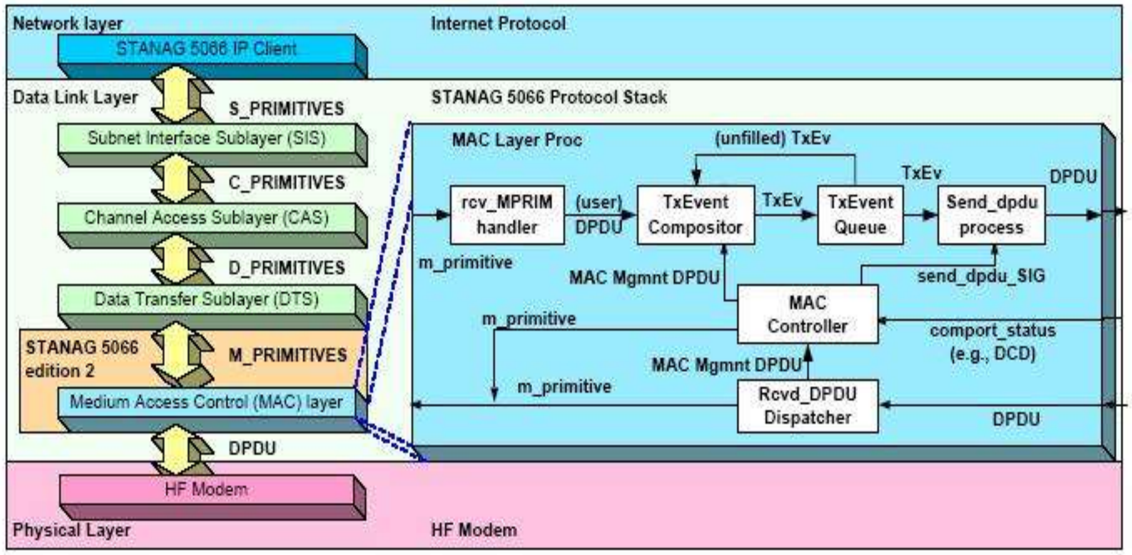
The full STANAG 5066 was originally developed for the ship-shore part of NATO's BRASS project which needed a link layer ARQ protocol. STANAG 5066 is located at the data link layer and defines an interface to applications (clients) which will use the network. It also defines an interface to the HF data modem. The 5066 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 IP based traffic, the standard did not originally define a direct IP interface, instead, for STANAG 5066 networks to serve IP packets, they needed 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.

However the Military does not make use of 5066-ARQ for basic peer-to-peer messaging as the do FS-1052 ARQ in tactical radios.




The 5066-ARQ protocol, as does 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.

The STANAG 5066 DLP component unlike FS-1052B DLP is not implemented in practice for basic terminal peer-to-peer use for ARQ messaging without the use of an Internet Protocol (IP) layer. However that does not preclude 5066 DLP being implemented as such in say MARS-ALE. What it does mean is that such use would be relegated to MARS-to-MARS applications. In addition, although MARS could develop a full MARS STANAG 5066 stack and field application layer tools to meet its operational needs, direct interoperability with MARS military sponsors is not possible. However a bridge could be created between a MARS 5066 system and any other 5066 system(s) desired.

**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.

However the Military does not make use of 5066-NRQ for basic peer-to-peer messaging as the do FS-1052B BRD in tactical radios.

## STANAG 4538 and MIL-STD-188-141B

See STANAG 4538 under WAVEFORMS above for general details of the modem 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 – BW0-BW5 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.

In the U.S. Government HF communications sector STANAG 5066 with or without 2G ALE vs. STANAG 4538 (3G ALE) is the standard. However the use of STANAG 5066 does not mean interoperability as the vendor provided STANAG 5066 systems above the STANAG 5066 stack are vendor specific.

The implementation of HF-email with support for file 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. 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 and application layer tools for a MARS specific STANAG 5066 implementation for MARS-to-MARS application. However to bring about interoperability with MARS sponsors one or more bridges to sponsor(s) STANAG 5066 system(s) will be required.

An alternative to STANAG 5066 for MARS would be to implement STANAG 4538 with no STANAG 5066. To implement STANAG 4538 just for single channel operation with the purpose of achieving an HF traffic automation system would require about the same amount of effort at the application layer and less at the physical modem layer. The benefit of the STANAG 4538 approach would be a system that would be provide interoperability with MARS our Military sponsors more readily.

The U.S. Military and Nation Guard units make heavy use of Harris Falcon tactical HF-ALE transceivers where a lot of point-to-point communications (and IP subnet) is handled via the Harris RF-6705 Tactical Chat (TacChat) tool. The use of this tool supports both ASCII messaging and Binary file transfers over ARQ protocols such as the Harris pFS1052 ARQ and 3G ALE LDL/HDL which see heavy use by our Military forces. It has also been determined that in support of MARS interoperability the Harris Falcon radios can be used with the TacChat tool in ASYNC or SYNC with the radios data modems for ASCII messaging. This discovery allows a new level of interoperability that MARS can address with additional software tools and the MS110A modems in common use.

# APPENDIX A

## Data Rate<br>and<br>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 MS110A is auto baud 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 MS110A 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 MS110A 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 MS110A 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 MS110A 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

Software Defined tools used
in MARS that support
MIL-STD-188-110D

MS-DMT: The developing MIL-STD Data Message Terminal (DMT) tool started life as a test bed for development, testing and demonstration of the software defined concept of a data modem terminal tool hosted under MS-Windows on the PC Sound Device as the physical modem component. The intent being to provide the MARS member with an inexpensive alternative to the traditional hardware modem.

The then existing MIL-STD-188-110A modem core which found limited use in MARS-ALE with FED-STD-1052 DLP was used as the basis of developing a full featured application for MARS the needs in the use of ASYNC for ASCII messaging initially.

At present MS-DMT provides for MIL-STD-188-110A ASYNC and SYNC modes and full binary data streams with data rates from 75bps through 2400bps coded and 4800bps un-coded in compliance with the performance requirements MIL-STD-188-110D section 5.3.1.1. and STANAG 4415 at 75bps.

MS-DMT has been provided with an 8-bit High Speed Asynchronous serial Data Port to support the use of external terminal tools as used with hardware modems. A full remote control command set has been implemented. A DTE TCP/IP and UDP Data Port capability is planned. MS-DMT now also exists as both x86 and x64 versions.

MARS-ALE: The developing MARS-ALE toolset is being updated to the improved MS110A modem core developed for MS-DMT where support for selectable ASYNC and SYNC with internal ASCII terminal use has been implemented. At present there is no support in place for external terminal tools, however the same Data Port support found in MS-DMT is planned for implementation.