CHAPTER 9

DIGITAL MODES

900. INTRODUCTION

The purpose of this chapter is to describe the common digital communication modes used in NAVMARCORMARS, including a summary of basic parameters, capabilities, and operational characteristics of each.

910. BASIC DIGITAL MODES CONCEPT

NAVMARCORMARS utilizes several digital modes of transmission in seeking high speed, error free, reliable high volume traffic transfer. Regardless of the mode, network structures are organized to utilize each mode to its fullest capability and optimum potential. Proper use of these modes and the 24 hour system capability afforded by message switches provides world wide 24 hour traffic transfer capability to the MARS Data System (MDS). The MDS is discussed in Annex E.

920. RADIOTELETYPE (RTTY)

921. RTTY BACKGROUND

For decades, amateur radio, the military, and MARS services employed radio-teletype digital systems to pass record traffic. Prior to the 1970's, RTTY transmission and reception was done utilizing tuning units (TUs) and converters, mechanical teleprinters, paper tape perforators and reperferators, local "loop" power supplies, and associated peripheral equipment. In the 1970's and 1980's, as society was propelled into the computer age, RTTY systems became smaller, quieter, and more efficient as teleprinters were replaced with monitors and computer page printers, and as TU's and modulators were replaced with computers and terminal node controllers (TNC's).

922. RTTY CONCEPTS

A binary 5-digit sequence table assigns a unique binary code to each letter of the alphabet and certain punctuation marks (and teleprinter commands). Text is generated using this binary code, and messages are sent by transmitting the resultant digital string of data.

923. RTTY ERROR CHECKING

There is no automatic error correction capability in this mode. Various "garble tables" exist to assist receiving stations attempting to resolve errors. Common practice "on-the-air" is to request "fills" by voice after a radioteletype message is received (if errors or hits exist).

924. RTTY MODE CHARACTERISTICS

NAVMARCORMARS RTTY transmissions utilize a 100% duty cycle. Since there is no error correction inherent in RTTY transmissions (paragraph 923), signal strength, signal-to-noise ratio, propagation conditions, and other circuit variables have a significant impact on how successful RTTY communications links will be. If a RTTY signal fades or is covered by interference, the receiving RTTY terminal will lose copy.

925. RTTY THROUGHPUT

All NAVMARCORMARS RTTY is sent at 100 words per minute.

930. AMTOR

931. BACKGROUND

a. AMTOR has been utilized for many years for long haul traffic transfer. Besides providing communications under conditions where other modes will not support the desired communications paths, AMTOR provides a degree of automated error checking of each character received.

b. AMTOR has been used for many years in commercial ship-to-shore communications. ("SITOR" and "ARQ" are associated modes.) Although there have been many different versions of the standard established for AMTOR (e.g. CCIR 476-1, 476-3, CCIR 625), most of them are compatible with potential future standards which add upgrades of the mode or additional capabilities (e.g. full ASCII character representation).

932. AMTOR CONCEPTS

a. In an AMTOR transmission, the transmitting station sends a group of three characters in a string (a transmission burst) and then "listens" for a response from the receiving station. The data bursts are composed of a series of binary tones generated by a modem connected to the transmitter. The modem can send two possible tones - a high tone (called "0") and a low tone (called "1"). The tones are separated by 170 or 200 Hz in frequency (e.g. 2100 Hz and 2300 Hz, etc.). Similar to radioteletype, AMTOR utilizes a binary table where each alpha-numeric character has a unique combination of seven 1's and 0's assigned to define what that character is.

b. Besides defining the alphabet and a table of punctuation characters, certain binary characters are used for control signals sent back and forth from the transmitting and receiving stations.

c. Only one station can send traffic at a time.

d. AMTOR also offers the capability for one station to call another through the use of a selective call sign (SELCAL) with each station being assigned a unique SELCAL.

933. AMTOR ERROR CHECKING

a. The AMTOR error checking algorithm operates by checking to verify that the seven binary bits for each alpha-numeric character and control signal are comprised of four 1's and three 0's. Once this error checking is completed for the bits sent, the received 7 units are compared to a table to determine what letter, punctuation or control code has been sent.

b. Since the 7 unit combination may not have been heard correctly by the receiving station but the criteria of four 1's met, there are times when errors are received.

c. It should also be noted that since four of the seven tones sent for each character must be a 1, the number of characters that can be defined and utilized by this mode is limited.

d. Under noisy conditions AMTOR users should always check message accuracy since the error checking method utilized by AMTOR is not 100 percent accurate.

934. AMTOR MODE CHARACTERISTICS

a. The basic AMTOR transmit/receive cycle:

(1) The sending station sends three characters (twenty-one bits of 0's and 1's) then turns the transmitter off and "listens".

(2) The receiving station applies error checking to the twenty-one bits (or three letters) received, and then responds

back to the sending station that it is ready for the next three characters.

(3) If any of the characters do not meet the four 1's test, the receiving station sends back a control code telling the sending station to send the three characters again.

b. The critical timing for this cycle to occur is 450 milliseconds (210 milliseconds for the sending station to send the 3 characters and 240 milliseconds for the receiving station to send back a control character saying it has received the three characters correctly). If the sending station does not get a response back within the 450 milliseconds, it again sends the three characters.

c. The duty cycle of AMTOR is 47%.

935. <u>AMTOR THROUGHPUT</u>

a. In AMTOR the speed of the signals being sent is 100 baud, but practical throughput is generally much less. Due to overhead (such as the receiving station sending back a character saying it has received the last three characters successfully), the actual throughput under ideal conditions is only 50 baud. It is lower when channel conditions deteriorate. The short bursts of information back and forth result in AMTOR succeeding under many adverse conditions (including interference) where other transmission modes fail.

b. Due to the critical timing restrictions (i.e. the 450 milli-second transmit-receive cycle) and the fixed speed of radio waves, this mode at one time could not be used for distances exceeding approximately 26,000 kilometers (15,000 miles). Some modern terminal node controllers or modems allow the sending station to vary the time it waits to receive an answer back. This option significantly increases the potential range.

c. The addition of more control codes has allowed this mode to be able to transfer the complete ASCII data set.

d. MARS Data System (MDS) afloat and overseas stations utilize this mode extensively. (Additional discussion of the MDS is presented in Annex E.)

940. FORWARD ERROR CORRECTION (FEC)

941. FEC BACKGROUND

Forward Error Correction or FEC is actually a "sub-mode" derived from AMTOR and is often used to start an AMTOR traffic transfer.

942. FEC CONCEPTS

FEC is used quite often to broadcast messages to many stations on a channel since it does not require the receiving station to acknowledge transmissions.

943. FEC ERROR CHECKING

The FEC mode provides a degree of error correction simply by sending the same data twice. The same character is sent again 5 characters after the first time it is sent. The same binary error detection methods as used with AMTOR are applied to FEC transmissions - that is, if the data received does not pass the "seven unit (bit) test" (four "1's" and three "0's"), the algorithm waits for the second time the character is sent and applies the same test the second time. If it fails the test the second time, a space is printed indicating an error for that character. If the character passes the test the first time, the second time is ignored.

944. FEC CHARACTERISTICS

a. FEC works on a duty cycle of 100% with one station constantly transmitting (similar to RTTY, FEC does not employ a transmitting signal from the receiving station).

b. The FEC mode is further enhanced by the transmission of phasing signals. Phasing signals are sent at the beginning of the transmission as well as at the end of each line to allow all users to adjust receiver frequency.

c. Use of selective call signs (SELCAL's) are an advantageous benefit of FEC which allows selective printing of the message by those stations monitoring the frequency. These stations are identified at the beginning of the broadcast by sending their SELCAL. Once the intended station receives this identification from the sending station, it will automatically start receiving and printing text. Error correction procedures are the same as in the normal FEC mode.

950. PACKET RADIO

951. PACKET RADIO BACKGROUND

Packet radio is a digital method of communications adapted from a standard computer protocol (X.25) by which computers communicate with each other. The version adopted for NAVMARCORMARS use is AX.25. Packet radio was originally developed for VHF use, but has since been modified for HF.

952. PACKET RADIO CONCEPTS

a. Using packet on high frequencies requires extremely good communication conditions.

b. Packet radio carries significant "overhead" for the amount of traffic sent, but this overhead provides considerable information, providing the ability to easily establish a network.

c. Packet radio provides 100 percent error free communication (see paragraph 953) as well as the ability for more than one group of stations to utilize a frequency at the same time. The system senses the existence of other signals on the frequency and will delay transmitting until the frequency is clear.

d. Packet radio (and its associated hardware) has permitted the development of sophisticated message systems (switches, called packet BBS's in Amateur Radio) that have made automatic unattended forwarding of traffic possible. Terminal Node Controllers (TNC's) facilitate all the "handshaking" between computers allowing users with little knowledge of computer systems to communicate utilizing sophisticated communication protocols.

953. PACKET RADIO ERROR CHECKING

The same calculation used by the sending station to calculate the frame check sum (see paragraph 954) is also used to calculate a frame check sum value by the receiving station. If the frame check sum value calculated is the same as the one sent, the packet is considered to have been transmitted error free. (If it is not the same, the receiving station's TNC automatically requests the sending station to resend the last packet burst.)

954. PACKET RADIO MODE CHARACTERISTICS

a. The main features that packet radio offers are totally error free communications and the ability to handle the full ASCII character set.

b. With proper geographic placement of stations on a suitable (clear) frequency, a very robust network can be established using packet.

c. Data compression techniques are available to reduce the size of a large file being transferred. The same techniques, in reverse, can be applied to decompress the traffic (file) back into its original format after it is received.

d. Packet radio works by sending bursts of information (much longer than AMTOR bursts). These bursts contain ASCII characters of data (preceded and followed by control characters and other overhead information). The overhead information includes a means for determining the data was received without error. Each packet burst contains:

(1) Synchronization data;

(2) A "flag" of eight bits to signal start of data

(3) The address of the sending station

(4) Eight bits of control information for handling the packet

(5) The data

(6) The Frame Check Sum value (calculated using a mathematical formula applied to the data being transmitted) and

(7) An ending flag.

955. PACKET RADIO THROUGHPUT

a. HF packet radio is sent at 300 baud. In actuality, throughput (data transfer) is much less due to frame overhead (see paragraph 954 above).

b. Poor HF conditions can significantly degrade packet performance.

c. Packet transmission lengths depend on how much data is being sent but are generally limited to 80 characters. These relatively long bursts provide opportunity for HF noise to reduce the throughput. If there are no interference problems HF packet throughput, even with its high information overhead, could be 15 to 20 characters per second (cps).

d. Two additional problems contribute to slow throughput. If an error is detected, the entire burst of data (and all its accompanying "overhead") has to be sent again. In addition, the longer bursts increase the likelihood an error will be received.

960. PACTOR

961. PACTOR BACKGROUND

PACTOR is a protocol that merges the best characteristics of packet and AMTOR. Newer modes, called PACTOR II and PACTOR III, have been developed but are compatible with the older mode. Only the older version is discussed here.

962. PACTOR CONCEPTS

PACTOR ensures data is transmitted accurately. Similar to packet, PACTOR works with a full ASCII set. The PACTOR mode also offers the best characteristics of AMTOR by using fixed timing of transmissions and short bursts (desirable qualities for noisy circuits).

963. PACTOR ERROR CHECKING

a. Unlike AMTOR's "four 1's" test (paragraph 933), the error checking algorithm used in packet transmissions (paragraph 953) is applied to the whole PACTOR data burst being sent. Similar to the packet mode, the same error checking algorithm is used by the receiving station and applied to the data to determine whether or not there were errors in the transmission. The data is sent again if an error is detected. Four control signals are used.

b. Coupled with the compression feature described in paragraph 964, PACTOR has a limited capability to correct errors in the data received through a method called memory ARQ. Several techniques are applied to transmissions in which errors are detected to attempt to reliably correct the errors.

964. PACTOR MODE CHARACTERISTICS

a. PACTOR is similar to AMTOR in that data is sent, and an acknowledgment is returned, by the receiving station using a fixed timing structure and full synchronization. The packets of information are sent, then acknowledged by short control signals sent from the receiving station.

b. A PACTOR burst is composed of:

(1) 8 bits of data in a header (allowing fast synchronization)

(2) The data to be transmitted

(3) 8 bits of data to tell the receiving station status information (such as station QRT, transmission mode, etc.), and

(4) The error frame checksum value (calculated from the data included in the total transmission).

c. PACTOR offers the capability to perform automatic data compression on the traffic being transferred. This compression uses a technique that can provide as much as 50 percent reduction in the number of bits of information that has to be transferred for each ASCII character (thereby gaining even more throughput for channel time usage). Both the sender and receiver are unaware of this compression taking effect because the PACTOR TNC automatically provides these features.

965. PACTOR MODE THROUGHPUT

a. This robust mode can be up to four times faster than AMTOR. Additional capabilities offered that greatly improve the throughput are:

(1) Automatic speed change (200 baud to 100 baud and/or 100 baud to 200 baud), as conditions warrant, and

(2) Automatic compression of data at transmission and decompression after the data is received.

b. The speed change capability is achieved by changing the amount of data that is transferred (192 bits at 200 baud; 80 bits at 100 baud). The length of the transmissions does not change but the amount of usable information changes when the speed is changed.

c. Speed change is determined by the receiving station's PACTOR unit automatically. Consequently, there is much more data transmitted with every PACTOR burst than is realized with AMTOR.

970. CLOVER II

971. CLOVER II BACKGROUND

Clover II is a relatively new mode that promises high volume traffic transfer achieved under many different HF conditions. Despite its relatively high cost, it claims the following significant advantages over other digital modes:

a. Clover II automatically and accurately corrects errors in the data received (so the re-transmission of data is very infrequent).

b. Clover II transfers any type of 8-bit data.

c. Clover II is speed adaptive (i.e. automatically selects transmission speed to optimize throughput) for any given set of conditions.

972. CLOVER II CONCEPTS

a. A Clover II signal is comprised of four specific tones which can be modulated in many different ways to achieve optimum throughput. The protocol automatically selects the modulation method and baud rate (based on feedback signals from the receiving station) that results in the optimum throughput of data with minimum errors.

b. The pulse rate is 31.25 per second. The intelligence is derived from the difference between the phase or amplitude of successive pulses. These processes are totally automated (the computer interfaced with the Clover II modem makes the changes).

973. CLOVER II ERROR CORRECTION

A very valuable feature of Clover II that ensures high data throughput is the error correction algorithm. Clover II transmissions send blocks of data in fixed lengths of either 17, 51, 85, or 255 byte blocks. Clover II provides far more extensive error correction capability than other modes. Obviously, if conditions are bad not all errors can be corrected. Clover II has the capability to correct as many as 31 data bytes in every 188 bytes transmitted. For those bytes which cannot be repaired, only the blocks containing the errors need to be retransmitted.

974. <u>CLOVER II MODE CHARACTERISTICS</u>

a. There are ten possible modulation modes (six using phase shift modulation, two using amplitude shift modulation, and two using frequency shift modulation) suited for various HF conditions (from "very poor" to "excellent"). The Clover II modem automatically adapts itself to optimize throughput. Four tone pulses (spaced by 125 Hz) are used with eight milliseconds between each pulse. The four tones are treated as four independent channels (with a frequency offset of 125 hertz between channels).

b. The specific modulation method chosen by the algorithm is the one used for all four channels.

c. Clover II technology offers the following modulation modes and theoretical data rates:

(1) 16-phase, 4-amplitude modulation for a block data rate of 750 bits per second.

(2) 8-phase, 2-amplitude modulation for a block data rate of 500 bits per second.

(3) 8-level phase shift modulation for a block data rate of 375 bits per second.

(4) 4-level phase shift modulation for a block data rate of 250 bits per second.

(5) Binary phase shift modulation for a block data rate of 125 bits per second.

(6) 2-channel diversity binary phase shift modulation; block data rate of 62.5 bits per second.

(7) Frequency shift modulation for a block data rate of 62.5 bits per second.

(8) 4-channel diversity binary phase shift modulation; block data rate of 31.25 bits per second.

(9) 2-channel diversity frequency shift modulation; block data rate of 31.25 bits per second.

d. Overall spectrum efficiency using this method provides a signal which is only 500 Hz wide at a bandwidth of -50 db.

e. One critical problem with Clover II is that the frequency must be accurately tuned. The system will not tolerate more than plus or minus 30 Hz deviation between the receive and transmit station frequencies. (This is less of a problem for message switch operators since their radios are on 24 hours a day.) On-screen tuning indicators are provided to aid in adjusting for precise frequency accuracy.

975. CLOVER II THROUGHPUT

a. The theoretical higher data rates are not achieved except under good band conditions. Lower data rates result when band and propagation conditions deteriorate. Optimum rates are reduced by some overhead (control signals), but increased throughput is achieved through error detection and correction (the data does not have to be transmitted when an error is corrected).

b. The receiving Clover II station directs the sending station to modify transmission parameters to optimize throughput. At the receiving site, a very sophisticated signal analysis is done after every transmission with the method of modulation changed if needed. (The receiving station tells the sending station to switch modes.)

c. Along with the exchange of information is the capability for the receiving station to control the power output of the transmitting station (AFSK microphone gain output control from the Clover II modem).

980. SOUND CARD MODES

Recently, there have been many new modes developed around the computer sound card. A brief description of some of these new modes is provided below:

a. PSK31 (and derivatives) - This mode uses phase-shift keying of a single audio tone. This results in a very narrow band width on the order of a continuous wave (CW) signal. The mode uses a varicode which has shorter character lengths for the most commonly used letters. It is optimized for lower case characters. Variations include QPSK31, PSK63 and PSK125, with the last two having higher throughputs and slightly wider signals.

b. MT63 - This mode provides a very robust Walsh forward error correction (FEC) scheme transmitting 64 separate tones shifted over time. Possible modes of operation are:

500 Hz, short interleave (6.4 seconds interleave)
500 Hz, long interleave (12.8 seconds interleave)
1000 Hz, short interleave (3.2 seconds interleave)
1000 Hz, long interleave (6.4 seconds interleave)
2000 Hz, short interleave (1.6 second interleave)
2000 Hz, long interleave (3.2 seconds interleave)

Throughput varies from approximately 5 characters per second at 500 Hz bandwidth to 20 characters per second for 2000 Hz bandwidth.

c. MFSK - Multi-Frequency Shift Keying - The current mode is based on the Piccolo and Coquelet transmission modes used by the British Foreign Service during World War II. This mode uses either eight or sixteen separate tones with a forward error correction scheme providing a throughput of about 4 characters per second. For best results, a frequency error of less than 5 Hz is required.

d. Domino - This is a very new mode based on MFSK which uses Incremental Frequency Keying (IFK). Domino attempts to provide the benefits of MFSK with a much wider frequency tolerance. It is specifically designed for keyboard-to-keyboard operations with three throughputs of 3, 4 or 6 charcters per second. There is no FEC.

e. Q15X25 - This is an attempt to provide a more robust AX.25 mode similar to packet. It uses 15 tones separated by 125 Hz each modulated at 83 Hz. The bandwidth is approximately 2500 Hz. The mode uses FEC and time and frequency interleaving. Raw data throughput, exclusive of FEC and overhead is about 25 characters per second. Initial testing of this mode indicates that it requires fairly good propagation conditions.

f. Automatic Link Establishment (ALE) - This mode, which is still under development for the personal computer sound card, is based on Federal Standard 1052 and Military Standard 188-141B and provides a means of automatically linking to another station and sending data or allowing voice communications on the link established. This mode should allow interconnecting of MARS stations with other government stations without purchase of the expensive radios and modems currently in use at government agencies.

981. OPERATION WITH SOUND CARD MODES

The following sound card mode standards will be used within NAVMARCORMARS:

a. All sound card modes - Radios will be operated in upper sideband mode (USB).

b. MT63 - The lower edge of the 500 Hz, 1000 Hz or 2000 Hz data envelope will be placed at 500 Hz above the USB suppressed carrier.

c. PSK31 - The center of intelligence will initially be centered at 1000 Hz above the suppressed USB carrier. Establishing additional conversations above or below this initial frequency is authorized as long as the 3 KHz bandwidth is not violated.

d. Q15X25 - The center of intelligence will be set at 1375 Hz above the suppressed USB carrier.

e. Other sound card modes - Operate the radio in USB and use the default center frequency of the software you are using. If stations are using different programs, they need to confirm they are using the same data frequency.

990. MESSAGE SWITCH OPERATION

a. With the advent of many rapid changes in communication technology, Navy Marine Corps MARS has adopted and developed operating practices for each mode. These practices should be strictly observed to ensure rapid and reliable communications.

b. Since each mode is part of an overall system, the communication parameters that have been established should be strictly observed to ensure the network is functioning optimally.

c. Along with the new communications technologies (and their attendant abilities to offer error free, unattended communications) comes the technology of message switch operation and computer automation of traffic routing. This automation includes the ability to create many different routing paths that traffic can traverse to get to its final destination. Navy-Marine Corps MARS has taken advantage of this technology and developed its world wide MARS Data System (MDS).

d. Since communications technology is improving so quickly, a standard in message switch operation has been established by Navy Marine Corps MARS to ensure further modes can be easily adapted. In addition, this standard provides full support to all members and their computer hardware. That standard is the mailbox software developed by AA4RE which has been further developed by MDS members for MDS usage.

e. The MDS is described in further detail in Annex E.

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