CLOVER-2000 WAVEFORM & PROTOCOL

HAL Communications Corp.
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1. CLOVER Background

"CLOVER" is the name of a series or class of modem modulation techniques ("waveforms") specifically designed for use over high frequency (HF) radio systems. "CLOVER-II" was the first CLOVER waveform sold commercially, developed by Ray Petit and HAL Communications in 1990-92. "CLOVER-2000" is a higher-rate and wider bandwidth version of CLOVER developed by HAL Communications in 1995. CLOVER-2000 is supported only in high-performance versions of the PCI-4000 modem (the "PCI-4000/2K" and "GL-4000", HAL P/N 900-04001 and 900-04011) and the DSP-4100 modem. CLOVER-2000 cannot be supported for operation in the DXP38, P38, or in "standard" versions of the PCI-4000 modem (P/N 900-04000 or 900-04010).

2. CLOVER-2000 Waveform

2.1 Time/Frequency Domain

The CLOVER-2000 waveform uses eight tone pulses that are spaced in frequency by 250 Hz. The parameters of the CLOVER-2000 tones are shown in Table 1.

TABLE 1
CLOVER-2000 TONE FREQUENCIES

Tone Pulse	Frequency
Fc (center)	1500.0 Hz
1	625.0 Hz
2	1625.0 Hz
3	875.0 Hz
4	1875.0 Hz
5	1125.0 Hz
6	2125.0 Hz
7	1375.0 Hz
8	2375.0 Hz

Note that, unlike CLOVER-II, the tone pulses in CLOVER-2000 are *not* transmitted in direct frequency order. Rather, the sequence of CLOVER-2000 tone frequencies is spaced to minimize adjacent tone-channel interference. The tone pulse sequence is sent with 2 milliseconds (ms) between the center of each pulse (2 ms between pulse 1 and 2, 2 ms between pulse 2 and 3, etc.). A complete tone pulse sequence is repeated every 16 ms; i.e., 16 ms elapse between the 1st and 2nd occurrence of tone pulse #1. The eight tone pulses are then combined to produce the composite tone pulse sequence diagrammed in Figure 1. Figure 2 shows a three-dimensional amplitude, time, and frequency representation of the CLOVER-2000 modulating signal. Figure 3 shows the CLOVER-2000 frequency spectra.

Although Figures 1 and 2 have been simplified and idealized to clarify this discussion, Figure 3 shows the actual measured spectra of CLOVER-2000 modulation generated by the HAL DSP modem (PCI-4000/2K or DSP-4100/2K).

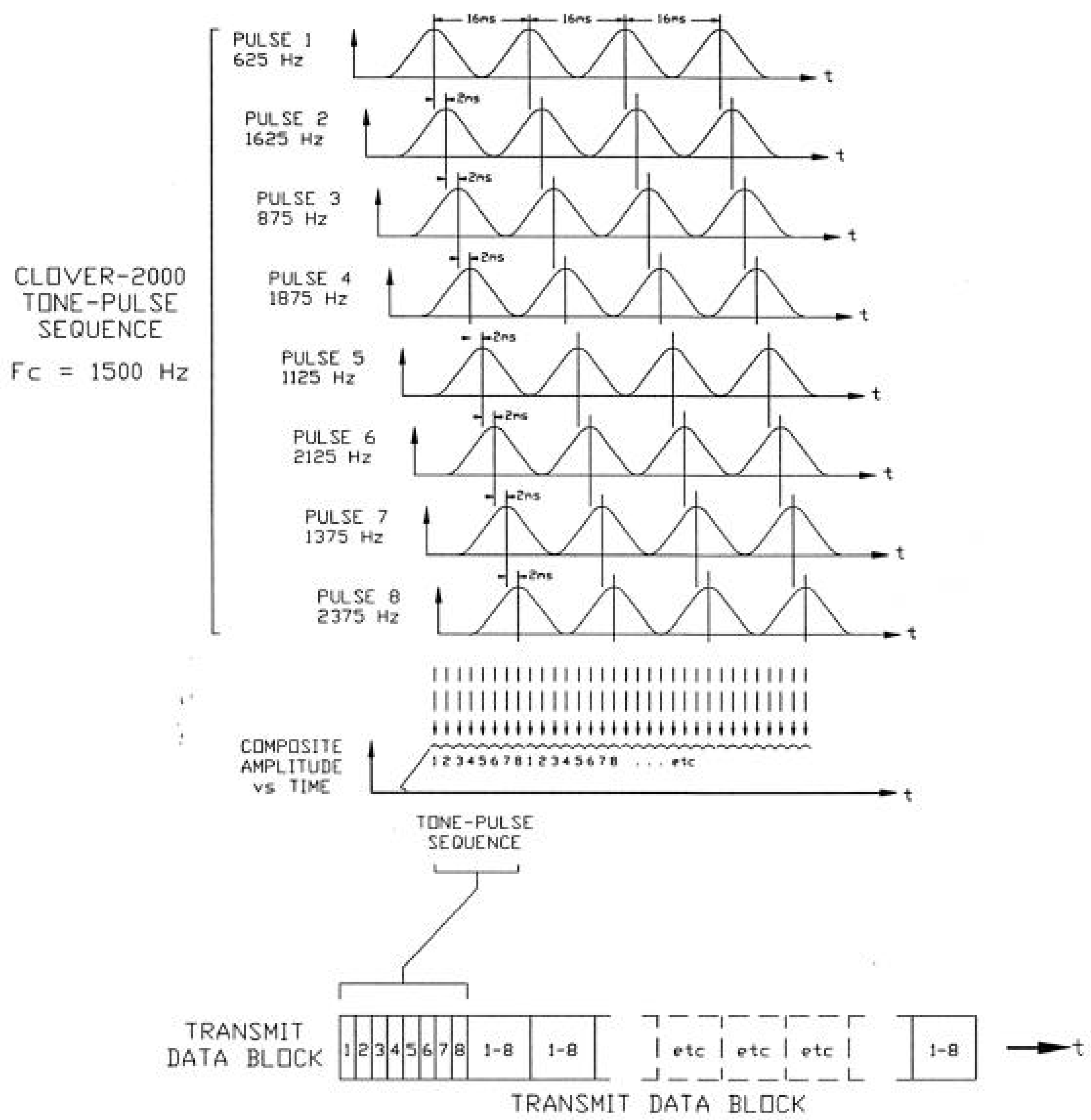


Figure 1. CLOVER-2000 Tone Pulse Sequence

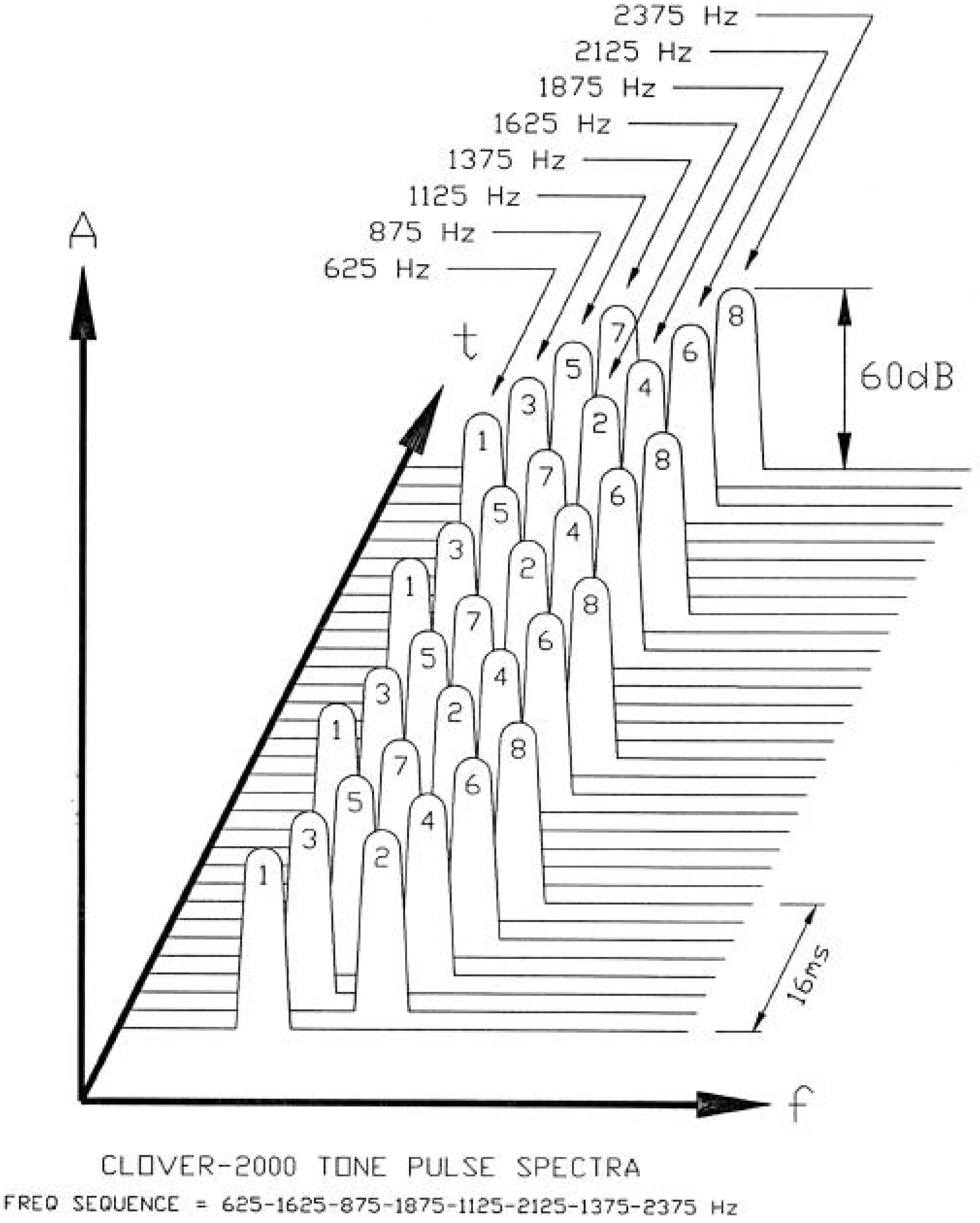


Figure 2. CLOVER-2000 Time/Frequency Relationship

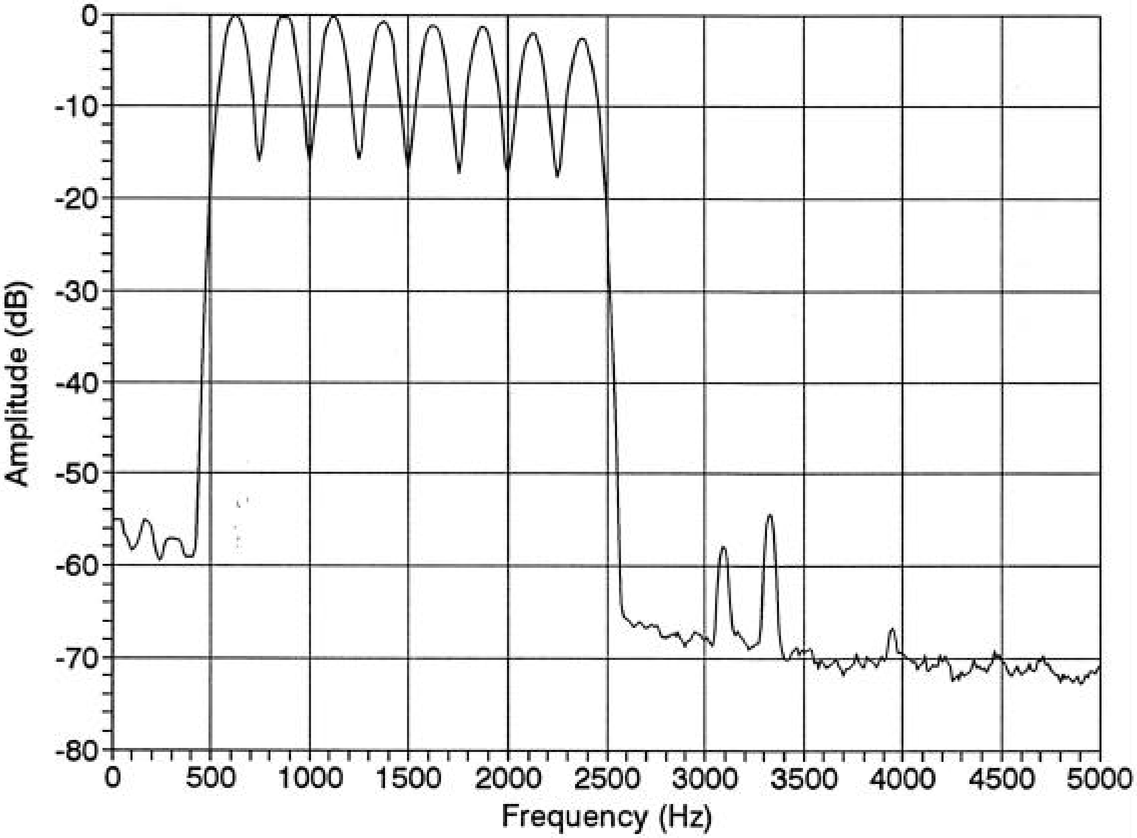


Figure 3. Measured Frequency Spectra of CLOVER-2000

The spectral efficiency of a CLOVER-2000 signal is quite evident in Figure 3. This spectra is obtained by using amplitude shaping of each of the eight tone pulses. A Dolph-Chebychev function with -60 dB side-lobe level is used as the shaping function.

> *NOTE: CLOVER-2000 is a J2 emission that is applied to the audio input of an SSB HF transmitter. "FSK" modes provided in some HF transmitters cannot be used with CLOVER-2000 modulation.*

Key parameters of the CLOVER-2000 emission are:

Occupied Bandwidth	=	2000 Hz @ -50 dB below peak level
Crest Factor (pk/avg)	<	2:1 (voltage) < 6 dB (power)
CCIR Emission	=	2K0H J2 DEN or 2K0H J2 BEN

2.2 Data Modulation

Data is impressed or modulated upon the CLOVER-2000 signal by varying the phase and/or amplitude of the tone pulses. Further, all data modulation is differential on the same tone pulse; data is represented by the phase (or amplitude) difference from one pulse to the next. For example, when binary phase modulation is used, a data change from "0" to "1" may be represented by a change in the phase of tone pulse #1 by 180 degrees between the 1st and 2nd occurrence of pulse #1. Note that the phase is changed between occurrences of a tone pulse (while the pulse amplitude is zero) and not when the tone pulse is turned ON. Therefore, the phase of each tone pulse is constant for the entire time that the pulse is "ON". This is true for all modulation formats of CLOVER-2000.

The CLOVER-2000 spectra are the <u>same</u> for all modulation forms.

CLOVER-2000 uses eight tone pulses. The phase and/or amplitude of each tone pulse is modulated and demodulated as a separate narrow-bandwidth data channel. As noted above, all modulation of a tone pulse is differential - between occurrences of a given tone pulse. Since the time spacing between tone pulse frames is fixed at 16 ms:

The base modulation rate of a CLOVER-2000 signal is <u>always</u> 62.5 symbols/sec.

The low symbol rate makes CLOVER-2000 demodulation extremely resistant to pulse width/delay distortion that is caused by multiple path HF propagation. For example, time dispersion caused by HF "multi-path" distortion may often cause a time uncertainty of 1 to 5 ms in the received signal. Traditional FSK data demodulation systems are very susceptible to this distortion whenever the dispersion approaches 1/4 to 1/2 of the basic pulse width. For this reason, use of FSK is generally restricted to minimum pulse widths of 7 to 13 ms, corresponding to maximum FSK data rates of 75 to 150 baud. Higher FSK data rates may sometimes be used on HF, but only when multi-path distortion is low (usually when the operating radio frequency is close to the Maximum Usable Frequency, or "MUF"). Because of its low symbol rate (62.5 bps):

CLOVER-2000 is extremely tolerant of HF "multi-path" distortion.

CLOVER-2000 uses multiple tone channels to increase the effective data throughput rate. The previous example used binary phase shift modulation (BPSM) on tone pulse #1. Actually, the same modulation format is applied to all eight tone pulses of CLOVER-2000. Thus, 8 data bits are sent by differential binary phase modulation for each 16 ms tone pulse frame. Even though the base modulation rate is only 62.5 bits-per-second (bps), the effective data rate using BPSM on all eight-tone pulses is eight times that, or, 500 bps. This is one way in which CLOVER-2000 sends data at a relatively high data rate but maintains a very low symbol rate.

CLOVER-2000 uses multiple tones to increase the data rate.

Note the above usage of "Phase Shift Modulation" (PSM) rather than "Phase Shift Keying" (PSK). "PSK" is traditionally used to describe the modulation of a constant carrier that results in a wide signal bandwidth. The phrase "Phase Shift Modulation" (PSM) is used to describe CLOVER which uses differential modulation when tone pulses have zero amplitude and does not produce a wide frequency spectra.

In much the same manner that using multiple tones increases the data throughput, CLOVER-2000 also uses multi-level differential phase modulation of each tone pulse. For example, if each pulse is modulated using QPSM (Quad Phase Shift Modulation), the differential phase of each pulse may be changed in 90-degree increments, 2 bits of data modulated on each tone pulse, and 16 bits of data sent in each 16 ms tone-pulse frame. This increases the net data rate by a factor of 16 from the base rate (to 1000 bps). Similarly, 8-ary PSM (8-level, 8PSM) provides an effective bit rate of 1500 bps.

Extending this concept even further, CLOVER includes two amplitude modulation modes: 2-level and 4-level Amplitude Shift Modulation (2ASM, 4ASM). 4-level ASM is used with 16PSM to produce the fastest modulation with an effective data rate of 3000 bps. Also, 2-level ASM may be used with 8PSM modulation to produce an effective rate of 2000 bps. Regardless of modulation format, the base symbol rate for any one CLOVER-2000 tone pulse remains at 62.5 bps and the total spectra is as shown in Figure 3.

> *CLOVER-2000 uses multi-level and multi-format differential modulation to increase the effective data rate.*

A logical question at this point might be:

> *"If multi-tone and multi-level modulation produces high throughput, why bother with the slower data modes?*

The answer is, of course, that complex modulation modes also require high detector precision and very stable signals. For example, consider that 16-level phase modulation uses phase changes of 22.5 degrees to represent the state of 4 data bits per tone pulse. To accurately detect this change, the phase "jitter" or dispersion caused by propagation must be less than ±11.25 degrees. Further, the receiver's detector must be capable of resolving phase changes as small as ±11.25 degrees which means that the internal phase reference for detection must be very phase stable. In short:

> *Stable ionosphere conditions are required to use the "faster" modes.*

Recognizing that HF propagation conditions are often less than optimum and may deteriorate rapidly from "ideal" conditions, CLOVER-2000 includes several very robust modulation modes as well as the "fast" modes. A total of ten different modulation modes were originally defined for use by CLOVER-2000. Actual on the air testing of various modes has shown that six of these modes are particularly well suited for HF communications.

> *Multiple modulation modes allow CLOVER to operate over a wide range of ionosphere conditions.*

The modulation modes of CLOVER-2000 are shown in Table 2.

TABLE 2
CLOVER-2000 MODULATION MODES

Mode	Description	Effective Bit Rate	Mode Used
16P4A	16 Phase, 4-Amplitude Modulation	3000 bps	ARQ & Bdcst
8P2A	8 Phase, 2-Amplitude Modulation	2000 bps	ARQ & Bdcst
8PSM	8-level Phase Shift Modulation	1500 bps	ARQ & Bdcst
QPSM	4-level Phase Shift Modulation	1000 bps	ARQ & Bdcst
BPSM	Binary Phase Shift Modulation	500 bps	ARQ & Bdcst
2DPSM	2-Channel Diversity BPSM	250 bps	Broadcast only

2.3 Error Detection and Correction

HF radio can be a very cost-effective and convenient means to send digital data over very long distances. This is particularly true in locations which are not served by wire lines (telephone) and satellite relays are either not available or very expensive. HF radio equipment can be quickly placed in remote field locations and is often ideal for use in emergencies and locations which lack any other means of communications.

However, HF radio propagation may add severe distortion to data signals, causing errors and loss of data. The task of the HF modem device is to accept ionosphere distortion as it occurs and adjust, correct, or compensate the recovered signal to minimize data errors or loss.

CLOVER-2000 uses special *forward error correction* (FEC) data encoding which allows the receiving station to correct errors without requiring a repeat transmission. This is a very powerful error correction technique that is not available in other common HF data modes such as AX.25 packet radio or AMTOR ARQ mode.

Reed-Solomon FEC data coding is used in all CLOVER modes. This is a byte and block oriented code. Errors are detected on bytes of data (8-bits) rather than on the individual bits themselves. This block-oriented code is ideally suited for HF use in which errors due to fades or interference are often "bursty" (short lived) but cause total destruction of a number of sequential data bits. CLOVER-2000 data is sent in fixed-length blocks of 17 bytes, 51 bytes, 85 bytes, or 255 bytes.

Error correction at the receiver is determined by "check" bytes which are inserted in each block by the transmitter. The receiver uses these check bytes to reconstruct data which has been damaged during transmission. The capacity of the error corrector to fix errors is limited and set by how many check bytes are sent per block. Obviously, check bytes are also "overhead" on the signal (non-productive data bytes) and their addition effectively reduces the efficiency and therefore the "throughput rate" at which user data is passed between transmitter and receiver.

CLOVER-2000 has three Reed-Solomon code rate (efficiency) options: 60%, 75%, and 90% ("efficiency" being the approximate ratio of real data bytes to total bytes sent). "60% efficiency" corrects the most errors but has the lowest net data throughput. “90% efficiency” has the highest throughput but fixes few errors. There is therefore a trade-off between raw data throughput vs. the number of errors which can be corrected without resorting to retransmission of the entire data block.

Note that while the "Effective Bit Rate" numbers listed in Table 2 go as high as 3000 bps (bits-per-second), inclusion of other desired features in CLOVER-2000 add overhead and thus reduce the net throughput or overall efficiency of a CLOVER transmission. Reed-Solomon error correction encoding makes CLOVER-2000 very robust in the face of severe ionospheric distortion but also reduces the efficiency of the transmission. As will be noted in later sections, protocol requirements of FEC and ARQ modes for synchronization and control also add overhead and reduce the net efficiency.

Tables 3 and 4 detail the relationships between block size, coder efficiency, data bytes per block, and correctable byte errors per block.

TABLE 3
DATA BYTES TRANSMITTED PER BLOCK

	------------ Reed-Solomon Encoder Efficiency ------------			
Block Size	60% (Robust)	75% (Normal)	90% (Fast)	100% (off)
17	8	10	12	14
51	28	36	42	48
85	48	60	74	82
255	150	188	226	252

TABLE 4
CORRECTABLE BYTE ERRORS PER BLOCK

	------------ Reed-Solomon Encoder Efficiency ------------			
Block Size	60% (Robust)	75% (Normal)	90% (Fast)	100% (off)
17	1	1	0	0
51	9	5	2	0
85	16	10	3	0
255	50	31	12	0

Reed-Solomon data coding is the primary means by which errors are corrected in CLOVER Broadcast mode (also called "FEC mode"). In ARQ mode, CLOVER-2000 employs a three-step strategy to combat errors. First, channel parameters are measured and the modulation format is adjusted to minimize errors and maximize data throughput. This is called the "Adaptive ARQ Mode" of CLOVER-2000. Second, Reed-Solomon encoding is used to correct a limited number of byte errors per transmitted block. Finally, data blocks in which errors exceeding the capacity of the Reed-Solomon decoder are repeated. Adaptive ARQ mode is discussed in section 3.3.3.

2.4 CLOVER Waveform Modes

As detailed in Table 2, CLOVER-2000 has a set of six different modulation formats that may be used to send and receive data. In addition, each of these modulation formats may be sent using four data block lengths (17, 51, 85, or 255 bytes) and three Reed-Solomon coder efficiencies (60%, 75%, and 90%). There are 72 different waveform modes which could theoretically be used to send data via CLOVER (6 x 4 x 3). However, the performance characteristics of many of these modes overlap (minimum S/N, data throughput, phase dispersion tolerance, etc.). Other system limitations and considerations for optimizing the FEC and ARQ protocols place further limits on the selection of block length and coder efficiency in particular. When these factors are weighed and optimized, the result is that there are 6 different waveform combinations which are useful for HF communications. The optimum waveform modes for each protocol are discussed in the following sections.

2.5 Baud, Data Rate, and Throughput

The terms "Baud", "data rate", "overhead", and "throughput" are all used to describe CLOVER-2000 emissions. The following conventions are used to describe the data "speeds":

The <u>SYMBOL RATE</u> of CLOVER-2000 is always 62.5 Baud.

This is true for all modulation forms and all error-corrector settings of CLOVER. It is true for either Broadcast (FEC) or ARQ modes.

The <u>Data Bit Rate</u> in CLOVER-2000 varies with the modulation form.

Data rate is a measure of the rate at which data bits may be sent using the various forms of modulation available in CLOVER-2000. The data rate is always an integer multiple of the base symbol rate (62.5). As may be seen in Table 2, multi-level modulation provides data bit rates of 250, 500, 1000, 1500, 2000, and 3000 bps (bits-per-second). As used in this discussion, bit rate numbers do not include the effects of "overhead".

"Overhead" is used to describe any function or operation in CLOVER-2000 that adds transmitted bits or adds time delays which tend to reduce the data flow between transmitter and receiver below that implied by the modulation data rate. The Reed-Solomon error corrector adds data bits (actually data bytes) for error correction use; block numbering and check sums also require additional data bytes. These are overhead parameters that are necessary for proper operation but which also reduce the number of bytes in each block that may be used to send data between stations.

As will be described in following sections, Broadcast (FEC) and ARQ modes each add overhead to the CLOVER transmission. Broadcast (FEC) and ARQ both require CLOVER Control Blocks (CCB's) for synchronization and link control. ARQ mode adds time delays to switch transmitters and receivers ON and OFF. These are also necessary overhead parameters that further reduce the net rate at which data may be passed.

For the purpose of clarity, CLOVER-2000 documentation uses *throughput* to describe the over-all rate at which data is passed between transmitter and receiver. Data throughput when using CLOVER-2000 is described in units of bytes-per-second (byps). Unless otherwise specified, each "character" is assumed to be 8 bits (1 byte) long.

<u>Throughput</u> is the net data flow between two stations, including overhead.

Throughput is specified in units of <u>bytes-per-second</u> (byps).

Unless otherwise specified, throughput values are for a <u>one-way</u> transmission path.

Reviewing, Baud is used to describe the base symbol rate of CLOVER-2000 (62.5), bits-per-second (bps) describe the data bit rate within a modulation block, and bytes-per-second (byps) describe the rate at which information is passed between two CLOVER-2000 stations.

Note that CLOVER-2000 always transmits and receives data in 8-bit increments. However, CLOVER-2000 is bit transparent - it always sends and receives the original number of data bits and in the original sequence. Compressed data coding may therefore be used with CLOVER-2000 modems without any modification of the algorithm or data stream. Of course, the effective throughput of compressed data will generally be greater than that of the original uncompressed data. However, all compression algorithms are context sensitive. For this reason, all discussion and data presented regarding CLOVER-2000 is for the throughput of *uncompressed* data.

3. CLOVER-2000 Protocols

CLOVER-2000 data may be sent using Broadcast (FEC) or ARQ protocols. Both of these protocols have minor variants that are tailored for specific applications. A unique and optimum set of waveform parameters is offered for each protocol.

3.1 CLOVER Control Block (CCB)

The CLOVER Control Block (CCB) is the coordinating control signal used in both the Broadcast (FEC) and ARQ protocols. The CCB contains information that tells the receiving modem details of the data blocks that will follow. The CCB is used to:

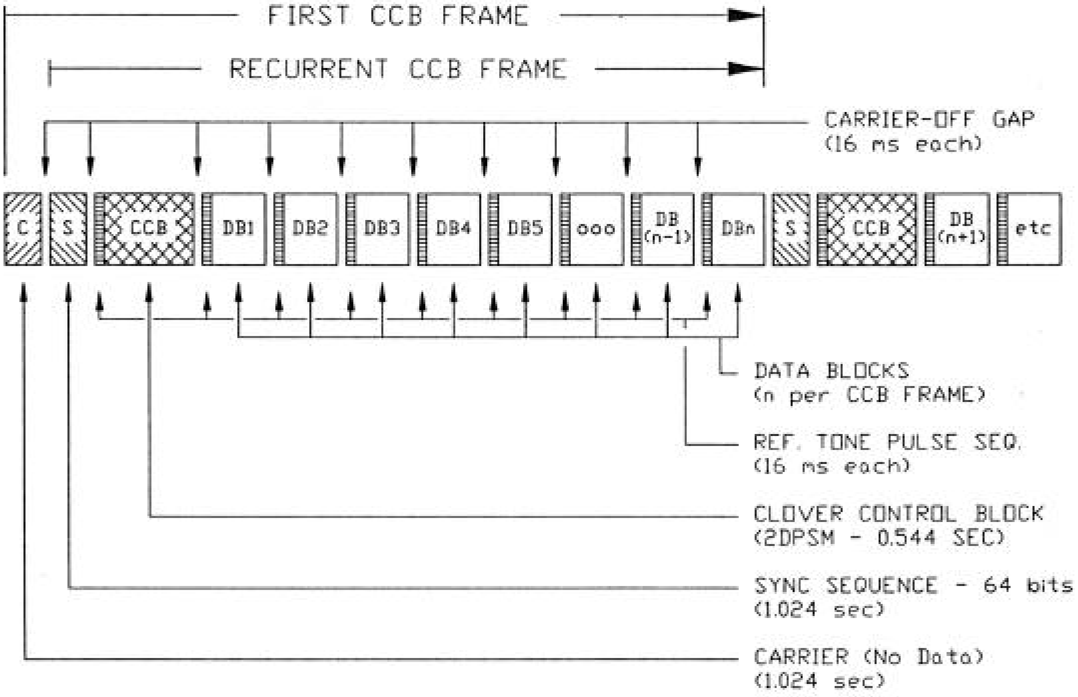
a. Send MYCALL
b. Send Waveform parameters of data blocks
c. Synchronize receiver detector
d. Connect request (ARQ mode)
e. Disconnect request (ARQ mode)
f. Repeat request (ARQ mode)
g. Keyboard entry text (ARQ mode when time permits)
h. Exchange channel statistics (ARQ mode, when time permits)
i. Call CQ (ARQ mode)

The CCB is *always* sent using a very robust waveform format. In general, the CCB uses 17 byte blocks with 60% coder efficiency. The CCB modulation mode is constant and the lowest level used in the protocol. Correct reception of the CCB is essential to further reception and decoding of data blocks that follow.

3.2 Broadcast (FEC) Protocol

CLOVER-2000 (Broadcast) FEC mode allows a sending station to transmit data to one or more receiving stations. This mode is also often called a *broadcast* and sometimes an unproto mode. Broadcast (FEC) mode is a one-way transmission and does not provide error correction via repeat transmission. However, the Reed-Solomon error correction encoder (section 2.3) is used to provide receive error correction of all Broadcast (FEC) transmissions. The data transmission format used for Broadcast (FEC) mode is shown in Figure 4.

Broadcast (FEC) mode transmission does not use adaptive waveform control. Rather, the sending station must choose a transmitting modulation format in advance and assume that conditions between his station and all other stations are adequate for the chosen mode.



RATE	MOD	BLOCK	EFFIC	CCB	BLOCK TIME	BLKS/ FRAME	FEC FRAME TIME	THRU-PUT BYTES/SEC
167	16P4A	255	60%	2DPSM	0.688 sec	9	8.096 sec	166.7
113	8P2A	255	60%	2DPSM	1.024 sec	6	7.952 sec	113.2
87	8PSM	255	60%	2DPSM	1.360 sec	5	8.576 sec	87.4
53	QPSM	85	60%	2DPSM	0.688 sec	9	8.096 sec	53.4
28	BPSM	85	60%	2DPSM	1.360 sec	5	8.576 sec	28.0
14	2DPSM	51	60%	2DPSM	1.632 sec	4	8.272 sec	13.5

Figure 4. CLOVER-2000 Broadcast (FEC) Mode Format

Since Broadcast (FEC) transmissions cannot use repeat transmission or adaptive waveform selection, all Broadcast (FEC) transmissions are sent using 60% Reed-Solomon error correction efficiency. The block lengths used for each Broadcast (FEC) data "speed" are chosen for an optimum balance of throughput and receive synchronization requirements in a changing ionosphere.

Note in Figure 4 that each group of data blocks is preceded by the transmission of a CLOVER Control Block (CCB). The CCB announces the sending station's call sign and the modulation format of the data blocks which follow. Also note that the CCB and each data block are separated by "gaps" (no-signal periods) and a reference tone pulse frame.

The 16 ms "gaps" between CCB and data blocks are used to dynamically measure the received Signal-To-Noise ratio (S/N) and adjust signal detection in CLOVER to current operating conditions. This allows the CLOVER demodulator to quickly compensate for rapidly varying signal amplitudes when propagation is poor or when receiver AGC is adversely affected by interfering signals. The 16 ms "REF" period at the start of each CCB and data block provides the frequency and phase reference required to decode the balance of the CCB or data block.

The Broadcast (FEC) data waveform modes vary for each rate chosen. These modes are chosen to optimize Broadcast (FEC) performance (throughput, error correction, and system synchronization) for each rate. The Broadcast CCB is always sent using 2DPSM modulation, 17 byte block size, and 60% encoder efficiency. Six data throughput choices are available for Broadcast transmission. Details of the Broadcast (FEC) modes are shown in Figure 4.

The "Rates" of Figure 4 are approximations of the computed bytes-per-second data throughput (last column) for each setting. Throughput calculation is based upon 8-bit bytes and includes time required for "overhead" functions (CCB, reference sequence, gaps). The effect of compression coding is not included in these calculations.

The "BLOCK TIME" column shows the time required to transmit each block of data. Since CLOVER uses a block protocol, all bytes in a block must be received before any data in the block can be passed to the receiving device - i.e., displayed on the receive terminal. Therefore, the "BLOCK TIME" is an indicator of how frequently the receive screen will be updated.

3.3 ARQ Protocol

ARQ protocol of CLOVER-2000 provides fully adaptive and error-corrected communications between two stations. It is a two-station point-to-point mode; one station "links" to a second station and data flows between the two stations. The full advantages of adaptive waveform control and error correction via repeat transmission are provided to these two stations.

The ARQ mode uses a two-layer protocol. The lower, more basic layer involves exchange of only CLOVER Control Blocks between the two ARQ stations. All link maintenance operations are performed at the CCB level. This structure assures that the ARQ link integrity is always preserved. While a limited amount of data may also be exchanged within the CCB's (called "Chat Mode"), bulk data transfers are made using the data block layer of the ARQ protocol. The data block layer uses longer blocks and high-rate modulation waveforms to expedite data transfer.

3.3.1 CCB Protocol Layer

CLOVER Control Blocks (CCB's) are used to coordinate the two ARQ stations. As is the case for Broadcast mode, CCB's in ARQ mode are always sent using a more robust waveform than that used for data transmission. CCB's perform the link control functions listed in section 3.1.

In ARQ mode, CLOVER Control Blocks (CCB's) always use the following waveform format:

Modulation = BPSM = Binary Phase Shift Modulation
Block Size = 17 bytes
Efficiency = 60%

The timing structure of the CCB-layer of the ARQ protocol is shown in Figure 5. The "CCB Frame" includes time delays to compensate for propagation delays, transmitter/receiver delays, and modem processing delays.

3.3.2 ARQ Data Block Layer

Data is communicated between two ARQ stations by adding a series of data blocks to the CCB protocol. This mode is illustrated in Figure 6. Although CCB waveform parameters remain fixed, the waveform of the data blocks is adaptively adjusted to match current propagation conditions.

As in the case of Broadcast (FEC) mode, a varying number of data blocks are sent in each ARQ/CCB time frame. The number of data blocks and other timing parameters are adjusted so that the total time for each ARQ frame is exactly 5.440 seconds, regardless of modulation waveform combination used. 255 byte long data blocks are used in all ARQ modes. The Reed-Solomon coder efficiency is set to 60%, 75%, or 90% depending upon the ARQ Bias selected (Robust, Normal, and Fast bias, respectively). ARQ bias will be discussed in section 3.3.4. ARQ mode parameters are shown in Figure 6.

3.3.3 Adaptive ARQ (AUTO-ARQ)

The CLOVER-2000 AUTO-ARQ mode provides a three-fold strategy to attack the problems of HF data signal distortion.

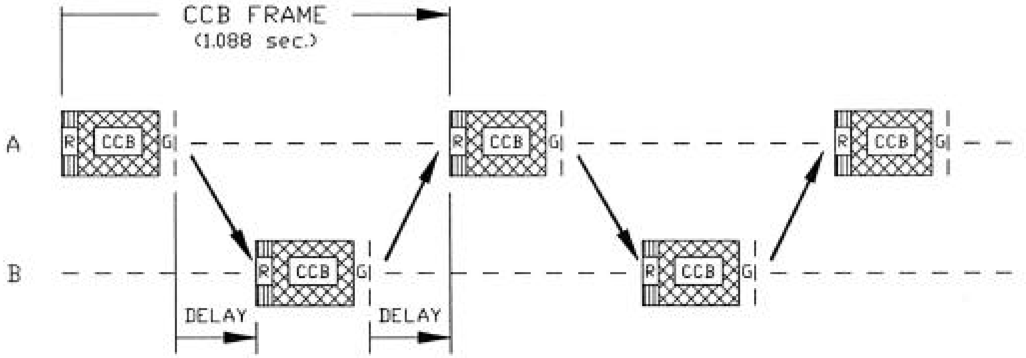
1. *Adaptive modulation waveform control*. The CLOVER-2000 demodulator measures S/N ratio, frequency offset, phase dispersion, and error corrector loading on every block of data received. The current signal conditions are known and used to adaptively change the other station's transmitter parameters to match these conditions.

2. *Reed-Solomon forward error correction on all data transmitted*. Using NORMAL Bias, a total of 31 flawed data bytes may be repaired for every 188 bytes transmitted without requiring repeat transmissions. In comparison, CCIR-476 (SITOR), P-MODE*, or AX.25 packet radio can detect errors but cannot correct these errors without retransmission.

3. *Selective Repeat ARQ protocol*. When byte errors in ARQ mode exceed the capacity of the Reed-Solomon decoder, only the damaged data blocks are repeated. In comparison, CCIR-476 (SITOR) and P-MODE must repeat all data of a pulse if one character is damaged. One character error in AX.25 requires that the entire flawed packet and all packets within a multiple packet format must be repeated.

*The word "P-MODE" is the HAL designation for a communications protocol that may also be known as "Pactor", a registered trademark of the Spezielle Communications Systeme (SCS) firm in Hanau, Germany. HAL affirms that, to the best of its knowledge, "P-MODE" is compatible and interoperable with the protocol SCS calls "Pactor" and with the link establishment and weak signal modes of the protocol SCS calls "Pactor-II".

CLOVER-2000 BASIC ARQ CCB FRAME



DELAYS:

R = Reference Sequence = 0.016 sec.
CCB = CLOVER Control Block
= BPSM/17/60 = 0.272 sec.
G = No-Signal Gap = 0.016 sec.

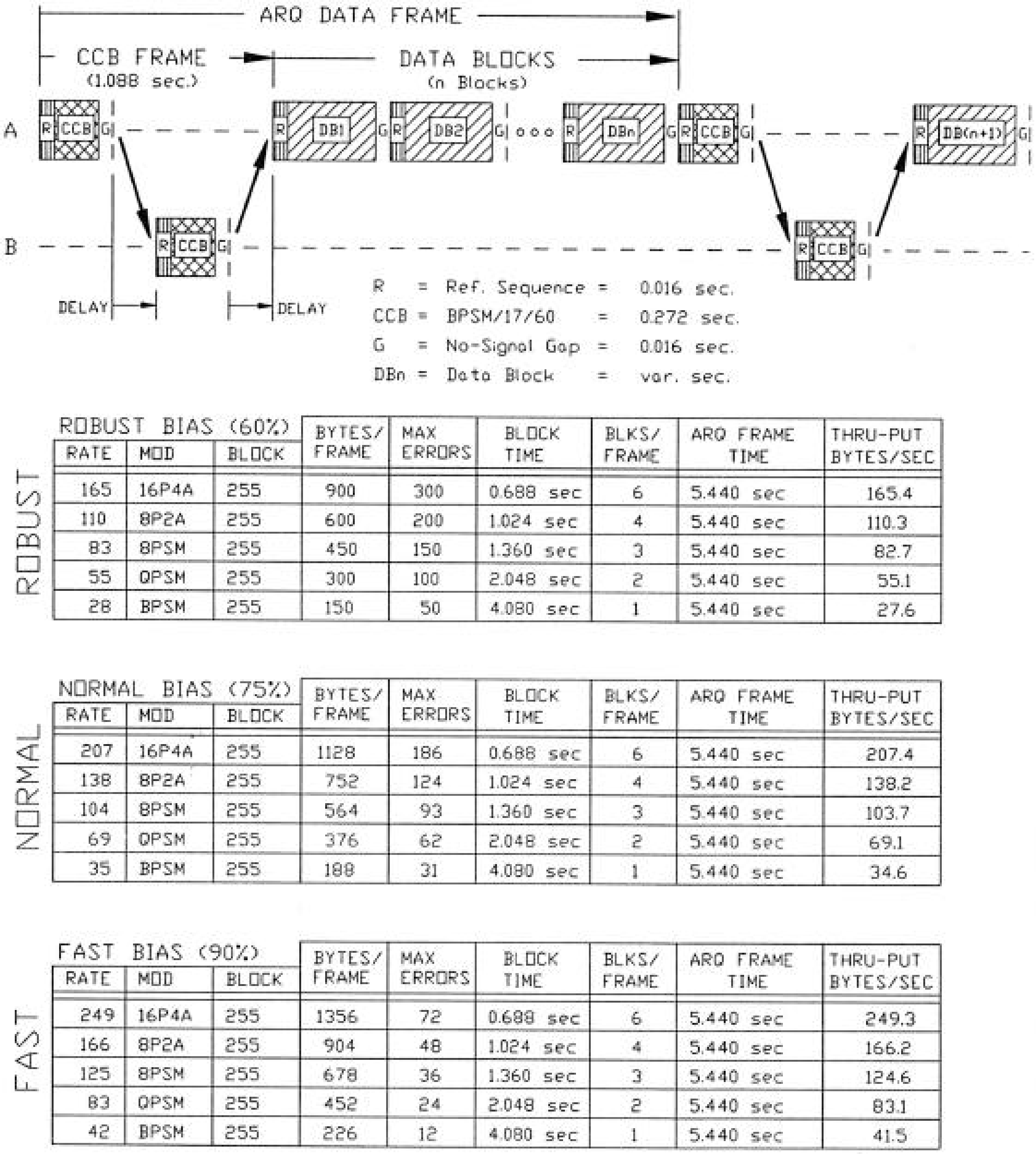
t(prop) = Propagation = 0.096 sec. (max)
t(filter) = Filter Delay = 0.032 sec.
t(coder) = R-S Coder = 0.080 sec.
t(PTT) = PTT Delay = 0.032 sec.

CCB FRAME TIMING:

PARAMETER	TIME	TPS FRAMES
REF (A)	0.016	1
CCB (A)	0.272	17
GAP (A)	0.016	1
t(A-B prop)	0.096	6
t(B-fil)	0.032	2
t(B-coder)	0.080	5
t(B-PTT)	0.032	2
REF (B)	0.016	1
CCB (B)	0.272	17
GAP (B)	0.016	1
t(B-A prop)	0.096	6
t(A-fil)	0.032	2
t(A-coder)	0.080	5
t(A-PTT)	0.032	2
	1.088 sec.	68.0 TPS Frames

NOTE: "TPS" = Tone Pulse Sequence (16 ms)

Figure 5. CLOVER-2000 – ARQ Mode - CCB Layer Timing



R = Ref. Sequence = 0.016 sec.
CCB = BPSM/17/60 = 0.272 sec.
G = No-Signal Gap = 0.016 sec.
DBn = Data Block = var. sec.

ROBUST BIAS (60%)

RATE	MOD	BLOCK	BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
165	16P4A	255	900	300	0.688 sec	6	5.440 sec	165.4
110	8P2A	255	600	200	1.024 sec	4	5.440 sec	110.3
83	8PSM	255	450	150	1.360 sec	3	5.440 sec	82.7
55	QPSM	255	300	100	2.048 sec	2	5.440 sec	55.1
28	BPSM	255	150	50	4.080 sec	1	5.440 sec	27.6

NORMAL BIAS (75%)

RATE	MOD	BLOCK	BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
207	16P4A	255	1128	186	0.688 sec	6	5.440 sec	207.4
138	8P2A	255	752	124	1.024 sec	4	5.440 sec	138.2
104	8PSM	255	564	93	1.360 sec	3	5.440 sec	103.7
69	QPSM	255	376	62	2.048 sec	2	5.440 sec	69.1
35	BPSM	255	188	31	4.080 sec	1	5.440 sec	34.6

FAST BIAS (90%)

RATE	MOD	BLOCK	BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
249	16P4A	255	1356	72	0.688 sec	6	5.440 sec	249.3
166	8P2A	255	904	48	1.024 sec	4	5.440 sec	166.2
125	8PSM	255	678	36	1.360 sec	3	5.440 sec	124.6
83	QPSM	255	452	24	2.048 sec	2	5.440 sec	83.1
42	BPSM	255	226	12	4.080 sec	1	5.440 sec	41.5

Figure 6. CLOVER-2000 ARQ Mode - Data Block Layer Timing

It is important to note that under adaptive waveform control the receiving station measures signal parameters and dictates the modulation mode to be used by the transmitter. Thus, in the ARQ link, MY transmitter is controlled by HIS receiver, not by any parameter that might be set or changed at MY terminal.

3.3.4 Adaptive ARQ Bias Parameter

The AUTO-ARQ format and modes used are shown in Figure 6. The "BIAS" setting of AUTO-ARQ is used to control the mode switching strategy.

ROBUST bias gives the highest error correction but lowest throughput. It also requires a long integration time in good conditions before the effective data rate is increased. ROBUST is useful in situations where conditions must be maintained on an unstable path, regardless of data throughput. This mode is most useful when fixed frequency operation below 7 MHz is the only choice (high multi-path condition). ROBUST bias uses 60% Reed-Solomon encoder efficiency. While a 255 byte block will send only 150 bytes of data, a total of 50 byte errors of that block (1/3 the number sent) may be corrected without repeat transmission.

Conversely, FAST bias uses minimum in-block error correction and will quickly shift to high rate modes. This mode maximizes data throughput and will be most useful on stable paths and frequencies. FAST bias uses 90% coder efficiency, sending 226 data bytes per block and may correct up to 12 byte errors in each block.

NORMAL bias provides a good operational balance between error correction, throughput, and rate change responsiveness. NORMAL mode is recommended for most uses of CLOVER-2000, especially when CLOVER is used in a frequency scanning HF station. NORMAL bias uses 75% efficiency, sending 188 data bytes per block and may correct 31 byte errors in each block.

3.3.5 ARQ Mode Performance

Figures 7, 8, 9, and 10 illustrate the measured data throughput performance of CLOVER-2000 mode for each of the three bias conditions. These measurements were all conducted under laboratory conditions using a precision noise source (AWGN, 3000 Hz noise bandwidth).

3.3.6 ARQ Connection

Unlike CLOVER-II, CLOVER-2000 has only one connect mode, corresponding to the "Robust Connect Mode" of CLOVER-II. CLOVER-2000 operations are 4 times faster than for CLOVER-II and thus the need for a fast connect procedure for scanning stations is met with the "standard" ROBUST connection procedure.

An ARQ connection proceeds as follows:

Originating Station:	Send Connect Request CCB (contains HISCALL)
Responding Station:	Send "Here Is" CCB (Acknowledges with HISCALL)
Originating Station:	Send "I Am" CCB (sends MYCALL)
Responding Station:	Send Signal Reports CCB (of Originating signal)
Originating Station:	Send Signal Reports CCB (of Responding signal)

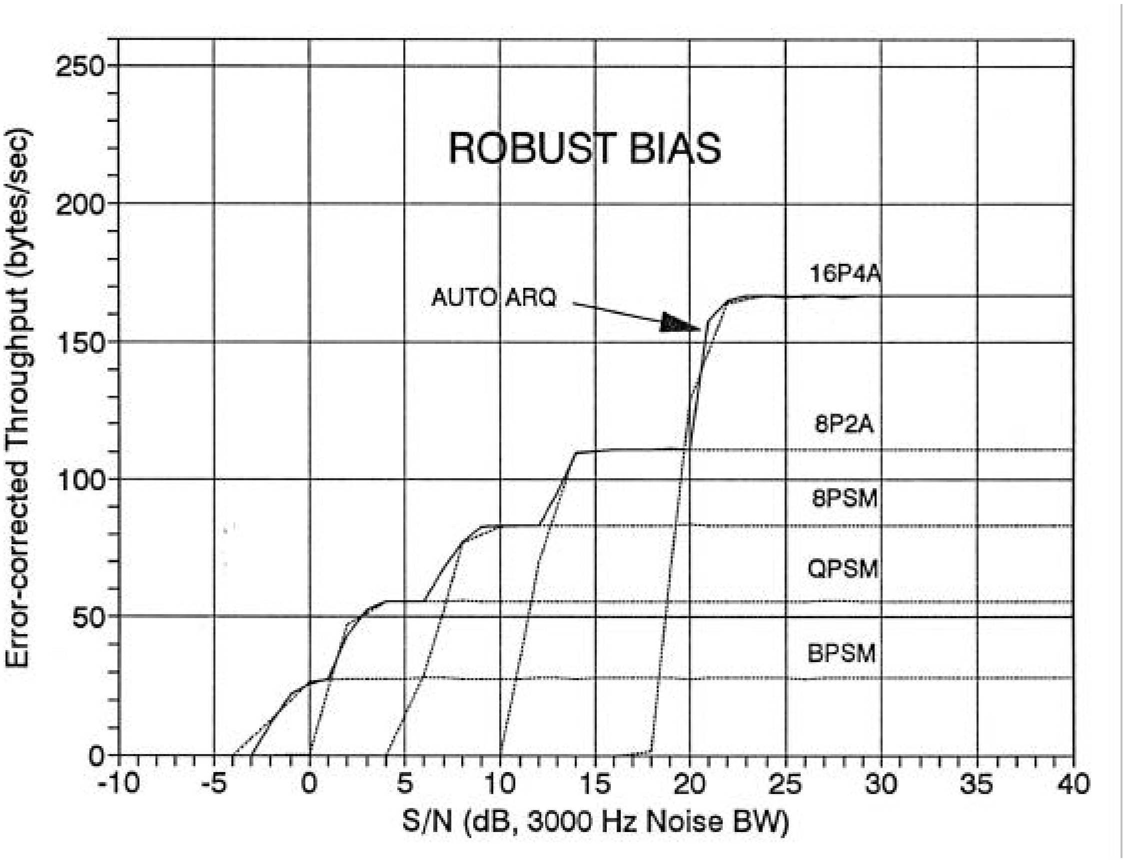


Figure 7. CLOVER-2000 ARQ Throughput - Robust Bias

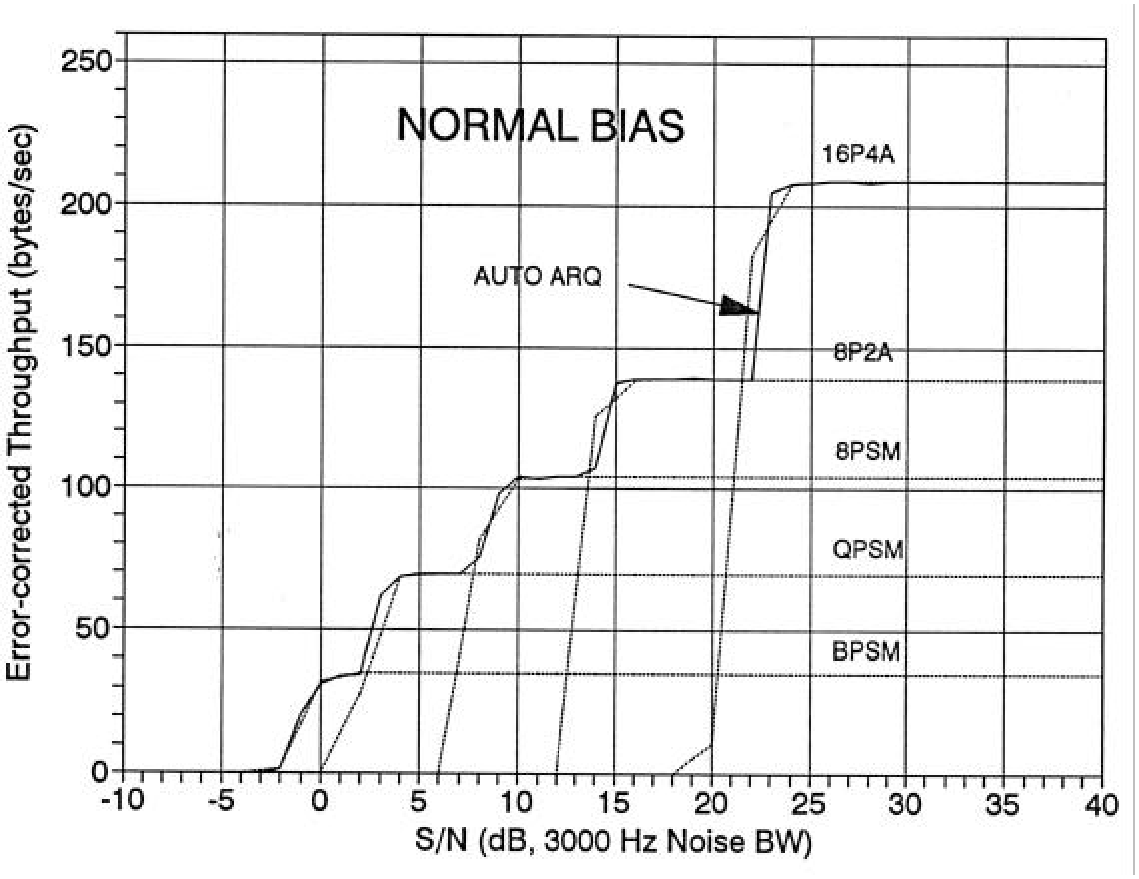


Figure 8. CLOVER-2000 ARQ Throughput - Normal Bias

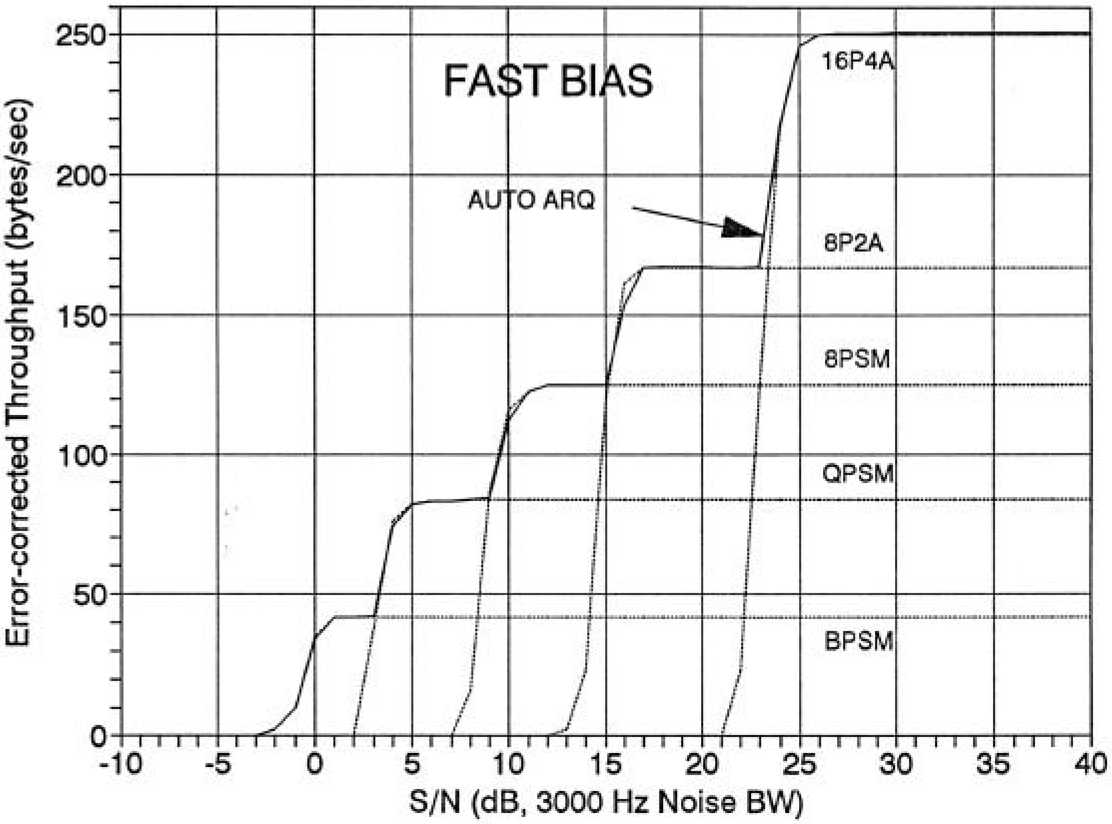


Figure 9. CLOVER-2000 ARQ Throughput - Fast Bias

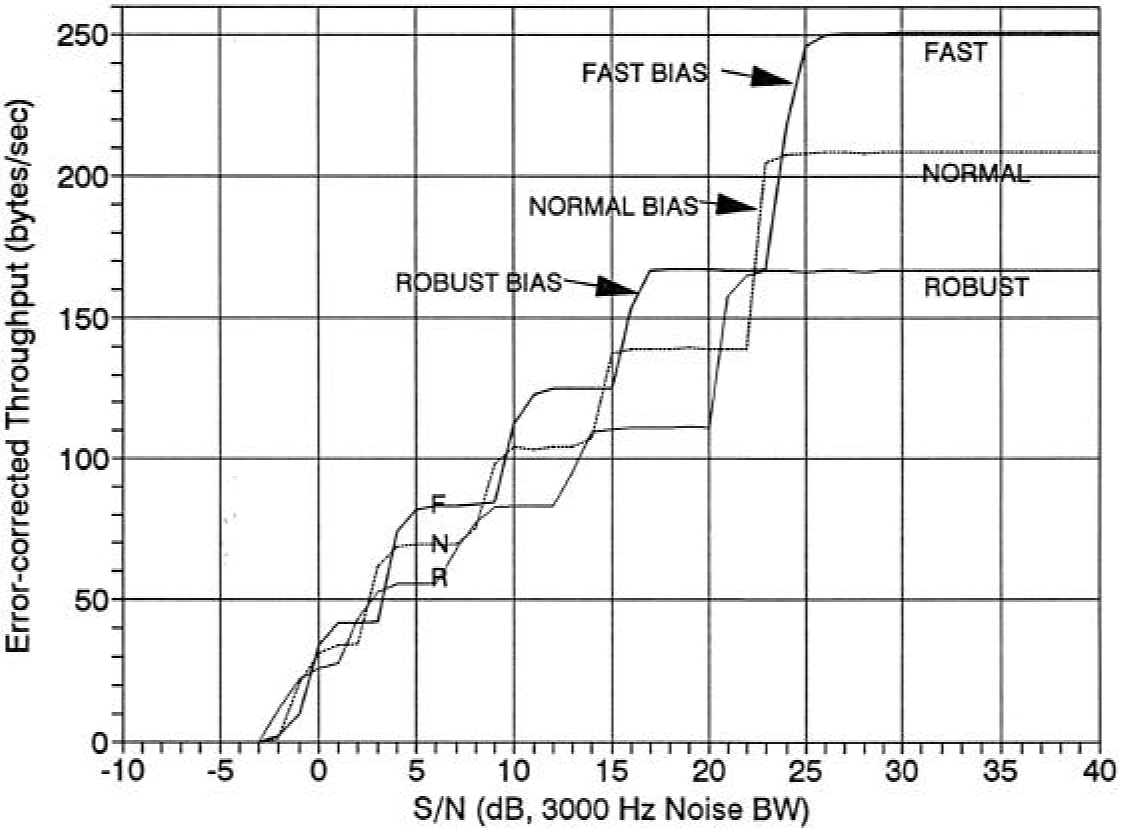


Figure 10. CLOVER-2000 ARQ Throughput - Bias Comparison

3.3.6 One-Way and Two-Way ARQ

TOR (SITOR or AMTOR) and P-MODE send in only one direction at a time and require use of the OVER command to change the direction of data flow. AX.25 packet radio is flexible and either station may send data to the other station without use of an OVER command. CLOVER ARQ mode does not require an OVER command (like packet), but uses a precisely timed ARQ frame similar to that of SITOR. When first linked, two CLOVER ARQ stations operate in "chat mode". Both stations may send a limited amount of data to the other (6 bytes per CCB). When the amount of buffered transmit data at one station exceeds 255 bytes, that modem shifts into data block mode, sending in the format shown for station "A" in Figure 6. Data from station "A" now flows at a high rate and in large blocks. However, data from station "B" will still be passed to "A" within the CLOVER Control Block (CCB). When station "A" has sent all of its buffered data, it reverts to the initial "CCB-level" of the protocol and both stations may continue in "chat mode". If station "B" now has bulk data to send, its modem shifts into data block mode and "A" remains in "chat mode". This procedure is a very close match to the way that all current HF Bulletin Board Stations (BBS) operate. For example, to read a BBS message, your station makes short command transmissions (using "chat mode") and the BBS makes long transmissions (the requested message in block mode). Conversely, when you store a message in the BBS, your station uses block mode to send the message and the BBS responds with prompts and acknowledgments in "chat mode".

CLOVER-2000 also supports high rate block mode transmissions in both directions. In this case, when both station "A" and station "B" have large amounts of transmit data to send, both transmissions use block mode and data flow in the communications channel alternates direction each ARQ frame (approximately every 5.5 seconds). This is called the "Two-way ARQ mode" of CLOVER operation. Since transmitters and receivers switch ON and OFF alternatively, the mode is not truly "Full-Duplex" - data does not flow in both directions simultaneously.

Selection of "chat", "one-way", or "two-way" ARQ modes of operation is automatic and dynamic. The mode used is determined by the amount of buffered transmit data to be sent. The ARQ mode is always adjusted to make the most efficient use of the available time on the communications channel. CLOVER-2000 is therefore both bandwidth efficient and time efficient.

3.3.7 ARQ CQ Mode

The CLOVER CCB is also used to make a “general call for communications" - commonly known as "CQ". In this case, the originating station sends a CQ CCB that includes his call sign. The receiving station's modem recognizes the CQ CCB, and decodes the call sign. If the receiving station desires, he may then press a key and initiate ARQ communications with the calling station. The listening station may also choose to ignore the CQ call by not taking any action.

3.3.8 ARQ Disconnect

Two types of disconnects are available in ARQ - "NORMAL" and "PANIC". A NORMAL disconnect request is processed in the order it is received. All data loaded into the modem prior to the disconnect is sent and acknowledged before the link is stopped. A PANIC disconnect will immediately cease transmitting at the originating station. The other station will then cease only when its retry counter is exceeded.

3.3.9 SEL-CAL & Scan-Control

CLOVER modems include a SEL-CAL switch output that may be used to control frequency scanning transmitters and receivers. The SEL-CAL output may be set for either *continuous* (low at connect, high at disconnect), or *pulsed* operation (pulse low at connect, pulse low at disconnect).