CLOVER-II 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" is the first CLOVER waveform sold commercially, developed by Ray Petit and HAL Communications in 1990-92. "CLOVER-II" has been implemented in the HAL PCI-4000, P-38, and DSP-4100 modem products. CLOVER waveforms are characterized by the following general properties:

a. Very low base data rate.
b. Time-sequence of amplitude-shaped pulses.
c. Very narrow frequency spectra.
d. Differential modulation between pulses.
e. Multi-level modulation

2. CLOVER-II Waveform

2.1 Time/Frequency Domain

The CLOVER-II waveform uses four tone pulses which are spaced in frequency by 125 Hz. Four different 500 Hz wide audio channels have been defined for CLOVER-II. The parameters of each channel are shown below in Table 1. The factory default channel is No. 4 with a center frequency of 2250 Hz.

TABLE 1
CLOVER-II TONE FREQUENCIES

Frequency	CHAN 1	CHAN 2	CHAN 3	CHAN 4
Fc (center)	750.0 Hz	1250.0 Hz	1750.0 Hz	2250.0 Hz
F1 (tone #1)	562.5 Hz	1062.5 Hz	1562.5 Hz	2062.5 Hz
F2 (tone #2)	687.5 Hz	1187.5 Hz	1687.5 Hz	2187.5 Hz
F3 (tone #3)	812.5 Hz	1312.5 Hz	1812.5 Hz	2312.5 Hz
F4 (tone #4)	937.5 Hz	1437.5 Hz	1937.5 Hz	2437.5 Hz

The four tone pulses are sent in time sequence with 8 milliseconds (ms) between the center of each pulse (8 ms between pulse 1 and 2, 8 ms between pulse 2 and 3, etc.). A complete tone pulse sequence is repeated every 32 ms; i.e., 32 ms elapse between the 1st and 2nd occurrence of tone pulse #1. The four 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-II modulating signal. Figure 3 shows the resulting CLOVER-II frequency spectra.

Please note that while Figures 1 and 2 have been simplified and idealized to clarify this discussion, Figure 3 shows the actual measured spectra of CLOVER-II modulation generated by the HAL DSP modem (PCI-4000, P38, or DSP-4100).

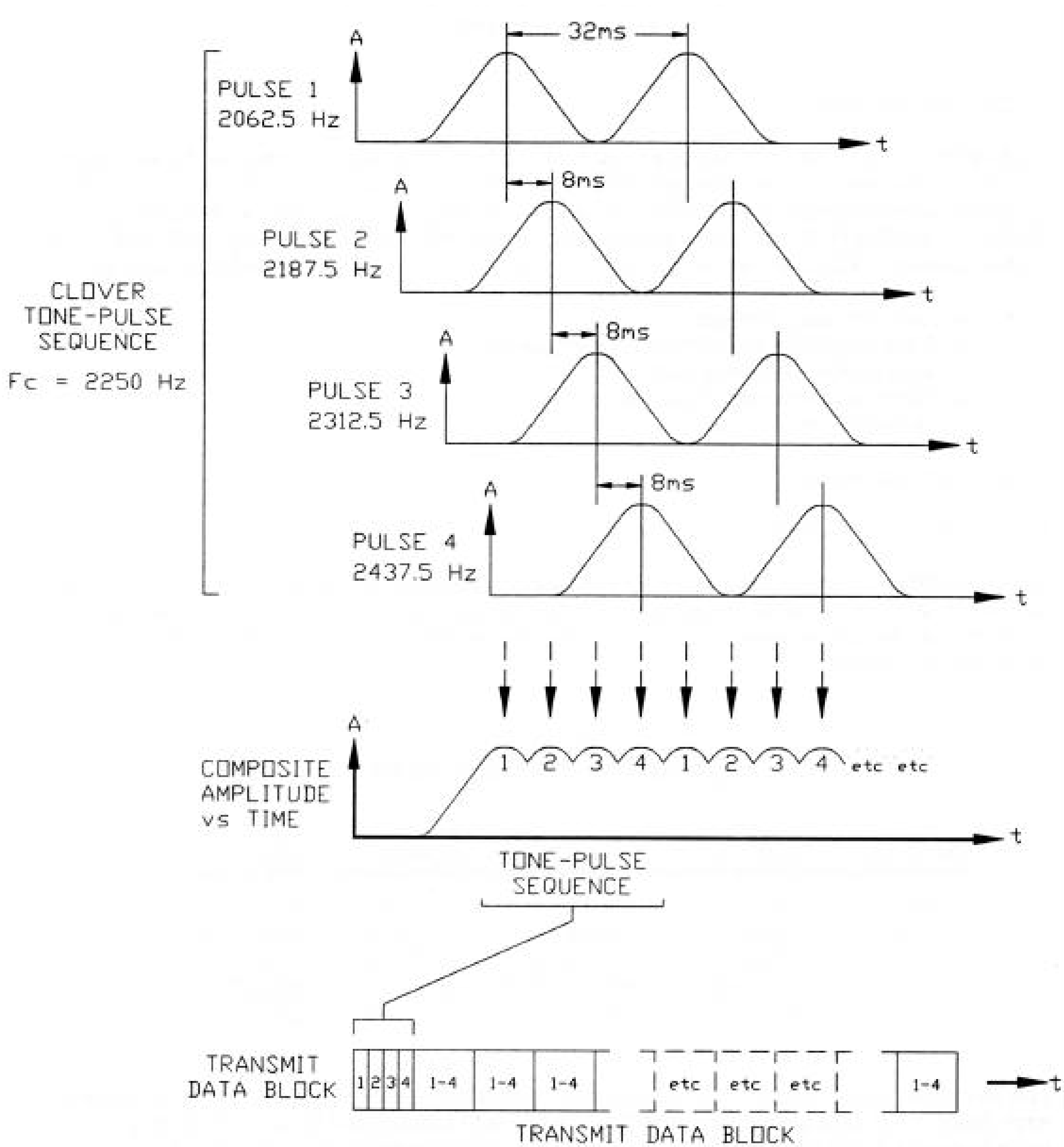


Figure 1. CLOVER-II Tone Pulse Sequence

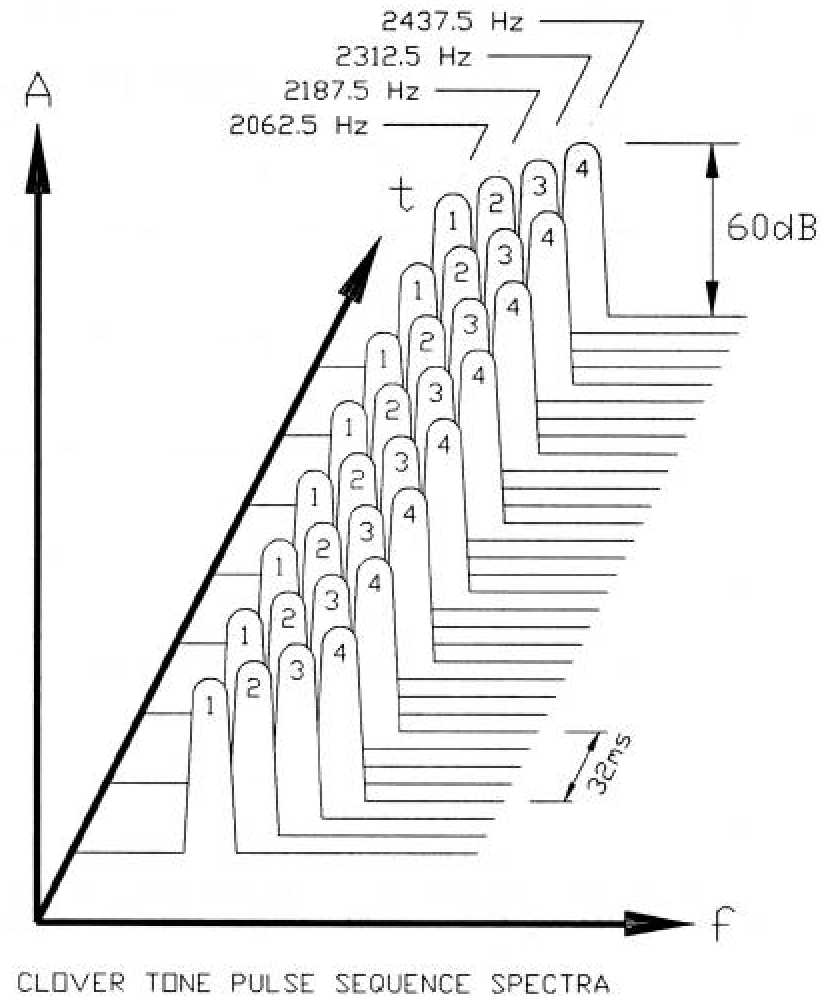


Figure 2. CLOVER-II Time/Frequency Relationship

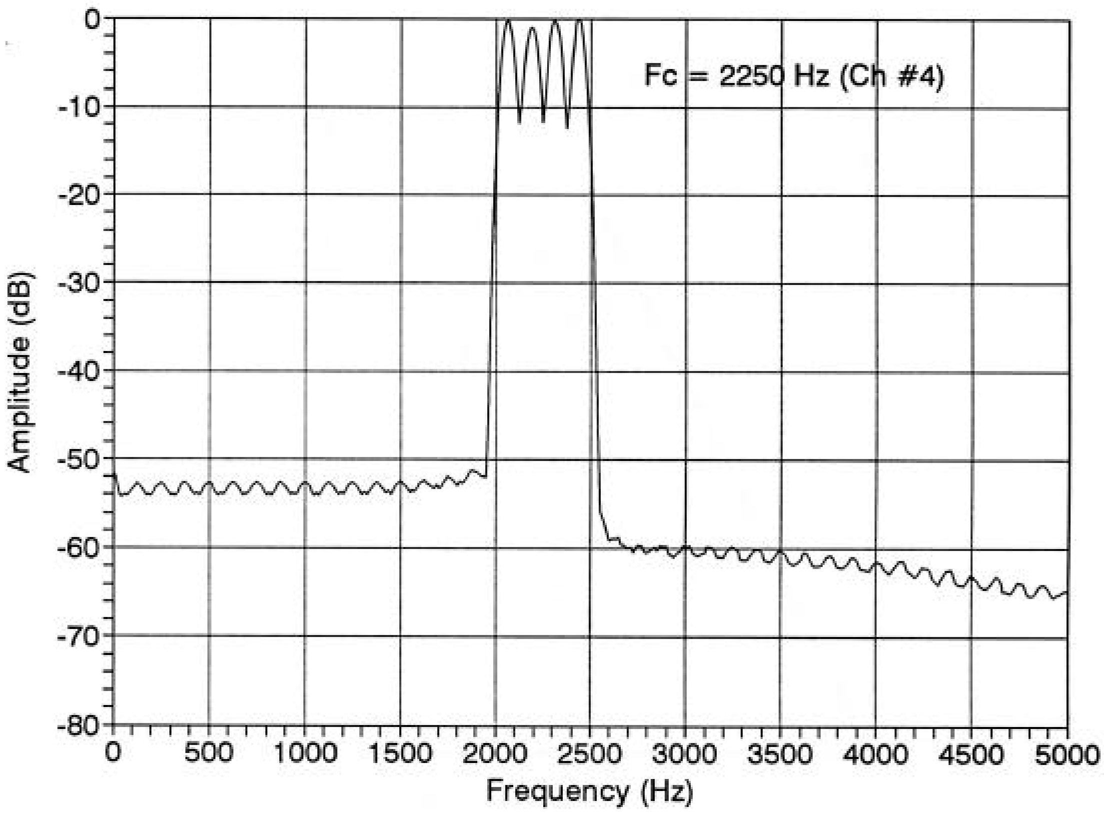


Figure 3. Measured Frequency Spectra of CLOVER-II

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

> *NOTE: CLOVER-II 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-II modulation.*

Key parameters of the CLOVER-II emission are:

Occupied Bandwidth	= 500 Hz @ -50 dB below peak level
Crest Factor (pk/avg)	< 2:1 (voltage) < 6 dB (power)
CCIR Emission	= 500H J2 DEN or 500H J2 BEN

2.2 Data Modulation

Data is impressed or modulated upon the CLOVER-II 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 that pulse. 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-II.

The CLOVER-II spectra is the <u>same</u> for all modulation forms.

CLOVER-II uses four 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 32 ms:

The base modulation rate of a CLOVER-II signal is <u>always</u> 31.25 symbols/sec.

The low symbol rate makes CLOVER-II 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 (31.25 bps):

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

CLOVER-II 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 four tone pulses of CLOVER-II. Thus, 4 data bits are sent by differential binary phase modulation for each 32 ms tone pulse frame. Even though the base modulation rate is 31.25 bits-per-second (bps), the effective data rate using BPSM on all four tone pulses is four times that, or, 125 bps. This is one way in which CLOVER-II sends data at a relatively high data rate but maintains a very low base rate.

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

Note the above usage of "Phase Shift Modulation" (PSM) rather than "Phase Shift Keying" (PSK). Since "PSK" is traditionally used to describe the modulation of a constant carrier which 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-II 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 8 bits of data sent in each 32 ms four tone-pulse frame. This increases the net data rate by a factor of 8 from the base rate (to 250 bps). Similarly, 8-ary PSM (8-level, 8PSM) provides an effective bit rate of 375 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 16P4A, the fastest modulation with an effective data rate of 750 bps. Also, 2-level ASM may be used with 8PSM modulation to produce 8P2A which has an effective rate of 500 bps. In all cases, the base symbol rate for any one CLOVER-II tone pulse remains at 31.25 bps and the total spectra is as shown in Figure 3.

> *CLOVER-II 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-II 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-II. 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-II are shown below in Table 2.

TABLE 2
CLOVER-II MODULATION MODES

Mode	Description	Effective Data Rate	Used in
16P4A	16 Phase, 4-Amplitude Modulation	750 bps	ARQ & FEC
8P2A	8 Phase, 2-Amplitude Modulation	500 bps	ARQ & FEC
8PSM	8-level Phase Shift Modulation	375 bps	ARQ & FEC
QPSM	4-level Phase Shift Modulation	250 bps	ARQ & FEC
BPSM	Binary Phase Shift Modulation	125 bps	ARQ & FEC
2DPSM	2-Channel Diversity BPSM	62.5 bps	FEC 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-II 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-II 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-II has four "coder efficiencies" options: 60%, 75%, 90%, and 100% ("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. "100% efficiency" turns the Reed-Solomon encoder OFF and has the highest throughput but fixes no 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 Data Rate" numbers listed in Table 2 go as high as 750 bps (bits-per-second), inclusion of other desired features in CLOVER-II add overhead and thus reduce the net throughput or overall efficiency of a CLOVER transmission. Reed-Solomon error correction encoding makes CLOVER-II 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%
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%
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 "FEC" mode (also called the "broadcast mode"). In ARQ mode, CLOVER-II 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-II. 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-II has a set of six different modulation formats which 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 four Reed-Solomon coder efficiencies (60%, 75%, 90%, and 100%). There are 96 different waveform modes which could theoretically be used to send data via CLOVER (6 x 4 x 4). 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-II emissions. The following conventions are used to describe data "speeds" of CLOVER-II:

The <u>SYMBOL RATE</u> of CLOVER-II is always 31.25 Baud.

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

The <u>Data Rate</u> in CLOVER-II 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-II. The data rate is always an integer multiple of the symbol rate (31.25) of CLOVER-II. As may be seen in Table 2, multi-level modulation provides data rates of 31.25, 62.5, 125, 250, 375, 500, and 750 bps (bits-per-second). As used in this discussion, data rate numbers do not include the effects of "overhead".

"Overhead" is used to describe any function or operation in CLOVER-II 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 all necessary 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, FEC and ARQ modes each add overhead to the CLOVER transmission. 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 which further reduce the net rate at which data may be passed.

For the purpose of clarity, CLOVER-II documentation uses throughput to describe the over-all rate at which data is passed between transmitter and receiver. Further, throughput using CLOVER-II 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 one-way transmission path.

Reviewing, Baud is used to described the base symbol rate of CLOVER-II (31.25), bits-per-second (bps) describe the data rate within a modulation block, and bytes-per-second (byps) describe the rate at which information is passed between two CLOVER-II stations.

Note that CLOVER-II always transmits and receives data in 8-bit increments. However, CLOVER-II 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-II 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-II is for the throughput of *uncompressed* data.

3. CLOVER-II Protocols

CLOVER-II data may be sent using FEC ("broadcast") or ARQ protocols. Both of these protocols have minor variants which 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 FEC and ARQ protocols. The CCB contains information which tells the receiving modem details of the data blocks which will follow. The CCB is used to:

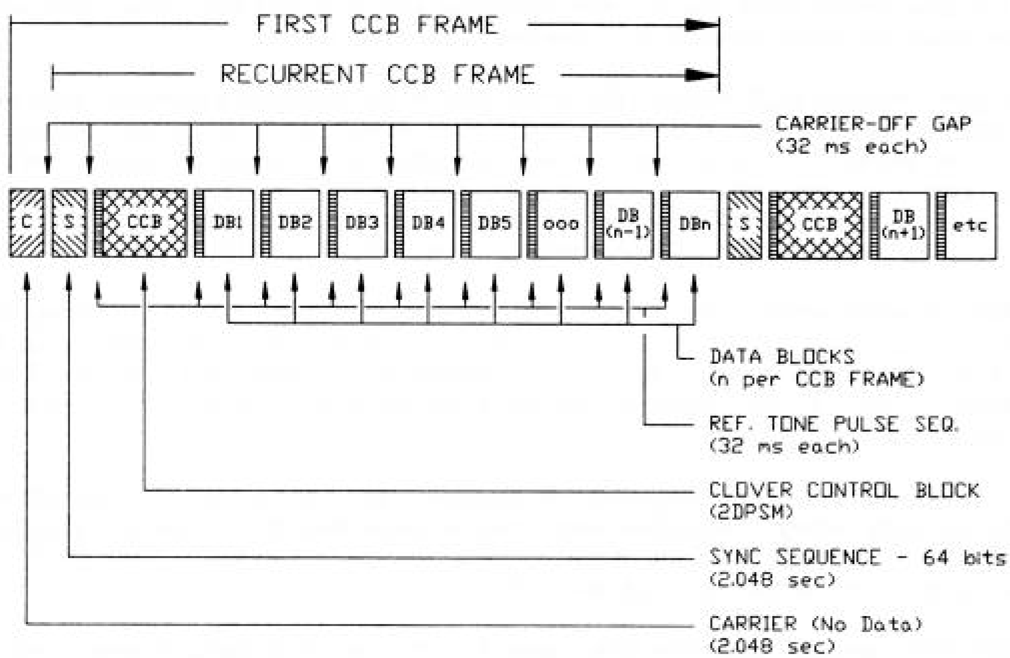
a. Send MYCALL
b. Send Waveform parameters of data blocks
c. Synchronize receiver detector
d. Connect request (ARQ mode)
e. Disconnect request (ARQ mode)
f. Repeat request (ARQ mode)
g. Keyboard entry text (ARQ mode when time permits)
h. Exchange channel statistics (ARQ mode, when time permits)
i. Call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

CLOVER-II 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. 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 FEC transmissions. The data transmission format used for FEC mode is shown in Figure 4.

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
46	16P4A	255	60%	2DPSM	2.720 sec	9	29.376 sec	45.0
31	8P2A	255	60%	2DPSM	4.080 sec	6	29.184 sec	30.8
24	8PSM	255	60%	2DPSM	5.440 sec	5	31.840 sec	23.6
15	QPSM	85	60%	2DPSM	2.720 sec	9	29.376 sec	14.9
8	BPSM	85	60%	2DPSM	5.440 sec	5	31.840 sec	7.5
4	2DPSM	51	60%	2DPSM	6.528 sec	4	30.688 sec	3.7

Figure 4. CLOVER-II FEC Mode Format

Since FEC transmissions cannot use repeat transmission or adaptive waveform selection, all FEC transmissions are sent using 60% Reed-Solomon error correction efficiency. The block lengths used for each 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 32 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 32 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 FEC data waveform modes vary for each FEC rate chosen. These modes are chosen to optimize FEC performance (throughput, error correction, and system synchronization) for each rate. The FEC CCB is always sent using 2DPSM modulation, 17 byte block size, and 60% encoder efficiency. Six data throughput choices are available for FEC transmission. Details of the 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 is the "work-horse" mode of CLOVER-II. While messages may be broadcast using FEC mode (one point to multiple point transmission), only ARQ mode provides fully adaptive and error-corrected communications. ARQ 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.

CLOVER-II ARQ 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 at a high, 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 FEC 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. The throughput rate during data block transmission is generally much higher than that used in the CCB.

As in the case of FEC, 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 19.488 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-II AUTO-ARQ mode provides a three-fold strategy to attack the problems of HF data signal distortion.

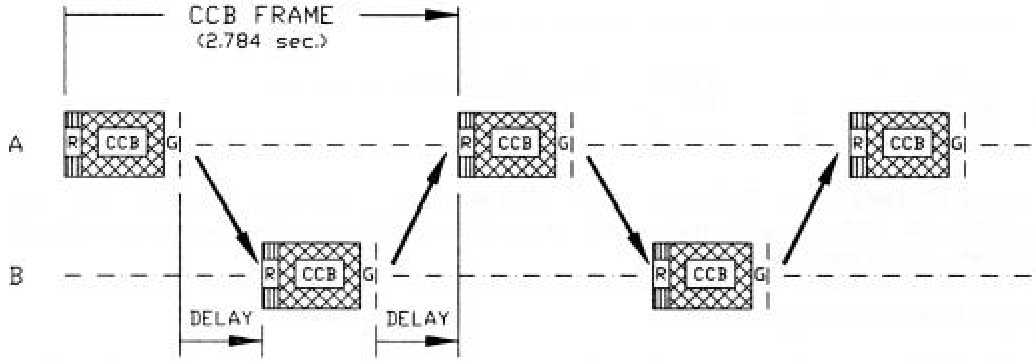
1. Adaptive modulation waveform control. The CLOVER-II demodulator measures S/N ratio, frequency offset, and phase dispersion on every block of data received. The current signal conditions are known and used to adaptively change the other station's transmitter parameters to match these conditions.

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 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-II BASIC ARQ CCB FRAME



R	= Reference Sequence	= 0.032 sec.		
CCB	= CLOVER Control Block			
	= BPSM/17/60	= 1.088 sec.		
G	= No-Signal Gap	= 0.032 sec.		

DELAYS:

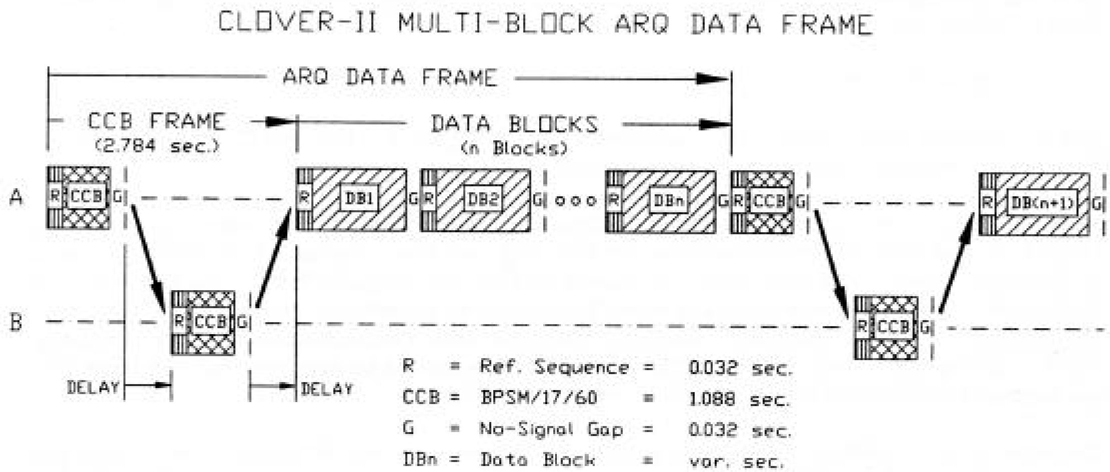
t(prop)	= Propagation	= 0.096 sec. (max)
t(filter)	= Filter Delay	= 0.032 sec.
t(coder)	= R-S Coder	= 0.080 sec.
t(PTT)	= PTT Delay	= 0.032 sec.

CCB FRAME TIMING:

PARAMETER	TIME	TPS FRAMES
REF (A)	0.032	1
CCB (A)	1.088	34
GAP (A)	0.032	1
t(A-B prop)	0.096	3
t(B-fil)	0.032	1
t(B-coder)	0.080	2.5
t(B-PTT)	0.032	1
REF (B)	0.032	1
CCB (B)	1.088	34
GAP (B)	0.032	1
t(B-A prop)	0.096	3
t(A-fil)	0.032	1
t(A-coder)	0.080	2.5
t(A-PTT)	0.032	1
	2.784 sec.	87.0 TPS Frames

NOTE: "TPS" = Tone Pulse Sequence (32 ms)

Figure 5. CLOVER-**II** - CCB Layer Timing



ROBUST

ROBUST BIAS (60%)			BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
RATE	MOD	BLOCK						
46	16P4A	255	900	300	2.720 sec	6	19.488 sec	46.2
30	8P2A	255	600	200	4.096 sec	4	19.488 sec	30.8
23	8PSM	255	450	150	5.440 sec	3	19.488 sec	23.0
15	QPSM	255	300	100	8.160 sec	2	19.488 sec	15.4
8	BPSM	255	150	50	16.320 sec	1	19.488 sec	7.7

NORMAL

NORMAL BIAS (75%)			BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
RATE	MOD	BLOCK						
58	16P4A	255	1128	186	2.720 sec	6	19.488 sec	57.9
39	8P2A	255	752	124	4.096 sec	4	19.488 sec	38.6
29	8PSM	255	564	93	5.440 sec	3	19.488 sec	28.9
19	QPSM	255	376	62	8.160 sec	2	19.488 sec	19.3
10	BPSM	255	188	31	16.320 sec	1	19.488 sec	9.7

FAST

FAST BIAS (90%)			BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
RATE	MOD	BLOCK						
70	16P4A	255	1356	72	2.720 sec	6	19.488 sec	69.6
46	8P2A	255	904	48	4.096 sec	4	19.488 sec	46.4
35	8PSM	255	678	36	5.440 sec	3	19.488 sec	34.8
23	QPSM	255	452	24	8.160 sec	2	19.488 sec	23.2
12	BPSM	255	226	12	16.320 sec	1	19.488 sec	11.6

Figure 6. CLOVER-II ARQ 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 at frequencies that are near the MUF (Maximum Usable Frequency). 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-II, especially when CLOVER is used in a frequency scanning HF BBS station. NORMAL mode uses 75% coder efficiency, sending 188 data bytes per block and may correct 31 byte errors in each block. FEC modes use the equivalent of "ROBUST" bias.

3.3.5 ARQ Mode Performance

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

3.3.6 ARQ Connection

CLOVER-II has two connect modes - NORMAL and ROBUST. NORMAL connect mode is specifically designed to link two ARQ stations within 1.5 seconds. This is compatible with BBS stations that use frequency scanning receivers. ROBUST connect mode will link two ARQ stations in approximately 5 seconds and under weaker signal conditions than when NORMAL is used. Use ROBUST mode for all communications that do not require very fast linking. Once linked, CLOVER shifts to adaptive control which is the same regardless of the connect mode.

A ROBUST 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)

A NORMAL connection differs only in that a short "ping" exchange of the Responding Signal's call sign is sent:

Originating Station:	Send HISCALL in short "ping"
Responding Station:	Echo-back 1's complement of call sign

Continue as for ROBUST link

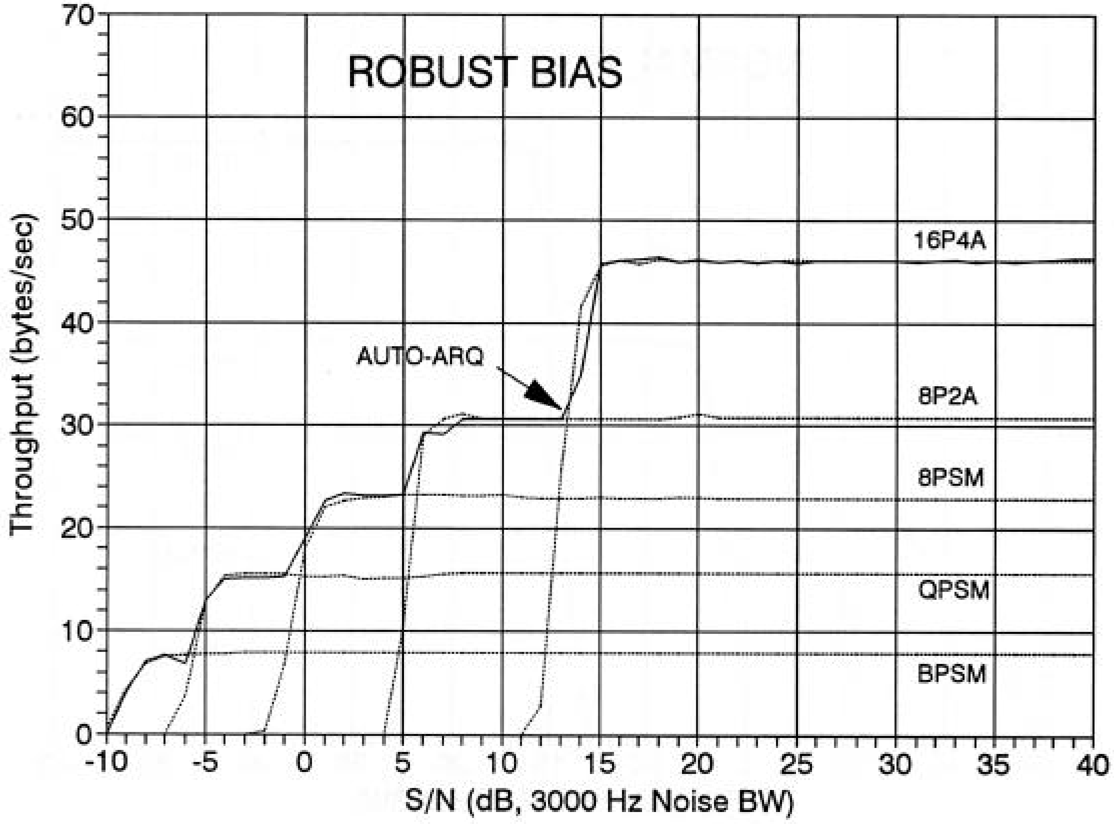


Figure 7. CLOVER-II ARQ Throughput - Robust Bias

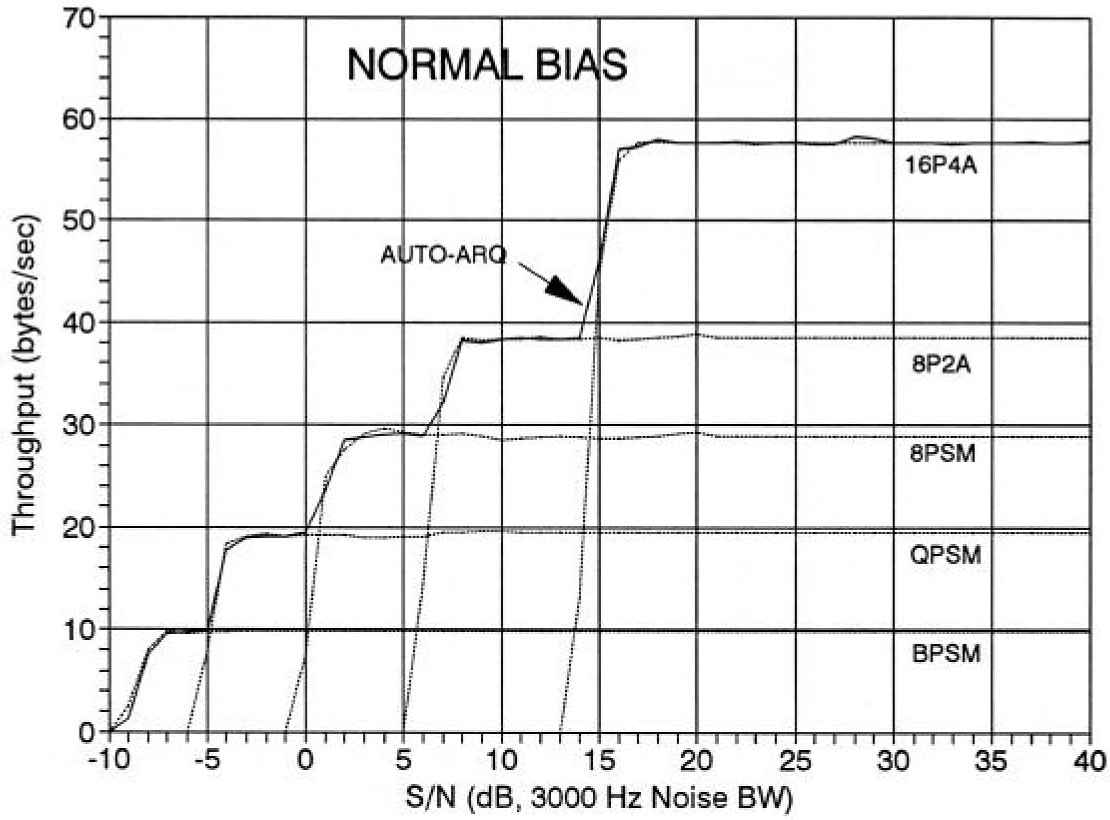


Figure 8. CLOVER-II ARQ Throughput - Normal Bias

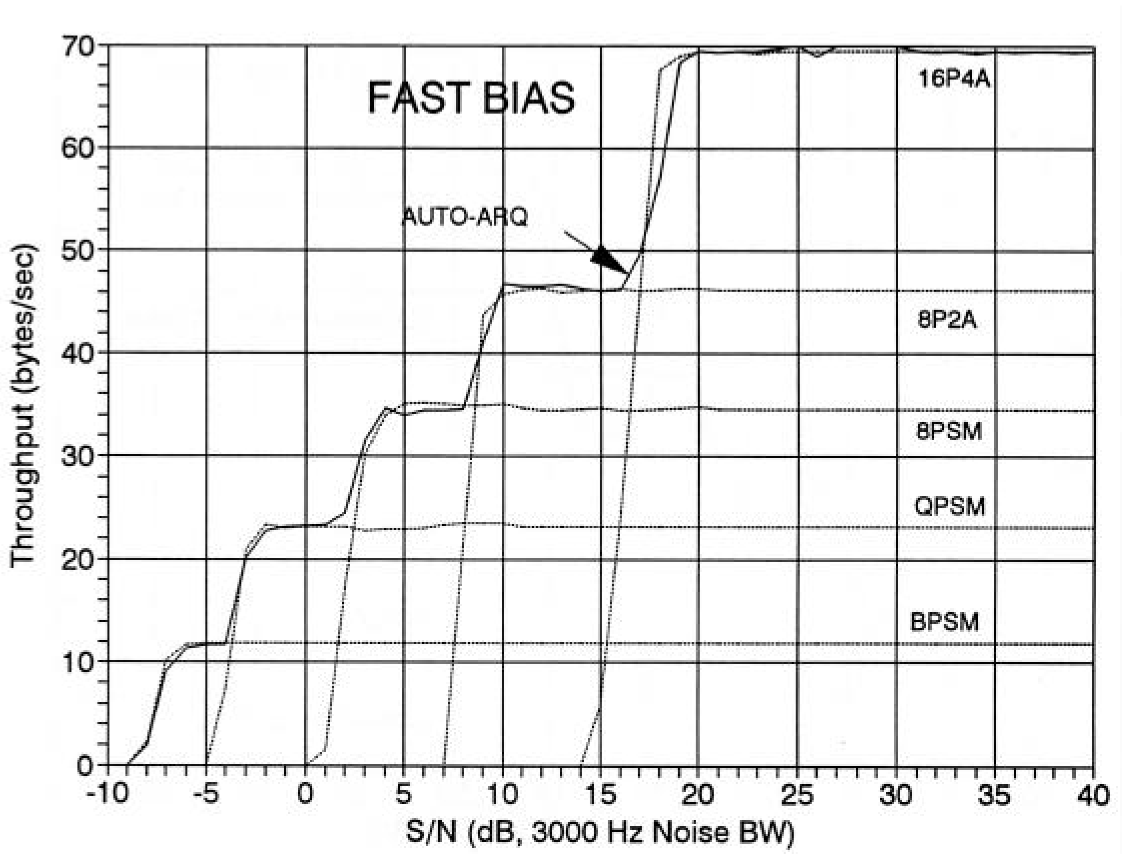


Figure 9. CLOVER-II ARQ Throughput - Fast Bias

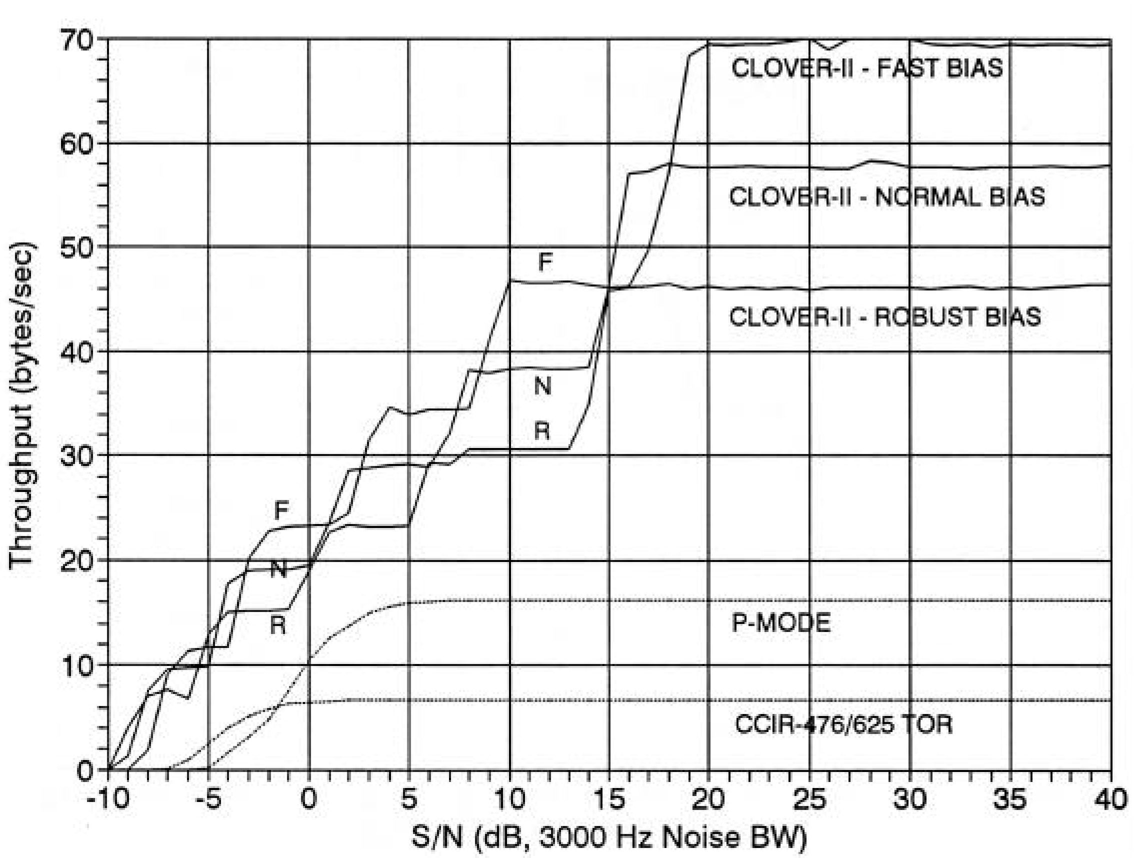


Figure 10. A Mode Comparison - CLOVER vs other ARQ Modes

3.3.7 One-Way and Two-Way ARQ

CCIR-476 (SITOR) 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 AMTOR. 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 BBS stations 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-II 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 20 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-II is therefore both bandwidth efficient and time efficient.

3.3.8 ARQ Chat and Short-Block Modes

As noted above, "Chat" mode is provided to support short transmissions of commands, yes/no type of answers, and other "order-wire" communications. Chat mode is not fast - the maximum throughput is 6 characters in every CCB frame, or 2.155 characters (or bytes) per second. But, chat mode is very robust and it may, in fact, be faster than block mode if only a few characters are to be sent. Consider that the ARQ frame time for all block modes is 19.488 seconds. The large block modes always send 255 bytes per block and 1 to 6 blocks per ARQ frame (see Figure 6). Even if there are only 6 bytes to be sent, the full 255 byte block(s) must be sent.

The "Chat Count" option in HAL terminal software allows user setting of the transition from "chat" to "block" mode. If the Chat Count is set to "0", the transmitting modem will shift directly to block mode if any data is in the transmit buffer. If chat = "1", one CCB of "chat data" will be sent before changing to block mode. Similarly, chat = "2" results in the transmission of two CCB chat frames (12 characters total), and so for up to 9 CCB frames (54 characters). If the primary usage of the modem will be for large data file transfers, the chat count should be set to "0" so that chat mode is bypassed and all data is sent in block mode. Conversely, if a mixture of order-wire and file transfer traffic is anticipated, set "chat" between 1 and 3.

The “chat count” and transition to block mode is further tempered by the status of the modem’s internal FIFO (First-In, First-Out) transmit data buffer. This buffer will store up to 512 bytes of data to be transmitted and provides output “flags” when it is “empty”, “half-full” (255 bytes), and “full”. The “half-full” flag is used as follows:

1. If the chat count is exceeded and there are less than 255 bytes of pending data still stored in the transmit FIFO buffer, the transmitting station will shift to “short block mode” as illustrated in Figure 11. Short block mode sends a single 85 byte block in each ARQ frame and provides a transition “speed” mode between chat mode and full large block modes.

2. Regardless of the chat count setting, if the transmit FIFO is more than “half-full” (contains more than 255 bytes of data to be transmitted), the transmitting modem will shift immediately to “large” block mode, sending data in the format shown in Figure 6.

3. While in “short-block mode”, if the transmit FIFO exceeds “half-full”, the transmitter will shift to large block mode for the next ARQ frame.

4, The chat count and transitions to short- or long-block mode are reset whenever the transmit data FIFO has been emptied - all pending transmit data has been loaded into the mode. There is no downward transition from large- to small-block mode.

3.3.9 ARQ AUTOPOWER

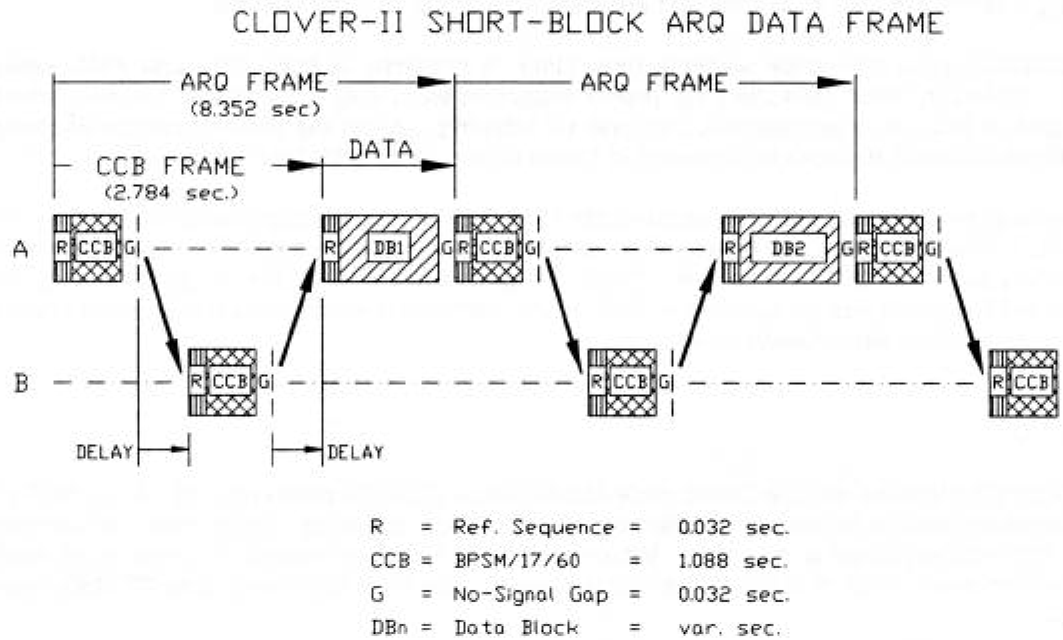
CLOVER-II ARQ mode also includes the capability to dynamically adjust the power output of each transmitter. In most cases, the performance limit for data exchange is set by phase and frequency dispersion, and not by insufficient received signal power. When AUTOPOWER is ON, the CLOVER demodulator computes the "excess received S/N ratio" on each data frame, adds a safety margin, and the commands the transmitting station to adjust its power accordingly. Thus CLOVER uses only the minimum transmitter power required to carry-on communications. Often, the transmitter power output is 1 Watt or less. As in the case of adaptive modulation control, MY receiver sets HIS transmitter power. AUTOPOWER may be turned ON or OFF via PC-CLOVER command. AUTOPOWER is not used if either ARQ station has AUTOPOWER turned OFF. It is recommended that all automated stations turn AUTOPOWER ON and that user stations also set AUTOPOWER ON as much as possible. In some cases, the presence of strong ON/OFF local noise may require setting AUTOPOWER to OFF. CLOVER ARQ will adapt to this situation, but time may be gained by forcing both transmitters to full power (AUTO = OFF).

3.3.10 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.

3.3.11 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.



BIAS	MOD	BLOCK SIZE	BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
ROBUST	BPSM	85	48	16	5.440 sec	1	8.352 sec	5.7
NORMAL	BPSM	85	60	10	5.440 sec	1	8.352 sec	7.2
FAST	BPSM	85	74	3	5.440 sec	1	8.352 sec	8.9

Figure 11. CLOVER-II " Short-Block" ARQ Mode

3.3.12 SEL-CAL & Scan-Control

The HAL DSP 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). The "NORMAL" (Ping) connect mode should be used to link with stations using frequency scanning equipment.

3.4 LISTEN Mode

Stations may monitor ARQ or FEC transmissions of stations using CLOVER-II emission. Listening stations are able to decode text and call signs of the sending stations.

Reed-Solomon error correction within a data block is provided in both FEC and ARQ listen modes. However, error correction via repeat transmission is only provided to the two linked ARQ stations and not to any stations that may be listening. When the error-correction capacity of the Reed-Solomon decoder is exceeded in Listen mode, all data for that block is lost.

The listening station must correctly receive the CCB before any following data blocks may be decoded. If reception of a CCB is missed or corrupted, all data blocks between this and the next successfully received CCB will be lost. Since the period between CCB's is approximately 30 seconds in FEC mode and 20 seconds in ARQ mode, patience is required by the listening station operator, particularly when tuning a new signal.

3.5 CW ID

HAL CLOVER modems include Morse code identification (CW ID) which may be set to OFF or for automatic operation in ten minute intervals. The MYCALL character stream may also be sent in CW from the keyboard at any time. When used, CW ID always sends at a rate of 20 wpm (words-per-minute) using standard 1/3 dot/dash weight. CW ID is sent using tone #2 of the four tone set.