CLOVER - The Technology Grows and Matures

Lessons Learned and Pleasant Surprises

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The "CLOVER" waveform idea was first presented to radio amateurs by Ray Petit in the July, 1990 issue of QEX. His narrow-bandwidth mode that required custom radio transmitter and receiver design soon evolved into a more universal waveform for use with any HF SSB transceiver - called "CLOVER-II".

Development of CLOVER-II was not as simple or as fast as we had expected. It seemed like we were frequently "re-inventing the wheel" and development schedules were re-written every week. After a few false starts and a couple "wrong turns", CLOVER-II was finally shipped and put on-the-air in late 1992. Since then, thousands of CLOVER modems have found their way into ham shacks around the world. CLOVER-II is now available in several different versions of the PCI-4000, the P38, and the DSP-4100 modems as well as in customized systems for commercial and government customers. CLOVER has now been used in every conceivable HF radio application. This includes ham radio, ship traffic, aircraft communications, bank data transfer, computer file transfer, image transmission, and even digital voice. Virtually anything that can be digitized and stored in a PC has been sent somewhere via HF radio and CLOVER, often at data throughput rates that match or exceed those we see on 1200 baud VHF packet radio.

Early CLOVER Lessons:

CLOVER started with a great burst of enthusiasm. We had a bunch of new ideas and a "hundred or so" ways to implement each one. The new DSP architecture promised unheard of design freedom. This was our first product where virtually *every detail* was set by software. We soon became quite familiar with the phrases: "It's only software." - usually followed by - "It will take how *long* to make that change?" We demonstrated the "gas laws" often, especially the one that states "gas expands to fill the available volume". Our version is "Software expands to fill available memory space and consume all processor time".

CLOVER itself experienced many evolutional changes. The first version had a bandwidth of 100 Hz, one tone and used only one phase shift modulation mode. During development, the CLOVER waveform soon expanded to four tones, a bandwidth of 500 Hz, and a total of 160 different modulation modes - a real "knob-twister's paradise"! Coming from the HF packet world, we also intended to fix some of the problems we'd seen with AX.25 on 20 Meters. The CLOVER ARQ protocol therefore includes selective block repeat, in-block error correction coding, bi-directional data flow (no "OVER" command), and adaptive modulation control. While some or all of these ideas had been

used previously, CLOVER was the first to combine the multi-level, multi-mode modulation waveform with an ARQ protocol specifically designed for use over HF radio links. No doubt about it, CLOVER is a *complicated* mode.

Predicting software completion turned out to be very risky business. The first target release date was "April, 1991". This quickly slipped to "fall, 199 1" to "April, 1992" and finally to "November, 1992 (actually the *last* day of November, *1992).* AND - we weren't done! During the first 6 months of CLOVER's commercial life, we issued 8 no-cost software up-grades. We've since provided almost 50 software changes to CLOVER and DSP software, the most recent occurring this summer - July, 1996.

While the hardware schematic and block diagram have been very stable, parts cost and availability have been continuing problems. Price and delivery promises made in 1990 by suppliers have proven to be "optimistic dreams". This is particularly true of the Motorola DSP components. The cost of these parts remains high and periodically they become "non-deliverable". In early 1995, frustrated with this high cost and unpredictable delivery, we redesigned the modem to use the much less expensive and more available TMS320C25 processor and related parts. The P38 modem is the result, the first and so far only DSP modem with a list price under $400 (it usually sells in the "mid-$300 range).

Finally, CLOVER has experienced the typical problems of a pioneering mode. Correctly tuning the radio receiver to exactly match a CLOVER signal takes practice. Virtually all radios made since 1990 can meet the +10 Hz tuning increment requirement, but you need a "soft touch" on the knob and patience to make small corrections and then wait. Once learned, tuning a CLOVER signal is easy - BWT - it's not like any other mode you've ever used! Likewise, tuning the transmitter for no ALC and less than "Max-Smoke" output takes personal discipline, particularly hard for us old-time RTTY types. These are not new problems in HF radio. The early SSB pioneers faced the very same problems in the 1950's. Tuning-in an SSB signal was a lot harder than tuning an AM signal. 40 years later, we think nothing of tuning an SSB signal - "No big deal"! Likewise, we all soon learned that adjusting a linear amplifier was a lot different than tuning the AM finals for "cherry-red plates". Inaccurate tuning and incorrect transmitter adjustment severely limit CLOVER performance and have frequently been the underlying problem behind "it doesn't work" complaints. After 5 years, CLOVER is finally tuning the corner where we are getting comfortable with using it and can also say "no big deal" about these problems.

Marine CLOVER:

Ships at sea have used the "SITOR" mode for I-IF data communications for 30 years. Special frequency channels are allocated for ship-to-shore *Narrow Bandwidth Direct Printing Telegraph* (NBDP) use. "Paired frequencies" are used with ships transmitting on one set of channels and shore stations on another set. Within the "ship" or "shore" sub-bands, the channels are spaced exactly 500 Hz apart. Particularly in the case of shore station allocations, every 500 Hz wide channel is in active use, usually by very powerful transmitters (1 kW to 10 kW). It is therefore very important that adjacent channel

interference be prevented. HAL has teamed with Globe Wireless of Half Moon Bay, California to develop a special version of CLOVER that is tailored to meet ship-to-shore requirements. While the original CLOVER-II waveform has a frequency spectra that is exactly 500 Hz wide (@ -50 dB), this leaves no "guard band" between adjacent channels for tuning error. A marine version was therefore developed that has a -50 dB bandwidth of 400 Hz, well within the FCC Part 80 limits for use on NBDP HF channels. We call this version "CLOVER-400". The spectra of CLOVER-400 and the FCC limits are shown in Figure 1.

Globe Wireless has created a "Global Radio Network" of public coast stations distributed around the world. All public coast stations are tied into the global network via whatever common carrier service is most cost effective for that location (wire line, satellite, Internet, etc.). Regardless of its location at sea, a ship can establish HF radio contact with one or more network coast stations. When not actively sending data, each ship receiver constantly scans the frequency list of Globe stations, listening to traffic or SITOR "free signals", and logging signal quality data for each station heard. At any given time, the shipboard computer therefore "knows" which frequency and station is optimum for communications. Each ship acts as a "passive sounder", obtaining "LQA" data (Link Quality Assessment) for each usable coast station *without the need to transmit.*

All coast stations are equipped to use either SITOR or CLOVER-400 on NBDP HF channels. To maintain compatibility with older vessels, communications start in SITOR mode and then switch to CLOVER-400 when the shore station recognizes a CLOVER-equipped ship. Use of CLOVER not only increases the speed at which data is delivered, it also provides error-corrected 8-bit data transfer of any computer file, be it text, data, image, or executable software. In fact, new software for the CLOVER modem on each ship is passed via CLOVER on HF radio - the system upgrades itself All this is accomplished at a fraction of the cost the user would otherwise have to pay for satellite communications.

Voice Bandwidth CLOVER:

While amateur data modes emphasize narrow bandwidth (500 Hz or less) to conserve limited spectrum, commercial and military HF allocations are virtually all for "voice bandwidth" channels (ship-to-shore excepted). The U.S. Civil Air Patrol (CAP) has made full use of the four "tone channels" of CLOVER-II to expand the capacity of their limited number of HF channel allocations. The CAP technique is to share an HF voice channel between four non-interfering and independent CLOVER ARQ links. This application takes advantage of CLOVER's exceptionally high stop-band suppression. Selection of the CLOVER-II "tone channel" is a user-set feature included in all PCI-4000 and DSP-4 100 modems (not available in the P38 modem). The CAP CLOVER "multiplex" of a voice channel is shown in Figure 2.

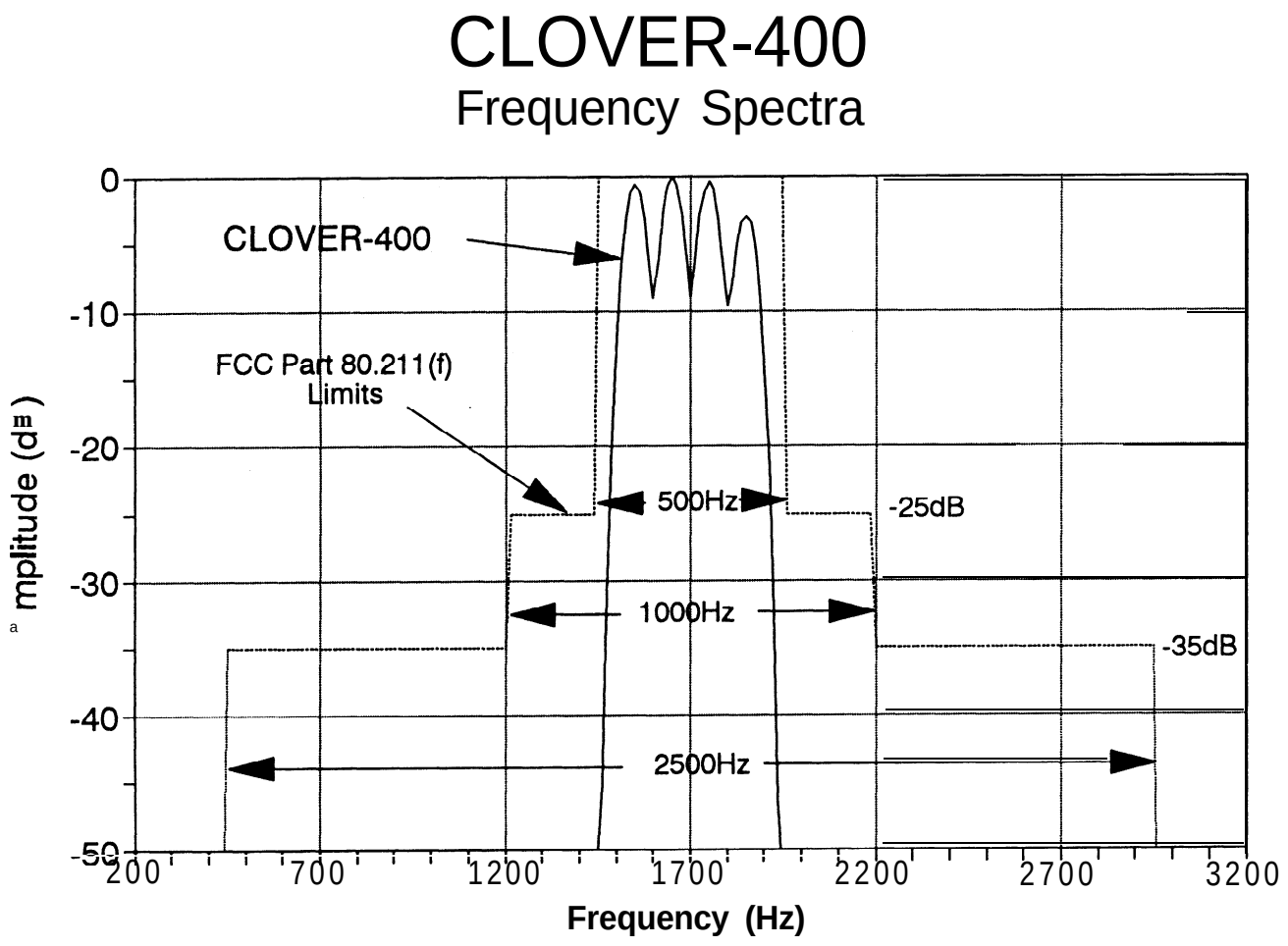

CLOVER-400
Frequency Spectra
CLOVER-400
FCC Part 80.211(f)
Limits
500Hz
1000Hz
2500Hz
-25dB
-35dB
0
-10
-20
-30
-40
-50
200
700
1200
1700
2200
2700
3200
Frequency (Hz)

Figure 1.

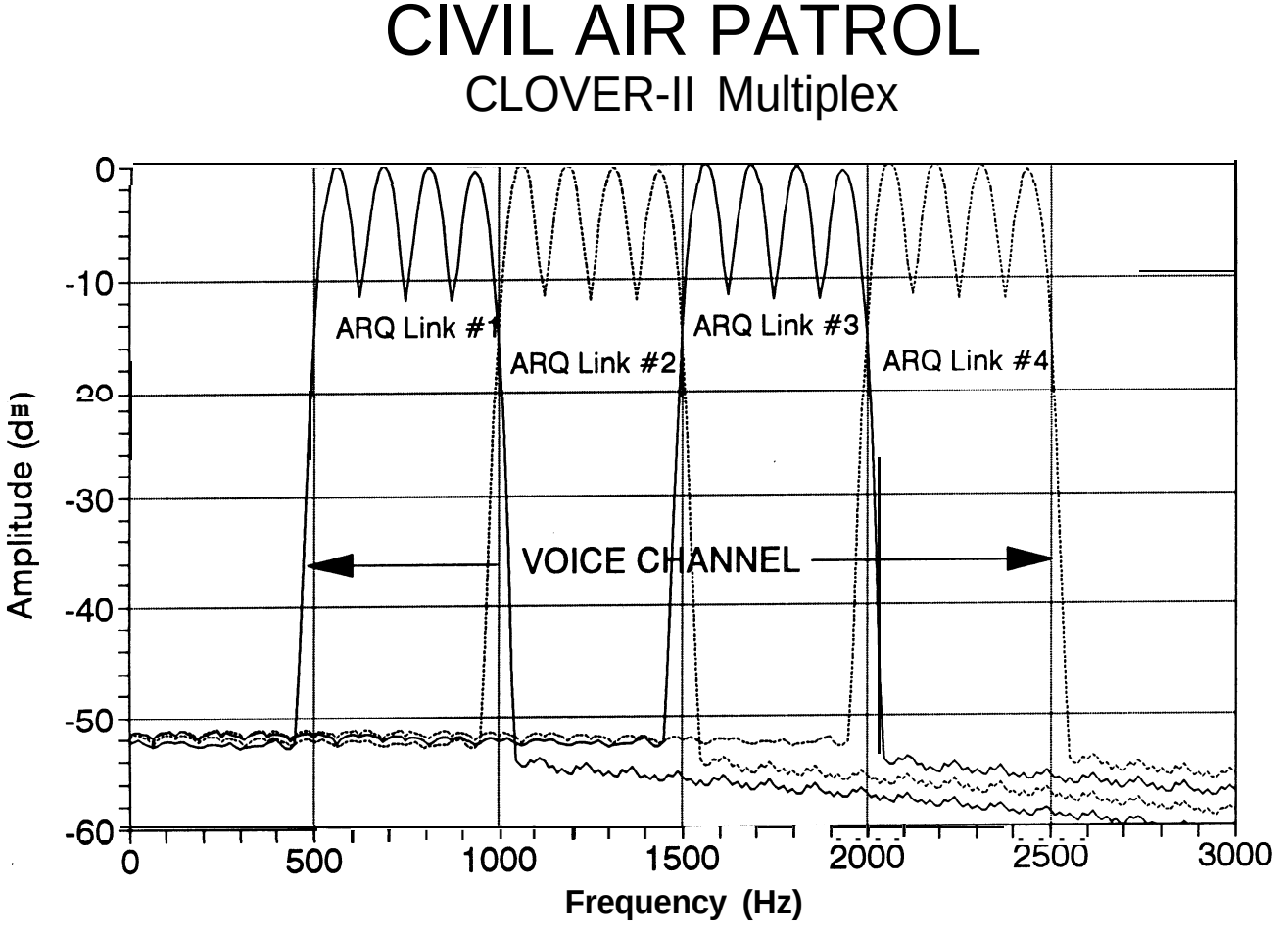

CIVIL AIR PATROL
CLOVER-II Multiplex
0
-10
-30
-40
-50
-60
Amplitude (dB)
ARQ Link #1
ARQ Link #2
ARQ Link #3
ARQ Link #4
VOICE CHANNEL
0
500
1000
1500
2000
2500
3000
Frequency (Hz)

Figure 2.

CLOVER technology has also been expanded to gain higher data throughput by using more tones and a higher symbol rate. "CLOVER-2000" uses 8 tones, a symbol rate of 62.5 Baud, occupies a bandwidth of 2000 Hz, and has a data throughput rate that is approximately 4 times that of CLOVER-II - up to 250 bytes/sec. (2000 bits/sec). The spectra of CLOVER-2000 is shown in Figure 3, typical throughput characteristics in Figure 4, and ARQ timing information in Figure 5.

On-the-air testing of CLOVER-2000 has shown that it is very robust and often provides better communications than simple scaling of CLOVER-II performance might predict. Over an 800 mile path on 10 MHz at mid-day, CLOVER-2000 has reliably provided data transfer at an average rate of 1000 bits-per-second, and frequently running at 1500 to 2000 bits/sec for 5 to 10 minute periods. The wider bandwidth and faster symbol rate of CLOVER-2000 (compared to CLOVER-II or CLOVER-400) do not cause excessive block failure or repeats. In fact, the short ARQ frame of 5.5 seconds makes CLOVER-2000 very responsive to changes in the ionosphere.

CLOVER Modems:

There are now three modem products that support one or more versions of CLOVER - the PCI-4000, the P38, and the DSP-4100. There have been 4 major versions of the PCI-4000, two of which are still in current production. The "standard" PCI-4000, first introduced in 1993, will support CLOVER-II and FSK modes (RTTY, AMTOR, Pactor) but cannot be used with CLOVER-400 or CLOVER-2000. CLOVER-400 capable modems (called "GL-4000") are only available from Globe Wireless. Use of CLOVER-2000 (or CLOVER-400) requires a faster 68000 processor and additional memory. This hardware version is called the "PCI-4000 Plus". All versions of the PCI-4000 use on-board DSP and 68000 software that is upload via the PC data bus. Software up-dates can be quickly and easily obtained fi-om the TECHLINE BBS.

A low cost DSP modem was introduced in 1995 to provide CLOVER technology to radio amateurs at minimum cost. As noted earlier, it was necessary to change the DSP system from the Motorola DSP56001 to the TI TMS320C25 (plus related components). The TI 'C25 is a "previous generation" device and does not have the speed or convenient instruction set of the 56001. Fitting CLOVER-II into the 'C25 was a real "squeeze". As might be expected, this required a few trade-offs in performance and reduction of some of the deluxe features of the "high horsepower" PCI-4000. In particular, the P38 does not have processing power to receive the highest two amplitude modulation modes - 8P2A and 16P4A. The P38 will, however, communicate via CLOVER-II with any other P38, PCI-4000, or DSP-4100 equipped station. Like the PCI-4000, DSP and 68000 software for the P38 is loaded via the PC bus and up-dates are readily available from TECHLINE.

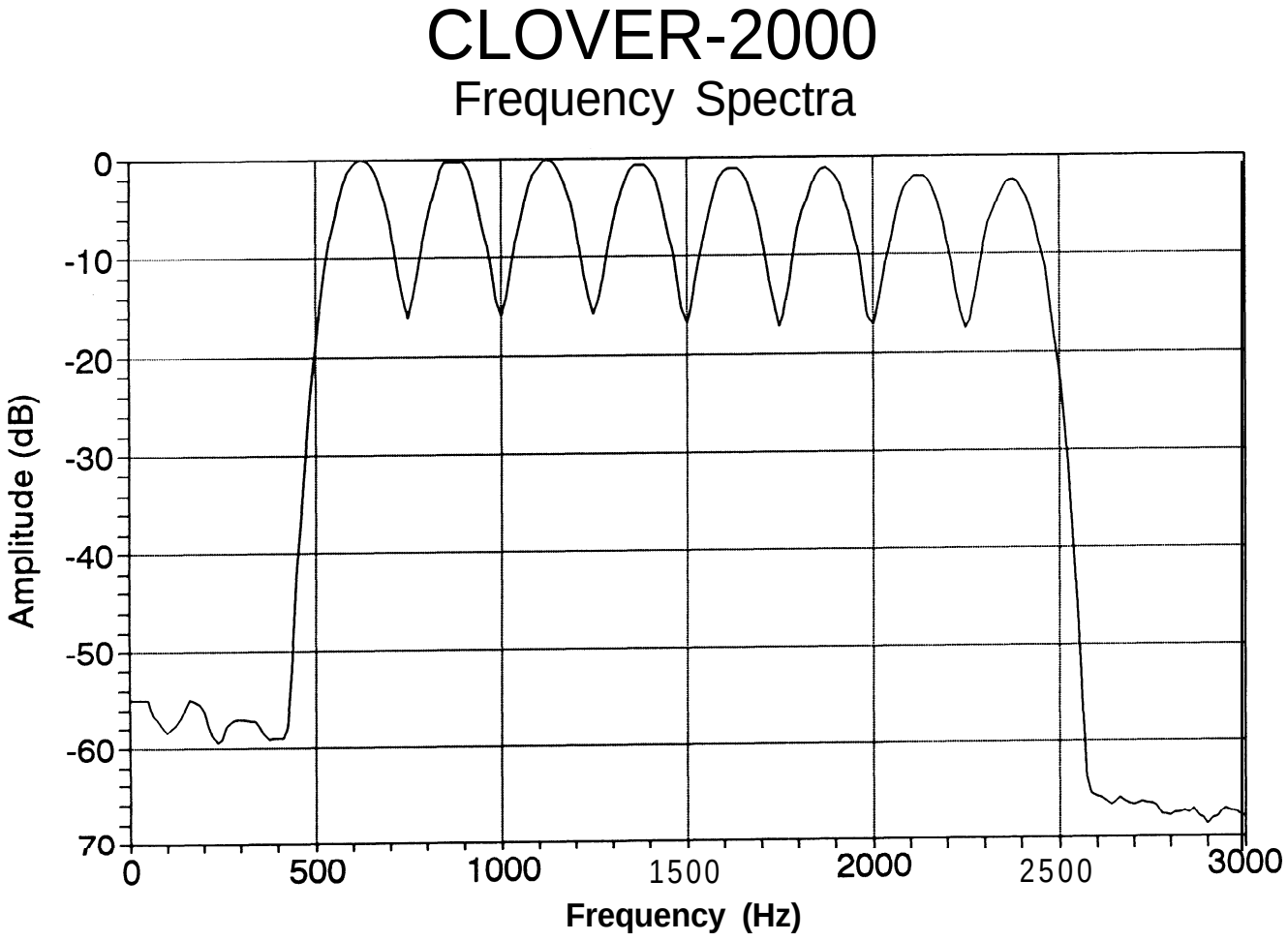

CLOVER-2000
Frequency Spectra
Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
0
500
1000
1500
2000
2500
3000
Frequency (Hz)

Figure 3.

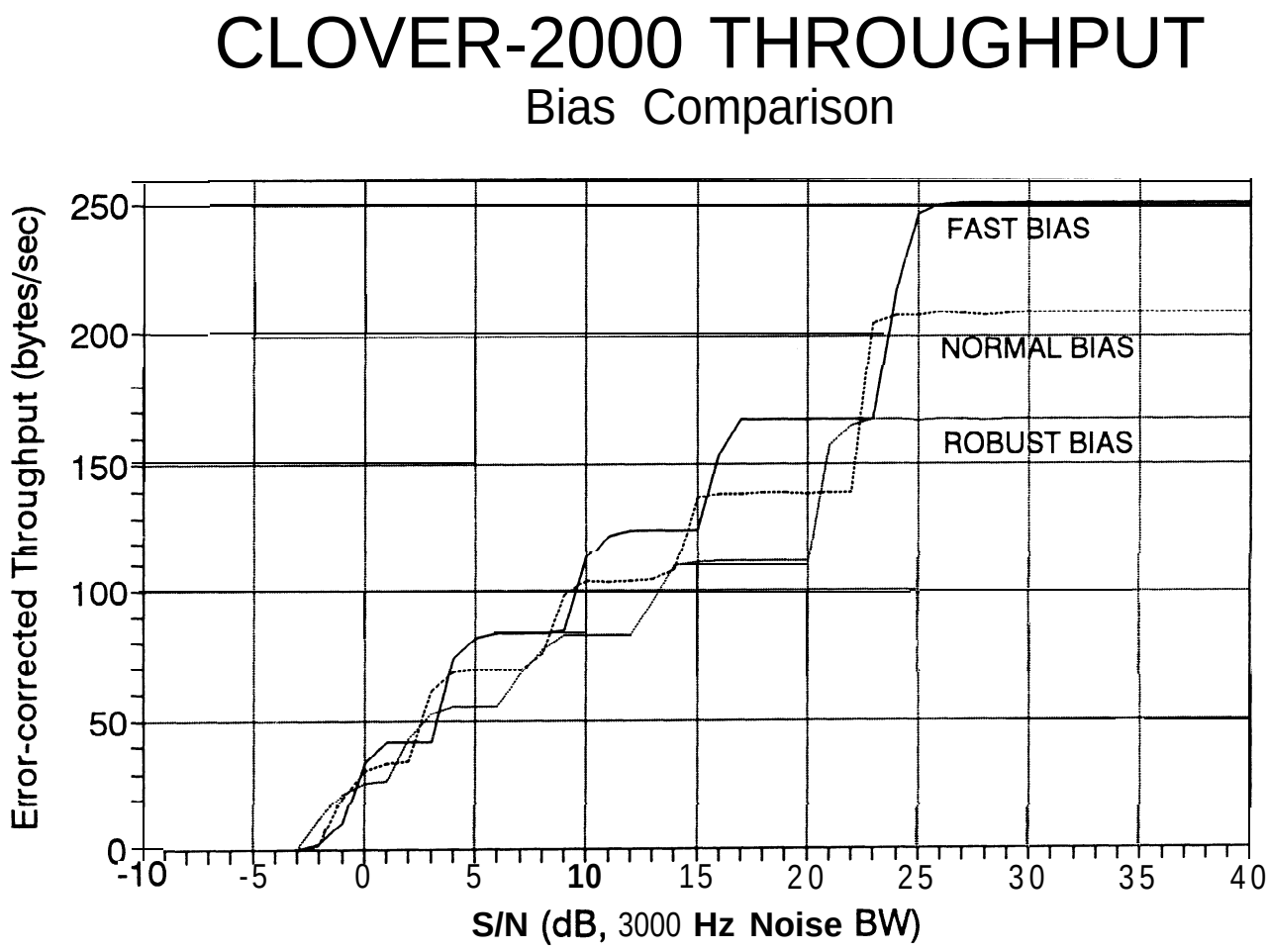
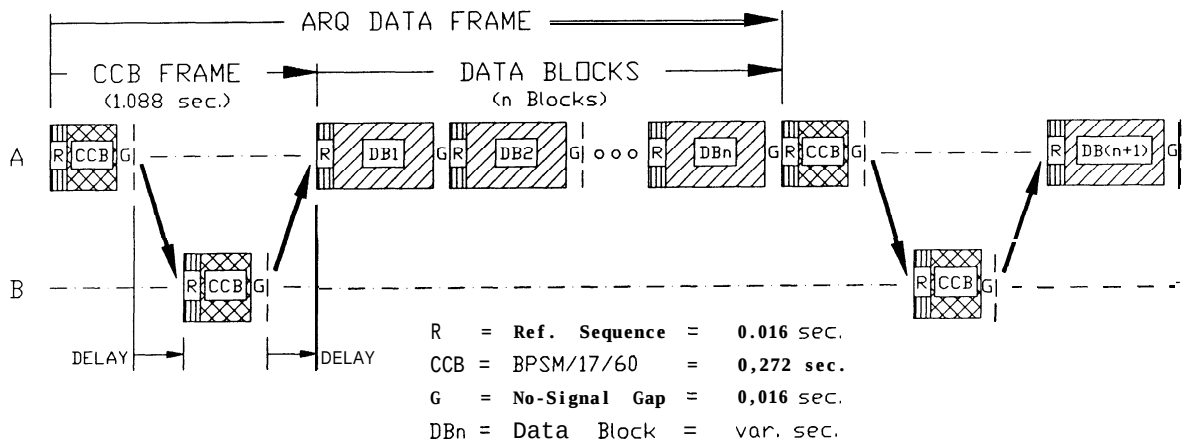

CLOVER-2000 THROUGHPUT
Bias Comparison
Error-corrected Throughput (bytes/sec)
250
200
150
100
50
0
FAST BIAS
NORMAL BIAS
ROBUST BIAS
-10
-5
0
5
10
15
20
25
30
35
40
S/N (dB, 3000 Hz Noise BW)

Figure 4.

CLOVER-2000 MULTI-BLOCK ARQ DATA FRAME



ROBUST

RATE	MOD	BLOCK	BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
ROBUST BIAS (60%)								
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

RATE	MOD	BLOCK	BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
NORMAL BIAS (75%)								
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

RATE	MOD	BLOCK	BYTES/ FRAME	MAX ERRORS	BLOCK TIME	BLKS/ FRAME	ARQ FRAME TIME	THRU-PUT BYTES/SEC
FAST BIAS (90%)								
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 5.

The DSP-4 100 modem was introduced in late 1995. Unlike the PCI-4000 and P3 8, the DSP-4100 is not a plug-in card for a PC. Rather, the DSP-4100 operates from 12 VDC, handles data and commands via an RS-232 serial I/O port, and has status lamps on the front panel. In short, the DSP-4 100 looks and acts much like a standard phone line modem, but it is used with HF radio systems. The DSP-4100 is proving to be the most popular configuration for commercial use of CLOVER, particularly in applications where battery power and/or lap-top computers must be used. The DSP-4100 uses non-volatile Flash ROM which also may be upgraded by loading new DSP or *68000* software via the serial port. Thus, software in all three DSP modems can be easily upgraded without opening a cabinet and replacing EPROM IC's.

In The Future:

CLOVER continues to grow and improve. Present software gives performance and features that were not available when CLOVER started. The "it's only software" development problem is finally working in our favor. Within limits, virtually every CLOVER modem sold can be upgraded in the field at little cost to the user. Custom versions of the hardware, terminal software, and CLOVER itself have been and continue to be developed to meet the needs of its users. CLOVER-2000 and the DSP-4100 have greatly extended the horizon for use of CLOVER technology. CLOVER modem hardware and software is already being installed inside some models of HF transceivers. In these systems, there are no outward signs that CLOVER is being used unless you turn up the receiver volume control and hear the distinctive 4- or 8-tone "CLOVER twitter".

The future direction of CLOVER technology - waveform, protocol, software, and hardware - will be determined by the user. CLOVER provides the "missing link" that makes HF radio an attractive cost-effective alternative to satellite or wire-line data communications.

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