THE BREMSAT PHASE-MODULATED COMMUNICATIONS LINK

Don K. Lefevre, President

Cynetics Corporation
P.O. Box 2422
Rapid City, SD 57709

ABSTRACT

BREMSAT is a small scientific satellite being constructed by the West German Zentrum fur angewandte Raumfahrttechnologie und Mikrogravitation (ZARM), at Bremen University . BREMSAT's payload consists of five scientific experiment packages. The satellite is scheduled for Get-Away-Special (GAS) Canister launch during the German D-2 shuttle mission in March 1992.

Cynetics Corporation is constructing the TT&C link for the satellite, using its standard CMX9600 modem. This modem is the result of Cynetics' development program for phase-modulated (PM) communications systems for small satellites. The CMX9600 is a 9.6 Kb/s, Bi-Phase Shift Keyed (BPSK) modem using a 70-MHz IF and synchronous matched-filter detection.

As we reported at the 1989 Small Satellite Conference, many small satellite systems use Frequency-Shift Keying (FSK) for communications. FSK is a sub-optimal modulation which suffers a best-case 3 dB degradation in signal-to-noise ratio when coherently demodulated. When non-coherent demodulation is used, as it often is, additional degradation in signal-to-noise ratio occurs.

Antipodal phase modulations, such as Bi-Phase Shift Keying (BPSK) and Quadra-Phase Shift Keying (QPSK) are optimal modulations which do not suffer the signal-to-noise ratio degradations of FSK. Thus, when phase-modulation is used for downlinking, the satellite's transmitter power can be decreased. This saved power is available for payload and bus operations. Or, a smaller satellite with less solar cell area may be used.

FSK has been utilized in the past due to the perception that implementing an FSK system is simpler than implementing a phase-modulation system. However, with the advent of off-the-shelf phase-modulation TT&C links, such as the CMX9600, satellite system designers can easily incorporate the more power-efficient phase modulation techniques into their satellites.

1. INTRODUCTION

Bremsat is a small satellite being constructed by the West German Center of Applied Space Technology and Microgravity (Zentrum fur angewandte Raumfahrttechnologie und Mikrogravitation - ZARM) at the University of Bremen. Figure One is a photograph of a model of Bremsat.

Bremsat will be launched from a Get-Away Special Canister during the 1992 German D-2 Space Shuttle Mission. The satellite has five microgravity-related experiments which will study microgravity effects during three orbital phases. This paper describes the communications system being constructed by Cynetics Corporation for the Bremsat Mission.

2. THE BREMSAT MISSION

Bremsat will perform its five scientific experiments during three launch phases. These three phases are: 1) the "Microgravity Phase" during the stay in the shuttle payload bay; 2) the Orbital Phase; and, 3) the Re-entry Phase.

Scientific Experiments

Microgravity experiment number E-1 is a measurement of the heat conductivities of solutions of hexaflourisopropanol and dimethypropylen-urea with variable concentrations. This experiment will be conducted during the Microgravity Phase in the shuttle bay.

The second experiment, E-2, is active during the Microgravity and Orbital Phases. Its purpose is to measure residual acceleration forces to determine the micro-g quality on board the shuttle and in orbit.

Experiment E-3 will measure low orbit micrometeorite and dust densities and dynamics during the Orbital Phase. The fourth experiment, E-4, will also be performed during the Orbital Phase. It will measure the exchange of energy and momentum between the molecular gas flow and the satellite.

E-5, the final experiment, consists of pressure and temperature measurements during the early re-entry phases of the satellite.

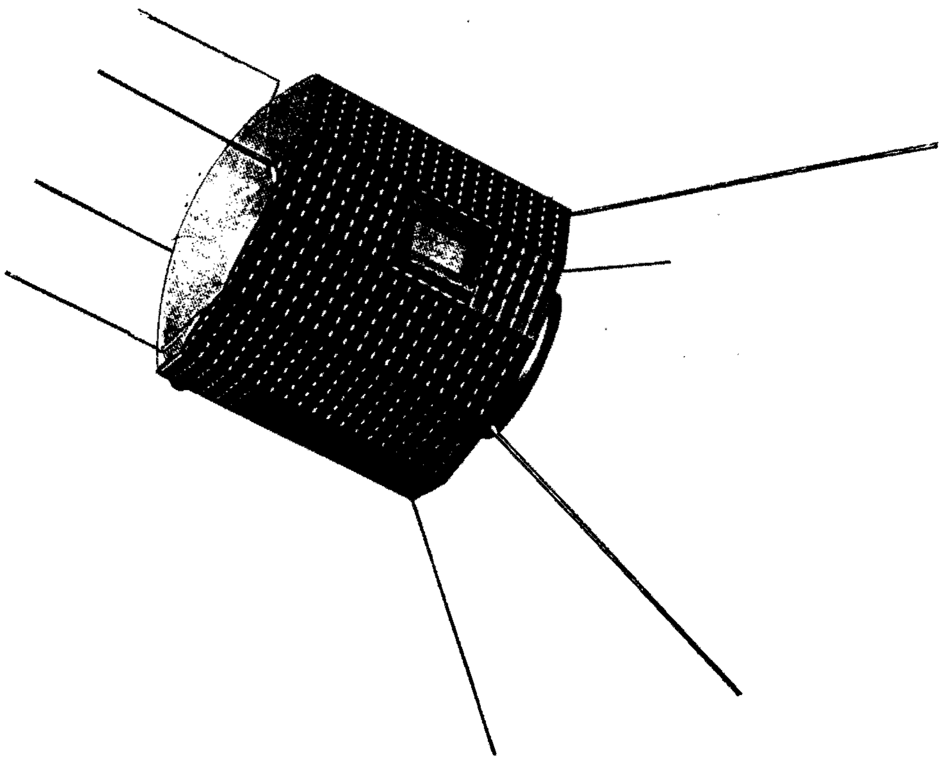

Figure One: Bremsat Model

3. COMMUNICATIONS SYSTEM

3.1 Communications System Overview

Mission Profile

The data from the Shuttle-bay experiments E-1 and E-2 will be stored and upon ejection from the Shuttle, the stored data will be transmitted to the ground and the third experiment will begin. Data will be stored for the Orbital Phase Experiments and downloaded during passes over the ground stations. During the re-entry phase, data from experiment E-5 will be transmitted until re-entry ionization prevents further communications.

3.2 Modulation Choice

Bi-Phase Shift Keying (BPSK) has been chosen for Bremsat, and it is a good modulation choice for many small satellites. It represents a step toward moderately greater complexity, but much greater power efficiency, than frequency-shift keying (FSK). BPSK can save at least half of the transmitter power required for FSK. This power savings can be used for increased data rates, decreased solar cell area, or increased payload power. BPSK also provides an upgrade path into the higher order modulations which may eventually be required by regulatory agencies.

Figure 2 shows the bit-error rate (BER) as a function of SNR for the ideal case for BPSK, coherent FSK, and non-coherent FSK. The 3 dB (a factor of 2) degradation of FSK over BPSK is evident, as is the additional degradation of non-coherent FSK.

Since small, solar-powered satellites are necessarily power-limited, a power-efficient modulation scheme should be employed in most small satellite systems. This is not to say that there will not be applications where a requirement for receiver simplicity may mandate the use of power-inefficient modulations. For example, a low data-rate satellite may be required to transmit to a large number of receivers. An FSK implementation may decrease the receiver cost sufficiently to overcome the 3 dB disadvantage. However, the 3 dB advantage of BPSK could still be applied to doubling the data capacity of the same satellite, resulting in a potential doubling of revenue from the satellite. Also, the cost advantages of using a specific modulation type over another may decrease with the number of receivers. It is also true that economic concerns alone will not drive this decision, but also regulatory restrictions on bandwidth; the ease or difficulty of obtaining frequency allocations; limits on radiated power; etc.

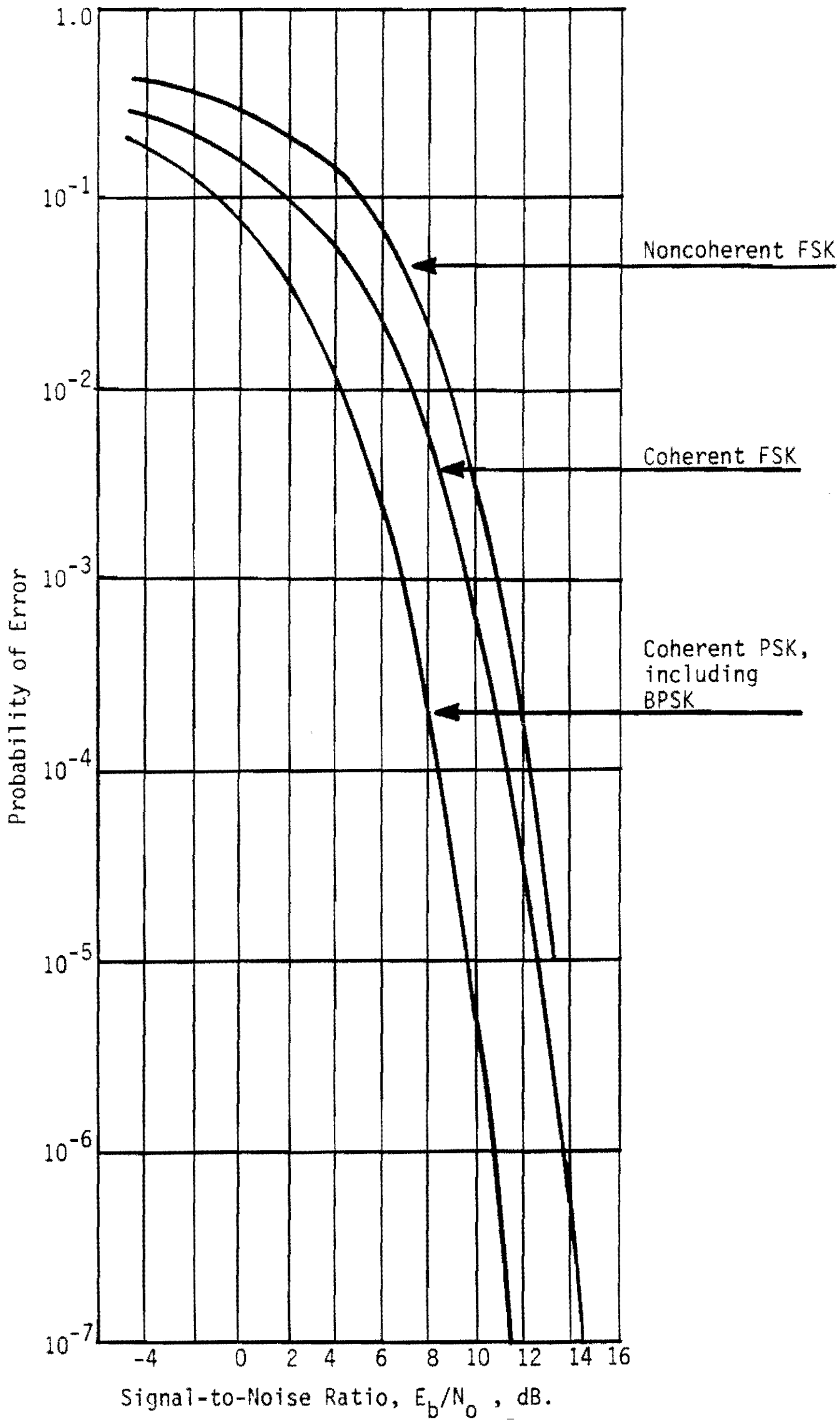

Figure 2. BER performance of BPSK, coherent FSK, and noncoherent FSK.

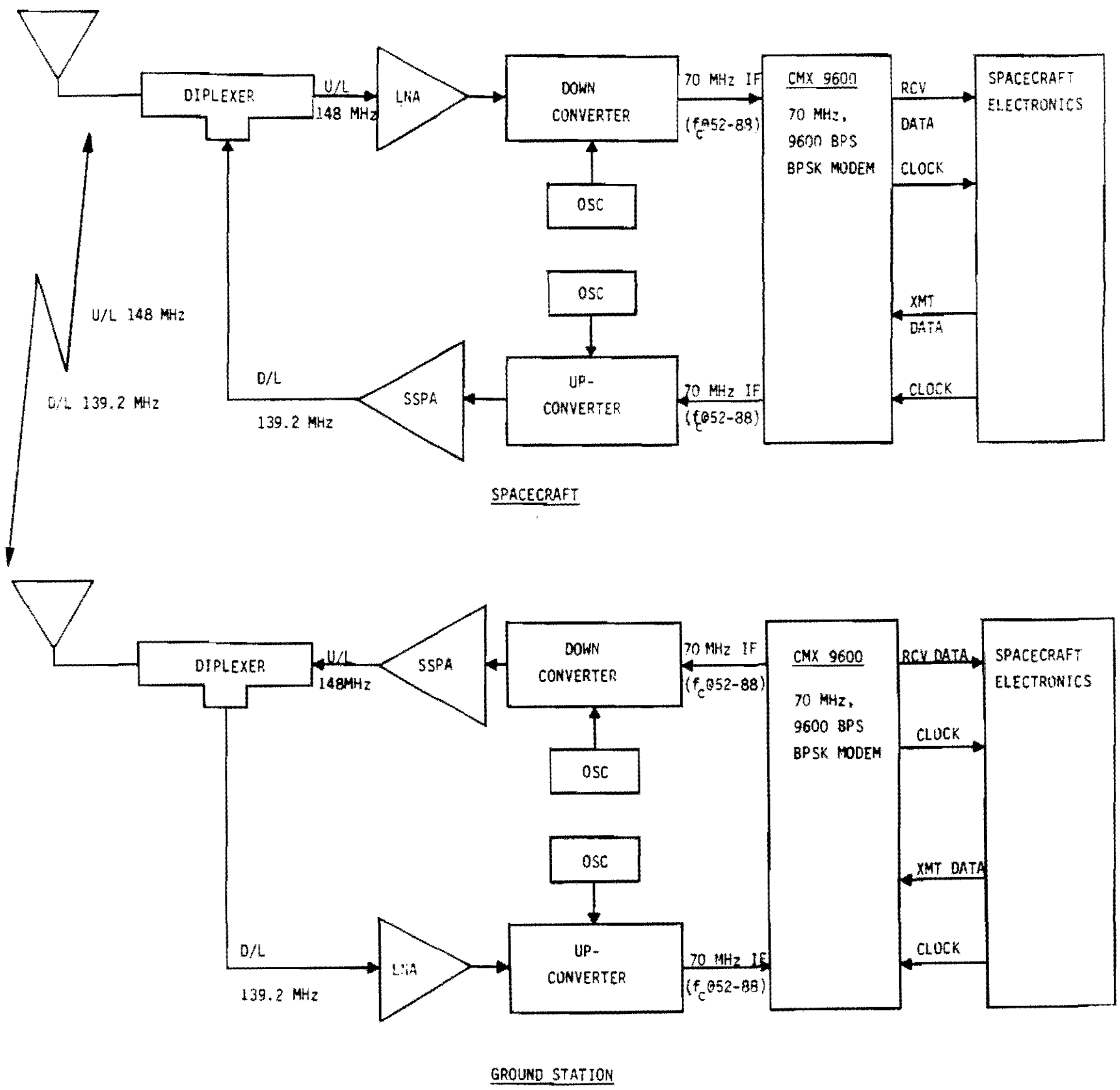

Fig. 3 Bremsat Communications System Block Diagram

3.3 Communications System Description

Communications System Philosophy

The design philosophy for the Bremsat Communications System has been to create a system of great simplicity which is also power efficient. This has been achieved by using power-efficient phase modulation, standard IF frequencies and data rates, and off-the-shelf components. The goal has been to achieve "cable-in-the-sky" user transparency.

Standard IF Frequencies

As shown in Figure Three, the Bremsat Communications System Block Diagram, the first IF is the satcom IF standard frequency of "70 MHz." This refers to a center frequency of between 52 and 88 MHz for the transmit and receive IF's. The actual Bremsat 1st IF frequencies are being chosen at present, with the minimization of up-and downlink crosstalk as the primary goal. In the demodulator portion of the CMX9600 modem shown in Figure Two, a standard 10.7 MHz second IF has been used.

Standard Data Rate

The 9600 bps data rate of the CMX9600 modem allows the device to be used for a variety of applications, including bent-pipe SCPC data transmission through standard geosynchronous C-band satellites. This standardization ensures low modem costs.

3.4 RF Systems

Both ground and spacecraft transmitters use solid-state power amplifiers (SSPA's) with a few watts of output power. At the time of this writing, the SSPA selection was awaiting the determination of the ground system antenna gains.

3.5 CMX9600 Modem

The development of the CMX9600 BPSK modem was reported on at the 1989 Small Satellite Conference [3]. The CMX9600 is a conventional implementation of differentially-encoded BPSK - without forward error correction. (FEC can be added external to the modem.) Simplicity of implementation for the sake of reliability was a major goal of the modem development. Features include:

- standard IF frequencies
- simple, high-quality phase-linear channel filtering
- proprietary high-speed bit synchronization

Figure Four is a block diagram of the CMX9600. Figures Five and Six show the CMX9600 modem prototype.

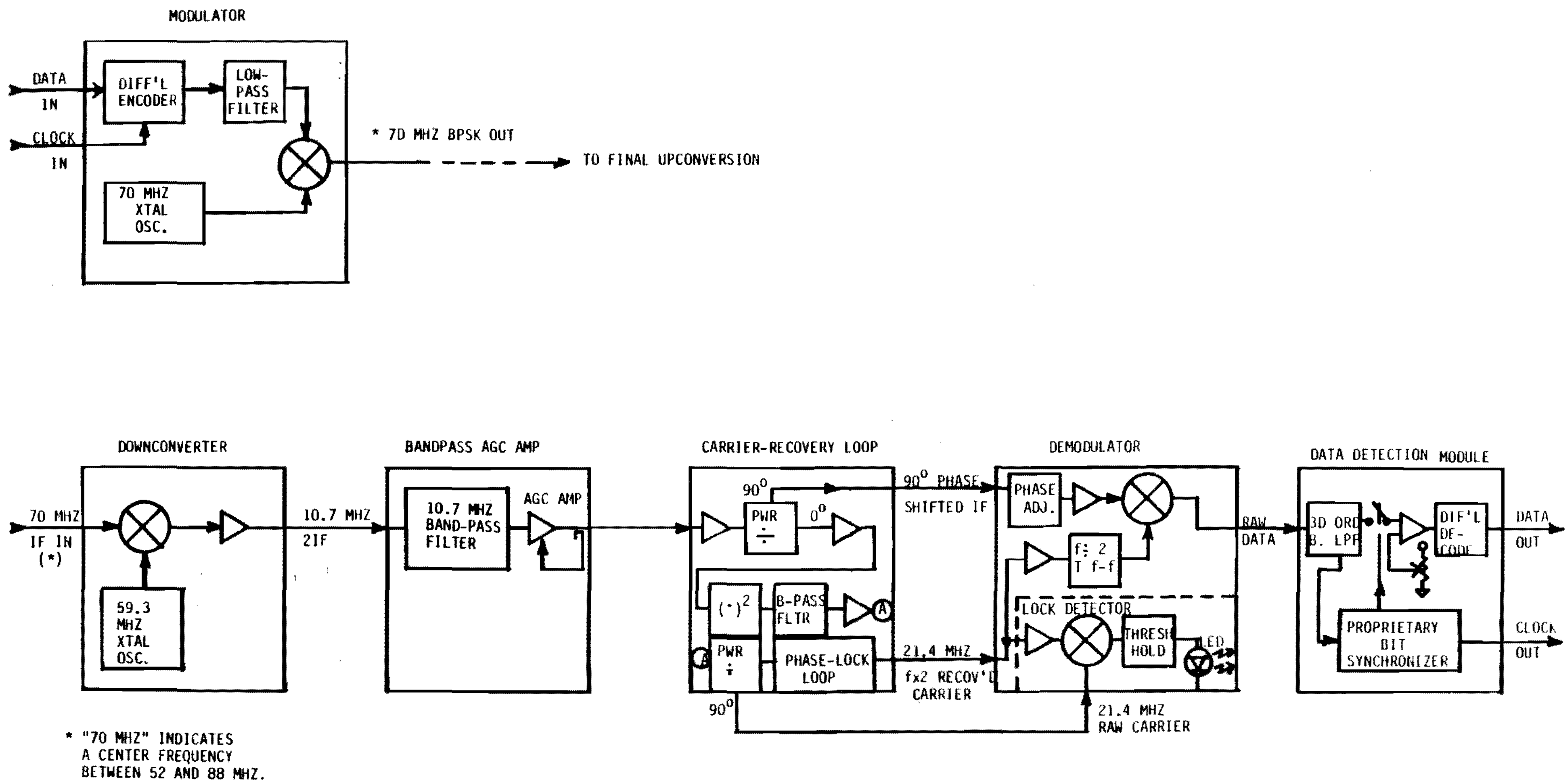

Figure 4. CMX9600 Modem Block Diagram

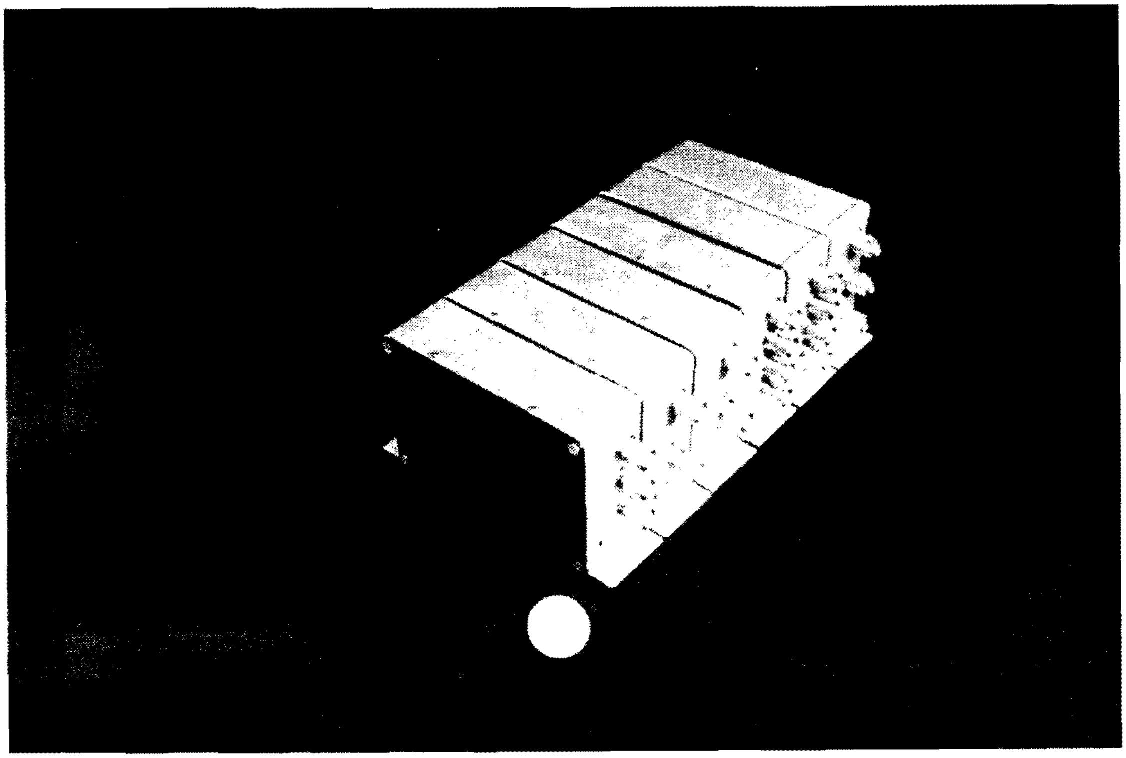

Figure 5. The CMX9600 BPSK Satellite Communications Modem Prototype

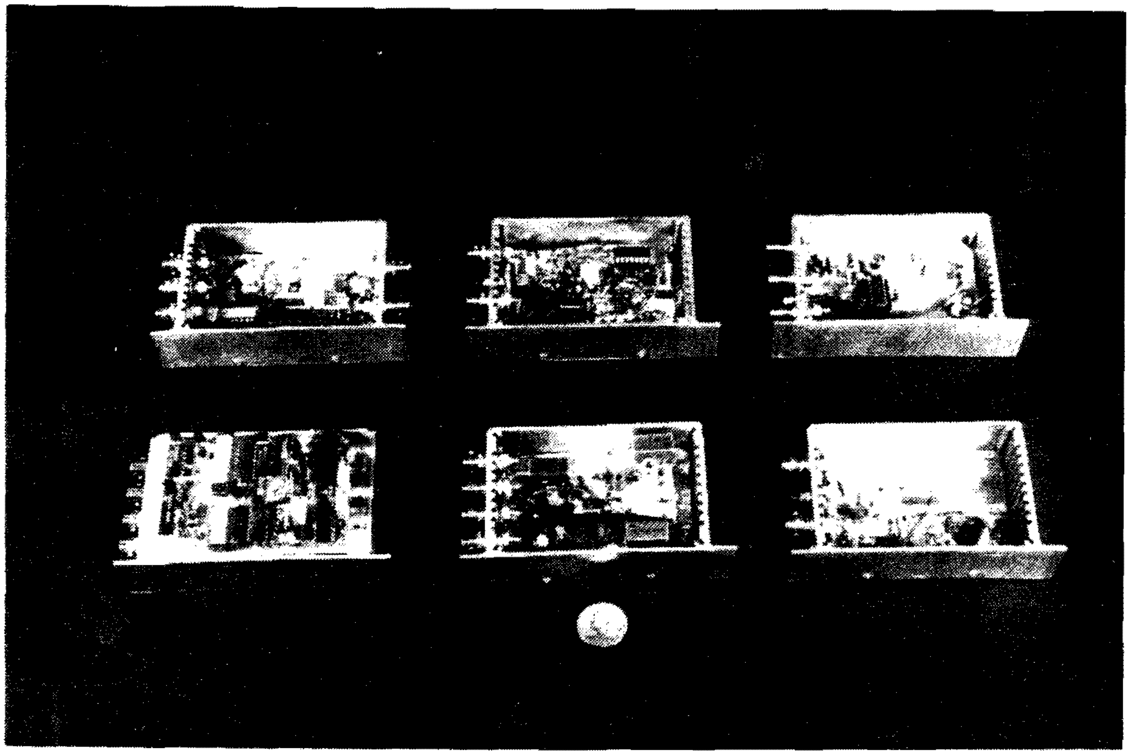

Figure 6. The CMX9600 Modem Prototype - Module Interiors

Table 1.

BREMSAT CMX9600 SPACECRAFT AND GROUND MODEM SPECIFICATIONS

GENERAL

Data Rate:	9600 bps.
Modulation Type:	Differentially Encoded BPSK.

MODULATOR

Output Frequency:	Fixed, 52-88 MHz.
Frequency Stability:	± 5 ppm/month, nominal.
Output Level:	-15 dBm ± 0.5 dBm.
Output Impedance:	50 ohms.
Output Connector:	BNC Female or SMA Female.

DEMODULATOR

Input Frequency:	Fixed, 52-88 MHz.
Input Level:	-39 to -9.5 dBm.
Input Impedance:	50 ohms.
Input Connector:	BNC Female or SMA Female.
Carrier Recovery (Residual Doppler Correction):	
-Loop Pull-In:	286 Hz. (Nom.)
-Loop Lock-In:	1764 Hz. (Nom.)
Clock Recovery:	Synchronization within 50 bits after carrier lock.
BER Performance:	Within 2 dB of Theoretical.

DIGITAL INTERFACE

Type:	TTL or RS-232.
Connector:	BNC Female.
SIZE:	13cm X 6.9cm X 21.9cm.
WEIGHT:	1600 grams.
POWER:	0.4 A @ 12 vdc.
TEMPERATURE:	0-70° C.

(SUBJECT TO CHANGE)

Table One gives the specifications for the CMX9600 modem used for the Bremsat system.

4. Comparison of Conventional and DSP Modem Implementations

The modem in the Bremsat Communications System is a conventional system constructed with CMOS integrated circuits. It has a moderate specified implementation loss which allows inexpensive off-the-shelf components to be used.

Recently [4,5], NASA's Jet Propulsion Laboratory (JPL) has sponsored the development of several low rate (2400-4800 bps) modems for mobile satellite communications systems. These modems have been implemented using Digital Signal Processing (DSP) integrated circuits and they give excellent BER performance at low data rates. Modem functions of Doppler correction, carrier recovery, bit synchronization (clock recovery), matched filtering, data detection and Viterbi decoding have all been implemented on single DSP's.

However, a common cautionary note has been to not touch the DSP chip, for fear of blistered fingers. In other words, the DSP chips have consumed large amounts of power - up to five watts in one reported case. Since the functions of downconversion, automatic gain control and IF filtering can not be performed by the DSP chip, a DSP-based modem would suffer from the DSP chip's power usage and still need to provide power for those functions as well.

Recently, new DSP devices with significantly lower power consumptions have been introduced. The advent of these devices may allow the improvement of small satellite modems without sacrificing spacecraft power efficiency.

Future Developments

Cynetics is investigating the use of DSP-based modems for lightsat applications. The information gained from the construction and operation of the Bremsat Communications System will be used in these investigations to determine the usefulness and risks of using DSP-based spacecraft modems in small satellite systems.

REFERENCES

1. H. Igleseder, H.J. Rath, P. Schlomm, "Brem-Sat, a Small University Satellite", ZARM, University of Bremen, 1990.

2. "Brem-Sat, a German D-2 Mission", ZARM, University of Bremen, 1990.

3. D.K. Lefevre, "A Power-Efficient BPSK Communications System for Small Satellites," Proceedings of the Third Annual AIAA/USU Conference on Small Satellites, 1989.

4. W. Rafferty, editor, - Proceedings of the Mobile Satellite Conference, NASA JPL, May 1988.

5. D.H.M. Reekie, editor, Proceedings of the Second International Mobile Satellite Conference - IMSC 90, (JPL Publication 90-7), NASA JPL and the Canadian Department of Communications, June, 1990.