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EUROPEAN SURVEY OF ONBOARD COMPUTER TECHNOLOGIES FOR SATELLITE CONTROL

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Executive Summary

This investigation of European onboard computer technologies was undertaken for three principal reasons:

1. Advances in the state-of-the-art of microprocessors in the last decade have been so significant that there are today numerous microprocessors that are fully capable of handling onboard a satellite all the computational requirements necessary for autonomous control of the satellite.
2. The European Aerospace Industry on its own and under the auspices of the European Space Agency (ESA), has made great strides in the last 7 years in developing and employing such microprocessors for onboard data handling and autonomous Attitude and Orbit Control Systems (AOCS) on a wide variety of European satellites. Some of the European developments in this area both in hardware and software merit a lot of attention.
3. Third, Canada has embarked on the development of fourth generation satellites (M-SAT, RADARSAT, ANIK E/F), and it is timely to investigate some new approaches to controlling these and follow-on satellites.

The investigation convered several centres of ESA (ESTEC, ESOC and ESA HQ), and all the major European industries acitve directly or indirectly in the use of onboard computer technologies for satellite control. These were:

U.K.	BAe
	Ferranti
	Marconi
France	Matra
	CIMSA
Netherlands	HSA
W. Germany	MBB
	Dornier
Sweden	Saab-Scania
Italy	Laban

The results of the investigation substantiated to a large extent, and even exceeded, the initial expectations of European onboard computer technology.

First it was found out that there is a great deal of interest in Europe in the question of autonomous control of both Low Earth Orbit (LEO) and geosynchronous satellites. Several European studies were conducted on the subject in the last few years bearing out the feasibility of complete onboard control. There appear to be, however, some political and economical consideration in Europe, especially at ESOC, questioning the short term benefits of autonomous control in view of the large investment in and capability of established ground control stations in Europe.

Second, European Industry has developed several microcomputers and microprocessors especially suited for onboard applications. Most of these are 16-bit CMOS micros with unique software developed in Europe. These micros include Ferranti's F100-L, HSA's FAST, Matra's 6001, Saab's OBC, Laben's HμP 8024, CIMSA's M68, MBB's MODUS, Dornier's MUDAS-R, Marconi's ITU, and BAe's SMM.

It appears that Europe is moving ahead towards the adoption of onboard control technologies as well as onboard data handling capabilities for future satellites, such as L-SAT, EXOSAT, SPACELAB, ISPM, ECS, MARECS, TVSAT, TELECOM-1, SPOT, GIOTTO, SPACE TELESCOPE, etc.

Canada should review in detail these capabilities, an overview of which is presented in this report, to evaluate the potential applicability of European technology in this area, including the standardized approach to OBDH and MACS to future Canadian space missions.

Furthermore, Canada should give serious consideration to developing, possibly in cooperation with Europe, a standardized onboard module for autonomous orbit and attitude control of both LEO and geosynchronous satellites.

I. Objective of the Investigation

This investigation of European on-board computer technologies for satellite control, has been undertaken for three principal reasons.

First, advances in the state-of-the-art of microprocessors in the last decade have been so great, that such microprocessors are now easily able to perform onboard a satellite all the orbit and attitude computations necessary for control of the satellite, as well as all the other onboard data handling requirements.

Second, European aerospace Industry on its own and under the auspices of the European Space Agency (ESA), has made great strides in the last 7 years in developing and employing such microprocessors for onboard data handling and autonomous Attitude and Orbit Control Systems (AOCS) on a wide variety of European satellites. Some of the European developments in this area both in hardware and software merit a lot of attention.

Third, Canada has just embarked on the development of fourth generation satellites (M-SAT, RADARSAT, ANIK E/F), and it is timely to investigate some new approaches to controlling these and follow-on satellites.

This investigation covers both Low Earth Orbiting (LEO) satellites and geosynchronous satellites. The need to control both attitude and position of geosynchronous satellites, and thus the requirement to measure and determine attitude and orbit, has been established with the advent of geosynchronous satellites.

Initially both orbit and attitude were ground controlled, especially for spinning satellites. Most 3-axis satellites are now controlled onboard autonomously with some backup control exercised by ground stations. The orbit of most satellites is still essentially ground controlled, however.

With the marked increase in number and applications of LEO satellites such as remote sensing satellites, meterological satellites, and special application satellites, there is now an increased need to not only control accurately the attitude of such satellites, but control their orbit position as well in order to adjust or change ground coverage as required. Frequently such satellites are out of sight of a controlling ground station when the need to adjust orbit position arises.

Consequently, we feel that there will be a greater demand than ever for precise orbit and attitude control of both LEO and geosynchronous satellites in the future, and it is speculated that most of these requirements could be executed autonomously onboard the satellites themselves.

Presently, progress made in integration density on semi-conductor chips, combined with the explosive developments in digital technology, make a broad choice of microprocessors available to spacecraft electronic designers. These mircroprocessors range from the simplest ones (8 and 12-bits) introduced into ESA spacecrafts earlier, to the more sophisticated 16-bit devices which are now available in the market. Moreover, 32-bit microprocessors are also being introduced, though more gradually.

Thus microprocessor technology is now providing a computing capability equivalent or exceeding the capability of most minicomputers introduced in the early 70's, in versatility, high level programming, speed, storage and reliability. On top of that these microprocessor devices are naturally very small,light and have low power requirements.

These developments are very timely in view of the higher data handling needs of present and future space missions brought about by larger space structures, longer life time, higher data rate requirements, more precise orbit and attitude control, and missions to outer space.

These microprocessors must be, of course, space qualifiable before they can be considered for most satellite missions, imposing special limitations on power, size and weight as well as radiation resistance. This requirement has led to the development or adaptation of such microprocessors by the aerospace industry in Europe rather than by the typical microprocessor manufacturers.

In general, the space applications of microprocessors can be divided into two categories: Spacecraft Control and Payload Functions.

Spacecraft Control includes:

- Telecommand acquisition, analysis and execution
- Telemetry formatting and transmission
- AOCS (Attitude and Orbit Control System)
- Pyrotechnics functions

- Power Supply distribution
- Thermal functions
- Fault tolerance functions

The Payload Functions include:

- Execution of payload operation programming
- Housekeeping of payload components
- Management of payload components
- Payload events control

This survey is primarily concerned with spacecraft control aspect, especially orbit and attitude control, but most of the findings and analysis presented in the report are also applicable to the other spacecraft and payload functions.

It is especially noteworthy that ESA has developed a standardized approach to On-Board Data Handling (OBDH), commonly referred to as the ESA OBDH subsystem. This subsystem will be described in a later section of this report.

The following approach has been adopted in the presentations of the results of the survey in this report:

1. Detailed list of the survey participants and analysis of the onboard computer technologies of the European Industry (Sections II & III).
2. Assessment - and trade-off considerations of European capabilities for autonomous satellite control (Sections IV & V).
3. Recommendations for Canadian future activities (Section VI).

II. European Companies and Space Agencies Surveyed

The following centres of the European Space Agency were visited as part of the survey:

1. ESTEC- Noordwijk, Netherlands

Contacts:

S. Ciarrocca, On-Board Data Handling
P. May, Engineering Management
D.N. Soo, Power and Control Systems
A.W. Preukschat, Communications Satellites Dept.

2. ESA HQ - Paris, France

Contacts:

G. Berretta, Preparatory Program on Future Telecommunications
H. Pfeffer, Preparatory Program on STS
J. Vanderkerckhove, Technical Directorate
A.M. Hieronimus, Coordination & Monitoring Office

3. ESOC - Darmstadt, Germany

Contacts:

H. Kummer, Mission and Technical Coordination
P.B. Lemke, Mission Management Group
W. Wimmer, Spacecraft Systems Branch
R.E. Munch, Orbit and Attitude Division
A.S. Johnson, Data Processing Division

The following aerospace companies in Europe were visited as part of the survey:

1. British Aerospace Dynamics Group, Space and Communications Division - Stevenge, Herfordshire, U.K.

Contacts:

W.M Kennerley, Electronics Dept.

M. Burton, Systems Analysis

B. Vendi, AOCS

2. Ferranti Computer Systems, Bracknell Division - Wokingham, Berkshire, U.K.

Contact:

C. Whitby, Computer Sales Dept.

3. Marconi Space Defence Systems - Portsmouth, Hants, U.K.

Contact:

J.A. Robinson, Data Handling & Power

4. Hollandse Signaal Apparaten B.V. (HSA), (Subsidiary of Philips)-Hengelo, Netherlands

Contacts:

G.H. Krijgsman, Aerospace Division

J.A. van Stuijvenberg, Marketing Space Systems

5. Messerschmitt - Bolkow-Blohm GMBH* (MBB), Space Division,- Munich, West Germany

Contacts:

M. Gern, Space Division

H. Widman, SPAS-01 Software

J. Ederle, Systems Studies and Industrial Development

(*) ERNO and MBB are now one integrated company

6. Dornier Systems Gmbh - Friedrichshafen, West Germany

Contacts:

R. Gunzenhauser, Electronics Systems Division

M. Whlaka, Electronics Systems Division

F. Pittermann, Electronics Systems Division

G. Lippner, Space Division

H. Hogmann, Marketing Satellite Communications

7. Matra S.A., Electronics & Automatic Systems Division - Velizy-Villa Coublay, France

Contacts:

G. Gaquiere, Data Handling Dept.

M. Turin, OBDH, Data Handling Dept.

M.J. Broquet, Spacecraft Control, General Studies Dept.

8. Compagnie d'Informatique Militaire, Spatiale et Aeronautique (CIMSA), (Subsidiary of Thomson CSF) - Velizy, France

Contacts:

L. Moussy, Space Commerical Service

M. Forgues, Informatique Dept.

M. Roger, Communications Dept.

The following aerospace companies were not visited but are included in the survey based on written material they provided:

1. Saab-Scania A.B. - Goteborg, Sweden

Contact:

H. Borjesson

2. Laben S.A.- Milano, Italy

Contact:

A. Beretta, Marketing Dept.

III. Analysis of Onboard Computer Technologies of European Industry

The following section contains an overview of the onboard computer technologies of the 10 major European companies, whose activities relate directly or indirectly to applications of such computers in space.

The companies included here are, by country:

U.K.	British Areospace
	Ferranti
	Marconi
France	Matra
	CIMSA
Netherlands	HSA
W. Germany	MBB
	Dornier
Sweden	Saab-Scania
Italy	Laben

Company Name: British Aerospace (BAe)
Microcomputer Designation: SMM (Spacecraft Microcomputer Module)

GENERAL DESCRIPTION OF MICROCOMPUTER

The major objectives of the SMM are:

- Provide an onboard computing facility for spacecraft by developing an overall system concept, a serial data bus system, standard hardware and software.
- Develop a microcomputer test bed for current and future use.
- Investigate new technologies applicable to an SMM system.
- Perform any critical breadboarding as a minimum to demonstrate the operation of an SMM, serial data bus, and input/output hardware.

The SMM system comprises a number of intelligent microcomputer modules and non-intelligent random logic modules, interconnected by way of serial data bus. The interface between modules and the serial data bus has already been successfully implemented using a single ULA device. Use of the bus by microcomputers must be controlled by means of a bus controller module and a suitable module polling mechanism. Microcomputer module software must also be synchronised by means of regular timing stimuli. One way of distributing these is by way of timing messages on the bus. These two functions have been implemented in the form of a single 40 pin ULA device, termed BUSCOT (Bus Controller Timer).

SPECIFIC CHARACTERISTICS OF MICROCOMPUTER

- The SMM is based on Ferranti's F-100L microprocessor (16-bit)
- Single 40-pin dual-in-line ceramic encapsulation
- Bipolar CDI technology
- Up to 14 address priority list
- Pre-setable software cycle period on power-up
- Rotating/fixed priority schemes
- Open-collector drivers to ASBIC
- 'POLL FALL', 'TIMEOUT' error signals
- Open collector address bus for bypassing PROM in simple applications
- Single +5 volt supply
- TTL compatible
- Full military specifications available (radiation hard)

DESCRIPTION OF SOFTWARE CAPABILITIES

- Software used in the system is:
  FERRANTI F100-L
  - Cross Assembler
  - Cross Linker
  - Full Structured Programming
  - Load Supervisor
  - Interactive Debugging

SPACE MISSION APPLICATIONS

The SMM will be used onboard L-SAT for AOCS (attitude control only). Aerospatiale is developing the software. Additional candidate space applications are:

- Digital Filtering
- Battery Monitoring
- Antenna Pointing Mechanism
- TT & C Interface
- Reaction (or momentum) Wheel Control
- Solar Array Positioning Mechanism

MISCELLANEOUS INFORMATION

BAe has made the following significant achievements on SMM:-
Designed a distributed computed facility suitable for space
- Developed a serial data bus standard
- Written a complete software operating system for three different processors
- Introduced semi-custom LSI techniques to space applications
- Demonstrated the versatility of an SMM-based system
- Provided sound base line designs for future spacecraft projects
- Evolved a microcomputer development test bed suitable for all future developments
- Carried out a comprehensive study for ESA on Autonomous Stationkeeping System (ASKS).

Company Name: Ferranti Computer Systems Limited
Microprocessor Designation: F100-L

GENERAL DESCRIPTION OF MICROPROCESSOR

The F100-L is an advanced 16-bit microprocessor designed and manufactured in the U.K. by Ferranti. It is a low power dissipation static LSI microprocessor encapsulated in a single 40 pin DIL package. It has a single address Instruction Set which is implemented in conjunction with a single accumulator, and has four addressing modes (Direct, Point-Indirect, Immediate Data, and Immediate Indirect). Additional instructions (eg. Fast Multiply, Fast Divide, Fast Fourier Transform algorithm, etc.) can be incorporated in the instruction repertoire by external Special Processing units (SPU).

A single chip SPU (F101-L) provides fast multiply/divide functions and interfaces directly to the F100-L. 16-bit parallel I/O Bus and LSI Interface Seat are available. This microprocessor is designed for application in a wide variety of online central situations, ranging from the simplest single microprocessor system with a small amount of memory and one or two Input/Output devices, up to more complex systems involving several microprocessors, high Input/Output data rates and several tens of thousands of words of memory.

SPECIFIC CHARACTERISTICS OF MICROPROCESSOR

- 16 bit word length for instructions and data to suit high accuracy requirements of realtime applications.
- Addressing capabilities: 32k 16 bit words.
- 40 pin DIL encapsulation using bipolar CDI technology.
- 16 bit parallel I/O bus (Asynchronys Data and Address).

- Comprehensive instruction repertoire.
- External functions.
- Memory mapped I/O.
- Direct Memory Access.
- Vectored program interrupt.
- Single 5V supply.
- TTL compatible.
- U.K. Military specifications (BS9000), including a -55°C to +125°C temperature range.
- Cumulative Ionization of test level 5 x 10E5 Rad (Si) and no degradation to highest applied Dose and therefore suitable for space applications.
- Multiply/divide unit (F101-L) which interfaces to the F100-L with no additional circuitry.

DESCRIPTION OF SOFTWARE CAPABILITIES

The software is Cross Product Development Software which enables testing programs, F100-L processors and system peripherals. It has a Resident Development Software which allows any program development and testing on F100 systems. A CORAL66 compiler is available for programming in a high level language. A growing range of subroutines is available in a subroutine library to incorporate in system program. F100L assembler is one of the languages used on this processor.

SPACE MISSIONS APPLICATIONS

The demonstrated ability of the F100-L to withstand a high level of radiation makes it a suitable candidate for consideration in space systems where the ability to survive long term exposure is of critical importance (eg.

geosynchronous missions). In addition the F100-L possesses reliability, fault tolerance, and temperature range required by military specifications.

MISCELLANEOUS INFORMATION

Improvement and changes to the F100-L microprocessor specifications are embodied in the new version known as the F200-L, currently under development. It is both hardware and software compatible with the existing F100-L, but by using a parallel rather than a serial function unit, and by eliminating the need for external synchornising flip flaps, the performance has been increased by a factor of about 2.5. In addition, the function performed by the multiply divide unit (F101-L) have now been incorporated within the processor.

Company Name: Marconi Space Defence Systems
Microcomputer Designation: ITU (Intelligent Terminal Unit)

GENERAL DESCRIPTION OF MICROCOMPUTER

Marconi has developed the ITU for space application with the following two modules:

1. A standard general purpose microprocessor to be used as an off-the-shelf item to meet a variety of future requirements.

2. A special purpose application - to interface module tailored to each new requirement.

The ITU has a modular software system having a general-purpose executive plus subroutines specific to the application. The system will be initially demonstrated by modelling the interfaces and applications programmes on the known attitude control requirements of the ISPM spacecraft.

There are 4 ITU interface specifications:

1. - OBDH Telecommand interface
2. - OBDH Telemetry interface
3. - a) Sun Sensors interface
   b) Conscan interface (measurement of pointing error between spin axis and spacecraft-earth vector)
4. - a) Roll Phase Pulse interface
   b) Heater Power interface
   c) Thruster Drive interface

SPECIFIC CHARACTERISTICS OF MICROCOMPUTER

Central processing is done by an RCA CDP 1802 microprocessor in conjunction with 4K bytes of ROM and 1K bytes of RAM. Typical instruction times are 8 µ sec long. Then instruction time is split into two, an instruction fetch cycle, when the program instruction is taken from the ROM and an instruction execute cycle when the program instruction is obeyed. The Central Processing Unit is the heart of the system. Outputs from the ITU are highly accurate due to the 2 MHz crystal clock, the software algorithms and the events datation methods used.

DESCRIPTION OF SOFTWARE CAPABILITIES

The ITU software receives the following inputs.

- Telecommands to control its operations.
- Indication that a new telemetry word may be located.
- Real time occurrence of up to six sun pulse events every rotation of the spacecraft.
- Current 'real time' on request.
- Regular program interrupt at 2µsec intervals.
- Indication of RAM compare failure.
- Indication of A/D comparison status and state.
- Interrupt from the programmable interval timer.
- Thruster status.

The ITU software generates the following outputs..

- Telemetry data as defined by the TLM list.
- Thruster Heater Control signals (ON/OFF status).
- Isolation value control (ON/OFF status).
- Thruster control (ON/OFF status).
- A roll reference pulse trigger.

- A digital output for D/A conversion.
- A reset signal to the Watchdog Timer.

SPACE MISSION APPLICATIONS

EXOSAT - Attitude control systems utilizing redundant INTEL 8080 (8-bit) microprocessor. The S/W is on PROMS.

ISPM - Attitude control system utilizing RCA CDP 1802 (8-bit) microprocessor.

GTS - (Geosynchronous Technology Satellite) - Marconi has considered using an autonomous, onboard control system for this U.K. satellite but the mission was cancelled.

MISCELLANEOUS INFORMATION

Marconi is also involved in the development of star sensor system with the following features:

- For Earth pointing spacecraft
- Supersedes horizon sensor
- Removes Gyro Drift by using stars as reference
- Uses CCD array
- Field of view 9.5° x 20 arc secs
- Two coordinates (transit time. 20.sition)
- Accuracy about 3 secs (ESA requires 30)
- Processing including centroid by built in microprocessor.

Company Name: MATRA
Microprocessor Designation: 6100 family

GENERAL DESCRIPTION OF MICROPROCESSOR

MATRA has developed, since 1976, onboard systems using microprocessors for the following tasks:

- The decoding of the telecommands and formatting of telemetered data, data processing, control and supervision of the overall satellite (platform and payload) and complex attitude and orbit control (AOCS). Main design goals of these systems were: high reliability, low power and flexibility. To fulfil these requirements, the multiprocessing architecture was chosen. Multimicroprocessor (MMP) was used as the processing unit of an attitude and orbit control loop.

SPECIFIC CHARACTERISTICS OF MICROPROCESSOR

- CMOS technology (very low power)
- 12-bit word size
- 6100 Microprocessor family (emulates the 12-bit PDP-8/E)
- Manufactured by INTERSIL (second sourced by HARRIS)
- Other key chips of the family:
  * 6101 Programmable Interface Element (PIE)
  * 6102 memory extension/DMA/interval timer controller
  * 6402 universal asynchronous receiver/transmitter
  * 6xxx memories (ROM,PROM,RAM)
- 6100 family is able to withstand about 10 KRads (Si) and therefore is suitable for space applications
- The MATRA processor was designed with multiprocessing architecture N($1 \leqslant N \leqslant 6$) identical processing units share

common resources via a single reliable common bus. This architecture offers:

- Reliability
- Modularity

DESCRIPTION OF SOFTWARE CAPABILITIES

Its software architecture is organized in the following manner:

- Identical supervisors in each processing unit
- User's program in the common memory organized in software chains composed of software modules
- Parallel processing of modules in processing unit
- Reservation of a module by a processing unit in the system memory ('mailing box')
- Content is saved in a context memory
- system is able to handle up to 12 interrupts

In software development portion:

- The intercept prototying system from Intersil
- A dual floppy disc
- A video terminal (or ASR 33 teletype)
- A two pass assembler (PAL-III)
- The software package of the PDP-8/E from Digital Equipment

CROSS-assembler

The PAL-III cross assembler or FOPAL-III written in FORTRAN is implemented into three computer systems: PACER, SEL, NOVA (Data General).

SPACE MISSION APPLICATIONS

MATRA has provided the microprocessor and electronics for the AOCS onboard the ECS satellite spacecraft (for attitude control during N-S and E-W stationkeeping manoeuvers.).

Open loop compensations on the pitch torque are carried out by a modular low power processing unit with a 6100 CPU, 3K words of PROM, 256 words of RAM. The sensors include an infra-red earth sensor and a yaw gyro detector. The actuators are roll and yaw thrusters.

MATRA was selected by COMSAT to develp an Integrated Attitude Sensing System (IASS) to apply 3-axis detection and estimation in an active attitude control and stabilization system. For the purpose of testing, in real 3-axis dynamic conditions of roll-yaw gyros, earth sensor and sun sensors, MATRA has developed a prototype of a digital gyro-package and microprocessor electronics for sensors simulation and gyro data processing. The digital electronics includes a 6100 CPU, 1K RAM, 3K PROM, noise generator, parallel bus interface, 16 analog inputs and 8 analog outputs (12-bits).

MISCELLANEOUS INFORMATION

In relation to its onboard computer technology capability MATRA has the following experience:

SPACELAB- developed the software for the onboard microcomputers (MITRA 125 MS), as a subcontractor to MBB/ERNO, using HALS real time high-level language.

SPOT- using a SAAB OBC (with AMD 2900 chips), developed system, using REPROM's for 3-axis attitude control, battery management, and data handling

Recoverable Space Platform- to be launched by STS for material experimentation. Will have onboard computer.

TELECOM 1- will use HARRIS INTERSIL 6100 microprocessor for 3-axis attitude acquisition, attitude control during stationkeeping, and sensor bias analysis

ESA Studies on Microprocessors- MATRA has carried out several studies for ESA recently on microprocessors for space applications, as well as submitted a proposal to ESA for Autonomous Stationkeeping System.

INTEL 8086- this is a relatively new and highly promising microprocessor. Its HMOS technology, however, has never been proven under severe radiation environment. The INTEL 8086 will be manufactured in Europe, under license, by a newly formed venture of MATRA and HARRIS.

Company Name: CIMSA
Microcomputer Designation: M68

GENERAL DESCRIPTION OF MICROCOMPUTER

The M68 data processing system has been specifically designed to meet data processing needs in military and space applications requiring the utilization of robust, compact microcomputers operating in difficult environments.

SPECIFIC CHARACTERISITICS OF MICROCOMPUTER

The M68 microcomputer (16-bit) is built around the processing unit (UT board). This PC board contains a microprocessor (Motorola 68000) and an associated RAM and REPROM memory. It controls a bus on which a number of other PC boards can be connected to expand system capabilities (memory, interrupts), to couple the peripheral devices, and to enter logic and analog data. Troubleshooting can be rapidly performed using internal and external test tools: function turn around schemes (modem, data transit/receive), test PC boards and cables, test programs built into operational programs, technical panel and dialog type writer. Temperature range of operating: $-25^{\circ}C$ to $+55^{\circ}C$; and storage temperature is: $-55^{\circ}C$ to $+85^{\circ}C$.

DESCRIPTION OF SOFTWARE CAPABILITIES

Available software packages are used to prepare and debug programs, as well as control interfaces and test circuitry. Usable software packages include:

- The realtime operational monitor MOP68,
- The program production software,
- The debugging aid monitor,
- The input/output software (handlers),
- The programs libraries,
- The test software.

A special high level language, Language a Temps Real (LTR), developed by the French Defence Ministry, is used for applications programming.

SPACE MISSION APPLICATIONS

This Microcomputer is suitable for difficult environments such as: extreme operating temperatures, shocks, vibrations, explosive environment, dusts, humidity, etc., and still remaining cost effective. The M68 may be used in all real time data processing fields characterised by short processing loops: analog and digital measurment acquisition, equipment monitoring and control, data concentration/dispatching, telecommunications, distributed data processing, and more.

MISCELLANEOUS INFORMATION

CIMSA has also developed several innovations of the MITRA 125 minicomputer. The 15M/125X, is a 32-bit minicomputer, with standard software, 1M byte memory, high reliability, and is extremely rugged. Like its predecessors, the 15M/05, and 125MS, it meets rigid military operating specifications.

There are 3 MITRA 125MS minicomputers (16-bit) onboard the SPACELAB; one for housekeeping, one for experiments control, and one backup.

Company Name: Hollandse Signaalapparaten BV (HSA)
(A Philips Subsidiary)

Microprocessor Designation: FAST

GENERAL DESCRIPTION OF MICROPROCESSOR

The FAST microprocessor (16-bit) is a micro-version of the standard Philips P800 mini computer family, having the same hardware/software interfaces. Besides HSA, the FAST is also manufactured by other Philips subsidiaries, Signetics in the U.S. and Mullard in the U.K.

It has recently been evaluated and considered by ESA as a possible onboard computer for space applications.

As FAST belongs to the P800 minicomputer family it has 16 internal registers of 16 bits for general purpose use together with the standard P800 instruction set. The standard instruction set is extended by 8 extra instructions:

- Muliplication
- Division
- Character (Byte) handling instruction
- Double length instruction
- Multiple save and restore of sixteen internal registers
- Special instructions for multiprocessing purposes.

It should be noted that the special instructions for multiprocessing are only implemented in FAST.

SPECIFIC CHARACTERISTICS OF MICROPROCESSOR

- FAST is implemented on a single chip and packed into a standard 40 pin ceramic package

- Clock frequency depending on version can be 3.3 MHZ or 5 MHZ
- Instruction execution times varying from 2.1 µsec to 7.2 µsec
- Uses a single +5VC supply voltage and single clock, the interface signal of FAST are TTL compatible
- 0.9 mm is the microprocessor's lid's thickness
- The radiation sources used in this framework are particle accelerators and a radioactive source. For electron radiation the Van de Graaf electron accelerator is used, which allows both ionization and displacement damage.
- Device radiation resistance up to a total radiation dose of 100 KRad.

All these latter mentioned qualifications make FAST suitable for space applications.

DESCRIPTION OF SOFTWARE CAPABILITIES

As already stated Philips microprocessor (FAST) has been derived from the Philips-P800 minicomputer family. FAST is fully software compatible with the mentioned commercially available minicomputer. This compatibility is of great value for the development and the testing of the in-flight software. To perform this task standard system software is available. This standard system software consists of control, processing, service and utility programs having a modular structure. A very suitable system software package is a disk oriented system consisting of:

- System generation
- Disc operating monitor, also I/O drivers for relevant peripherals

- Assembler which converts source modules written in assembler language into object modules suited for linking to other object modules
- Linkage editor
- Debugging package
- Line editor
- High level language, programming support includes all items necessary, such as compilers and translators, for customers to write their own applications, FORTRAN and BASIC are the two languages that can be utilized

SPACE MISSION APPLICATIONS

- HSA has first used an onboard computer (OBC) on the Astronomical Netherlands Satellite (ANS) in 1974 for attitude control and data handling. It was a special purpose computer developed by Philips.
- The joint Dutch/U.S./U.K. satellite IRAS, (International Astronomical Satellite), to be launched in 82/83, will have an adapted P851 OBC, especially configured for space environment, for attitude control and onboard data handling.
- Dornier will use the same IRAS OBC for the Space Telescope project.
- The FAST microprocessor will be used on future space applications.

MISCELLANEOUS INFORMATION

A Universal Microcomputer Development System (UMDS) is available for developing, debugging and testing onboard software for the FAST.

Company Name: MBB
Microcomputer Designation: MODUS

GENERAL DESCRIPTION OF MICROCOMPUTER

MODUS is a modular universal data handling system developed by MBB initially for use onboard the shuttle pellet satellite (SPAS-1). It is intended, however, to be usable onboard other future mission.

SPECIFIC CHARACTERISITICS OF MICROCOMPUTER

- 16-bit word size
- software on ROM's
- can use any of the following microprocessors AMD 2900, MOTOROLA 68000, T.I. 9900, INTEL 8086
- bit slice processor (4 chips)
- power supply 5V or 12V

DESCRIPTION OF SOFTWARE CAPABILITIES

The software for the MODUS microcomputer is normally developed in Assembler on a PDP-11/34, using MODUS cross-assembler. Other computers could also be utilized. The Object program is then transfered to HP2645 data cartridges which are capatible with the MODUS.

The programs are finally loaded on RAM's or ROM's for use by MODUS.

MBB is currently developing a PASCAL cross-compiler for MODUS.

SPACE MISSION APPLICATIONS

MODUS is being used onboard SPAS-1 for data acquisition, operation of experiment, telemetry and command functions and 3-axis attitude control using rate gyros only.

It is possible that ESA's Micro-Gravity Platform, to be launched by the STS, will use the MODUS microcomputer for onboard orbit control.

MISCELLANEOUS INFORMATION

MBB's related experience in the use of onboard computers include:

EXOSAT - OBDH system using SAAB OBC, with the software being designed by MBB and implemented by ESA and contractors. (Attitude Control onboard EXOSAT uses INTEL 8086)

TVSAT - Attitude and orbit control (not determination) using SAAB OBC with AMD chips. The software is being developed by MBB entirely

Company Name: Dornier Gmbh
Microcomputer Designation: MUDAS-R
Model: DP426-R and DP431-R

GENERAL DESCRIPTION OF MICROCOMPUTER

The Modular Universal Data Acquisition and Processing System for High Reliability Applications (MUDAS-R) has been developed by Dornier as a standardized approach to many onboard computation requirements. Model DP426-R is based on the military version of INTEL 8086 microprocessor. All circuitry besides the CPU and clock generator are based on CMOS technology.

SPECIFIC CHARACTERISTICS OF MICROCOMPUTER (DP426-R)

- Technology: CMOS (CPU-Chip HMOS)
- 8 and 16 bit parallel computation
- Instruction set according to INTEL CPU 8086
- Full arithmetic and logical instructions including multiplication and division
- Clock frequency 4 MHZ
- Memory area up to 1M byte addressable, RAM and ROM
- Serial interface for connection of TTY or Display
- Suitable for multiprocessor applications and redundant systems
- Bidirectional system bus, 20 address-, 16 data and 9 control lines
- Power supply: +5V and +10V
- Power consumption: 3.5W
- Operation temperature: $-30^{\circ}C$ $+80^{\circ}C$
- Dimensions: 176 / 100 / 10 mm
- Mass: 0.19 kg

DESCRIPTION OF SOFTWARE CAPABILITIES

PEARL (Process and Experiment Automation Realtime Language) is a high level language developed especially for use with MUDAS-R. Compilers and operating systems for several computers are available. PEARL is also a candidate for standardization by ISO. Major features of basic PEARL are:

- a system-part to describe the hardware configuration and the flow of data
- multitasking
- synchronisation (semaphores)
- clock-and-duration-variable
- names for interrupts
- process-, standard- and file -I/O
- arithmetic and control statements, blocks and subroutines like in other languages (PL/I, FORTRAN)
- arrays and structures like in other languages

SPACE MISSION APPLICATIONS

- 16 bit Micro system for AOCS on TV-SAT
- Material Science Laboratory for SPACELAB
- Microwave Remote Sensing Experiment (MRSB) on SPACELAB
- FOC (Faint Object Camera) data handling and Scientific Data Memory on the Space Telescope
- Serial Data Bus for OBDH
- Space Processing Lab
- SPACELAB CDMS Subsystem Computer Operating System Software (SCOS) in collaboration with MATRA
- Control System for Instrument Pointing System (IPS) on SPACELAB
- Control of scientific experiment onboard AEROS, HELIOS, ISEE/MOTHER/DAUGHTER, ISPM

MISCELLANEOUS INFORMATION

DORNIER along with the DP426-R, has developed another microcomputer with somewhat different characterisitcs called DP431-R, which is a full CMOS version. The CPU is based on ALU chips: MC 14 581, MC 14 582. For all other characteristics one should refer to DP426-R. Incidentally, DORNIER is using HSA's P851 OBC for the SPACE TELESCOPE Project.

Incidentally, DORNIER as a sub-contractor to BAe on GIOTTO, is developing the AOCS (for attitude control only) using the RCA COSMAC 1802 microprocessor, (8-bit) and a star mapper. On the same mission DORNIER will also use an NSC 800 microprocessor (16-bit) for a German scientific experiment.

Company Name: Saab-Scania AB
Minicomputer Designation: SAAB OBC

GENERAL DESCRIPTION OF MINICOMPUTER

The SAAB OBC (onboard computer) is a modular minicomputer system which exhibits many unique features. The system can be configured to meet a wide range of requirements thus exploiting the flexibility and versatility intrinsic in a modular design.

It has been integrated according to new high reliability concepts including fault tolerant operation with self-repairing capability for unattended multi-year operation.

A minimum system may be expanded either to enhance system reliability through the use of redundant modules or to increase the computation throughput, or to meet special requirements. The modules are interconnected by a common Inter Module Bus, the design of which offers redundancy as well as a multiprocessing capability.

SPECIFIC CHARACTERISTICS OF MINICOMPUTER

The OBC has the following basic capabilities:

- Operation	16 bits parallel	
- Instruction Set	Full arithmetic capability	
	Full logic capability	
	Shift/Rotate	
	Register to Register transfers	
- Execution times	ADD, SUB, LOAD	2.7 µs
	(Depending of memory	

access time)	DOUBLE PREC ADD SUB 4.5 μs
	MULTIPLY 18.0 μs
	DIVIDE 24.0 μs
	FLOATING ADD about 50 μs
	FLOATING MPL about 60 μs
- Arithmetic	Two's complement, Fixed point Single and double precision Floating point 24 bits mantissa, 8 bits exponent
- Subroutine handling	Stacking and restacking of register contents stack in main memory
- Addressing	single word instruction
- Memory banks	MB1 and MB2 Non volatile, MB3 volatile
- Vital program ROM	Capacity 1K words TTL PROM
- I/O	6 address bits
- Dimensions	500 x 500 x 285 mm
- Weight	Approx 25 kg
- Reliability	Whole OBC $\geqslant$ 0.98
- Technology	CPU-TTL, memory-NMOS

DESCRIPTION OF SOFTWARE CAPABILITIES

Matra has developed the software for use by the OBC on the SPOT satellite. The OBC/SPOT support software consists of editor, assembler and debug. There are two assembles - one which will be executed on host computers (XAL) and another which will be executed on the OBC/SPOT and its test equipment (PIAA).

SPACE MISSION APPLICATIONS

- Ariane: used for control and monitoring purposed on 3rd stage
- EXOSAT: used for experimental data processing
- SPOT: used for control and data processing
- TVSAT (German): used for AOCS functions

MISCELLANEOUS INFORMATION

Saab-Scania is currently involved in a number of other space oriented activities.

- The Telemetry, Tracking, and Command subsystem for ECS and MARECS programmes
- Data Handling Equipment for the French national program TELECOM1
- Prime contractorship for the Swedish scientific satellite VIKING

A new version of the SAAB OBC is now under development, taking advantage of the latest LSI technology to reduce the size and weight of the OBC and increase its fault tolerance.

Company Name: LABEN

Microcomputer Designation: LABEN Hybrid Microcomputer (HμP 8024)

GENERAL DESCRIPTION OF MICROPROCESSOR

The LABEN HμP 8024 is a stand alone, component-like, miniaturized general purpose computer (16-bit). It includes components of the Z-80 microprocessor family (Z-80 CPU, Z-80 DMA, Z-80 PIO chips).

SPECIFIC CHARACTERISTICS OF MICROCOMPUTER

- Complete micro-computer capabilities
- Z-80 processor instruction set
- Multiprocessing capabilities
- Built-in powerful DMA
- Built-in 16 bit I/O port
- Ease of memory expansion up to 8K bytes
- Program erase/load/modify via electrical pulses
- Complete access to address, data, control buses
- 2.5 MHz clock frequency
- Low power consumption (2 Watt max)
- Compact housing, 1.16" x 2.2" hermetic flat package
- Operating temperature range -20°C to +60°C

DESCRIPTION OF SOFTWARE CAPABILITIES

An operating system tailored to the microcomputer architecture and for space application has been developed.

This OS can be entirely loaded into the EAROM area and allows for HμC monitoring, I/O handling, application programs scheduling and execution.

In this case a quite general purpose application approach can be achieved. In fact, the HμC appears to the user as a completely freezed device with its H/W capabilities and firmware OS program. The user application programs (background/foreground) are loaded into external ROM area and driven by the OS resident into the HμC. A single application dedicated approach can be alternatively choosen, loading directly into the HμC EAROM space the user programs.

In that case the HμC is delivered without any software content and the user himself has to access the internal EAROM space.

A programmer module generates signals and proper timing for loading the HμC EAROMS. The module can interface the HμC (destination) with a byte source via serial RS 232 line, allowing for automatic EAROM loading. In fact, EAROM loading can be also accomplished purely by suitable software program and using the internal HμC PIO. In other words the HμC can write by itself its own EAROM.

SPACE MISSION APPLICATIONS

- International Solar Polar Mission (ISPM): for MACS
- GIOTTO (Comet Mission)

LABEN'S related space experience includes:
- Data Handling Subsytem
- Electronics for Nutation and AOCS.

IV. Assessment of Overall European Capabilities for Autonomus Onboard Satellite Control

The overall capability for onboard satellite control requires three basic technologies:

1. Onboard microcomputers
2. Software for AOCS (Attitude and Orbit Control System) for determination and control
3. Adequate system of sensors and other devices for the nonambiguous resolution of orbit and attitude.

Let us first review the overall European microcomputer capability and especially these microcomputers and microprocessors that are space qualified.

We have seen in the previous section that there are several such micros in Europe, namely the Ferranti's F100-L (and F200-L), HSA's FAST, Matra's 6100, SAAB's OBC, Laben's Hμp 8024, CIMSA's M68, MBB's MODUS, Dornier's MUDAS-R, Marconi's ITU, and Bae's SMM.

The capabilities of each of these micros have been analyzed, and in general they were found to possess the computational capability necessary to perform the calculations, with appropriate software, for orbit and attitude determination in pseudo real-time. In fact most of the above micros are equivalent in word size (16-bit), speed and storage capability to mini computers of the mid 70's.

It has already been demonstrated universally that such minicomputers, using real time filtering techniques or limited batch processing, can determine orbits and attitudes and the necessary corrections to them for LEO and GEO satellites.

Obviously some of these micros have characteristics which are more or less adequate for specific onboard applications (e.g. power consumption, radiation tolerance, speed, etc.). However the overall onboard microcomputer and microprocessor capability in Europe is definitely up to the task.

It is important to review some of the more recent trends in microprocessor development in Europe, which will be at the forefront of the next generation of microprocessors.

First, 32-bit microprocessors are now under development phase at Thomson CSF, St. Gobain S.A. and other European companies, following similar developments in the U.S. and Japan.

High-level language programming, faster operating speeds and increased use of CMOS have also permeated the new 8 and 16-bit microprocessors. And there is a swing toward distributed processing tasks, made possible by dedicated chips designed to be attached to existing processors. With these chips, arithmetic operations (floating-point, multiplier, etc.) can be performed faster and with less program burden. At the same time, memory-management schemes implemented with special peripheral chips extend addressing capacities and make it possible to expand the microprocessor's memory with little or no software writing.

One of the biggest pushes is the increase in CMOS microprocessor designs, especially the fabrication of popular NMOS designs in CMOS. Not only do the new CMOS designs use less power than the original NMOS designs, an important fact for onboard applications, but they are also as fast or faster. Most designs are for 4, 8, and 16-bit microprocessors and other systems.

With the emergence of these and other highly capable software systems, firmware is definitely losing its importance in microprocessor systems.

Another important development is the extended capabilities of 16-bit microprocessor-based systems, due to the new attached processors and peripheral controllers for memory, input/output, and display features. These microsystem peripherals are gaining more local processsing power to reduce dependence on the limited data handling flow of the bus interfaces.

These message-directed slave chips have their own locally stored programs and respond to highly descriptive messages, which make stheir operation transparent to the master processing unit. This need for smart peripherals, which first appeared in the mainframe computer systems, are among the many trends in architectural design that are crossing over to the microsystem area as the latter's data handling requirements mature.

European overall capability for onboard data handling and onboard attitude control for 3-axis platforms have been established and flight tested for some time now.

The On-Board Data Handling (OBDH) system has been developed by ESA as a standard component for many of the European commercial and scientific satellites. OBDH is a digital bus decentralized data system for gathering, processing and distributing data and command signals in a spacecraft. It is applicable at spacecraft level (platform and/or payload) or sub-system level (telemetry, telecommand subsystem, AOCS, etc.) depending on the application concept involved.

The OBDH architecture can be adapted to various requirements, taking account of the following:

- data processing needs (onboard or ground)
- redundancy concept (depending on reliability factors)
- nature and volume of data exchanged

The OBDH system is built around the OBDH bus, ensuring:

- simplified harness
- standard, decentralized interfaces
- provision for use of standard terminal units

The OBDH can use any one of several available 8-bit or 16-bit microprocessors depending on the specific data requirements of a give spacecraft mission.

ESA is presently also developing a standardized module for attitude control, the Modular Attitude Control Systems (MACS). The MACS will consist of a control system data bus connecting through standard interface units to the ACS electronics and sensors. The project is due for completion in 1983/84.

As far as 3-axis onboard attitude control is concerned, several new systems have been developed in recent years in Europe. Especially noteworthy are some of the Matra systems, e.g.:

- Integrated Attitude Determination and Estimation System (IADES), using gyroscopes, and Matra 6100

microcomputer, and employing Kalman filter
- Strapdown Inertial Optical System (SIOS)
- Optical-Inertial Attitude Measurement System, using optical and inertial sensors.

In recent years both ESA and some national European space centres have conducted, in cooperation with European Industry, several specific studies addressing the feasibility of autonomous satellite control. The very fact that these studies were undertaken indicates a strong conviction on the part of the Europeans that the requisite technologies are now available or within easy reach for civilian applications.

The most noteworthy of these studies and proposals are:

1. "The Autonomous Stationkeeping System" - British Aerospace under ESA contract - 1978
2. "Optimal Autonomous Stationkeeping of Geostationary Satellites" - M.C. Eckstein and A. Leibold, DFVLR (Germany) - 1981
3. Proposal for "Autonomous Stationkeeping System", by MATRA to ESA - 1980
4. Proposal for "Autonomous AOCS for Low Earth Orbits and Geosynchronous Earth Orbits", by Dornier to ESA - 1980.

The BAe investigation, the most important one to date, studied specifically the feasibility of making a geosynchronous spacecraft capable of maintaining itself on station without the use of any ground facilities, to within an accuracy of $\pm 0.1^{\circ}$ in both longitude and latitude. The other ground rules for the study were that it should consider only sensors likely to be space proven by 1980, and the resulting system should be applicable to a 3-axis stabilized spacecraft with a 7 to 10 year lifetime using either hydrazine or electronic propulstion for orbit maneuvres. The type of spacecraft envisaged was typical of current ESA projects such as ECS, MARECS, L-SAT, etc. and either the ESA On-Board Computer (OBC) could be considered or a qualified microprocessor.

The results of this study show that a simple system exists which meets the ESA objective. This system uses a simple and powerful algorithm, has very modest computer requirements and requires only very limited hardware additions to the spacecraft. It is applicable to 3-axis spacecraft with a wide variety of control systems, thrusters, and masses and has only very limited interfaces with other spacecraft subsystems. The system uses signals from the existing spacecraft earth sensors (or antenna RF sensors) together with a Polaris sensor and a set of digital sun sensors, which could also be used for sun acquisition and yaw control by the spacecraft.

From these, and an onboard clock, it computes its latitude and longitude at intervals around the orbit. It computes its orbit parameters once per orbit by a least squares curve fit and then uses a classical stationkeeping strategy to maintaining itself on station.

It would be a cheap and valuable exercise to take a commercial microprocessor and program it with ASKS software. The microprocessor could then be interfaced with a standard minicomputer simulating the spacecraft orbit and attitude sensors and thrustors.

The DFVLR study investigated the feasibility and performance of a fully autonomous stationkeeping system for geostationary satellites, based on present state-of-the-art technology. The orbit is determined by onboard measurements obtained from an earth sensor, several sun sensors and a Polaris sensor. An epoch element filter, by sequential weighted-least-squares is used, in combination with a very simple orbit model to evaluate the measurements. The necessary orbit corrections are carried out by a low thrust electric propulsion system, according to an optimal strategy. Algorithms for both the orbit determination and the orbit correction phase were developed and tested by computer simulation of a one year stationkeeping period. The investigation concluded that autonomous stationkeeping to within $\pm 0.1^{\circ}$ in longitude and latitude is quite feasible.

The Matra proposal to ESA for an autonomous stationkeeping system is similar in concept to the BAe system except that it requires no star tracking inputs at all for orbit determination, only the conventional sun and earth sensors.

The Dornier proposal addresses both Low Earth Orbit and geosynchronous satellites, using the MUDAS-R microcomputer developed by Dornier.

In conclusion, it certainly appears then that European Industry possesses the necessary onboard computer technology, not only for autonomous attitude control and onboard data handling, but for autonomous stationkeeping control of both LEO and geosynchronous satellites.

V. Trade-off Considerations in Europe for Autonomous Satellite Control

There are basically three areas of trade-off that must be discussed, with respect to autonomous satellite control, in Europe today: Technical, Economical and Political.

From a technical point of view, the question is very simple. Is the existing or near-term onboard computer technology capable of performing all the tasks required for orbit and attitude control of a satellite, that have traditionally been performed by ground stations? Related questions deal with the system reliability, flexibility, adaptability, and maintainability.

It is the author's opinion, based on the findings of this investigation, that the requiste onboard computer technology in Europe exists and is rapidly approaching the state of maturity that will give it the other desired operational characteristics (i.e. reliability, flexibility, etc.).

The opinion in Europe is divided, however, on this score. European industry, especially through the efforts of Matra, BAe and Dornier, has campaigned in favour of autonomous satellite control. The technical work done by these companies, and others, proves the strong viability of on-board satellite control. These views are shared by most of the technical authorities at ESTEC, who would like to fund additional development work in the area of autonomous stationkeeping, and develop it into a standardized module similar to the OBDH and MACS systems.

At ESOC, on the other hand, the predominant opinion is in favour of the continuing role of ground support in controlling spacecrafts, at least for the near term.

The ESOC control centre, located in Darmstadt, West Germany, is the central decision making element for controlling most of ESA's satellites. It has overall responsibility for mission planning, scheduling, orbit and attitude prediction, satellite housekeeping, stationkeeping, data handling, etc.

The software system for real time control, Multi Satellite Support System (MSSS), can serve in parallel a series of different satellites in different mission phases. A more recent development at ESOC (1977) has been the implementation of closed-loop control via ground for GEOS-1 and GEOS-2. This necessitated the development of new satellite control techniques, and appropriate software for closed-loop control was implemented as an integral part of the 3rd generation of ESOC's flight control system.

According to ESOC, advantages of automatic control via the ground are the reduction of onboard complexity and the inherent increase in the onboard reliability, as well as a reduction of satellite development costs.

Present development trends, however, indicate that the importance of closed-loop control from ground will decrease in the long term due to an increased availability of standardized onboard technology.

Let us consider some of the economic trade-off factors. Clearly ESA has made a very substantial investment in developing the ESOC control centre and the vast network of ground stations supporting it. This investment is only now becoming economically justified with the increasing number of satellites ESA operates.

It has been demonstrated that onboard control, requiring no manpower and no equipment modification, is more economical on a case by case basis than the respective ground control. However, it must be admitted that it does not make a good economical sense in the near term to scrap or reduce ESOC's role in controlling satellites in favour of autonomous control.

In the long term, however, with escalating manpower and software costs, it will even make good economical sense for ESA to shift its control philosophy from ground to on-board systems.

Politically the trade-off is more complex in Europe. European Industry is anxious to produce microcomputers and microprocessors for space applications, as stated earlier, but there is a great deal of competition amongst the various European aerospace and comptuer companies which makes it all but impossible for ESA to select a unique micro for on-board applications. This has certainly been the experiencce with OBDH which set standards and defined interfaces but did not specify hardware.

Moreover, some European countries, notably West Germany, stand to lose a great deal if ESOC operations are scaled down. Consequently these countries will exert political pressure on ESA not to move too fast in adopting any new technology which will impact on their industrial return from ESA.

To summarize, technically speaking, European onboard computer technology has reached the point where it can be a viable alternative for ground computers in controlling satellites, but economical and political considerations in Europe may slow the process of implementation of this technology conisderably.

VI. Recommendations for Canadian Future Activities

It is evident from this study that the state-of-the-art of onboard computer technology has advanced to the point that no future satellite mission can ignore its specific benefits.

First, an account should be taken of the European onboard micro in any requirement for a onboard computers in future Canadian satellites.

Second, the standardized concepts of the OBHD and MACS should be studied in detail to see if such concepts can be beneficial in Canadian satellites.

Third, serious consideration should be given to developing in Canada, possibly in cooperation with Europe, a standardized onboard module for orbit and attitude control of geosynchronus satellites and low-earth-orbit satellites.

Last, the U.S. technology in this area should obviously not go unchecked before further development work in Canada related to on-board satellite control is undertaken. In the same view, the latest U.S. made microprocessors should be reviewed and compared with their European equivalents.