APPLICATION OF MICROPROCESSORS TO INTERPLANETARY SPACECRAFT DATA SYSTEMS

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The Jet Propulsion Laboratory has committed to the use of a microprocessor based distributed data system in the 1984 Galileo mission to Jupiter. There has been an evolution of this commitment following the advances in component and device technology. Early spacecraft were very simple with subsystems very much single function oriented. Our understanding was very high and the need for design and analysis tools very low.

As technology grew, so did the complexities of the systems. Step by step, subsystems and functions were combined thus increasing their capability as well as complexity. Missions became more ambitious and the returns were high. Costly design and analysis tools were developed to support system test and operations. With these tools we were able to some small degree analyze and/or predict the performance of the spacecraft.

The Galileo Command and Data Subsystem (CDS) evolved from the combination of two special purpose computers from previous spacecraft: the Flight Data Subsystem and the Computer Command Subsystem. The CDS architecture utilizing concepts investigated in the development of the Unified Data Subsystem (UDS) takes advantage of the microprocessor technology and serves as the core of the distributed microprocessors interconnected by a high speed data bus.

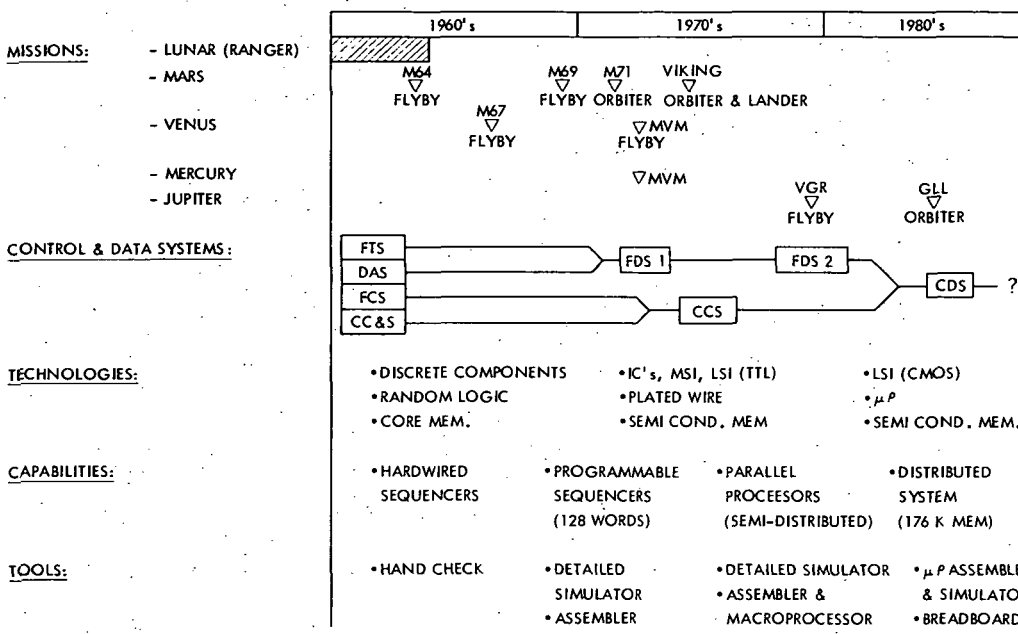
The CDS design is complete and breadboard integration and test are in process. The flight software is in the requirements and "prototype" design phase. Many obstacles have been encountered and overcome. Some worthy of mention are:

1) Choice of a microprocessor architecture based primarily on its power and radiation hardness qualifications.
2) High speed operation of CMOS logic.
3) Adaptation of a Higher order Language to a microprocessor and in particular to a processor with an architecture not well suited for the CDS application.
4) The difficulties in obtaining quantities of qualified parts that are very complex and have difficult requirements, i.e. radiation hardening.
5) Availability of design and analysis tools for understanding and validating distributed systems with concurrent processing.

Ongoing advanced development and preproject studies are primarily based on data system designs having the same requirements as the CDS. We are committed in the future to the continued application of microprocessors to distributed data systems; solutions to the above problems; and to continue to follow advances in technology with the incorporation of VLSI into modular fault tolerant building blocks.

In summary, technology and complexity have very rapidly advanced since the first Ranger spacecraft in the 1960s. The design and analysis tools have sadly lagged this progress leaving our ability to "best" design and understand what we have designed less than optimum. Along with our use of the new technologies of the future, we must also attack this deficiency.

THE CHRONOLOGICAL PATH TO MICRO-PROCESSOR APPLICATION



THE BASELINE - UDS

THE UDS, A DEVELOPMENT SPONSORED BY THE NASA UNDER CONTRACT NAS7-100 WITH THE CALIFORNIA INSTITUTE OF TECHNOLOGY AT JPL.

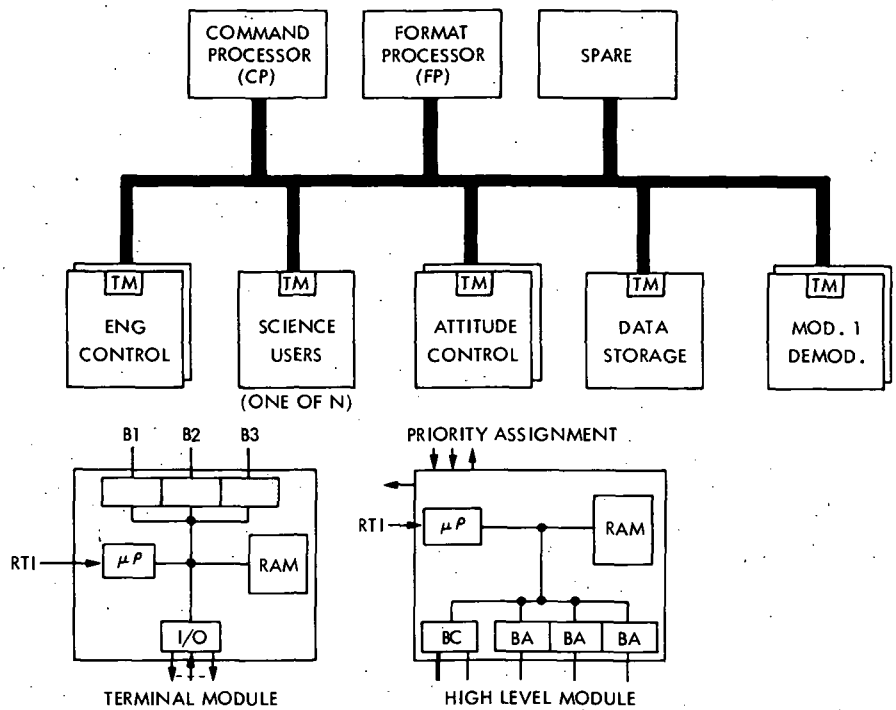
SALIENT FEATURES:

- REAL TIME CONTROL - PRECISE TIMING
- DISTRIBUTED ARCHITECTURE
  - + DISTRIBUTED FUNCTIONS (HI-LEVEL CONTROL, LOW-LEVEL EXECUTION)
  - + INTERACTION MINIMIZED
  - + HIERARCHICAL CONTROL
  - + COMPUTER INDEPENDENCE
- STANDARDIZED SOFTWARE AND SUPPORT EQUIPMENT
- STANDARD INTERFACES

FEASIBILITY DEMONSTRATED VIA:

- BREADBOARD OF BASIC SYSTEM UTILIZING NAKED MINI'S
- ONE REMOTE TERMINAL UNIT (RTU) INCLUDING 8080 MICROPROCESSOR
- DEVELOPED CONCEPT OF UDS DESIGN LANGUAGE (UDL)
- DESIGNED AND IMPLEMENTED "TYPICAL" APPLICATION SOFTWARE
- EXPLORED CONCEPTS OF DEBUGGING A DISTRIBUTED SYSTEM

THE UDS DESIGN
(MARINER CLASS S/C)



THE RTU

INITIALLY DEVELOPED AS A PART OF THE UDS.

- UDS I/O TYPE INTERFACES
- UDS BUS INTERFACE
- MICROPROCESSOR DRIVEN

PROPOSED FOR DEVELOPMENT AS A NASA STANDARD FOR POSSIBLE USE WITH:

- MMS (DHCS - NSSC-1)
- GALILEO
- VARIOUS PREPROJECT STUDIES

CONCEPT DIED

- BURDENED WITH UNIVERSAL I/O
- SALE OF THE CONCEPT - NO VOLUNTARY FIRST USER
- FEW SUPPORT FACILITIES

MAIN INHERITANCE FROM THIS EFFORT - RCA 1802 MICROPROCESSOR, IMPLEMENTATION CONCEPTS OF BA AND BC.

GALILEO

A COMMITMENT TO A DISTRIBUTED DATA SYSTEM UTILIZING THE MICROPROCESSOR TECHNOLOGY IN A FLIGHT DEVELOPMENT ENVIRONMENT

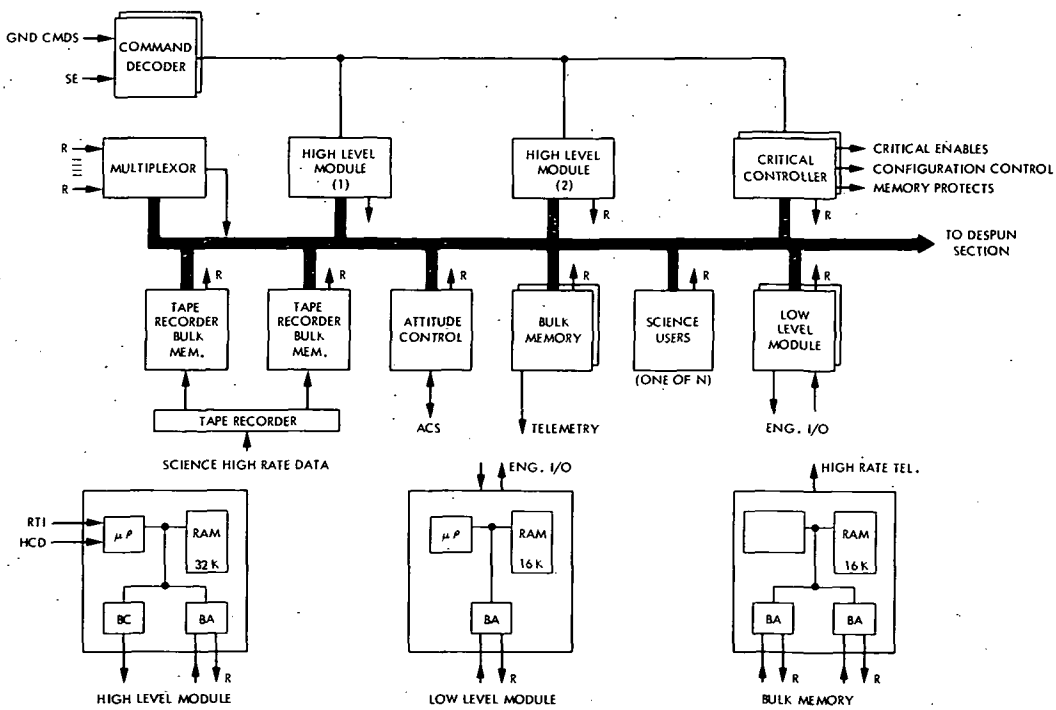
DRIVERS ON DEVELOPMENT

- UDS AS A BASELINE
- LOW POWER AND RADIATION DICTATE ACCEPTANCE OF THE RCA 1802
- COMBINING FDS AND CCS INTO SINGLE SUBSYSTEM
- CHEAPER OPERATIONS
- VOYAGER AS A BASELINE
- CMOS (4000 SERIES) SUPPORT LOGIC
- MUST USE HOL (SPECIFICALLY, HAL-S)
- NOTION THAT THE MORE YOU DO ON BOARD - THE CHEAPER ON GROUND

STATUS

- DESIGN COMPLETE (HARDWARE)
- ARCHITECTURAL DESIGN OF FLIGHT SOFTWARE IN PROGRESS. SOME PROTOTYPE/ BREADBOARD DESIGNS. (J. THOMAS PRESENTATION)
- BREADBOARD AND SUPPORT EQUIPMENT INTEGRATED DESIGN VERIFICATION IN PROCESS
- HAL-S HAS BEEN REMOVED AS A REQUIREMENT.
- DESIGNS FOR SOFTWARE AND OPERATIONS SUPPORT TOOLS IN PROGRESS.

GALILEO DESIGN



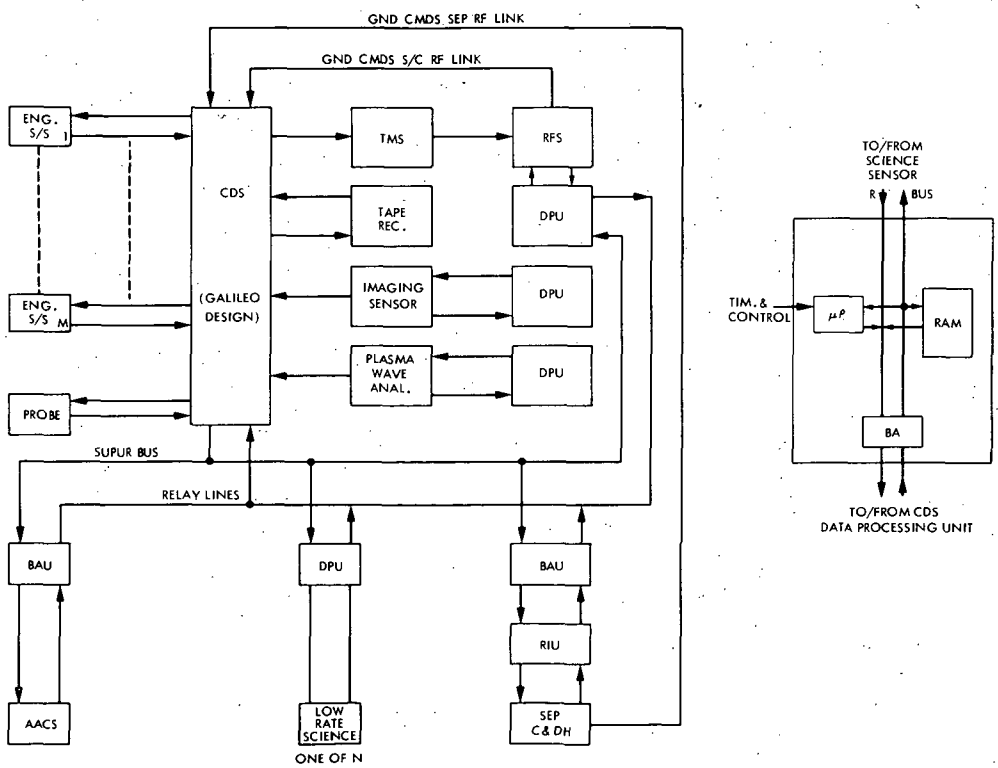
OTHER PROPOSED APPLICATIONS

COMET RENDEZVOUS

- MANY IMPLEMENTATIONS PROPOSED DEPENDING ON CHARACTER OF MISSION AT ANY GIVEN TIME AND ECONOMIC ENVIRONMENT.
  + BASED ON "CORE" DISTRIBUTED DATA SYSTEM
  + USERS NEED COMPUTING POWER
  + COMPUTING POWER DERIVED AS A STANDARD FOR THE S/C AND WOULD SIMPLY BE INCORPORATED INTO THE USER DESIGN (RTU SANS THE I/O).

OTHER PROPOSALS HAVE BEEN MADE, PRIMARILY BASED ON THE DISTRIBUTED SCHEME.

COMET RENDEZVOUS PROPOSED DESIGN



THE CHRONOLOGICAL PATH OF PROBLEMS

EARLY DESIGNS (M69, M71, M73)

- SIMPLE DESIGNS EASILY UNDERSTOOD
- COMPONENT COMPLEXITY LESS; EASILY TESTED AND SCREENED
  + PROCESS PROBLEMS (PURPLE PLAGUE, CORROSION, ETC.)
- HARDWARE AND SOFTWARE DESIGN AIDS AVAILABLE EARLY
  + DETAILED SIMULATOR
    - MEMORY SIZING
    - TIMING
    - TEST SOFTWARE DEVELOPMENT AND VALIDATION
  + ASSEMBLER/LOADER
- SIMPLER SOFTWARE (128/500 words)

RECENT DESIGNS (VIKING, VOYAGER)

- DESIGNS MORE COMPLEX
- INCREASED COMPONENT COMPLEXITY
- HARDWARE AND SOFTWARE DESIGN AIDS AVAILABLE EARLY
  + DETAILED SIMULATOR
  + ASSEMBLER/MACRO PROCESSOR

THE CHRONOLOGICAL PATH OF PROBLEMS (CONT.)

RECENT DESIGNS (VIKING, VOYAGER) CONT.

- INCREASED COMPLEXITY IN SEQUENCING
- ON-BOARD FAULT MANAGEMENT (LIMITED)
- MORE COMPLEX SOFTWARE
- DECREASING R&AD FUNDS

GALILEO AND FORWARD

- LACK OF EARLY DEVELOPMENT TOOLS
- VERY COMPLEX COMPONENTS
- INCREASED COMPLEXITY IN SEQUENCING, ON-BOARD FAULT MANAGEMENT
- MORE SEVERE ENVIRONMENTS
- LACK OF CONTINUITY OF MISSIONS
- FURTHER DECREASE IN R&AD FUNDS
- MUST BE CHEAP

SPECIFIC PROBLEMS

- DIFFICULTY IN APPLYING HOL (HAL-S) TO RCA 1802
- RCA 1802 ARCHITECTURE PROBABLY NOT BEST SUITED FOR CDS TASK.

THE CHRONOLOGICAL PATH OF PROBLEMS (CONT.)

SPECIFIC PROBLEMS (CONT.)

- RADIATION HARDENING PROBLEMS
- ARCHITECTURAL EVALUATION
  - MEMORY SIZING
  - BUS TRAFFIC
  - TIMING MARGINS
- DEVELOPMENT AND TEST OF TEST SOFTWARE
- COMPETITION IN LABOR MARKET